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DEPARTMENT OF MINES AND TECHNICAL SURVEYS

MINES BRANCH

OTTAWA

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

PART III

ONTARIO

by

J. G. Matthews

Industrial Minerals Division

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PREFACE

In 1949, the Mines Branch began an investigation into Canadian sources of clay and shale raw materials suitable for the production of lightweight aggregates. Part I of the investigation, covering the Province of Alberta, and Part II, covering the Provinces of Saskatchewan and Manitoba, have been published as Memorandum Series No. 117 and No. 120, respectively. This report, dealing with the Province of Ontario, contains the results of test work on samples from what were considered to be the most important known deposits within marketable distance of well populated areas.

The aim of the laboratory work has been to produce, at the lowest cost, the highest grade of aggregate, namely, a coated aggregate, by using the raw materials in their natural state. In view of the number of samples covered and the limited amounts of each, no work was done on the suitability of the materials for the production of sinter aggregates either in the rotary kiln or sintering machine. It should be noted, however, that many of the materials, classed as being unsuitable for coated aggregate, might be found very satisfactory for the production of sinter aggregates. For any one considering such production, the work covered in this report on raw materials for coated aggregate manufacture will at least eliminate consideration of the decidedly unfavourable materials while indicating those which merit further attention.

The samples collected weighed from 5 to 10 pounds and were taken by trenching so as to represent a true average of the deposit. Included are the test results of materials submitted by individuals or companies.

Reports and maps of the Geological Survey of Canada were of great assistance in locating outcrops.

John Convey,
Director, Mines Branch.

COATED LIGHTWEIGHT CONCRETE AGGREGATE FROM CANADIAN CLAYS AND SHALES

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INTRODUCTION

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 cause it to expand into light, cellular particles. The particles are usually well rounded due 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. Due 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 a 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 covering 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, designation 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 -1/2" + 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 shortness 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 for 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 bloaters 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, a frequent cause of non-uniformity is the varying amounts of free carbon. Depending upon their extent these variations may mean the elimination of the material as a possible raw material.

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

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 a commercial kiln producing coated aggregate would operate. It is possible to produce the same result at a lower temperature with an increased retention time but only at a great sacrifice in 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 a good bloating material is suited for coated aggregate manufacture or not is the degree of sticking and agglomeration of the particles when bloating. This property can be determined quite satisfactorily in the small kiln.

As a result of the stationary furnace and rotary kiln tests the materials were classified into five groups which are shown in a summary table for the province in Figure 4, page 48. These classifications are as follows:

1. Materials considered suitable for coated aggregate production.
2. Materials which are good bloaters 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 bloaters.
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 facts that 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. Both possibilities, 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 jigging 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 4 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, that is, compactness and fine grain, as well as the mode of shaping, were 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-silicate" 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 sulphur but only that sulphur retained at high temperatures in the complex compounds with iron and silica.

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 magnesium 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 aggregates, and on causes of bloating. Their work indicated that various compounds of iron, alkali, and alkaline earths furnished 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 bloaters would very probably be good bloaters, 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, page 15. 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 bloaters.

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 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 so important a determining factor as the conditions of high viscosity and wide vitrification range.

The composition diagram shown in Figure 2, page 17, 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 is the range in temperature between the point of incipient fusion and the point at which the viscosity has decreased to impractical 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

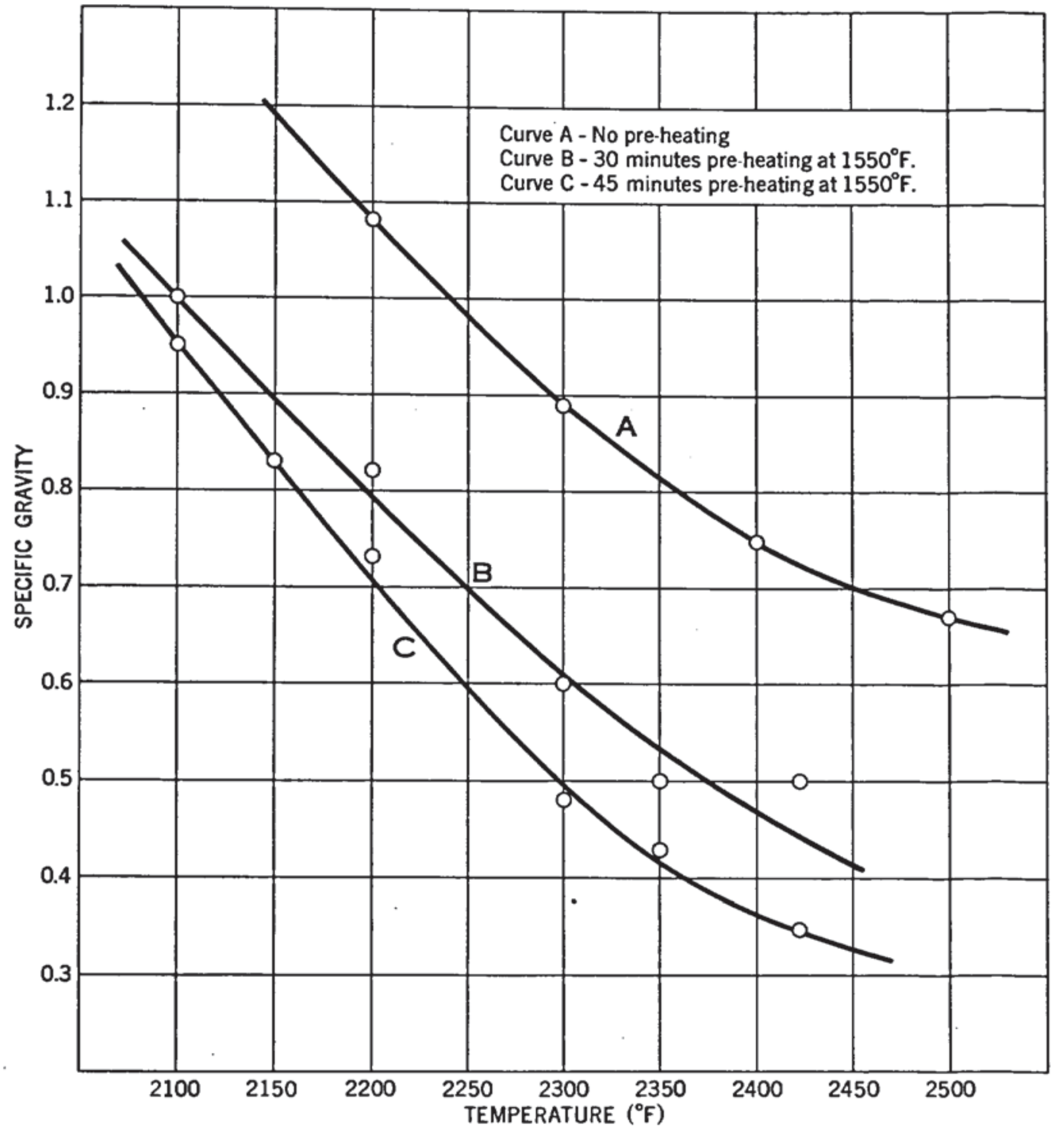


Figure 1 - Effect of preheating upon the specific gravity of bloated specimens of shale high in combustible carbon.

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, page 19, 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 still be high 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.

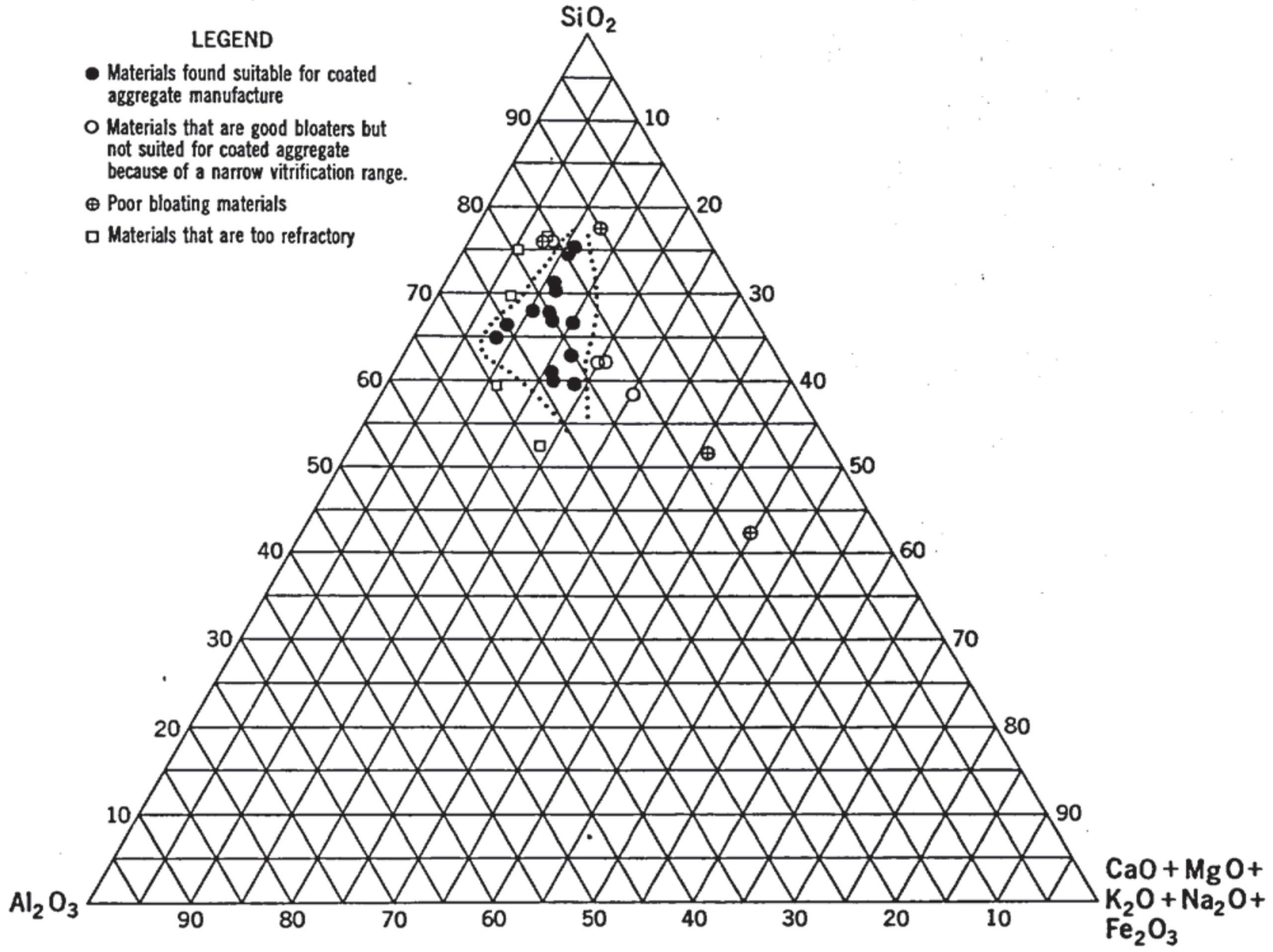


Figure 2 - Composition diagram of major oxides in clays and shales showing proportions required to produce coated aggregate. Dotted line represents approximate limits of materials suited for coated aggregate.

The chemical analysis of a clay or shale appears to be valuable for the defining of 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, page 17, and an excess of the K_2O + Na_2O fluxes over the CaO + MgO fluxes as illustrated in Figure 3, page 19.

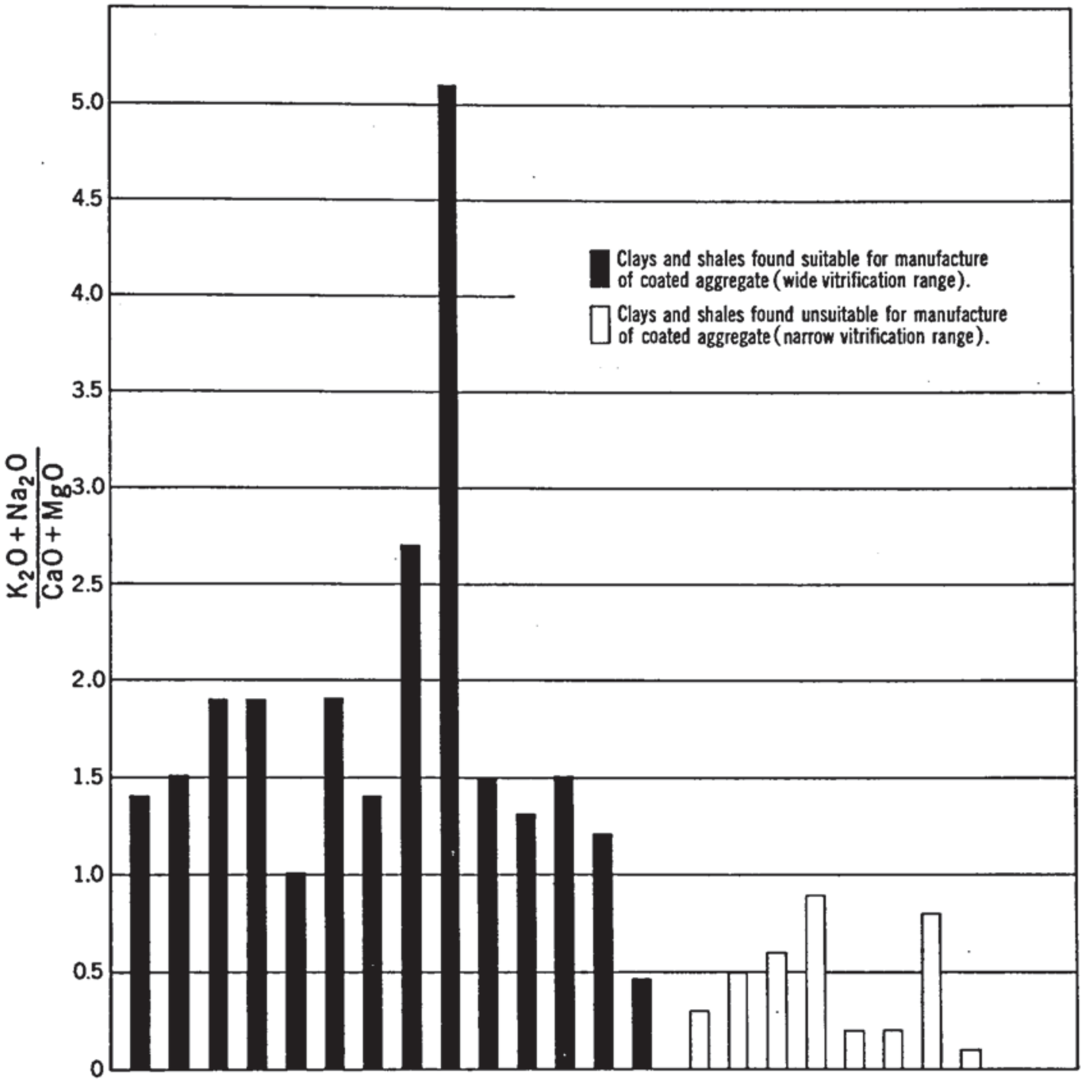


Figure 3 - Relationship of type of fluxes in clays and shales to width of vitrification range.

LOCATIONS, DESCRIPTIONS AND TEST RESULTS OF ONTARIO CLAYS AND SHALES

Of a total of 129 samples tested from 47 locations in Ontario, 37 samples from 13 locations gave favourable indications of being suitable for the manufacture of coated lightweight aggregate; 62 samples were classed as being good bloaters but having sticking and agglomerating characteristics; 26 samples proved to be poor bloaters and 5 samples were too non-uniform. Of the 37 samples with good results, 13 came from the Carlsbad shale in the Ottawa area, 6 samples were of a post-glacial clay from Cornwall; one was a clay from Napanee; 13 were from the Toronto area; 3 were of the grey shales of the Cabot Head member of the Medina formation at Hamilton and one was a brick clay from Coatsworth in Kent County.

The chief drawback to most of the clays and shales tested was their calcareous nature and resulting narrow vitrification range. An example may be had in the red shale of the Queenston formation which is so plentiful and easily accessible along the base of the Niagara escarpment. All samples taken of this shale proved to be excellent bloaters but due to the narrow vitrification range of the shale could not be made to bloat in the rotary kiln without serious trouble from sticking and agglomerating.

Descriptions of the clays and shales tested, with laboratory results, are given in the following text. The locations in eastern Ontario of clays and shales which have possibilities for the manufacture of coated, lightweight concrete aggregates, are shown in Map 4 at the end of the paper, and test results are summarized in Figure 4, also at the end of the paper.

OTTAWA

The Ottawa area is underlain primarily by Paleozoic rocks of Ordovician age. The irregularly eroded surface of Ordovician rocks is overlain directly by unconsolidated Pleistocene deposits of glacial till and clay as well as marine beds of clay and sand deposited from the post-glacial Champlain sea. The Ottawa area is shown in Map 1 which gives the major shale formations and approximate sample locations. The character and distribution of the main shale formations are as follows:

Billings Formation

The Billings formation is composed of black fissile shales. It is exposed in a horseshoe-shaped area with its curved tip lying under part of Ottawa. One arm extends southwesterly to the Gloucester fault where it is cut off. The other arm extends eastward in a band about two miles wide for a distance of about 20 miles.

Carlsbad Formation

The Carlsbad formation immediately overlies the Billings formation. It consists of grey shale with some impure limestone and sandy beds, being bounded in the southwest by the Gloucester fault and in the north by the Billings formation.

Queenston Formation

The Queenston formation, a red shale occasionally streaked grey-green, lies in an oval-shaped area north and west of Russell within the area occupied by the Carlsbad formation except in the south where it is bounded by the Gloucester fault. It overlies the Carlsbad formation but is separated from it by the Russell formation of interbedded shale and limestone.

Thirty-four samples were taken of the above three formations at locations shown in Map 1. Details follow.

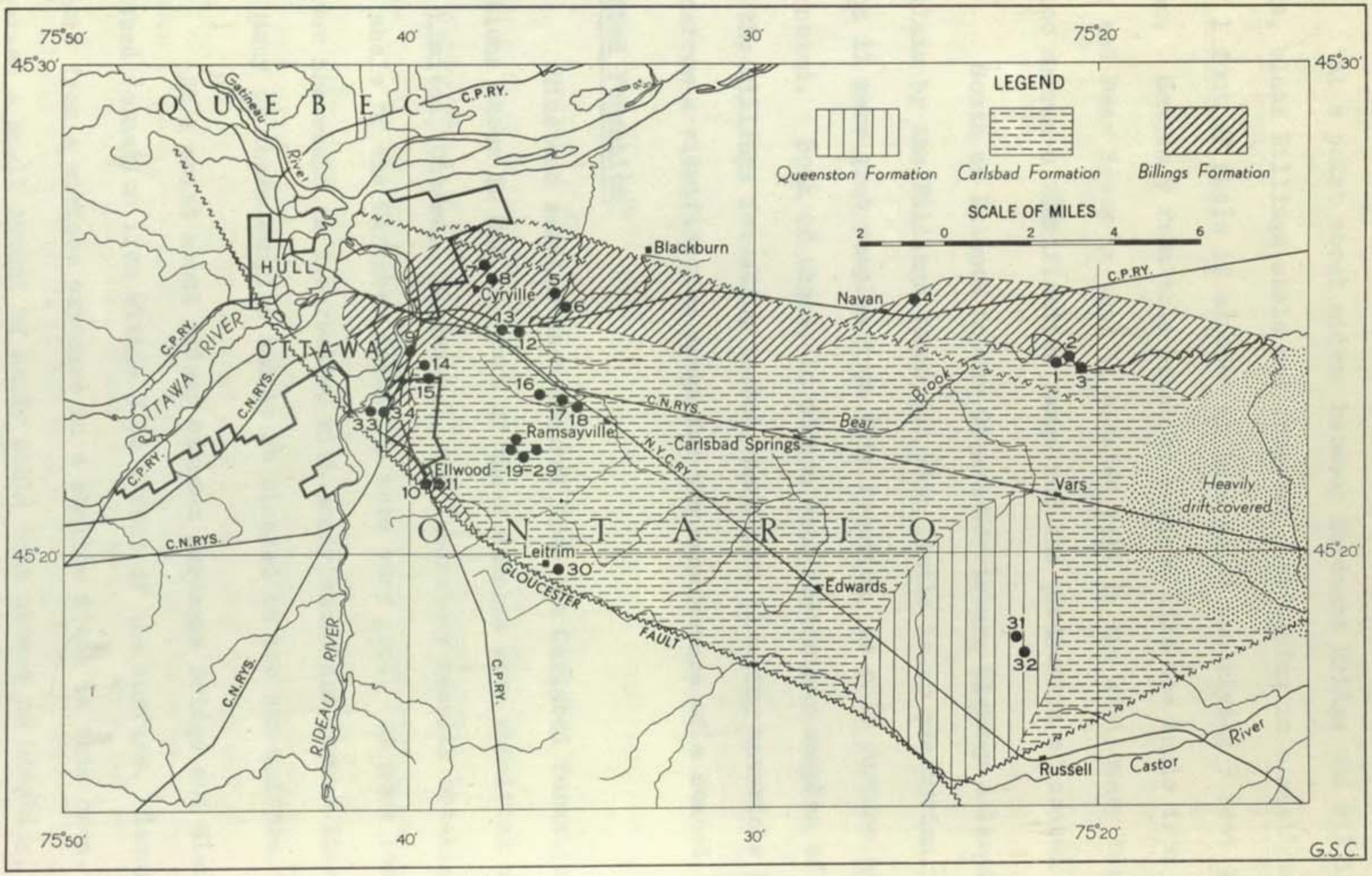
Billings Formation

The black, carbonaceous, fissile shales of the Billings formation were sampled in 6 locations. At Bear Brook, Samples 1, 2, and 3 were taken from exposures in the banks of the brook where about 5 feet of shale is exposed under 2 feet of overburden. All 3 samples proved to be excellent bloating materials in the stationary furnace, but gave poor results when processed in the rotary kiln. The vitrification range proved to be too narrow to allow the making of a coated aggregate in the rotary kiln. Serious sticking and agglomerating took place before satisfactory bloating.

Sample 4 consisted of typical Billings shale from a point one and one-half miles east of Navan. There are no shale exposures in the area but overburden is evidently light since shale had been thrown out in the digging of post holes. Sample 4 was a grab sample of some of this material. The shale appeared to be excessively high in carbon as only surface bloating took place under the rapid heat treatment of the stationary furnace. Rotary kiln tests were not considered warranted.

Billings shale is well exposed in both banks of Green Creek between Cyrville and Blackburn. Samples 5 and 6 came from this location. Both samples proved to be very good bloating materials when tested in the stationary furnace but each had too narrow a vitrification range to allow treatment in the rotary kiln for the production of a coated aggregate.

Just north of Cyrville, the Billings formation lies close to the surface. Sample 7 was a grab sample of shale from a basement excavation where overburden amounted to a thickness of 3 1/2 feet. Samples 8 from the same area was also a grab sample of shale taken from a road ditch where overburden was only a few inches thick. Both shale samples proved to be poor bloaters when given a rapid heat treatment, mainly because of the high content of carbon.



Map No. 1 Ottawa area showing major shale formations and approximate locations of samples.

At a point about midway between Hurdmans Bridge and Billings Bridge, black Billings shale was observed outcropping in a small creek bed. About 1 foot of shale is exposed at this point underlying 3 feet of overburden. Sample 9 from this location behaved like the shale from Green Creek and Bear Brook in that it bloated well in the stationary furnace but had too narrow a vitrification range for the production of coated aggregate.

South of Ellwood on the Ottawa-Morrisburg highway a large area is underlain by the Billings formation with little to no overburden. Samples 10 and 11 were grab samples from this location, as only surface exposures were noted. Both of these, in common with most other samples of shale from the Billings formation tested, were good bloating materials but possessed too narrow a vitrification range for the manufacture of a coated aggregate.

Carlsbad Formation

Nineteen samples were secured from the Carlsbad formation at 5 major locations shown in Map 1. Most of these samples were submitted by Hayley and Sons Limited, Ottawa. In general, the laboratory results obtained on the grey shale of the Carlsbad formation were very good. At some locations however the shale is interbedded with sandy shale and impure limestone so that many of these samples had to be classed as too non-uniform.

At a point about midway between Hurdmans Bridge and Blackburn, the Carlsbad formation lies within 3 to 4 feet of the surface. Samples 12 and 13 came from a surface exposure in a shallow ditch in this area. Sample 12 contained a small amount of sandy shale that showed no bloating, but the remainder of the sample had excellent bloating properties, giving a light, strong, well-rounded product with a bulk density of 51 lb./cu.ft., and a volume expansion of 175 per cent. The vitrification of this material was very wide, allowing easy temperature control. Sample 13 was classed as being too non-uniform because of the large amount of sandy shale present.

Two samples (14 and 15) of the Carlsbad formation came from an area about midway between Hurdmans Bridge and Billings Bridge. Sample 14 was taken in the creek bed opposite the Veterans Health Centre, and represented a 3-foot stratigraphic width of interbedded grey shale and thin (1" to 3") beds of shaley limestone. It proved to be a good bloater in the stationary furnace but the vitrification range was too narrow to give satisfactory results in the rotary kiln.

Sample 15 came from an old quarry a few hundred feet south-west of the location of Sample 14. It represented a 10-foot stratigraphic width of grey shale with narrow, rusty weathering beds of impure limestone. Several rotary kiln runs were made on this material with good results. The best test run gave a product with a bulk density of 41 lb./cu. ft., and a volume expansion of 100 per cent. The agglomerating temperature was about 2000°F. The amount of impure limestone present was not considered too excessive.

Three samples (16, 17 and 18) of Carlsbad shale were taken from exposures on a creek about one mile north-west of Ramsayville. Sample 16 was largely impure limestone and hence gave very poor results. Samples 17 and 18 were soft, light-grey coloured shales and may represent a weathered portion of the usually hard Carlsbad shale. Both of these materials bloated well but had a much too narrow vitrification range to allow rotary kiln processing.

Samples 19 to 25 were surface samples of the Carlsbad formation, taken in an area roughly one and a half miles southwest of Ramsayville. Bedrock in this area lies close to the surface. With the exception of Sample 20, which contained too high a proportion of impure limestone, all materials gave good results. Rotary kiln tests showed that the shale had a wide vitrification range and excellent bloating properties. The products made from these samples had volume expansions of from 25 per cent to 180 per cent and bulk densities of from 29 to 61 lb./cu.ft. Crushing strengths varied from 318 p.s.i. to 2070 p.s.i.

Samples 26 to 29 inclusive were diamond drill cores from four fifty-foot holes drilled in the same general area as the above surface samples. The shale in these sections contained narrow beds of limestone but the amount was not believed to be excessive. The core from the drill holes was crushed to pass a -1/2 inch screen. The feed thus contained a considerable proportion of fine material. Good results were obtained with products showing bulk densities for the -3/8" + 8 mesh fraction varying from 37.5 lb./cu. ft. to 46.5 lb./cu. ft. Crushing strengths varied from 318 p.s.i. to 1034 p.s.i. and volume expansions from 100 to 175 per cent. The maximum temperature to avoid agglomeration of the feed was found to be 2040°F. The wide vitrification range shown by the shale allowed the processing of the fine and coarse material in one operation. Impure limestone present in the feed bloated to a small extent but was much heavier than the expanded shale, and would probably lend itself easily to water separation if a still lighter product were desired.

The Carlsbad formation also lies close to the surface at Leitrim. Sample 30 was a grab sample of surface shale from this location. Although only a small amount of material was submitted, it gave very favourable indications of a wide vitrification range and good bloating properties when tested in the stationary furnace.

Queenston Formation

Two red shale samples (31 and 32) were secured from the Queenston formation. They were taken from a quarry operated-by the Ottawa Brick and Terra Cotta Company, Limited, located four miles north of Russell. A section of the quarry face was noted as follows:

Red clay	- 4 feet
Highly weathered red shale (Sample 31)	- 5 feet
Hard, red shale (Sample 32)	- 5 feet

Both of the above materials proved to be good bloaters but had a much too narrow vitrification range for the production of a coated lightweight aggregate in the rotary kiln.

Two samples of clay were taken from lightweight aggregate tests from the clay pit of the Ottawa Brick and Terra Cotta Company, Limited, located just west of Billings Bridge. Sample 33 was representative of the top bed of plastic grey clay, while Sample 34 was taken from the lower blue clay. The two beds are separated by a bed of sand. Both materials proved to be good bloaters but had too narrow a vitrification range for rotary kiln treatment.

CORNWALL

Cornwall is on the Canadian National, Canadian Pacific, and New York Central railways 57 miles by rail southeast of Ottawa and 69 miles by rail southwest of Montreal.

In the vicinity of Cornwall there occur several patches of stoneless clay in depressions between morainal ridges of glacial drift. At Gray's Creek in Charlottenburg Township, Glengarry County, 2 miles northwest of Cornwall, dark-brown peaty clay is well exposed in the creek banks. The nature of the topography and number of exposures along the creek suggest that there is a large area underlain by this clay. Top soil overburden amounts to about 6 inches to 1 foot in thickness. The dark-brown clay appears to have a thickness of from 3 to 5 feet and overlies a bluish-grey clay, probably of marine origin.

Six samples (35 to 40) of the brown clay were secured from the creek banks, covering a distance of one half mile upstream from where the Montreal highway crosses the creek. All samples proved to be excellent bloaters in the stationary furnace and all had a wide vitrification range. Rotary kiln tests gave quite good results although the crushing strengths were not very high. The products ranged in bulk density from 40 lb./cu.ft. to 49 lb./cu.ft., in crushing strengths from 159 p.s.i. to 636 p.s.i. and in volume expansions from 10 to 20 per cent. In view of the excellent volume expansions shown in the stationary furnace tests a longer retention time than that given in these rotary kiln tests seems desirable. Products from this material might have a somewhat low strength to weight ratio. However, because of good bloating properties and a wide vitrification range, this material appears to have good possibilities as a coated aggregate raw material. Further investigations seem warranted.

NAPANEE

The town of Napanee is approximately midway between Belleville and Kingston. The plant of Napanee Brick and Tile Works, south of the town, uses two kinds of clay, a stratified clay, believed to have been deposited from glacial Lake Iroquois, and a dark-brown peaty clay. The two are separated, laterally, by a ridge of glacial drift and both are underlain by sand. The dark-brown clay resembles that sampled at Grey's Creek near Cornwall.

The light-brown stratified clay is said to extend to a depth of 18 feet although only 10 feet was exposed in the pit. The lower 8 feet (Sample 41) seemed well stratified while the upper 2 feet (Sample 42) was evidently less so. Both samples showed good bloating in the stationary furnace but the vitrification range was narrow. In the rotary kiln tests the vitrification range proved to be too narrow to allow expansion without serious sticking and agglomeration.

The dark-brown peaty clay is said to underlie at least 30 acres and to have an average depth of 5 feet. Overburden consists of about 6 inches of top soil. In the stationary furnace this clay (Sample 43) appeared to have a somewhat narrow vitrification range but bloated well. The rotary kiln test gave a fair product with a volume expansion of 10 per cent.

The product was well rounded but definitely underbloated, showing a bulk density of 58 lb./cu. ft. As would be expected, the crushing strength was high, measuring 1273 p.s.i. The average temperature for the rotary kiln run was 2000°F. However, sticking and agglomeration became quite serious when the temperature was increased beyond 2010°F. It is evident that the vitrification range of this clay requires very accurate temperature control. The material warrants further work as it seems suitable for the manufacture of a coated lightweight aggregate.

BELLEVILLE

At the plant of D.W. Rollins, located 2 miles east of Belleville, dark-brown peaty clay is used in the manufacture of brick. A 2-foot width of clay (Sample 44) was available for sampling. In physical appearance this clay resembles the dark-brown clay found at Cornwall and Napanee. The amount of clay available, where sampled, is believed small. This material bloated well in the stationary furnace but the vitrification range was too narrow to give a good product in the rotary kiln. No volume expansion was evident when treated at just under the temperature at which serious sticking and agglomeration took place.

PETERBOROUGH

A light-brown sandy clay is used for the manufacture of brick by Curtis Brothers, Peterborough. It is brought from a point about 3 miles south of the city. This clay (Sample 45) proved to be a poor bloater with a very narrow vitrification range, fusing to a glass when tested in the stationary furnace. Rotary kiln tests were not warranted.

TORONTO

The Toronto area is underlain by Paleozoic shales of Ordovician age. The Dundas formation, formerly known as the Lorraine formation, underlies the city of Toronto and extends northward in a band about 20 miles wide. It consists of medium grey shale with thin lenticular calcareous and sandy beds. Immediately underlying the city of Toronto on the eroded surface of the Dundas formation are deposits of boulder clay, then inter-glacial beds of sand and clay followed by boulder clay and sand, and finally, by the shallow-water clay and sand of glacial Lake Iroquois. Several brick-producing quarries have exposed the above materials in the Toronto area. Map 2 shows the Toronto area giving the Dundas formation and approximate location of samples.

At the Greenwood Avenue plant of the Toronto Brick Company a section of the interglacial beds was observed as follows:

Sandy overburden	- 15 to 20 feet
Sandy clay (Sample 51)	- 4 feet
Grey clay with numerous thin beds of sand (Samples 49 and 50)	- 8 feet
Light-brown, stratified sandy clay (Sample 48)	- 5 feet
Stratified bluish-grey clay (Samples 46 and 47)	- 13 feet

All of the above samples (46 to 51 inclusive) proved to have too narrow a vitrification range for consideration as coated aggregate raw materials. The upper sandy clay (Sample 51) and the lower bluish-grey clay (Samples 46 and 47) proved to be good bloating materials while the remainder of the samples fused quickly to a glass without appreciable bloating.

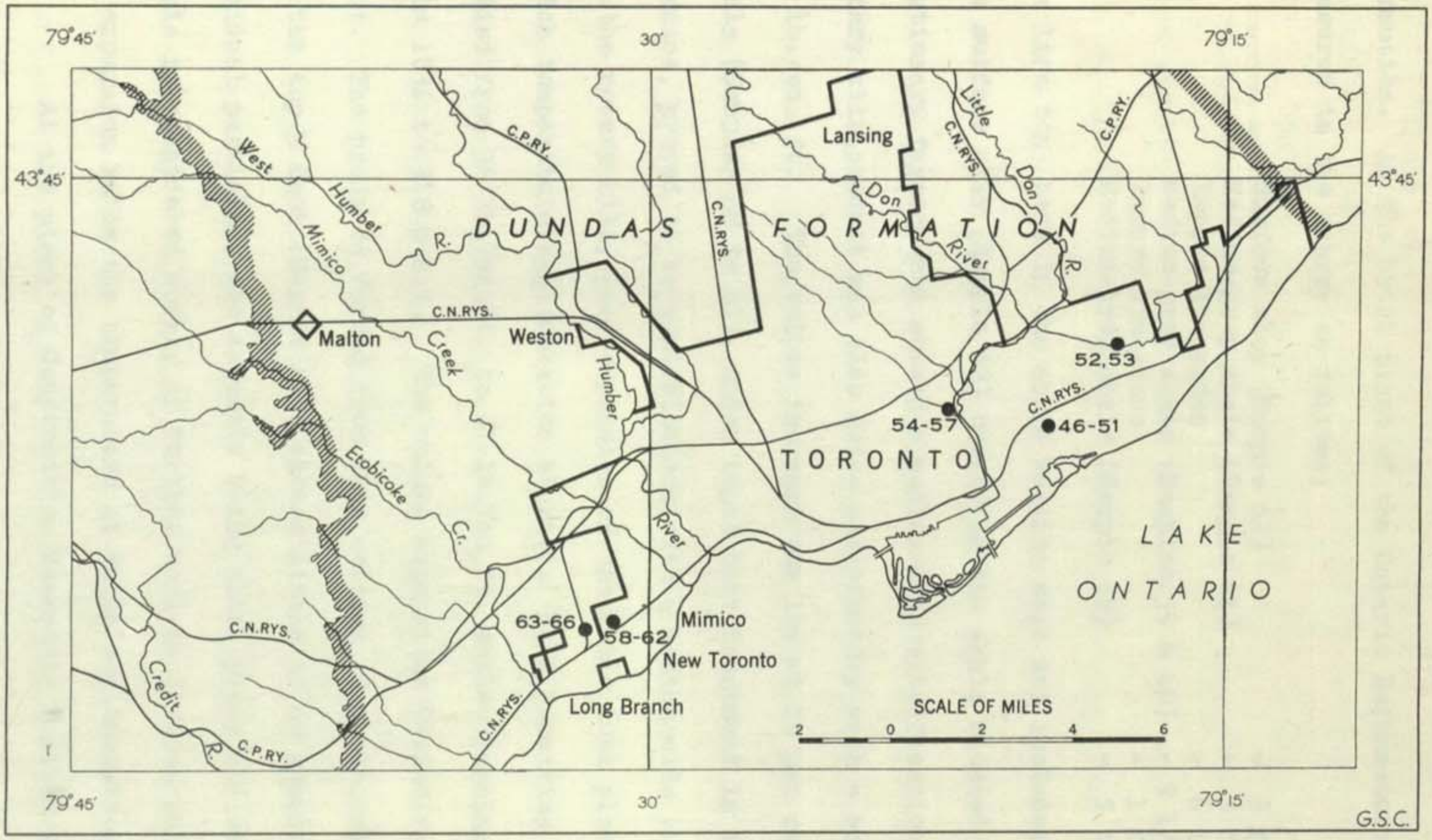
Silty, stratified clay deposited from glacial Lake Iroquois is used for the manufacture of brick at the plant of the Wright Brothers Brick Company on Dawes Road. The upper weathered 3 feet of the deposit (Sample 52 burns red while the underlying 11 feet (Sample 53) burns to a buff color. Several beds of white sand of 1 inch to 3 inches thickness were noted throughout the deposit. Both of these samples were poor bloaters and had an extremely narrow vitrification range, fusing quickly to a glass.

A 90-foot stratigraphic width of grey shale of the Dundas formation is exposed in the Don Valley quarry of the Toronto Brick Company. Overlying the shale are deposits of boulder clay and interglacial sands and clays which total approximately 100 feet in thickness. Frequent, thin hard bands were observed within the shale. These bands are both sandy and calcareous and are not continuous, frequently pinching out laterally. They are usually only a few inches thick.

Four samples (54, 55, 56 and 57) were taken in 10-foot sections of the bottom 40 feet of the quarry face. All four samples proved to be good bloaters in the stationary furnace and showed a medium-wide vitrification range. The calcareous and sandy particles showed no bloating under the same time-temperature conditions. The products formed in the rotary kiln tests showed good volume expansions when fired below the agglomerating temperature. The bulk densities were low but crushing strengths were also very low as the product consisted largely of thin platy particles. Very little rounding of the particles took place.

The lower 20 feet of the quarry face, represented by Samples 54 and 55, gave products with bulk densities of 33 lb./cu. ft. and 41 lb./cu. ft. respecitvely. Volume expansions measured 80 per cent and 75 per cent while the crushing strength for both products was 477 p.s.i. The average kiln temperature for both runs was 2020°F. while agglomeration took place above 2025°F.

The upper 20 feet of the section samples (Samples 56 and 57) gave products with bulk densities of 39 lb./cu.ft. and 41 lb./cu.ft. and crushing strengths of 318 p.s.i. and 159 p.s.i. Volume expansions for both samples measured 100 per cent. The average temperature for both of these runs was 1975°F. and agglomeration took place when the temperature was increased beyond 1980°F. This shale appears to warrant further investigation as a potential source of raw material for coated lightweight aggregates. The product, however, could be expected to have a low strength to weight ratio since the individual particles lack the spherical shape desired in an ideal coated aggregate. The sandy and calcareous material present showed no bloating under the conditions which were effective for the shale. If this shale is used the foreign material should be avoided as much as possible.



Map No. 2 Toronto area showing Dundas Formation and approximate locations of samples.

On the flat area near Mimico very thin drifts cover the Dundas formation. At the brick plant of the Ontario Reformatory, a section was measured in the quarry as follows:

Surface clay (Sample 62)	- 3 feet
Medium-grey shale (Sample 61)	- 3 feet
Impure limestone	- 6 inches
Medium-grey shale (Samples 59 & 60)	- 9 1/2 feet
Impure limestone	- 1 foot
Medium-grey shale (Sample 58)	- 5 feet

The limestone beds in the above section were not included in the samples. The surface clay (Sample 62) overlying the shale bloated well in the stationary furnace and showed a medium-wide vitrification range. The rotary kiln product was also quite satisfactory with a bulk density of 40 lb./cu. ft. The volume increase was low at 10 per cent. All the shale (Samples 58 to 61), under rapid heat treatment in the stationary furnace, proved to be good bloaters with a medium-wide vitrification range. In the rotary kiln, good expansion of the shale took place below 2030°F at which temperature agglomeration started. Bulk densities of the products varied from 36 lb./cu.ft. to 51 lb./cu.ft. while crushing strengths ranged from 1034 to 318 p.s.i. The volume expansions varied from 30 to 100 per cent. The products formed from this section of shale, with the exception of the top 3 feet (Sample 61), showed little to no rounding of the individual particles, the majority being thin, platy and weak. However this shale is considered worthy of further work as it does show a good degree of expansion below the temperature at which agglomeration takes place.

At the plant of Construction Materials Limited the grey shale of the Dundas formation is used for the production of brick. The company's quarry exposes a 48 foot width of shale containing the usual narrow beds of impure limestone. All four 12-foot samples proved to be good bloaters with a medium wide vitrification range. The upper 24 feet, represented by Samples 65 and 66, gave well-rounded products with bulk densities of 47 lb./cu.ft. and 36 lb./cu.ft. The volume expansions measured 75 per cent and 80 per cent and crushing strengths 557 p.s.i. and 318 p.s.i. The average kiln temperature was allowed to rise above 2010°F.

The lower 24 feet of the quarry face (Samples 63 and 64) appeared to be more thinly bedded than the upper half since the product contained a large amount of thin platy weak particles. The volume expansions for both runs was 100 per cent. The bulk densities of the products were 39 lb./cu. ft. and 37 lb./cu.ft. and crushing strengths were 318 p.s.i. and 159 p.s.i. The average kiln temperature for both runs was just under 1980°F. at which temperature agglomeration started. On the basis of these tests the upper 24 feet of the section exposed in the quarry would appear to be most suitable for development since the products have a better shape and a higher strength to weight ratio.

In summary, it appears that the shale of the Dundas formation in the Toronto area offers the greatest promise. It is evident that some sections of these beds have better firing properties than others. The vitrification range of the shale is not exceptionally wide. Close sizing of the feed and accurate temperature control would be necessary to produce a uniform product and to avoid agglomeration which takes place rapidly once the critical temperature-time conditions are exceeded. Thin-bedded sections of the shale would have to be avoided to eliminate a laminated product as also would the calcareous sandy layers present in varying amounts throughout the sampled sections. Hand sorting of this material before firing, or before gravity separation after firing, might have to be resorted to. In general the Pleistocene clays of this area are high in lime and consequently have too narrow a vitrification range for rotary kiln treatment in the production of coated lightweight aggregate. Some of these clays, however, might be well adapted to the sintering machine process for lightweight aggregate manufacture.

STREETSVILLE

Thinly bedded, flat lying, brick-red Queenston shale is quarried at Streetsville by F.B. McFarren Limited for use in the manufacture of bricks. A section of the quarry was noted as follows:

Red top soil	- 2 feet
Red shale with narrow grey-green calcareous bands (Sample 68)	- 5 feet
Red shale (harder than overlying shale) (Sample 67)	- 10 feet

Both of these samples bloated well in the stationary furnace but their vitrification ranges were much too narrow since no satisfactory bloating took place in the rotary kiln before sticking and agglomeration became serious.

MILTON

A 56-foot section of red Queenston shale was sampled in the quarry operated by the Milton Brick Company. Six samples (69 to 74) were taken, all with similar firing qualities. They bloated well in the stationary furnace tests but their vitrification ranges were too narrow. When fired in the rotary kiln at a temperature just under that at which sticking became serious (2050°F.), very poor products were formed.

HAMILTON

The Hamilton area is underlain by Ordovician and Silurian shales, limestones, and sandstones. The most important shale formations are the Queenston and Medina ones. The Queenston formation is uniform in physical appearance and firing properties, and consists of hard, red shale with occasional green streaks. The Medina formation includes shale, sandstone, and limestone. The shale, known as the Cabot Head member, consists predominantly of grey shale with narrow bands of sandy limestone. The approximate distribution of these shales in the Hamilton area is shown in Map 3.

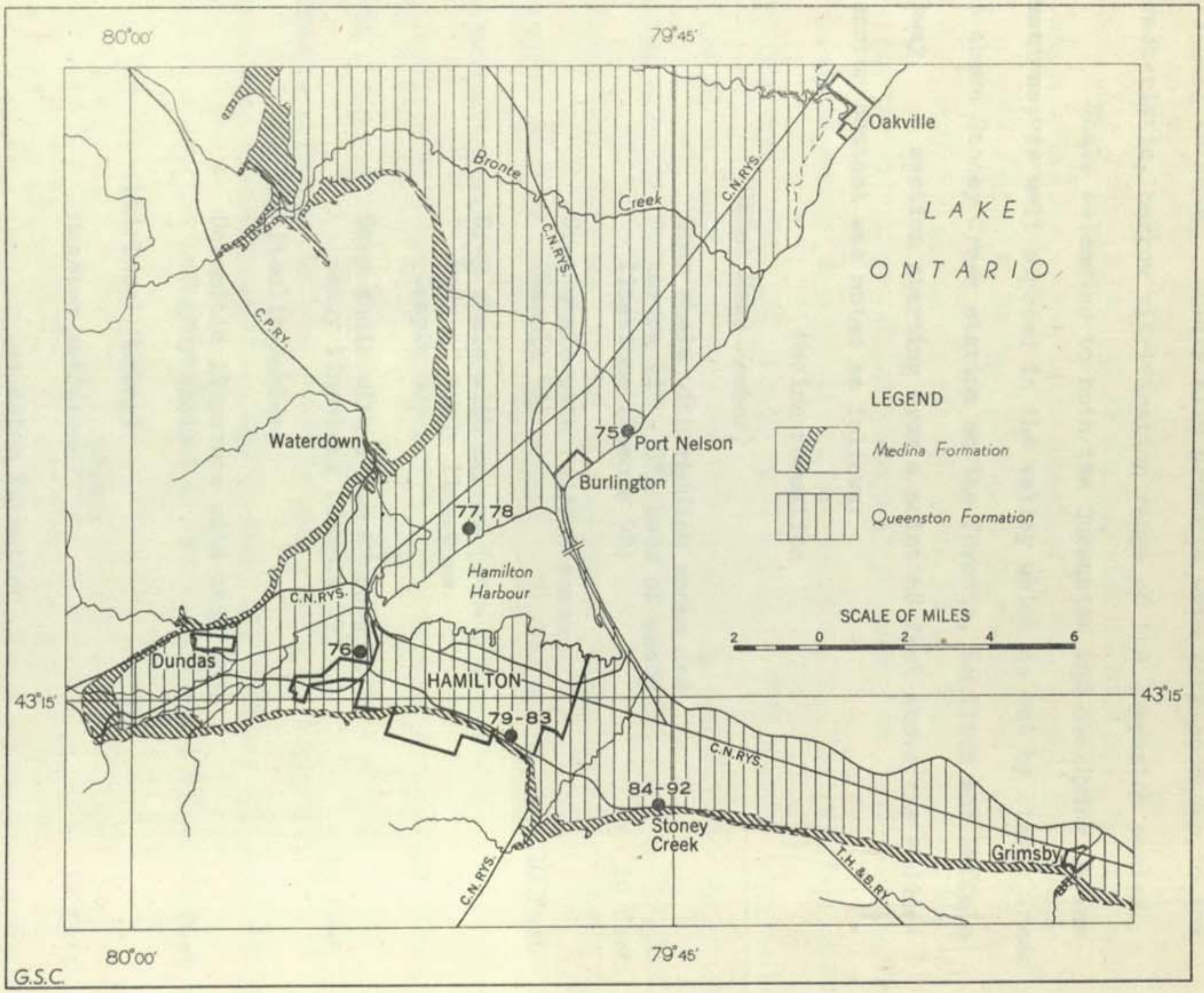
Clays deposited from glacial Lake Iroquois are found in the lower Dundas Valley lying behind the high gravel bar that extends north through Dundurn park.

At Port Nelson, approximately 2 miles northeast of Burlington, red Queenston shale was observed outcropping in a small creek. Sample 75 was representative of a 10-foot width of this shale exposed under 10 feet of weathered shale and topsoil. In the stationary furnace this shale bloated well but had a narrow vitrification range. Rotary kiln tests confirmed this since no satisfactory bloating took place below 2050°F, when the charge began to agglomerate very quickly.

A red, surface clay believed to have been deposited from the waters of glacial Lake Iroquois is used for the manufacture of flower pots by the Foster Pottery Company, Hamilton. This material (Sample 76) bloated well in the stationary furnace showing a wider vitrification range than the Queenston shale. However, the rotary kiln product seemed very poor and it is evident that close temperature control would be necessary to allow satisfactory bloating without agglomeration.

The Hamilton plant of the National Sewer Pipe Company uses a mixture of surface clay and Queenston shale for the production of sewer pipe. Samples 77 and 78 were grab samples from the stockpiles of shale and clay, respectively. The shale behaved in firing other samples of the Queenston shale. It bloated well but had too narrow a vitrification range to allow the production of a coated aggregate in the rotary kiln. The clay (Sample 78), which is merely weathered shale, had a somewhat wider vitrification range than the shale. This, however, was still insufficient to allow satisfactory bloating without agglomeration.

The Hamilton Pressed Brick Company operates a quarry in the Queenston shale exposing a 75-foot face near the top of the formation. Five samples (79 to 83) were taken. All these materials bloated well in the



Map No. 3 Hamilton area showing major shale formations and approximate locations of samples.

stationary furnace. Rotary kiln products were very poor due to the characteristic, narrow vitrification range of the Queenston shales.

Shale belonging to both the Queenston and overlying Medina formations, is well exposed in the valley which is cut by Stoney Creek just above Stoney Creek station on the Toronto, Hamilton and Buffalo railway. A section starting from a point 68 feet above the Medina-Queenston contact was noted as follows:

Medina Formation	
(Cabot Head Member)	
Grey shale with reddish zones and narrow (1" - 3") beds of sandy limestone (Sample 92)	- 10 feet
Grey shale with reddish zones (Sample 91)	- 10 feet
Grey shale with narrow (1" - 2") beds of sandy limestone (Sample 90)	- 18 feet
Grey shale with 1" to 6" beds of sandy limestone (Sample 89)	- 15 feet
(Manitoulin Member)	
Dolomitic limestone with thin beds of grey shale	- 5 feet
(Whirlpool Member)	
Massive sandstone	- 10 feet
Queenston Formation	
Uniform, hard, red shale with occasional green streaks (Samples 84 to 88)	- 85 feet

The Queenston shale, represented by Samples 84 to 88, behaved like other tested samples of the Queenston shale. All samples bloated well in the stationary furnace but poor products were obtained in the rotary kiln at temperatures just under that at which agglomeration started. The grey shales belonging to the Cabot Head member proved to be very good bloaters possessing a much wider vitrification range than the Queenston shale.

The occasional narrow beds of sandy limestone are detrimental but might be eliminated by careful mining.

The lower 15 feet of shale, represented by Sample 89, proved to be too non-uniform due to the large amount of included sandy limestone.

The overlying 38 feet of shale, represented by Samples 90, 91, and 92, gave very satisfactory products in the rotary kiln. The volume expansions for all three samples measure 75 per cent; the bulk densities of the products varied from 41 lb./cu. ft. to 49 lb./cu.ft.; and the crushing strengths varied from 1034 p.s.i. to 1114 p.s.i. The average kiln temperature for the three rotary kiln runs was 2030°F and agglomeration of the shale started when the temperature was increased beyond 2040°F. The products were well-rounded, light and strong. The amount of sandy limestone in the upper 38 feet of sampled shale did not appear to be excessive. Probably the greatest difficulty in utilizing the grey Cabot Head shale would be the availability of large, easily-quarried quantities. These shales form a steep slope along the Niagara escarpment and most outcrops are overlain by a considerable thickness of hard dolomite which would make quarrying costs prohibitive. Careful prospecting, however, might locate a sufficient quantity of shale where the overlying limestone has been removed by erosion.

GRIMSBY

The top of the Queenston formation and the bottom of the Medina formation are exposed in Grimsby Creek on the south side of the town of Grimsby. A section was measured as follows:

Medina Formation

(Whirlpool Member)

Massive sandstone - 10 feet

Queenston Formation

Red shale with occasional streaks of green sandy shale (Samples 93 to 96) - 80 feet

All the above samples bloated well in the stationary furnace but had the narrow vitrification range characteristic of the Queenston formation. No satisfactory bloating could be obtained in the rotary kiln when operated at temperatures lower than those at which the particles began to stick and agglomerate.

JORDAN

At Jordan, 7 miles west of St. Catharines, red Queenston shale is exposed in the banks of Twenty Mile Creek. Sample 97 was representative of 10 feet of the shale. This material bloated well in the stationary furnace but a poor product was obtained in the rotary kiln due to the narrow vitrification range.

ST. CATHARINES

A massive grey clay is worked for the manufacture of brick and tile by the Paxton Brick and Tile Company at St. Catharines. The deposit appears to have a thickness of at least 40 feet. Sample 98 was representative of the bottom 20 feet of the pit and Sample 99 of the upper 20 feet. Both of these materials proved to be poor bloaters in the stationary furnace. They had a narrow vitrification range and fused quickly to a glass. Rotary kiln tests were considered unwarranted.

QUEENSTON

Red, Queenston shale is exposed along the highway leading to the bridge at Queenston. A 30-foot section of the shale, immediately underlying the basal sandstone member of the Medina formation, was sampled for laboratory tests (Samples 100 and 101). Both samples bloated well in the stationary furnace but when processed in the rotary kiln their narrow vitrification range resulted in very poor products.

Two miles north of the above location a 30-foot section of the red shale was sampled on the west bank of the Niagara river (Samples 102 and 103). This section appears to be about 50 feet lower stratigraphically than the exposure at Queenston. The firing properties, however, were almost identical with those of the shale from Queenston.

NORWICH

Post-glacial clay is used for the manufacture of brick and tile at the plant of the Norwich Brick and Tile Company. A section of the clay pit was noted as follows:

Soil overburden with flint pebbles - 1 foot
Dark-brown clay (red-burning) (Sample 106) - 1 1/2 feet
Dark-brown clay (buff-burning)(Sample 105) - 4 feet
Light-brown clay (buff-burning) (Sample 104) - 2 feet

The upper red-burning clay (Sample 106), when tested in the rotary kiln, proved to be non-uniform. Some portions of it were very well bloated and possessed wide vitrification ranges whereas other portions were the opposite. The buff-burning materials (Samples 105 and 104) proved to be poor bloaters possessing narrow vitrification ranges.

BROWNSVILLE

At the brick plant of Dellier and Son, Brownsville, the following section was noted in the clay pit:

Topsoil - 1 foot
Dark-brown clay (red-burning)(Sample 108) - 2 feet
Dark-brown clay (buff-burning)(Sample 107) - 3 feet

In the stationary furnace these materials proved to be poor bloaters and had very narrow vitrification ranges, fusing quickly to a glass.

COATSWORTH

Local clay is used for the manufacture of brick and tile at the plant of A.W. Hill and Sons, located at Stevenson, near Coatsworth in Kent County. A sample of the clay used (Sample 109) was submitted by the company for laboratory testing.

Stationary furnace tests indicated that the material bloated well and had a wide vitrification range. These results were confirmed in the rotary kiln tests in which a satisfactory well-rounded product was formed. The product showed a volume expansion of 30 per cent, a bulk density of 46 lb./cu. ft. and a crushing strength of 557 p.s.i. The average kiln temperature for the run was 1935°F. while agglomeration started when the temperature was increased beyond 1950°F. Although the crushing strength of the product was somewhat low in relation to its weight, this material is considered to offer reasonably good possibilities as a raw material for coated lightweight aggregates.

ELGINFIELD

The plant of Chester McComb, Elginfield, uses post-glacial clay for the manufacture of brick. A section of 9 feet of clay was exposed in the clay pit but the deposit is reported to have a depth of 40 feet. The following section was measured:

Topsoil - 1 foot
Iron-stained, bedded, brown clay (red-burning) (Sample 111) - 4 feet
Light-grey clay (buff-burning) (Sample 110) - 5 feet

The materials were poor bloaters when tested in the stationary furnace and had very narrow vitrification ranges. Rotary kiln tests were considered unwarranted.

KITCHENER

At the plant of C. Koebel and Son, located at St. Clements, about 12 miles northwest of Kitchener, samples were obtained of a post-glacial clay used for the manufacture of tile. A section of the pit was noted as follows:

Topsoil - 1 foot
Dark brown clay (red-burning) Sample 113) - 2 feet
Light-brown clay (buff-burning) Sample 112) - 3 1/2 feet

The materials proved to be poor bloaters in the stationary furnace and had narrow vitrification ranges, fusing quickly to a glass.

A 6-foot sample of buff-burning clay (Sample 114) was secured at the plant of A.C. Martin, Wallenstein, about 15 miles northwest of Kitchener. When tested in the stationary furnace this clay proved to be a very poor bloater and had an extremely narrow vitrification range. Rotary kiln tests were not made.

A 10-foot section of clay was sampled in the clay pit of E.E. Seegmiller Ltd., located between Waterloo and Bridgeport. A section of the pit was noted as follows:

Light-brown clay with a few limestone pebbles (Sample 116) - 4 feet
Fine-grained, blue clay with a few scattered pebbles of red Queenston shale (Sample 115) - 6 feet

The upper clay represented by Sample 116 bloated poorly, and had a very narrow vitrification range. The lower blue clay proved to be good bloating material but also had too narrow a vitrification range to warrant rotary kiln tests.

BRAMPTON

Red shale belonging to the Queenston formation is used at the Brampton Pressed Brick Company. A section in the company's shale quarry was noted as follows:

Brown clay with pebbles - 6 feet
Red shale with streaks of sandy green shale (red-burning) (Sample 119) - 8 feet
Red shale with streaks of sandy green shale (buff-burning) (Sample 118) - 4 feet
Red shale with a few streaks of sandy green shale (red-burning) (Sample 117) - 7 feet

The above samples bloated well but their vitrification ranges were too narrow to allow satisfactory bloating in the rotary kiln below agglomeration temperatures.

CHELTENHAM

A 34-foot width of red Queenston shale is exposed in the quarry of the Interprovincial Brick Company's Cheltenham plant. Four stratigraphic samples (120, 121, 122 and 123) were taken from the quarry face. All proved to be good bloaters with narrow vitrification ranges. For the rotary kiln tests, the shale particles started to stick and to agglomerate at about 2070°F. Below this temperature the shale showed no appreciable expansion.

LIMEHOUSE

Two shale beds belonging to the top of the Cabot Head member of the Medina formation are exposed in a railway cutting at Limehouse. The upper 7-foot bed of grey shale is separated from the lower 3-foot bed of red shale by calcareous sandstone. The grey shale (Sample 125) contains thin limestone beds while the red shale (Sample 124) seems to be fairly pure. Both materials proved to be poor bloaters with very narrow vitrification ranges.

LINDSAY

The Wagstaff Brick and Tile Company and the Curtin Brick Yard are using surface clays for the manufacture of brick and tile at Lindsay.

At the Wagstaff Brick and Tile plant samples were taken from a light-brown plastic clay (Sample 126) and a sandy clay (Sample 127). Both of these materials are buff-burning. When fired rapidly in the stationary furnace both materials proved to be poor bloaters with very narrow vitrification ranges. Rotary kiln tests were considered unwarranted.

At the Curtin Brick Yard plant, a dark-brown buff-burning clay (Sample 128) and a red-burning clay (Sample 129) were sampled. Stationary furnace tests indicated that both materials possessed vitrification ranges too narrow to warrant rotary kiln tests. The buff-burning clay (Sample 128) showed very little evidence of bloating under a rapid heat treatment whereas the red-burning clay (Sample 129) bloated quite well.

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Map No. 4 Eastern Ontario showing locations of clays and shales having possibilities for the manufacture of coated lightweight concrete aggregate.

Figure IV

SUMMARY OF LIGHTWEIGHT AGGREGATE TEST RESULTS - ONTARIO

Materials having good possibilities for coated aggregate production		Materials that are good bloaters but are not considered suitable for coated aggregate manufacture because of sticking and agglomerating characteristics		Materials that are poor bloaters		Materials that are too refractory (showing no bloating or fusion when fired in stationary furnace at 2400 F for 5 minutes)		Materials that are too non-uniform in bloating qualities	
Locality	Sample No.	Locality	Sample No.	Locality	Sample No.	Locality	Sample No.	Locality	Sample No.
Ottawa-shale	12	Ottawa-shale	1-3	Ottawa-shale	4	(No refractory materials found)		Ottawa-shale	13
Ottawa-shale	15	Ottawa-shale	5,6	Ottawa-shale	7,8			Ottawa-shale	16
Ottawa-shale	19,21-25	Ottawa-shale	9	Peterborough-clay	45			Ottawa-shale	20
Ottawa-shale	26-29	Ottawa-shale	10,11	Toronto-clay	48-50			Hamilton-shale	89
Ottawa-shale	30	Ottawa-shale	14	Toronto-clay	52,53			Norwich-clay	106
Cornwall-clay	35-40	Ottawa-shale	17,18	St. Catherines-clay	98,99				
Napanee-clay	43	Ottawa-shale	31,32	Norwich-clay	104,105				
Toronto-shale	54-57	Ottawa-clay	33,34	Brownsville-clay	107,108				
Toronto-shale	58-61	Napanee-clay	41,42	Elginfield-clay	110,111				
Toronto-clay	62	Belleville-clay	44	Kitchener-clay	112,113				
Toronto-shale	63-66	Toronto-clay	46,47,51	Kitchener-clay	114				
Hamilton-shale	90-92	Streetsville-shale	67,68	Kitchener-clay	116				
Coatsworth-clay	109	Milton-shale	69-74	Limehouse-shale	124,125				
		Hamilton-shale	75	Lindsay-clay	126,127				
		Hamilton-clay	76	Lindsay-clay	128				
		Hamilton-shale	77						
		Hamilton-clay	78						
		Hamilton-shale	79-83						
		Hamilton-shale	84-88						
		Grimsby-shale	93-96						
		Jordan-shale	97						
		Queenston-shale	100-103						
		Kitchener-clay	115						
		Brampton-shale	117-119						
		Cheltenham-shale	120-123						
		Lindsay-clay	129						