Mines Branch Technical Bulletin TB 51

LIGHTWEIGHT CONCRETE AGGREGATES FROM CLAYS AND SHALES IN ONTARIO

by

H. S. Wilson*

ABSTRACT

The first half of the report includes a description of the various types of lightweight aggregates, the properties of lightweight concrete, the history of the expanded-clay and -shale industry, and production processes. Various theories on the causes of bloating are outlined and discussed. It is concluded that in most instances the chemical analysis of a material can be used to determine whether the liquid phase formed on heating will be of a viscosity to entrap bloating gases. The compounds that release bloating gas may be carbonates, organic matter, sulphates, sulphides, hydrous minerals, or ferric oxide. The laboratory equipment and test procedures are described, and a brief account of the Palaeozoic and Pleistocene geology of Ontario and Quebec is given.

The second half of the report consists of brief descriptions of the 111 locations from which 211 samples were taken, and the results of the tests made. Fifty-five samples from 30 locations show promise of being suitable raw materials for production by the rotary kiln process. Some others might be used in the sintering process.

---

* Senior Scientific Officer, Mineral Processing Division, Mines Branch, Department of Mines and Technical Surveys, Ottawa, Canada.

Direction des mines

Bulletin technique TB 51

AGRÉGATS LÉGERS À BÉTON FABRIQUÉS À PARTIR DES ARGILES ET SCHISTES ARGILEUX EN ONTARIO

par

H.S. Wilson*

RÉSUMÉ

La première moitié du présent rapport comprend une description des divers types d'agrégats légers, les propriétés du béton léger, l'évolution de l'industrie des argiles et schistes gonflants, et les méthodes de production. L'auteur passe en revue et évalue les différentes théories sur les causes du gonflement. Il conclut que dans la plupart des cas, l'analyse chimique du matériau employé peut servir à déterminer si la phase liquide qui résulte du chauffage sera suffisamment visqueuse pour retenir les gaz qui provoquent le gonflement. Les composés qui produisent les gaz de gonflement peuvent être des carbonates, des matières organiques, des sulfates, des sulfures, des minéraux hydratés, ou de l'oxyde ferrique. Cette partie contient une description de l'outillage de laboratoire et des méthodes d'essai, ainsi qu'un bref exposé de la géologie du Paléozoïque et du Pléistocène en Ontario et au Québec.

La deuxième partie du rapport décrit brièvement les 111 endroits d'où proviennent les 211 échantillons, ainsi que les résultats des épreuves. Cinquante-cinq échantillons provenant de 30 endroits différents représentent des matières premières susceptibles de produire de bons agrégats légers par le procédé du four rotatoire. Certains autres échantillons peuvent être utilisés dans le procédé de boulettage.

*Chargé de recherches principal, Division du traitement des minéraux, Direction des mines, ministère des Mines et des Relevés techniques, Ottawa, Canada.

CONTENTS

CONTENTS (cont'd)

FIGURES

PREFACE

In 1949, the Mines Branch began a survey of sources of raw materials for the production of lightweight concrete aggregate. Between 1952 and 1954, six Memorandum Series reports were published giving the results of tests on materials from various provinces. The six reports are:

Preliminary Report on Coated Lightweight Concrete Aggregate from Canadian Clays and Shales -

Part I	-	Alberta, No. 117
Part II	-	Manitoba and Saskatchewan, No. 120
Part III	-	Ontario, No. 121
Part IV	-	New Brunswick, Nova Scotia and Prince Edward Island, No. 122
Part V	-	Quebec, No. 126
Part VI	-	British Columbia, No. 128

Since publication of the above reports, the investigation of potential sources of lightweight aggregate raw materials has been extended and broadened as interest in this subject has grown in Canada. In the laboratory program, techniques of evaluation have been refined.

For the past few years, the provinces of Quebec and Ontario have received considerable attention. Technical Bulletin TB 48, entitled "Lightweight Concrete Aggregates from Clays and Shales in Quebec", which was published recently, is a consolidation of all phases of this investigation on raw materials from Quebec, and includes the results published in Part V.

This report is similar to TB 48 in that it comprises all work done to date on raw materials from Ontario, including the results published in Part III. The experimental work from Part III, which was written by J. G. Matthews, is identified by an asterisk (*) in this report.

The experimental phase of the investigation was primarily to evaluate the materials for processing by rotary kiln. Many of the materials considered unsuitable for this method could probably be processed by sintering.

The tests reported here are only preliminary, and are intended mainly to eliminate those materials that show little or no promise of being suitable. If more thorough investigations are to be carried out, work can be concentrated on those materials that show the most promise.

The section of this report describing geology refers to both Ontario and Quebec. Because of the continuity of formations and similarity of the geology concerning clays and shales, a more comprehensive picture of this phase of study is obtained by examining the geology of the two provinces at the same time. Although the clays of southern Ontario are lacustrine and those of southern Quebec are marine, they are both post-glacial and were deposited at approximately the same period.

INTRODUCTION

Definition of Lightweight Concrete Aggregate

A lightweight concrete aggregate is any inert material which, when bound together by cement, forms concrete of unit weight significantly less than that of concrete incorporating conventional aggregate. The unit weight of lightweight structural concrete is 90 to 110 lb/cu ft, and of conventional structural concrete, 140 to 150 lb/cu ft.

Lightweight Aggregate Materials

The most commonly used materials are clay, shale, slag, cinders, pumice, vermiculite, and perlite. Other materials, used little if any in Canada, are volcanic ash, tuff, scoria, and diatomite. The materials in the latter group are naturally-occurring lightweight aggregates. They need only to be crushed and properly graded to be used in concrete. Of the first group, only cinders and pumice do not need processing, other than crushing and grading, to render them suitable to be used in lightweight concrete. Clay, shale, slag, vermiculite and perlite require processing to develop their lightweight characteristics.

In Canada, the materials most widespread in occurrence are clays and shales which are found in all provinces. They are the so-called "common" clays and shales that are used in the manufacture of brick and structural tile. The other materials are found only in certain areas of the country.

Expanded slag, a by-product of the iron and steel industry, is produced at only three locations in Canada.

Cinders are derived from the combustion of coal. This was once the principal lightweight aggregate, but the number of sources of significant quantities of cinders has been decreasing for several years because of the increased use, by industry, of oil and gas rather than coal.

Pumice, which has been used to only a limited extent in Canada, is imported from the United States. Deposits are known to exist in the mountainous regions of Western Canada, but have not been developed commercially.

Vermiculite deposits exist in Ontario but few are comparable to some of those in other countries. Exfoliated vermiculite was produced locally from one deposit in 1957, but at present all the vermiculite used in Canada is imported from the United States and the Union of South Africa.

Perlite is also imported from the United States, although deposits have been found in central British Columbia.

This report deals exclusively with the clays and shales occurring in the provinces of Ontario and Quebec.

Properties of Lightweight Concrete

Structural concrete made with conventional aggregate, such as sand and gravel or crushed stone, usually has a unit weight of 140 to 150 lb/cu ft. Concrete of similar strength incorporating an expanded clay or shale lightweight aggregate has a unit weight of 90 to 110 lb/cu ft. A standard 8 x 8 x 16 in. conventional concrete masonry block weighs 42 to 46 lb. The same block made of lightweight concrete weighs 24 to 28 lb. This 30 to 40 per cent reduction in weight of concrete is the important feature of lightweight aggregate. Illustrations of the savings which have resulted from the use of lightweight concrete rather than conventional concrete include:

1. Lightweight concrete was used in the deck of the San Francisco-Oakland Bay bridge when it was built in 1936. The reported saving due to the reduction in weight was $3,000,000.

2. The cruciform, 42-storey, Royal Bank of Canada building, the central structure in the Place Ville Marie project in Montreal, is the largest office building in the Commonwealth. The use of 30,000 cu yd of lightweight structural concrete resulted in a saving of 1200 tons of structural steel, because the concrete weighed about 14,000 tons less than conventional concrete.

3. Canada's tallest lightweight concrete frame building is the National Trust Building in Toronto. Approximately 13,000 cu yd of lightweight structural concrete were used. This resulted in a saving in dead load of 6000 tons.

4. A saving of 1000 tons resulted from the use of lightweight concrete in the dome and ceilings of the Basilica at Ste. Anne de Beaupré, P.Q.

Many structures, such as homes, churches, bridges, auditoriums, officesand industrial buildings, using lightweight concrete in both monolithic and masonry forms have been built in Canada.

Although such concrete has a unit weight considerably less than that of conventional concrete, it frequently can be designed to have a compressive strength as high as 6000 psi. Structural concrete should have a compressive strength of at least 2000 psi. This can normally be achieved using lightweight aggregate and a cement factor of 5 bags per cu yd of concrete.

Comparing a lightweight concrete and a conventional concrete of equal compressive strengths, the modulus of elasticity of the lightweight concrete will be lower than that of the conventional concrete. If these two concretes are made into beams of the same size and loaded identically, the deflection of the lightweight beam will be the greater. However, if the two beams are of the same weight and width, the depth of the lightweight beam will be greater. When loaded identically, the deflection of the lightweight beam will be less than that of the conventional beam. It is evident that, if deflection of a beam is important, a lightweight concrete beam would have to be larger than would a beam made of conventional concrete (1).

Thermal conductivity of lightweight concrete is considerably lower than that of conventional concrete. Zoldners, Malhotra and Wilson (2) measured the coefficient of thermal conductivity of concretes made with aluminous cement and four different aggregates, at elevated temperatures. At various mean temperatures up to about 800°C, the coefficient of expanded shale concrete (84.96 lb/cu ft) was between 3.28 and 4.29 Btu/hr.sq ft.deg F/in., of anorthosite concrete (143.25 lb/cu ft) was between 6.01 and 7.79, of ilmenite concrete (231.01 lb/cu ft) was between 7.84 and 9.91, and of phonolite concrete (134.90 lb/cu ft) was between 5.04 and 9.60.

The National Bureau of Standards (3) compared one shale and two clay lightweight aggregate concretes with a concrete incorporating a sand and gravel aggregate. Four mixes were made with each aggregate, the cement content being varied from approximately 3 to approximately 9 bags per cu yd of concrete. The thermal conductivity of the shale aggregate concrete varied from 3.19 to 4.08 at a mean temperature of 119°C. The values of one clay aggregate concrete varied from 2.82 to 3.51, and of the other, from 1.36 to 1.93. The values of the sand and gravel concrete varied from 6.20 to 9.59. The unit weight of the oven dry shale concretes varied from 88 to 100 lb/cu ft. The first clay concrete weighed from 75 to 90 and the other weighed from 53 to 71 lb/cu ft. The unit weights of the sand and gravel concretes varied from 132 to 136 lb/cu ft.

Using the same concrete mixes, the curing shrinkages were measured. Measurements were made after the concretes were cured at 70°F and 55 per cent relative humidity for 100 days, and were calculated as per cent. The average shrinkage of the four mixes using shale aggregate was 0.082 per cent. The one clay aggregate concrete shrank 0.095 per cent and the other 0.069 per cent. The average shrinkage of the sand and gravel concretes was 0.051 per cent. This indicates that lightweight concrete shrinks more than conventional concrete in curing.

History of the Industry

The expanded shale industry began in the United States in 1920 when a patent was obtained by John Hayde. The first plant was built at Kansas City, Missouri. The first plant in Canada was constructed in 1927, near Toronto. The second plant in Canada was not built until 1953, but expansion of the industry has been rapid since then. There were twelve plants in operation at the end of 1962. Production during 1962 amounted to about 447,000 cu yd, valued at $2,500,000.

Production Methods

There are two processes by which a clay or shale is converted from its natural state to a lightweight concrete aggregate: by rotary kiln, and by sintering.

The rotary kiln process is the only one used in Canada. In this process a clay or shale is heated to incipient fusion in approximately 20 to 45 minutes and cooled rapidly. To result in a lightweight aggregate the raw material must bloat at nearly the same temperature as fusion begins. Feed is at least minus 2 inch.

A shale needs only to be crushed and screened to the desired size before being fed to the kiln. Some clays may also be handled in the same manner. Other clays, however, may not be sufficiently consolidated to maintain the desired size between the screening operation and the point in the kiln where they begin to harden. An excessive amount of too fine material would result. To overcome this, such clays must be ground finer than otherwise necessary and pelletized in a drum or disc pelletizer or by extrusion. Water sprayed onto the ground clay, combined with the tumbling or rolling action in a drum or disc, pelletizes the fine particles to the desired size. In extrusion, water is mixed with the clay until a plastic condition has been reached, and then it is forced through a die containing a number of small holes. The streams of clay emerging from the die are cut to the desired length. Both forms of pellets will normally be sufficiently dense to withstand handling without crumbling.

Some materials bloat below the temperature at which agglomeration of the pieces takes place. The pieces emerge from the kiln individually, and the resulting "coated" aggregate requires little crushing to obtain proper grading for use in concrete. Some materials, on the other hand, bloat only under conditions at which agglomeration occurs. The product obtained is in the form of clinkers, and crushing is necessary to obtain graded concrete aggregate.

A "coated" aggregate is more suited for structural concrete than the crushed aggregate, because it is less absorptive and not as harsh and consequently has greater workability with the same cement content.

The sintering process is not used in Canada but is fairly common in the United States. In this process, the raw material, crushed to about minus 3/8 inch, is mixed with 5 to 10 per cent coke or anthracite coal and partially pelletized. The product from the pelletizer is fed onto the grates of a sintering machine, to a depth of 8 to 12 inches. By far the most common machine is the travelling-grate type. As the grates move along the machine, the bed passes under an ignition hood where the fuel at the surface is ignited. As the bed progresses, a series of wind boxes below the grates exerts an induced draft, and draws the ignition zone progressively down through the bed. The draft and speed of the machine are regulated so that combustion of the fuel is complete by the time the end of the machine is reached. The product has been sintered to a rigid cake or clinker. Sections of the cake, which break off at the end of the machine, are crushed and graded for use as aggregate. The clay or shale used in this process need not bloat during sintering. The various sized particles fuse together to form a porous cake, which, when crushed, results in a rather harsh aggregate. It is more suited for use in masonry units than for structural concrete, because of this feature.

THEORIES ON BLOATING

For many years, the bloating of clays and shales has been of great interest to those who work with such materials. To brick manufacturers, it is an undesirable property and must be prevented. In the production of lightweight aggregate by the rotary kiln process, however, bloating is essential.

Many theories have been advanced as to why some materials will bloat and others will not. It is agreed that two basic reactions must take place at approximately the same time if a clay or shale is to bloat at elevated temperatures. First, a viscous glass must be formed to fill the pore spaces of the particle. Also, a gas or gases must be liberated by the dissociation of some of the constituents and be trapped by the glass. The gas causes the particle to bloat.

Considerable work has been done to determine the sources of the gases which cause bloating. One of the earliest theories was by T. E. Jackson (4) who thought oxygen, formed from the reduction of ferric oxide to the ferrous state, causes bloating.

Orton and Staley (5) disagreed with Jackson's theory on the basis that all clays containing ferric oxide should, therefore, bloat at the same temperature. They found that many clays containing iron do not bloat at all. They believed that oxidation of carbon could cause bloating. They also believed that iron sulphides do not dissociate, but dissolve in the glass first formed on heating. As the temperature is increased, progressively more silica also dissolves. They stated that as the acidity of the melt increases, the sulphur is released as sulphur dioxide, and bloating results.

Bleininger and Montgomery (6) made a study of the absorption and porosity of clays and shales at various firing temperatures. They gave examples of how finer grinding increases the vesicular structure of paving brick. They attributed bloating to carbon dioxide, sulphur dioxide, air, steam, and oxygen.

F. G. Jackson (7) showed by experimental work that a portion of the sulphur from pyrite is released below 775°C (1427°F). The amount of sulphur retained depends upon the composition of the clay and the kiln atmosphere. The more oxidizing the atmosphere, the less sulphur is retained. The remaining sulphur forms complex iron-sulphur-silica compounds, such as ferrous sulpho-silicate and ferrous thiosulphate. He stated that it is the decomposition of these compounds when vitrification begins that causes bloating. A ferrous silicate remains as a black core in the bloated clay.

Hewitt Wilson (8) believes bloating can be caused by air, steam, sulphur dioxide or trioxide, carbon dioxide or monoxide, oxygen, and hydrocarbons. The sources of these gases are carbon, sulphur, carbonates, and calcium sulphate.

Austin, Nunes and Sullivan (9) heated three clays slowly to 2300°F in a tube furnace and analysed the evolved gases quantitatively in an absorption train. They also investigated the effect on bloating of heating rate, rate of air flow past the specimens, and furnace atmosphere. The chemical analyses of the three clays were reported by Sullivan, Austin and Rogers (10). The gases evolved at bloating temperatures were carbon dioxide, sulphur dioxide, and water. The authors believe the carbon dioxide is formed from elemental carbon being oxidized by the reduction of ferric oxide. They believe it is not from the carbonates, as these dissociate completely by 1900°F. The water is not derived from the various clay minerals, as they lose their lattice structure between 800 and 1600°F, so must have been formed from other minerals. The authors claim that the sulphur dioxide could not have been formed directly from the oxidation of pyrite, because it loses one atom of sulphur below red heat, but the remaining iron sulphide is not decomposed by heating. Pyrite might oxidize to the sulphate, which would decompose, or might react with silica to release sulphur dioxide. Austin, Nunes and Sullivan found that, in general, the evolution of gases varies inversely as the rate of heating, and directly with the rate of air flow. Oxygen and air atmospheres have about the same effect on bloating. A nitrogen atmosphere improved the bloating of two clays but not of the third.

Sullivan, Austin and Rogers (10) produced expanded clay blocks by heating minus 6 mesh clay to the bloating temperature in a mould. They found that, in general, high-lime clays have shorter bloating ranges than do clays that are low in lime. Many of the clays bloated excessively and non-uniformly. To overcome this defect, they were heated to 1800°F in 2½ hours and calcined for 2 hours. When they were cooled, mixed, and heated again to the bloating temperature, a more uniform, controlled bloating resulted. Bloating temperatures varied between 2050° and 2400°F. In most tests, the best results were obtained when the atmosphere in the kiln was slightly reducing; i.e. one per cent carbon monoxide and no free oxygen.

Nicholson and Bole (11) produced cellulated clay blocks from clays and shales occurring in Ohio. They found they could bloat some non-bloating refractory clays by the addition of fluxes. The degree of bloating and the porosity could be controlled by certain additions of soda ash, dolomite, calcite, and magnesite. Controlled cellulation occurred even though the firing schedule required 31 hours to reach 2300°F (1260°C).

Conley, Wilson and Klinefelter (12) tested 81 clays and shales from several States and classified them as bloaters and non-bloaters. Chemical analyses were made in an attempt to correlate the chemical composition and the bloating quality. They could not prove any definite relationship, and were of the opinion that the mineralogical composition would be more important than the chemical composition in governing the bloating quality. Many non-bloating materials were made to bloat by the addition of certain chemicals. Compounds of iron, alkalies and alkaline earths, and carbon, sulphur and phosphorus, were used. As was to be expected, the additives did not react in the same way with all the clays. For instance, alkalies would assist bloating of one clay, but not of a second clay, whereas alkaline earths would work better with the second clay than the first. Individual investigations of each clay had to be undertaken.

Riley (13) plotted chemical compositions of a large number of clays on a triaxial diagram (Figure 1), and outlined a limited area within which bloating clays were situated. He believed that clays, the compositions of which were within this area, developed glass of sufficiently high viscosity to entrap gases which might be liberated. Clays that did not bloat, but whose chemical compositions fall within this "bloating area", did not possess constituents that would produce a bloating gas although a glass of proper viscosity would be formed. He demonstrated his theory by varying the silica and alumina content of some clays of improper composition, thus bringing them within the "bloating area". When tested, these clays bloated. Mixtures of kaolinite, silicic acid, and microcline were plotted (Figure 2, Points A, B, C, D). These mixtures did not contain gas-producing minerals. To these compositions, 2, 7, and 12 per cent of certain gas-producing minerals were added, bringing their compositions within the "bloating area". Additions of 2 per cent did not result in bloating and only in the case of dolomite added to composition C did a 12 per cent addition result in good bloating. In all other cases, the results were poor bloating, or overbloating and fusion. Seven per cent additions of pyrite, siderite and magnesite did not produce bloating, and of hematite and calcite, gave, at best, only poor bloating. When 7 per cent of calcite plus pyrite, and of calcite plus hematite, were added, good bloating took place.

Matthews (14) used Riley's system of plotting chemical compositions on a triaxial diagram to show the area within which bloating clays would have a sufficiently wide vitrification range to produce a "coated aggregate" (Figure 3). The composition limits of clays developing glass of the proper viscosity were slightly different to those found by Riley (Figure 1). He also found that the bloating of materials high in free carbon could be improved by preheating at 1550°F. He made chemical analyses on 14 materials having wide vitrification ranges, and 8 having narrow vitrification ranges. In all but one of the former group, the ratio of $Na_2O + K_2O$ to $CaO + MgO$ was greater than one. All clays in the latter group had ratios of less than one.

Cole and Zetterstrom (15) discussed how bloating can frequently be improved by lowering the glass-forming temperature by the addition of fluxes. The temperature at which gases are formed can be raised by heating faster with less air. The addition of some materials may increase the viscosity of the glass formed. Low-temperature fluxes are compounds of such alkalies as sodium, potassium and lithium. Iron minerals such as hematite, limonite, siderite, magnetite, and pyrite can be active fluxing agents. Compounds of the alkaline earths, calcium and magnesium, which alone are refractory materials, cause a short vitrification range when in eutectic combination with clays.

Prokopovich and Schwartz (16) found that a change in kiln atmosphere from oxidizing to reducing lowers the temperature at which maximum bloating occurs. They believe that oxygen, formed by the reduction of ferric oxide, is one of the major sources of gas during bloating. They believe it is possible that a reducing kiln atmosphere may lower the temperature at which the reduction of ferric oxide takes place, thus releasing oxygen for bloating at a lower temperature.

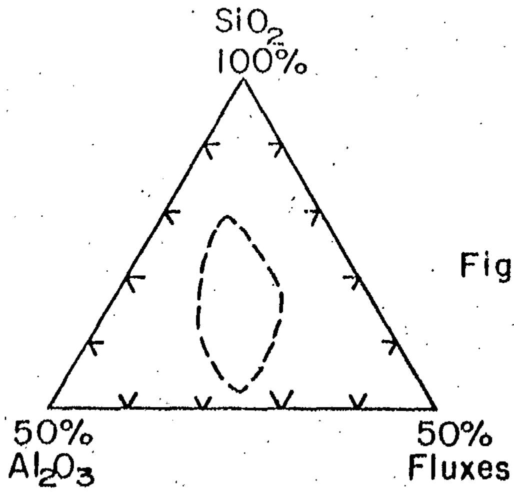

Figure : 1

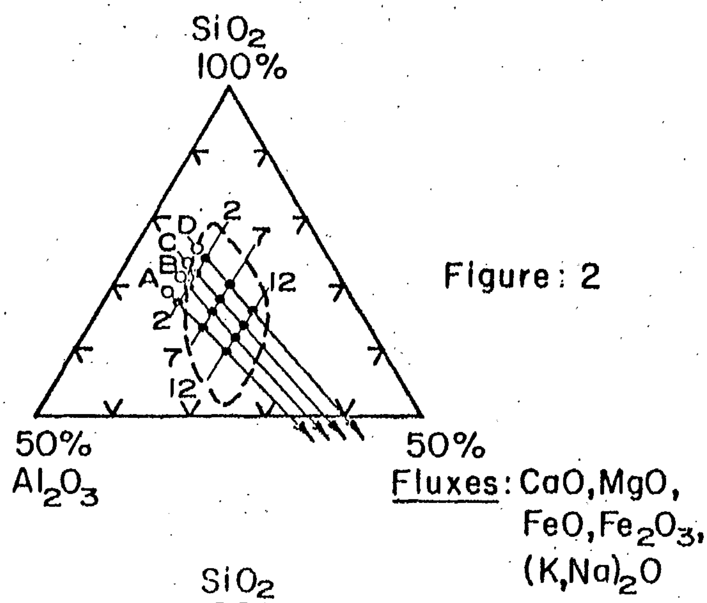

Figure : 2

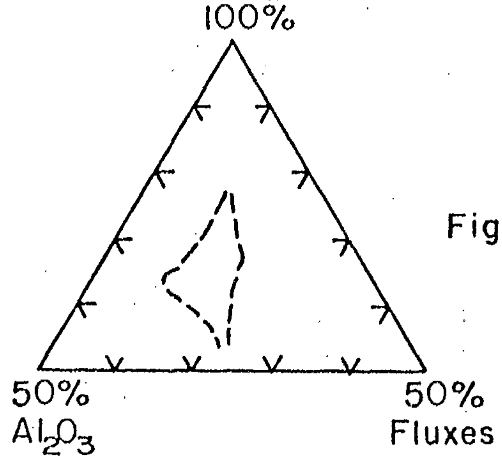

Figure : 3

Figures 1-3. Triaxial diagrams showing composition limits of bloating clays

Everhart, Ehlers, Johnson and Richardson (17) tested a large number of clays and shales from Ohio. As well as making bloating tests, they determined the mineral constituents by X-ray diffractometer and microscope. The gases that caused bloating were collected by crushing bloated pellets in a vacuum, and were analyzed. In over 80 per cent of the materials tested, carbon dioxide was the sole bloating gas. The other bloated materials contained both carbon dioxide and sulphur dioxide, but never sulphur dioxide alone. The predominant source of carbon dioxide was calcite, with dolomite and ankerite less common sources. In a few cases, coal was found to be the only source of carbon dioxide. Pyrite, and in a few cases marcasite, were the sources of the sulphur dioxide. Five samples high in iron were tested for free oxygen after bloating. In all cases, the oxygen content was less than is found in air. They concluded that some of the oxygen released by the reduction of ferric oxide was used to oxidize some other mineral.

They investigated the effect of various individual additives on the bloating properties of a shale and a fire clay. The minerals which had the greatest effect were pyrite, calcite, and nepheline syenite. Hematite and soda ash did not improve the bloating. The bloating of the fire clay was not improved to any degree by any of the additives, due to the refractory nature of the clay. The maximum temperature used was 2400°F.

Blyumen (18) used several Russian clays in his determination of the effect of chemical constituents on bloating. He believes that the surface tension, as well as the viscosity of the liquid phase formed on heating, is important. If the surface tension is excessive, the gas bubbles would not be able to expand, and only minor bloating would result. If the surface tension of the liquid is too low, the walls between the gas bubbles would rupture, resulting in large voids and relatively weak material. In his opinion, silica and alumina impart higher viscosity to the melt, and soda and potash increase the vitrification range and hence the bloating range. On the other hand, calcium, magnesium and ferrous oxides decrease the viscosity of a melt and shorten the vitrification range. He believes the gases responsible for bloating include: water vapour, sulphur dioxide derived from sulphides and sulphates, carbon monoxide and carbon dioxide from the oxidation of carbon and from the reduction of ferric oxide in the presence of carbon, and oxygen formed from the reduction of ferric oxide. He believes that water of constitution can be retained in the clay up to the bloating temperature. He cites a parallel in the manufacture of glass, where bubbles of water vapour have been found in glass fused at 1400° to 1500°C (2550° to 2730°F).

Pavlov (19) studied the viscosity changes of a number of Russian clays between 800 and 1200°C (1470 and 2190°F). He found that the changes in viscosity in relation to changes in temperature depended on the chemical composition. He found that to have viscosity characteristics suitable for satisfactory bloating, the following two conditions must be met:

(a) the ratio $\frac{\text{free silica}}{\text{total fluxes}}$ equals 4 or less - the lower the magnitude of the ratio, the better the bloating;

(b) the ratio $\frac{Fe_2O_3 + MgO + Na_2O + K_2O}{CaO}$ is greater than 4.

Hill and Crook (20) used chemical and mineralogical analyses in their investigation of the causes of bloating, using several Australian clays and shales as raw materials. They found that a high proportion of the iron contained in the materials fired to the bloating temperature was in the ferrous state. As the materials were heated through the bloating range, the proportion of ferrous iron increased. They believe that the reduction of ferric iron to the ferrous state, with the associated liberation of oxygen, is the principal source of bloating gas. They ruled out carbon dioxide from carbonate minerals as the bloating gas because carbonates were present only in small quantities in the majority of cases. The reduction of ferric oxide may be assisted by small amounts of carbon and also by oxides such as magnesium oxide.

DISCUSSION OF THEORIES

From the foregoing survey of literature, it is obvious there are many theories on the causes of bloating.

All writers agree that a viscous glass must be formed to entrap gases that might be liberated. Riley (13) defined approximate composition limits within which a glass formed should be of proper viscosity. Matthews (14), who plotted the compositions of 18 bloating materials, found the composition limits to be slightly different from those found by Riley. Riley partially proved his theory by preparing mixtures which would not release a gas and, by adding certain minerals, making them bloat. Figure 2 shows the compositions of the mixtures (A,B,C,D) and the effect on composition of adding 2, 7 and 12 per cent of various gas-producing minerals. Conley et al. (12) showed that theoretically one per cent or less of a gas-producing compound is necessary for bloating; although in Riley's work 2 per cent did not cause bloating. If Riley's theory is correct, an addition of 7 per cent of any gas-forming mineral is more than adequate to produce bloating. Such was not the case; 7 per cent additions of only dolomite, pyrite plus calcite, and hematite plus calcite, produced good bloating in all compositions. It is evident that the minerals added to the mixtures acted as fluxes as well as liberating gases. This indicates that the type of flux is of great importance. The double fluxes such as dolomite, pyrite plus calcite, and hematite plus calcite proved to be the best fluxes, as well as liberating gases. These minerals probably formed complex aluminum silicates. It is the writer's opinion that the additives' importance as fluxes is as great as their importance as sources of bloating gases. It is not sufficient to say that the composition as shown in the triaxial diagram alone will determine the viscosity of a glass, because the fluxes are grouped as one. It depends on the combination of fluxes present. Riley's theory probably holds true for a large number of clays and shales because they frequently contain an abundance of fluxes. Several of the authors agreed that certain fluxes have different effects on the viscosity of the glass; for instance, alkaline earth oxides (CaO, MgO) reduce the viscosity of a glass and shorten the vitrification range.

Considerable experimental work has been carried out in order to determine the sources of the gases responsible for bloating. This work has resulted in a variety of theories. Austin, Nunes and Sullivan (9) showed that carbon dioxide, sulphur dioxide, and water were liberated below and at the bloating temperature. Everhart et al. (17) found carbon dioxide and sulphur dioxide in the bloated pellets of clays and shales. Hill and Crook (20) found that oxygen formed from the reduction of ferric iron to the ferrous state caused bloating.

Carbon dioxide would be formed from carbonates and organic material, sulphur dioxide from sulphates and sulphides, and water would be released by any hydrous mineral such as clay minerals and micas. In a relatively pure state, and under slow heating rates, the dissociation or oxidation temperatures of these gas-producing minerals are known. Lightweight aggregates are produced under rapid firing conditions, and it is difficult to determine at what temperatures these reactions take place. Using slow heating rates, the reactions would virtually be complete before the vitrification temperature had been reached. Under rapid firing conditions, these reactions would not be complete before the pore spaces of the particles would be sealed by the glass formed at the vitrification temperature.

The reactions involving carbonates, carbon, sulphates, the hydrous minerals and the reduction of ferric oxide are fairly straightforward. The reactions with the sulphides are more complex. Pyrite and marcasite (FeS_2) lose a portion of the sulphur below 900°F. The remaining FeS may oxidize to ferric oxide or to a sulphate by 1475°F. The sulphur dioxide formed from these reactions may combine with free oxides (CaO, MgO, FeO, Fe_2O_3) to form sulphates, which are stable up to 2200°F. F. G. Jackson (7) claims such complex compounds as ferrous sulpho-silicate or ferrous thiosulphate may form, and release sulphur dioxide above 2000°F.

Oxygen formed from the reduction of Fe_2O_3 to $FeO.Fe_2O_3$ is either a bloating gas, or oxidizes some other mineral which causes bloating. Austin et al. (9) found that an oxidizing atmosphere is not necessary for bloating to take place. Hill and Crook (20) found that the proportion of ferrous iron increased as a clay was heated through the bloating temperature range.

In summary, if the chemical composition of a raw material falls within the limits shown in Figures 1 and 3 and if the alkaline earth content is relatively low, the glass formed on heating should be of proper viscosity for bloating. The compounds that release gases for bloating can be any one or combination of carbonates, organic material, sulphates, sulphides, hydrous minerals, and ferric oxide.

LABORATORY PROCEDURES

From each clay and shale sample to be evaluated, a representative portion, sized minus 1/2 plus 1/4 inch, was prepared for testing. With all shales and some clays this was accomplished by crushing and screening. Some clays were not sufficiently consolidated to withstand this and subsequent handling. These clays were ground to about minus 20 mesh and pelletized in a small concrete mixer or in a laboratory model extrusion machine. From the pelletized product, a feed, sized minus 1/2 plus 1/4 inch, was obtained by screening. All feed materials were dried prior to testing, to prevent decrepitation in the kilns.

Stationary Kiln Tests

The kiln, fired with natural gas, has a hearth area of 4 by 8 inches. The air-gas mixture was regulated to provide an oxidizing atmosphere at all temperatures. Small quantities of the sized feed were placed in the kiln at certain temperatures, and held at those temperatures for predetermined periods. The temperatures were generally between 2000 and 2400°F, although in some cases temperatures as low as 1900°F were used. The retention times were 4, 8 and 12 minutes.

This flash-heat treatment gave information on the relative degree of bloating and the temperature range over which bloating occurred. Beginning with the lowest bloating temperature and using increments of 50 degrees, tests were carried out until severe agglomeration of the material was observed.

These tests eliminated materials that did not show promise of being suitable for lightweight aggregate production by the rotary kiln process. Materials that were not considered promising possessed one or more of the following characteristics:

(a) Degree of bloating was insufficient to result in a significant reduction in unit weight.

(b) Temperature range over which bloating occurred was too short for normal rotary kiln operation. A bloating range of about 50 deg is considered necessary.

(c) There was a lack of uniformity of bloating, which would result in variation in unit weight and strength.

(d) They were too refractory to be produced economically. A temperature of 2300°F is considered the maximum temperature at which a lightweight aggregate can be produced economically.

Rotary Kiln Tests

All materials that gave promising results in the stationary kiln tests were evaluated further, using one or more rotary kilns. All such materials were fired in a 5 inch by 5 foot propane-fired kiln. The slope and the rotational speed were adjusted so that the material would be retained in the kiln for 6 to 7 minutes. The sized feed used in the stationary kiln was used also for these tests. About five pounds of material were used for each test.

Material from one location was evaluated in a 15 inch by 15 foot oil-fired rotary kiln. The slope and rotational speed were adjusted to give a retention time of about 20 minutes. About 150 pounds of sized feed were used in this test.

Sintering Tests

A limited number of tests were made using a sintering pot. The equipment used was a circular refractory pot 8 inches in diameter and 6 inches in depth. An induced down-draft which could be regulated by a damper was used to support combustion. Solid fuel was mixed with the raw material and partially pelletized in a concrete mixer. The mixture was placed in the pot and the fuel at the surface of the charge ignited by a gas-fired ignition hood. The period of ignition was about one minute. The induced draft drew the ignition zone down through the charge until the fuel had all been burned.

The objective of these tests was to obtain a sintered clinker of the fired material. The percentage of the charge obtained as clinker was recorded as the "recovery". The clinker was crushed to aggregate size.

Determination of Physical Properties

In all tests involving the 5 inch by 5 foot rotary kiln, the volume expansion of the material was calculated. The products obtained from all rotary kiln and sintering tests were crushed, screened, and recombined in the following proportions:

75% minus 3/8 inch plus 4 mesh

25% minus 4 plus 8 mesh

These proportions fall within the ASTM limits for a graded coarse aggregate.

The unit weight and crushing strength were measured on this graded product. The loose, dry, unit weight was measured by pouring the aggregate into a 1/30 cubic foot metal container. ASTM specifies a maximum of 55 lb/cu ft for graded coarse lightweight aggregate.

In early tests, the crushing strength was obtained as the pressure required to compact the aggregate one inch, when placed in a 2-inch diameter steel cylinder to a depth of 2-1/2 inches. The result was given as a single figure, in pounds per square inch. In later tests, the procedure was changed. The crushing strength was recorded as two figures: the pressures required to compact the aggregate one inch and a total of two inches, when placed in a 3-inch diameter steel cylinder to a depth of 5 inches. This is not a standard test, but is used only to give relative evaluation of aggregates in question. The only final evaluation of aggregate strength is in concrete tests.

GEOLOGY OF ONTARIO AND QUEBEC

Most of Ontario and Quebec is underlain by the Canadian Precambrian Shield, which has had a complex history of mountain building, erosion, and deposition. It consists mainly of granite and granitoid gneiss, and metamorphosed volcanic and sedimentary rocks (21). Material covering the rocks is generally glacial debris and lacustrine clay. It is the narrow area underlain by younger Paleozoic sedimentary rocks to the south of the Canadian Shield that is of most importance in this investigation. This area, the St. Lawrence Lowlands, extends from Lake Huron and Manitoulin Island to Anticosti Island in the Gulf of St. Lawrence. The lowlands are divided into three sections. The most westerly is a triangular-shaped section bounded by Lakes Huron, Erie and Ontario, and the Frontenac Axis, which is a tongue of the Canadian Shield separating two parts of the St. Lawrence Lowlands. Its western limit extends from Georgian Bay through Kingston, Ontario, and its eastern limit from the Ottawa River near Arnprior through Brockville, Ontario. The second section of the Lowlands extends from the Frontenac Axis to the City of Quebec, including the Ottawa and St. Lawrence River valleys. It is bounded on the east by a line extending from Lake Champlain to Quebec. The third section of the Lowlands comprises Anticosti and Mingan Islands, and a narrow strip along the north shore of the St. Lawrence River opposite these islands.

The rocks of the St. Lawrence Lowlands are of Ordovician, Silurian, Devonian and Mississippian age. The distribution of the rocks formed during these four periods is shown in Figure 4.

The shale formations of Ordovician age are Queenston (Becancour River), Dundas-Meaford (Wekwemikongsing, Russell, Carlsbad, Lorraine), and Utica (Collingwood, Gloucester, Sheguiandah, Billings). The shales of Silurian age are Salina, Rochester, Cabot Head, and Power Glen formations. The shale formations of Devonian age consist of Kettle Point and Hamilton. The shale-bearing formation of Mississippian age is Port Lambton. The names in brackets above indicate the names given the formations in different parts of the Lowlands.

Nearly all of Canada has been covered by glacial ice during four separate ages of the Pleistocene Epoch. The Wisconsin ice sheet, which covered the land during the last age, began its advance about 100,000 years ago and started to recede about 20,000 years ago. Many of the clay, sand and peat deposits found at depth in Ontario and Quebec are of pro-glacial and inter-glacial origin. The post-glacial surface clays are lacustrine in

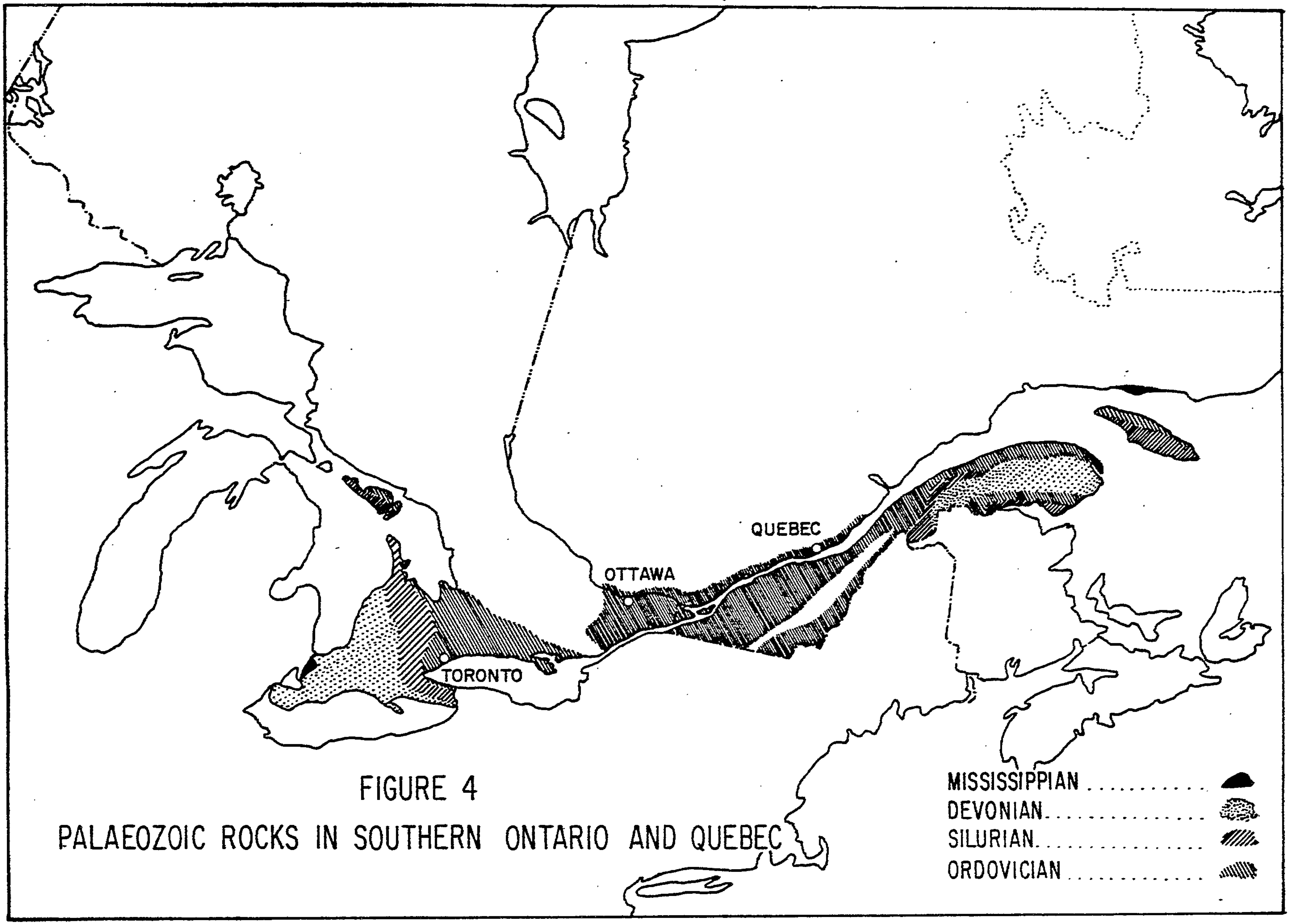

FIGURE 4
PALAEOZOIC ROCKS IN SOUTHERN ONTARIO AND QUEBEC

Ontario, and marine in Quebec. The Wisconsin ice sheet, which was up to 10,000 feet in thickness, caused depressions in the earth's surface. The recession of the ice sheet was not continuous, but was a series of retreats and advances in various areas. The first area of Eastern Canada to be exposed was southwestern Ontario. In the wake of the ice, a complex series of glacial lakes was formed. Most of the surface clays were laid down in these lakes, which were more extensive than the present Great Lakes. Drainage from these lakes was primarily via the Mississippi and Hudson River systems while the St. Lawrence River valley was still blocked by the ice sheet. As the earth's surface gradually rebounded to its present level, the lakes were reduced to their present size. The maximum extent of the glacial lakes is shown in Figure 5.

The depression of the St. Lawrence River valley permitted access of marine water from the Atlantic Ocean on the retreat of the ice from that area. This Champlain Sea extended along the St. Lawrence River nearly to Lake Ontario, and past Ottawa on the Ottawa River. Clays and sands were laid down in this sea. As the surface of the earth rose, the water receded, and the current conditions resulted. The area covered by the Champlain Sea is shown in Figure 5.

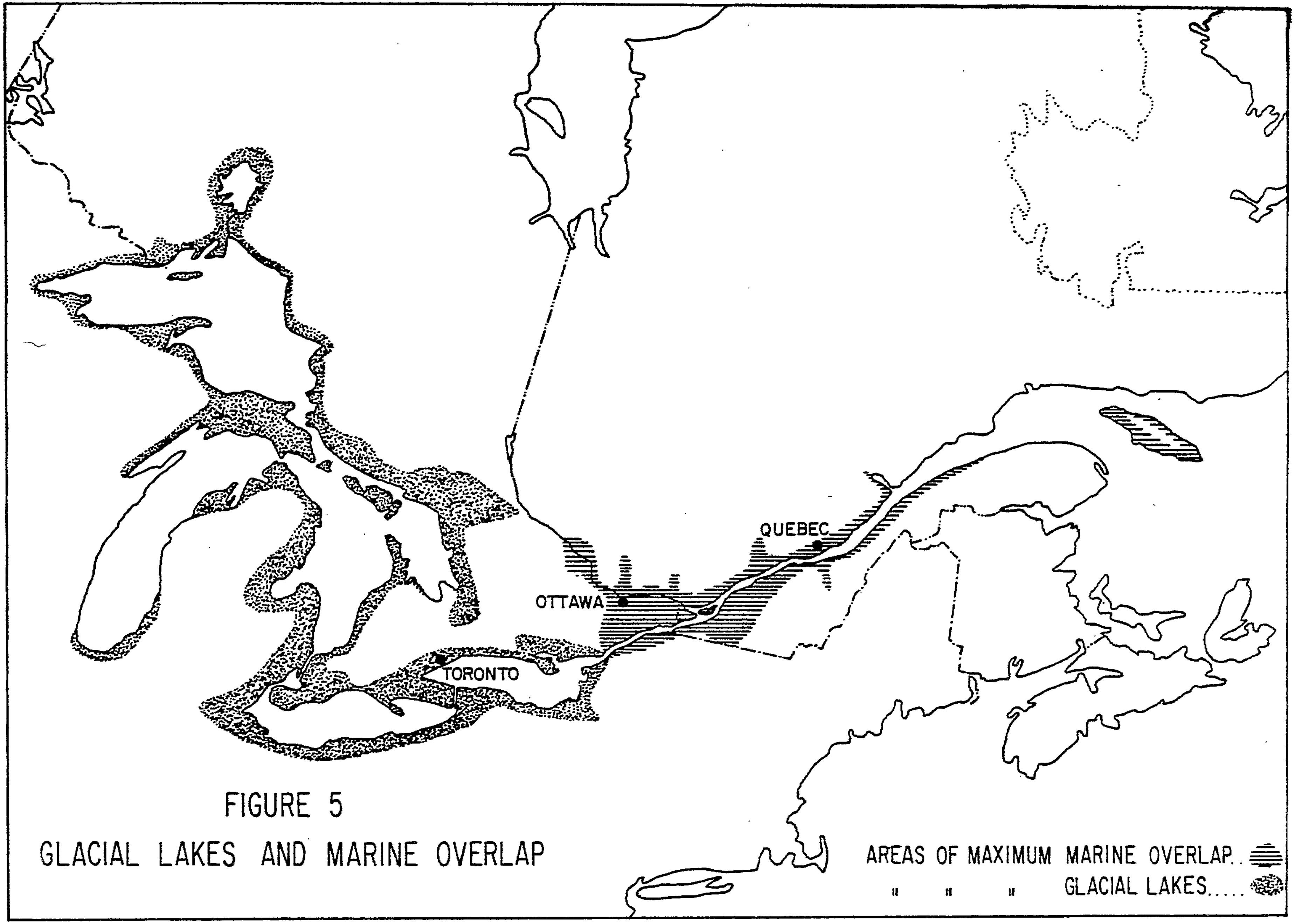

FIGURE 5
GLACIAL LAKES AND MARINE OVERLAP

EVALUATION OF CLAYS AND SHALES FROM THE PROVINCE OF ONTARIO

Algoma County

Echo Bay

A deposit of clay is exposed to a depth of 5 feet in the ditch along Highway 17, three miles east of Echo Bay and 17 miles east of Sault Ste. Marie. The top 3 feet of the clay (Sample 1) is greyish-brown, and the clay below (Sample 2) is brown with red streaks. Both clays proved to be poor bloaters when tested in the stationary kiln.

Rydal Bank

Up to 25 feet of clay is exposed in the bank of a creek just south of Rydal Bank beside County Road 561, which meets Highway 17 near Bruce Mines, 38 miles east of Sault Ste. Marie. The clay appears similar to that found near Echo Bay; the top 6 feet (Sample 3) is greyish-brown, and the next 10 feet sampled (Sample 4) is brown. Sample 3 did not bloat and only the larger pellets made with Sample 4 bloated, when these clays were tested in the 5-foot rotary kiln. The firing temperature used for Sample 3 was 2000° to 2060°F, and for Sample 4 was 1970° to 2010°F. Sample 4 expanded 35 per cent, the product having a unit weight of 55.8 lb/cu ft, and a crushing strength of 760 and 5100 psi for one- and two-inch compaction. This clay might be used to produce a coated lightweight aggregate, but would have to be tested further.

Walford

A grey-coloured clay outcrops at intervals over a distance of several miles along Highway 17 in the vicinity of Walford, 65 miles west of Sudbury. Sample 5 was taken from a 7-foot outcrop of grey clay containing red streaks, $1\frac{3}{4}$ miles west of Walford. It did not bloat when tested in the stationary kiln.

Brant County

Brantford

Brantford Clay Products Ltd. produces drain tile from a deposit of clay on the south side of the Grand River on the road between Brantford and Newport. The upper 8 feet of clay (Sample 6) was brown-coloured, and the lower 7 feet exposed (Sample 7) was grey-coloured. Neither clay bloated before fusion took place, in the stationary kiln.

Bruce County

Paisley

Paisley Brick and Tile Yard produces drain tile from a clay deposit 2 miles southeast of Paisley and about 25 miles southwest of Owen Sound. About 8 feet of grey-brown clay is exposed over a length of about 300 feet. A sample from this deposit (Sample 8) did not bloat below the fusion temperature, when fired in the stationary kiln.

Carleton County

Blackburn*

At a point about midway between Hurdman's Bridge, in the eastern end of Ottawa, and Blackburn, the Carlsbad formation lies within 3 to 4 feet of the surface. Samples 9 and 10 came from a surface exposure in a shallow ditch in this area. Sample 9 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 10 was classed as being too non-uniform because of the large amount of sandy shale present.

Black Rapids

A sandy clay is exposed to a depth of 10 feet over a length of 500 feet, along Highway 16, about 2 miles south of Black Rapids in the Rideau River and about 4 miles south of the Ottawa city limit. Sample 11, taken over the 10-foot exposure, bloated only slightly in the stationary kiln before fusion took place, and would not be suited to the rotary kiln process.

City View

An excavation, $\frac{3}{4}$ mile south of the Ottawa city limit, along Woodroffe Avenue, exposed clay to a depth of 8 feet. Sample 12 was taken from the top 4 feet, which is brownish-grey. Sample 13 was taken from the lower 4 feet of grey-coloured clay. Sample 12, when fired in the 5-foot rotary kiln at 1995° to 2020°F, expanded 35 per cent. The product had a unit weight of 47.6 lb/cu ft and a crushing strength of 390 and 1560 psi for one- and two-inch compaction. This clay shows promise of being suitable for coated lightweight aggregate production, but the bloating temperature range below the agglomerating temperature is short. Sample 13 bloated moderately only at the agglomerating temperature, and would probably not be suitable for the rotary kiln process.

---

* From Part III by J. G. Matthews.

Cyrville*

Billings shale is well exposed in both banks of Green Creek between Cyrville and Blackburn. Samples 14 and 15 came from this location. Both samples proved to be 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 16 was a grab sample of shale from a basement excavation where overburden was $3\frac{1}{2}$ feet thick. Sample 17 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.

Ellwood*

South of Ellwood on Highway 31, a large area is underlain by the Billings formation with little to no overburden. Samples 18 and 19 were grab samples from surface exposures in this location. 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.

Leitrim*

The Carlsbad formation lies close to the surface at Leitrim. Sample 20 was a grab sample of surface shale from this location. Although only a small amount of material was used, it gave favourable indications of a wide vitrification range and good bloating properties when tested in the stationary furnace.

Ottawa*

Twenty feet of grey-brown clay is exposed in a gully under Highway 17, two miles east of the Ottawa city limit. Sample 21 was taken across the top 15 feet of the exposure. When tested in the stationary kiln, this clay bloated well, but through a narrow temperature range. It probably would not be suitable for the production of a coated aggregate because of agglomeration at the bloating temperature.

Two samples (22 and 23) of the Carlsbad formation came from an area about midway between Hurdman's Bridge and Billings Bridge. Sample 22 was taken in the creek bed near the National Defence Medical Centre, and represented a 3-foot stratigraphic thickness of interbedded grey shale and thin (1 to 3 inch) 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 23 came from an old quarry a few hundred feet southwest of the location of Sample 22. It represented a 10-foot stratigraphic thickness 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 excessive.

Two samples of clay were taken from the clay pit of the former Ottawa Brick and Terra Cotta Company, Limited, located just west of Billings Bridge. Sample 24 was representative of the top bed of plastic grey clay, while Sample 25 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.

Ramsayville*

Three samples (26, 27, and 28) of Carlsbad shale were taken from exposures on a creek about one mile northwest of Ramsayville. Sample 26 was largely impure limestone and thus gave very poor results. Samples 27 and 28 were soft, light-grey 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 29 to 35 were surface samples of the Carlsbad formation, taken in an area about 1½ miles southwest of Ramsayville. Bedrock in this area lies close to the surface. With the exception of Sample 39, 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 psi to 2070 psi.

Samples 36 to 39 inclusive were diamond drill cores from four 50-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 minus ½-inch screen, and the feed therefore contained a considerable proportion of fine material. Good results were obtained with products showing bulk densities for the minus 3/8 inch plus 8 mesh fraction varying from 37.5 lb/cu ft to 46.5 lb/cu ft. Crushing strengths varied from 318 psi to 1034 psi, 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 gravity separation if a still lighter product were desired.

South March

The ditch beside Highway 17, 0.8 mile northwest of South March, exposes 5 feet of grey-brown clay. Sample 49 expanded 60 per cent when fired at 1990° to 2010°F. The unit weight of the product was 40.6 lb/cu ft and the crushing strength was 500 and 1930 psi. This clay bloats well but the bloating temperature range below the agglomerating temperature is short.

Dufferin County

Glen Cross

A deposit of Queenston shale outcrops for about ½ mile beside the county road between Highway 10 and Glen Cross, about 6 miles northeast of Orangeville. It outcrops for a thickness of 35 feet. The shale is basically red and contains 6-inch bands of green shale, spaced about 6 feet apart. Sample 41 was taken from the upper 20 feet, Sample 42 from the lower 15 feet, and Sample 43 was the green shale alone. In the stationary kiln tests, these materials bloated only slightly, below the temperature at which complete fusion occurred.

Durham County

Newcastle

Brown clay is exposed at the eastern and western ends of Newcastle, beside Highway 2. Samples 44 and 45 were taken from these two exposures, which were up to 6 feet thick. Neither sample bloated below the temperature at which severe agglomeration took place.

Elgin County

Port Stanley

On the shore of Lake Erie, 1½ miles west of Port Stanley, clay and sand are exposed to a depth of about 85 feet. The top 20 feet of brown clay is underlain by 15 feet of brown sand and about 50 feet of grey clay. The brown clay (Sample 46) did not bloat below the fusion temperature in the stationary kiln. The grey clay could not be reached for sampling.

Essex County

Essex

To the southeast of the town, drain tile was formerly manufactured by Essex Brick and Tile Limited, using a mixture of buff- and blue-coloured clays. The deposit is exposed to a depth of 15 feet, and a length of 400 feet. The top 3 to 6 feet are buff-coloured and the remainder is blue. Samples 47 and 48 were taken from these two clays. Neither bloated below the fusion temperature, in the stationary kiln.

Kingsville

Grey-coloured silt is exposed on the shore of Lake Erie between Leamington and Kingsville. Sample 49 was taken from 10 feet of a 30-foot exposure, 2 miles east of Kingsville, $\frac{1}{4}$ mile south of Highway 18. This material bloated only slightly below the fusion temperature when tested in the stationary kiln.

Frontenac County

Collins Lake

A dark-grey clay is exposed to a depth of 8 feet, at the north end of Collins Lake along the road between Sunbury and Inverary. Sample 50 was taken from the top 6 feet of the exposure on the bank of a small creek on the north side of the road. When fired in the 5-foot rotary kiln, between 1960 and 2000°F, this clay expanded 115 per cent. The graded aggregate had a unit weight of 25.3 lb/cu ft, and a crushing strength of 240 and 700 psi for 1- and 2-inch compaction. This clay shows promise of being suitable for production by the rotary kiln process.

Westbrook

Sample 51 was taken from a 6-foot exposure of brown clay at the eastern end of Westbrook beside Highway 2. It proved to be a poor bloater when tested in the stationary kiln.

Glengarry County

Bridge End

Sample 52 was taken from an 8-foot thickness of grey-brown clay, which is exposed for about $\frac{1}{4}$ mile on the bank of a creek crossed by the CPR bridge, 3.5 miles east of North Lancaster. It bloated well, but through a very narrow temperature range, in the stationary kiln, and does not show much promise of being suitable for the rotary kiln process.

Cornwall*

At Gray's Creek, 2 miles northwest of Cornwall, dark-brown peaty clay is well exposed in the creek banks. The nature of the topography and the number of exposures along the creek suggest that there is a large area underlain by this clay. Overburden is about 6 inches to 1 foot thick. The dark-brown clay appears to have a thickness of 3 to 5 feet and overlies a bluish-grey clay, probably of marine origin.

Six samples (53 to 58) of the brown clay were secured from the creek banks, covering a distance of ½ 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 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 psi to 636 psi, 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.

Lancaster

A clay similar to that at Bridge End was exposed in a trench dug for the Trans-Canada pipe line, beside Highway 34, 4 miles north of the CNR crossing at Lancaster. The clay was exposed to a depth of 6 feet, for a distance of at least ½ mile. Sample 59 bloated well, but through a short temperature range, when tested in the stationary kiln.

Grenville County

Prescott

An excavation for the foundation of a house exposed a grey clay to a depth of 4 feet, beside Highway 2, ½ mile east of the junction with Highway 16. Sample 60 was taken from the excavated clay. It expanded 55 per cent when fired in the rotary kiln at 2040° to 2085°F. The unit weight of the product was 37.1 lb/cu ft, and the crushing strength was 240 and 750 psi for 1- and 2-inch compaction. This is a promising material for the rotary kiln process.

Grey County

Owen Sound

A brown clay (Sample 61) and a Queenston shale (Sample 62) were formerly used by the Owen Sound Brick Co. Ltd. for the manufacture of brick. The deposit of clay is adjacent to the plant, in the east end of the town. The shale was from a deposit on the eastern side of the valley at Owen Sound. In the stationary kiln tests, Sample 61 did not bloat and Sample 62 bloated only slightly below the agglomerating temperature.

Halton County

Limehouse*

Two shale beds belonging to the upper part 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 63) contains thin limestone beds while the red shale (Sample 64) seems to be fairly pure. Both materials proved to be poor bloaters, with very narrow vitrification ranges.

Milton*

A 56-foot section of red Queenston shale was sampled in the quarry operated by the Milton Brick Company. Six samples (65 to 70) 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.

Port Nelson*

At Port Nelson, approximately 2 miles northeast of Burlington, red Queenston shale outcrops in a small creek. Sample 71 was representative of a 10-foot thickness 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.

Hastings County

Belleville*

At the brick plant formerly operated by D. W. Rollins, located 2 miles east of Belleville, dark-brown peaty clay was used in the manufacture of brick. A 2-foot thickness of clay (Sample 72) was available for sampling. 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.

Kent County

Chatham

Three clays are used by Emig Clay Products Limited for the production of brick and tile. The plant is situated on Stanley Avenue, Chatham. Sample 73 was taken from a stockpile of black clay brought to the plant from a deposit 8 miles distant. Tests showed it is a poor bloater. Two samples were taken from a deposit near the plant. Sample 74 was taken from the top 3 to 4 feet of the deposit of a brownish clay. It bloated 75 per cent when fired in the rotary kiln between 2010° and 2080°F. The aggregate had a unit weight of 35.4 lb/cu ft, and a crushing strength of 300 and 1200 psi for 1- and 2-inch compaction. This clay shows promise of being suitable for the production of lightweight aggregate. It is underlain by 6 to 8 feet of sand and a blue silty clay exposed to a depth of about 5 feet. Sample 75, taken from this blue clay, did not bloat below the fusion temperature.

A brownish clay (Sample 76) is exposed in a drainage ditch under Highway 2, 11 miles west of the Chatham city limit. The clay is visible to a depth of 5 feet. It bloated 75 per cent when fired at 1995 to 2040°F. The product had a unit weight of 37.0 lb/cu ft, and had a crushing strength of 395 and 1630 psi for 1- and 2-inch compaction. The clay shows promise of being a suitable raw material for lightweight aggregate production.

Coatsworth*

Local clay, 3 feet in thickness, is used for the manufacture of brick and tile at the plant of Hill Tile Limited, located at Stevenson, near Coatsworth. Stationary furnace tests indicated that the material (Sample 77) 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 psi. The average kiln temperature for the run was 1935°F; agglomeration started when the temperature was increased beyond 1950°F. Although the deposit is small and 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 aggregate.

Dresden

A deposit of clay about 1 mile north of Dresden, beside Highway 21, is used by Dresden Tile Yard Ltd. The deposit had been opened to a depth of 6 feet. The top $1\frac{1}{2}$ feet (Sample 78) is black, the remainder of the clay exposed (Sample 79) is grey-brown. Sample 78 bloated only slightly, below the agglomerating temperature, in the stationary kiln. Sample 79 shows promise of being suitable for lightweight aggregate production. It bloated 40 per cent when fired at 2020° to 2080°F in the rotary kiln. The graded aggregate had a unit weight of 45.9 lb/cu ft, and a crushing strength of 580 and 2720 psi for 1- and 2-inch compaction.

Fletcher

The top 3 feet of clay in this area (about 10 miles southwest of Chatham) is grey-brown. The clay below this is very calcareous and contains lime pebbles. Sample 80 was taken from the 3 feet of clay used by Fletcher Brick and Tile in the production of brick and drain tile. When tested in the rotary kiln, at 2010° to 2070°F, it bloated 85 per cent. The product had a unit weight of 31.5 lb/cu ft and a crushing strength of 450 and 1840 psi.

Sample 81 was taken 1 mile north of Highway 2, 3 miles from Fletcher. The top 2 feet of the deposit was sampled--bloating was 70 per cent when fired at 1965° to 2025°F in the rotary kiln. The aggregate had a unit weight of 33.6 lb/cu ft and a crushing strength of 670 and 2440 psi. Both of these clays show promise of being suitable for production of lightweight aggregate, but the deposits are only about 3 feet thick.

Tilbury

A 2 to 4 foot thickness of grey-brown clay is used by Central Brick and Tile Corporation Ltd. in the manufacture of drain tile, at the eastern end of Tilbury, beside Highway 2. The bloating temperature of Sample 82 in the rotary kiln was 2020° to 2080°F, with an expansion of 65 per cent. The graded product had a unit weight of 34.8 lb/cu ft and a crushing strength of 540 and 1940 psi. This clay, although in small quantity, shows promise of being a suitable lightweight aggregate raw material.

Tupperville

Clays from two deposits are used by Earl Lindsay and Sons Limited in production of drain tile, on the east bank of the Sydenham River near Tupperville. A deposit of grey-brown clay adjacent to the plant is exposed to a depth of 6 feet. Sample 83, taken from this deposit, did not bloat below the fusion temperature, in the stationary kiln.

The second deposit is about 2 miles northeast of the plant. The pit has been opened to a depth of about 15 feet. The top 7 feet (Sample 84) is grey-brown with a weathered appearance. When tested in the rotary kiln, it bloated 55 per cent, between 1970° and 2070°F. The unit weight of the graded product was 37.4 lb/cu ft, and the crushing strength was 710 and 2760 psi. Below the weathered clay, there is 8 feet of unweathered grey-brown clay (Sample 85). The floor of the pit was blue clay. Sample 86 was taken from the top 2 feet of the blue clay. Samples 85 and 86 were both poor bloaters. Only Sample 84 showed promise of being suitable for the production of lightweight aggregate.

Lambton County

Arkona

Hamilton shale outcrops in the banks of the Ausable River, at Rockglen Falls, 1 mile northeast of Arkona. The 30-foot outcrop is overlain by 10 to 20 feet of boulder clay and limestone. Sample 87 was taken from the upper 15 feet of the outcrop. It did not bloat below the fusion temperature in the stationary kiln.

Kettle Point

On the shore of Lake Huron, at Kettle Point, Ipperwash Beach, a 5-foot thickness of Kettle Point shale outcrops. Sample 88 did not bloat below the fusion temperature in the stationary kiln.

Petrolia

A 6-foot thickness of dark grey-brown clay is used by Fred W. Howlett and Sons Limited, at the southwestern end of Petrolia, for the manufacture of drain tile. Sample 89 was taken from the 6-foot exposure. It bloated well in the rotary kiln, but only at the temperature where agglomeration began.

Thedford

About one mile east of Thedford, along the CNR tracks, clay and shale are exposed in a cut. Brownish clay, up to 10 feet in thickness, overlies 20 feet of Hamilton shale. Sample 90 was taken over 5 feet of the clay, and Sample 91 from the upper 10 feet of the shale. Neither material bloated in the stationary kiln tests.

A deposit of Hamilton shale about 1 mile southwest of Thedford is used by George Coultis and Sons Limited for the manufacture of drain tile. A 20-foot exposure of the shale is overlain by 6 feet of boulder clay and 2 feet of limestone. Sample 92 was taken from the top 8 feet of the shale, and Sample 93 was a grab sample of shale from a shallow drainage ditch in the floor of the pit. The samples reacted similarly in the stationary kiln. Sample 92 was tested in the rotary kiln in lump form, and also after being ground and pelletized. The lump shale expanded 70 per cent when fired at 2030° to 2090°F. The unit weight was 39.0 lb/cu ft, and the crushing strength was 580 and 2520 psi for 1- and 2-inch compaction. In the pelletized form, it expanded 80 per cent when fired at 2030° to 2100°F. The unit weight of the product was 35.1 lb/cu ft, and the crushing strength was 340 and 1230 psi. This shale is a promising lightweight aggregate raw material.

Warwick

A light-grey clay is exposed at intervals for several miles along Highway 7, in the vicinity of Warwick. Sample 94 was from a 6-foot exposure about 3 miles east of the town. It bloated only slightly, below the fusion temperature, in the stationary kiln.

Lennox and Addington County

Napanee

Three clays are used in the manufacture of brick and tile by the Napanee Brick and Tile Works, situated southwest of the town of Napanee. The top 6 feet of the deposit (Sample 95) is a dark grey clay, the next 6 feet (Sample 96) is lighter grey clay, and the bottom of the pit is dark grey clay (Sample 97). All of these clays bloated only slightly below the temperature at which severe agglomeration took place when tested in the stationary kiln.

A 6-foot thickness of brown clay (Sample 98) outcrops in the bank of a small creek, 5 miles east of Napanee, beside Highway 2. It did not bloat in the stationary kiln tests.

Lincoln County

Grimsby*

About 80 feet of Queenston shale is exposed in the banks of Grimsby Creek, on the south side of the town of Grimsby. This shale is overlain by 10 feet of sandstone of the Whirlpool formation. Four samples were taken from the shale outcrop (Samples 99 to 102). They all bloated well in the stationary furnace, but had the narrow vitrification range characteristic of the Queenston formation.

Jordan*

At Jordan, 7 miles west of St. Catherines, red Queenston shale is exposed on the banks of Twenty Mile Creek. Sample 103 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 owing to the narrow vitrification range.

Queenston*

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. Both samples 104 and 105 bloated well in the stationary furnace but not in the rotary kiln because of their narrow vitrification ranges.

Two miles north of the above location, a 30-foot section of the red shale on the west bank of the Niagara River was sampled (Samples 106 and 107). This section appears to be about 50 feet lower stratigraphically than the exposure at Queenston, but the rock has almost the same firing properties.

St. Anns

About $1\frac{1}{2}$ miles east of St. Anns, along County Road 25, a brown clay is exposed to a depth of 8 feet. Sample 108 did not bloat in the stationary kiln.

St. Catharines

St. Catharines Brick and Tile Company Ltd. use a Queenston shale and overlying clay in the production of brick and tile. At the time of the tests, the deposit had been opened to a depth of 6 feet. The material exposed consisted of 1 foot of clay overlying 2 feet of soft shale and 3 feet of hard shale. For the tests, the three materials were mixed in the proportion 1:2:3 as in the deposit (Sample 109). Stationary and rotary kiln tests showed that the material bloated only above the agglomerating temperature. It was fired at 2180° to 2210°F in a 12-inch by 15-foot oil-fired rotary kiln. The unit weight of the graded product was 41 lb/cu ft, and the crushing strength was 1450 psi.

The blended clay and shale were sintered in an 8-inch diameter circular pot. The raw material was ground to minus 8 mesh, mixed with 10 per cent coke by weight, and pelletized prior to sintering. The unit weight of the sintered material was 37 lb/cu ft and the crushing strength at 1-inch compaction was 1050 psi. This material seems to be more suited to the sintering than to the rotary kiln process. Agglomeration of the material in a rotary kiln would be a serious problem.

Smithville

Five feet of brown clay (Sample 110) is exposed in the ditch beside the road joining Highway 20, just south of the village of Smithville. In the stationary kiln, this clay bloated only slightly at the agglomerating temperature.

Manitoulin County

Little Current

An outcrop of Sheguiandah shale occurs about 3 miles south of Little Current, beside Highway 68. The shale, which is black and grey-brown, is exposed to a depth of 12 feet. The face is weathered to a depth of about 4 inches. Sample 111 was of unweathered black shale; Sample 112 was of weathered black shale; and Sample 113 was of unweathered grey-brown shale. The three materials show promise of being suited to the rotary kiln process. Sample 111 bloated 100 per cent when fired at 2010° to 2050°F. The unit weight of the aggregate was 36.0 lb/cu ft and the crushing strength was 520 and 2400 psi for 1- and 2-inch compaction. Sample 112 expanded 100 per cent when fired at 2020° and 2050°F in the rotary kiln. The unit weight was 35.3 lb/cu ft, and the crushing strength was 470 and 2370 psi. Sample 113 expanded 110 per cent when fired at 1990° to 2050°F. The unit weight of the product was 32.0 lb/cu ft, and the crushing strength was 570 and 2330 psi.

Sheguiandah

Six feet of black Collingwood shale outcrops 1/4 mile south of Sheguiandah, along Highway 68. Sample 114 was taken from this 200-foot exposure. It did not bloat below the fusion temperature when tested in the stationary kiln.

Middlesex County

Elginfield*

The plant of Rydall Brick & Tile Limited, 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 116) . . .	4 feet
Light-grey clay (buff-burning) (Sample 115)	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.

Lambeth

A drainage ditch under Highway 4, 1¼ miles north of its junction with Highway 104, exposes 4 feet of grey-brown clay. Sample 117 expanded 45 per cent when fired in the rotary kiln at 2010° to 2050°F. The unit weight of the graded aggregate was 47.1 lb/cu ft, and the crushing strength was 595 and 2900 psi for 1- and 2-inch compaction. This is a promising raw material for production by the rotary kiln process.

Wardsville

A brown clay is exposed at intervals along Highway 2 in the vicinity of Wardsville. Sample 118 was taken from the upper 10 feet of a 20-foot exposure, ½ mile west of the town. In the stationary kiln, it did not bloat below the temperature at which fusion took place.

Norfolk County

Port Dover

Forty feet of brown silty clay is exposed in a high bluff overlooking Lake Erie, east of the long wharf extending into the lake at Port Dover. Sample 119 was taken from several accessible locations. It did not bloat below the fusion temperature in the stationary kiln.

Ontario County

Beaverton

Drain tile is manufactured from a clay deposit on the north side of Beaverton River, 1 mile east of Highway 12 at Beaverton, by Beaverton Brick and Tile. The top 3 feet of the clay (Sample 120) is grey to brown; the next 3 feet is grey (Sample 121); the floor of the pit is blue-grey clay (Sample 122), the thickness of which is not known. None of these clays bloated below the fusion temperature in the stationary kiln tests.

Whitby

The banks of the valley in which Lyon Creek flows, northwest of Whitby, expose a grey-brown clay of variable thickness. Sample 123 was taken from a location where an 8-foot thickness was evident. The clay bloated only slightly, below the fusion temperature.

Oxford County

Norwich*

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

Soil overburden with flint pebbles	-	1 foot
Dark-brown clay (red-burning)(Sample 126)	-	1½ feet
Dark-brown clay (buff-burning)(Sample 125)	-	4 feet
Light-brown clay (buff-burning)(Sample 124)	-	2 feet

The upper red-burning clay (Sample 126), 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 124 and 125) proved to be poor bloaters possessing narrow vitrification ranges.

Brownsville*

At the brick plant of Deller's Tile Limited, Brownsville, the following section was noted in the clay pit:

Topsoil	-	1 foot
Dark-brown clay (red-burning)(Sample 128)	-	2 feet
Dark-brown clay (buff-burning)(Sample 127)	-	3 feet

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

Peel County

Brampton*

Red shale belonging to the Queenston formation is used at the Brampton Brick Limited. 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 131)	-	8 feet
Red shale with streaks of sandy green shale (buff-burning)(Sample 130)	-	4 feet
Red shale with a few streaks of sandy green shale (red-burning)(Sample 129)	-	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.

Caledon

An excavation for the foundation of a house, 5½ miles south of Caledon, along Highway 10, exposed 6 feet of light brown clay. Sample 132 was a grab sample of the excavated clay. It did not bloat below the fusion temperature in the stationary kiln.

Cheltenham*

A 34-foot thickness of red Queenston shale is exposed in the quarry of Domtar Construction Materials Ltd.'s Cheltenham plant. Four stratigraphic samples (133 to 136) 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.

Credit Forks

About ¼ mile west of the CPR station, 1 mile west of Credit Forks, an extensive deposit of Queenston shale is exposed near the railway right-of-way. It is exposed to a depth of about 30 feet. Sample 137 was taken from the upper 8 feet of the outcrop. It bloated only slightly below the fusion temperature in the stationary kiln.

Erindale

Lorraine shale outcrops on the banks of the Credit River, just west of Erindale. Sample 138 was taken from a 5-foot section beside Highway 5 on the west side of the river. The shale is covered by 15 to 20 feet of overburden at that location. In the rotary kiln, the shale bloated 100 per cent when fired at 2015° to 2060°F. The graded aggregate had a unit weight of 37.0 lb/cu ft, and a crushing strength of 495 and 1880 psi for 1- and 2-inch compaction. This shale shows promise of being suitable for production by the rotary kiln process.

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 140)	-	5 feet
Red shale (harder than overlying shale)(Sample 139)	-	10 feet

Both of these samples bloated well in the stationary furnace but had narrow vitrification ranges.

Peterborough County

Peterborough*

A light-brown sandy clay was used for the manufacture of brick by Curtis Brothers, Peterborough. It was brought from a point about 3 miles south of the city. This clay (Sample 141) 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.

Renfrew County

Chenaux Dam

A grey clay with brown stains is exposed to a depth of 20 feet at the top of the bank of the Ottawa River at the site of the Chenaux Dam, about 10 miles north of Renfrew. Sample 142 was from the top 6 feet, and Sample 143 was from the 6 feet below. Both samples reacted similarly in the stationary kiln; bloating was only slight below the fusion temperature.

Glasgow Station

An excavation for a house foundation exposed 4 feet of grey clay, 2 miles east of Glasgow Station, beside Highway 17. Sample 144 was a grab sample of the excavated clay. It bloated well, but through a narrow temperature range when tested in the stationary kiln, and would not likely be suited to the rotary kiln process.

Russell County

Bear Brook*

At Bear Brook, 3 samples (145 to 147) were taken from exposures of the black, carbonaceous, fissile shales of the Billings formation on 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 because of a narrow vitrification range.

Cumberland

A grey-brown clay outcrops at various locations in the vicinity of Cumberland. Sample 148 was taken from a 6-foot exposure beside Highway 17, about $1\frac{3}{4}$ miles west of Cumberland. It expanded 25 per cent when fired at 2000° to 2040°F in the rotary kiln. The unit weight of the graded product was 49.3 lb/cu ft, and the crushing strength was 1110 and 5730 psi for 1- and 2-inch compaction.

Sample 149 was from a 15-foot exposure, $2\frac{1}{2}$ miles east of Cumberland. The clay outcrops on the banks of a gully under Highway 17. When fired in the rotary kiln at 2000° to 2025°F, it expanded 35 per cent. The unit weight of a graded aggregate was 44.9 lb/cu ft, and the crushing strength was 720 and 3080 psi. Samples from both of these locations showed promise of being suitable for the rotary kiln process.

Navan

A cut beside Highway 17, about $\frac{1}{2}$ mile east of the road leading from the highway to Navan, exposes 12 feet of grey-brown clay. Sample 150 was taken from 10 feet of this outcrop. In the stationary kiln tests it bloated well, but over a narrow temperature range, and does not show much promise of being suitable for the rotary kiln process.

Sample 151 consisted of typical Billings shale from a point 1½ 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 151 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.

Russell*

Two shale samples (152 and 153) were obtained from the Queenston formation at the quarry formerly operated by the Ottawa Brick and Terra Cotta Company, Limited, 4 miles north of Russell. A section of the quarry face was noted as follows:

Red clay	-	4 feet
Highly weathered red shale (Sample 153)	-	5 feet
Hard, red shale (Sample 152)	-	5 feet

Both of the shales 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.

Sudbury County

Hagar

A brown clay was exposed in a trench dug for a natural gas pipe line paralleling Highway 17. Sample 154 was excavated clay from a location about 10 miles west of Hagar, where the clay had been uncovered to a depth of 6 feet. It bloated only slightly below the agglomerating temperature in the stationary kiln.

Whitefish

Isolated deposits of clay occur west of Sudbury. Samples 155 and 156 were taken from a deposit beside Highway 17, about 5 miles west of Whitefish. Sample 155 was from the top 6 feet of brown clay; Sample 156 was from 4 feet of the lower grey silty clay. A thickness of 12 feet was exposed above the highway. Sample 155 bloated moderately well, but only at the agglomerating temperature. Sample 156 bloated only slightly below the fusion temperature. The two clays were ground, mixed in equal proportions, and pelletized. The mixture bloated only slightly, below the fusion temperature.

Victoria County

Lindsay*

The Wagstaff Brick and Tile Company, and the Curtin Brick Yard, both abandoned a number of years ago, used 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 157) and a sandy clay (Sample 158). 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 159) and a red-burning clay (Sample 160) were sampled. Stationary furnace tests indicated that both materials possessed vitrification ranges too narrow to warrant rotary kiln tests. The buff-burning clay (Sample 159) showed very little evidence of bloating under a rapid heat treatment, whereas the red-burning clay (Sample 160) bloated well.

Waterloo County

St. Clements*

At the St. Clements Tile Yard, 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 162)	- 2 feet
Light brown clay (buff-burning) (Sample 161)	- 3½ feet

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

Wallenstein

Drain tile is manufactured by N. S. Bauman Limited, south of Wallenstein. The pit, situated near the plant, has been opened to a depth of 14 feet. The top 12 feet of the clay is brown, the lower 2 feet are grey. Sample 163 is from the top 4 feet of brown clay, Sample 164 is from the next 8 feet of brown, laminated clay and Sample 165 is from the grey clay. Sample 163 expanded 120 per cent when fired at 1980° to 2040°F in the rotary kiln. The unit weight of the product was 30.5 lb/cu ft and the crushing strength was 330 and 1170 psi for 1- and 2-inch compaction. Neither Sample 164 nor 165 bloated below the fusion temperature in the stationary kiln. Only the top 4 feet of this deposit show promise of being suitable for the rotary kiln process.

Waterloo*

A 10-foot section of clay was sampled in the clay pit of Kitchener Brick Co. Ltd., located between Waterloo and Bridgeport. A section of the pit was as follows:

Light brown clay with a few limestone pebbles (Sample 167)	- 4 feet
Fine-grained, blue clay with a few scattered pebbles of red Queenston shale (Sample 166)	- 6 feet

The upper clay, represented by Sample 167, 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.

Welland County

Fort Erie

Black Salina shale outcrops on the shore of Lake Erie, 100 yards east of the Peace Bridge at Fort Erie. Sample 168 was made up of loose material from the 2-foot exposure. It did not bloat below 2300°F, and is probably too refractory to be used in the rotary kiln process.

Niagara Falls

A red clay is exposed beside the Queen Elizabeth Way, 2 miles south of its junction with Highways 3A and 20. A 7-foot section outcrops above the highway. Sample 169, taken over the whole depth of exposure, bloated moderately in the stationary kiln, but only at the agglomerating temperature.

Thorold

Sample 170 was from the Rochester dolomitic shale in the quarry of Walker Brothers at Thorold. It bloated moderately, but only at the agglomerating temperature.

Wentworth County

Burlington

Samples 171 and 172 were from a deposit of Queenston shale formerly used by Natco Clay Products Limited in the manufacture of structural tile. The deposit is situated near the plant at Burlington (Aldershot).

Sample 171 was of the red shale, and Sample 172 was of the green shale, which occurs in bands in the red shale. Sample 171 bloated only slightly below the agglomerating temperature. Sample 172 did not bloat below the fusion temperature.

Clappisons Corners

A ditch for a natural gas pipe line uncovered a brown clay beside Highway 5, about 2 miles west of Clappisons Corners. Sample 173 was a grab sample of the clay excavated from the 6-foot deep trench. It did not bloat below the fusion temperature.

A 6-foot section of grey Rochester shale outcrops in the Clappison Cut on Highway 6, south of Highway 5. It is overlain by about 10 feet of limestone. This shale (Sample 174) bloated slightly and non-uniformly, only at the agglomerating temperature.

Hamilton*

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 175) 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 accomplish satisfactory bloating without agglomeration.

The National Sewer Pipe Company used to use a mixture of surface clay and Queenston shale for the production of sewer pipe at the Hamilton plant. Samples 176 and 177 were grab samples from the stockpiles of shale and clay, respectively. The shale behaved in firing like 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 177), 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 Queenston shale exposing a 75-foot face near the top of the formation. Five samples (178 to 182) were taken. All these materials bloated well in the stationary furnace. Rotary kiln products were very poor due to the characteristic, narrow vitrification range of this shale.

Stoney Creek*

Shales, belonging to both the Queenston and overlying Medina formations, are well exposed in the Stoney Creek valley, just above Stoney Creek station on the TH & B Railway. The following section was noted:

Medina Formation

(Cabot Head Member)

Grey shale with reddish zones and narrow (1 to 3 inch) beds of sandy limestone (Sample 191)	-	10 feet
Grey shale with reddish zones (Sample 190)	-	10 feet
Grey shale with narrow (1 to 2 inch) beds of sandy limestone (Sample 189)	-	18 feet
Grey shale with 1- to 6-inch beds of sandy limestone (Sample 188)	-	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 183 to 187)	-	85 feet

The Queenston shale, represented by Samples 183 to 187, bloated well in the stationary furnace but not in the rotary kiln.

The grey shales, belonging to the Cabot Head member, proved to be very good bloaters and possess a much wider vitrification range than the Queenston shale. The occasional narrow beds of sandy limestone are detrimental but might be avoided by careful mining.

The lower 15 feet of shale, represented by Sample 188, proved to be too non-uniform owing to the large amount of included sandy limestone.

The overlying 38 feet of shale, represented by Samples 189, 190, and 191, gave satisfactory products in the rotary kiln. The volume expansions for all three samples measured75 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 to 1114 psi. 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 Cabot Head grey shales would be the lack of large, easily-quarried quantities. They 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 dolomite had been removed by erosion.

York County

The Dundas (Lorraine) formation, Ordovician period, underlies Toronto and a 20-mile wide area to the north. The formation consists of medium-grey shale with thin, lenticular, calcareous and sandy beds. On the eroded surface of the formation, under the city, are deposits of boulder clay, overlain successively by beds of inter-glacial sand and clay, boulder clay and sand, and the shallow-water clay and sand of post-glacial Lake Iroquois. These materials have been exposed in the quarries of several brick-producing companies.

Mimico*

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

Surface clay (Sample 196)	-	3 feet
Medium-grey shale (Sample 195)	-	3 feet
Impure limestone	-	6 inches
Medium-grey shale (Samples 193 and 194)	-	9½ feet
Impure limestone	-	1 foot
Medium-grey shale (Sample 192)	-	5 feet

The limestone beds were not included in the samples. The surface clay (Sample 196) overlying the shale bloated well in the stationary furnace and showed a medium-wide vitrification range. The rotary kiln product was also satisfactory, with a bulk density of 40 lb/cu ft. The volume increase of 10 per cent was low. Under rapid heat treatment in the stationary furnace, all the shale samples (192 to 195) 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, and crushing strengths ranged from 318 to 1034 psi. The volume expansions varied from 30 to 100 per cent. The products formed from shale from this section, with the exception of the top 3 feet (Sample 195), showed little to no rounding of the individual particles, the majority of the particles being thin, platy and weak. However, this shale is considered worthy of further work as it does show a high degree of expansion below the temperature at which agglomeration takes place.

New Toronto

A deposit of Dundas shale at New Toronto is used by Construction Materials Limited in the manufacture of brick. The deposit has been opened to a depth of about 50 feet. Sample 197 was a grab sample of the shale. In the rotary kiln, it expanded 135 per cent when fired at 1990° to 2040°F. The unit weight of the resulting aggregate was 32.8 lb/cu ft and the crushing strength was 340 and 1360 psi. This is a promising shale for the production of lightweight aggregate by the rotary kiln process.

North York

A deposit of clay beside the plant of Booth-Yeats Limited is used in the manufacture of brick and tile. The top 5 feet of the clay is brown and the clay below, reportedly having a thickness of 80 feet, is blue. The deposit has been opened to a depth of 15 feet. Sample 198 was of the brown clay and Sample 199 was of the blue clay. Sample 198 did not bloat below the agglomerating temperature, and Sample 199 bloated only slightly, below the fusion temperature.

Toronto*

At the quarry on Greenwood Avenue, which was formerly operated by Toronto Brick Company, a section of the inter-glacial beds was observed as follows:

Sandy overburden	- 15 to 20 feet
Sandy clay (Sample 205)	- 4 feet
Grey clay with numerous thin beds of sand (Samples 203 and 204)	- 8 feet
Light-brown, stratified sandy clay (Sample 202)	- 5 feet
Stratified bluish-grey clay (Samples 200 and 201)	- 13 feet

These samples (200 to 205) proved to have too narrow a vitrification range for consideration as coated aggregate raw materials. The upper sandy clay (Sample 205) and the lower bluish-grey clay (Samples 200 and 201) proved to be good bloating materials, but the others fused quickly to a glass without appreciable bloating.

A 90-foot stratigraphic thickness 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 not continuous laterally. They are usually only a few inches thick.

Four samples (206 to 209) 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 206 and 207, gave products with bulk densities of 33 lb/cu ft and 41 lb/cu ft. Volume expansions measured 80 per cent and 75 per cent, and the crushing strength for both products was 477 psi. The average kiln temperature for both runs was 2020°F, and agglomeration took place above 2025°F.

Samples 208 and 209, from the upper 20 feet of the section, gave products with bulk densities of 39 lb/cu ft and 41 lb/cu ft and crushing strengths of 318 psi and 159 psi. 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.

Silty, stratified clay, deposited from post-glacial Lake Iroquois, was used for the manufacture of brick at the plant on Dawes Road, formerly operated by Wright Brothers Brick Company. Clay from the weathered 3 feet of the deposit (Sample 210) burns red, and from the underlying 11 feet (Sample 211) burns buff. Several beds of white sand from 1 inch to 3 inches in 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.

DISCUSSION OF RESULTS

Of these 211 samples of clay and shale from the province of Ontario, 55 showed promise of being suitable for production of lightweight aggregate by the rotary-kiln process. The bloating in the rotary-kiln tests was sufficient that the unit weight of the resulting coarse aggregate was less than 55 lb/cu ft, as specified by ASTM. The crushing strengths were generally comparable to those of commercially produced lightweight aggregates. The temperature ranges through which bloating took place, below the agglomerating temperature, were wide enough that a coated lightweight aggregate could probably be produced.

The 55 samples were:

Sample 4: Clay - Rydal Bank, Algoma County
9: Shale - Blackburn, Carleton County
12: Clay - City View, Carleton County
20: Shale - Leitrim, Carleton County
23: Shale - Ottawa, Carleton County
29-39: Shale - Ramsayville, Carleton County
50: Clay - Collins Lake, Frontenac County
53-58: Clay - Cornwall, Glengarry County
60: Clay - Prescott, Grenville County
74: Clay - Chatham, Kent County
76: Clay - Chatham, Kent County
77: Clay - Coatsworth, Kent County
79: Clay - Dresden, Kent County
80: Clay - Fletcher, Kent County
81: Clay - Fletcher, Kent County
82: Clay - Tilbury, Kent County
84: Clay - Tupperville, Kent County
92,93: Shale - Thedford, Lambton County
111-113: Shale - Little Current, Manitoulin County
117: Clay - Lambeth, Middlesex County
138: Shale - Erindale, Peel County
148: Clay - Cumberland, Russell County
149: Clay - Cumberland, Russell County
163: Clay - Wallenstein, Waterloo County
189-191: Shale - Stoney Creek, Wentworth County
192-195: Shale - Mimico, York County
196: Clay - Mimico, York County
197: Shale - New Toronto, York County
206-209: Shale - Toronto, York County

The remainder of the materials tested bloated insufficiently or in a narrow temperature range, too close to the agglomerating temperature.

A number of the materials in this latter group might be used to produce clinkered aggregate in a rotary kiln, but agglomeration might be too severe and cause difficulty in production. Some of the materials could probably be used to produce aggregate by the sintering process, for which bloating is not necessary and should not be excessive.

CONCLUSIONS

The literature survey indicates that the chemical composition of a raw material does not govern the bloating qualities. It does, however, give an indication of the viscosity of the melt that will be formed on heating the material to the bloating temperature. The gases that cause bloating may be one or a combination of: water vapour, sulphur dioxide, sulphur trioxide, carbon monoxide, carbon dioxide, and oxygen.

Two hundred and eleven samples from 111 locations in the province of Ontario were tested. Of these, 55 samples from 30 locations showed promise of being suitable for the production of coated lightweight aggregate by the rotary-kiln process. The other materials either bloated in narrow temperature ranges or bloated poorly. Some of these might be used in the sintering process. A clay and shale blend from one deposit was sintered satisfactorily.

The tests reported here are of a preliminary nature and are meant only to indicate which materials show promise. It would be necessary to carry out large-scale tests to obtain such information as: precise temperatures at which bloating takes place, temperatures at which agglomeration begins, severity of agglomeration, optimum kiln atmosphere, unit weight and strength of product, and concrete-making properties of the aggregate.

REFERENCES

(1) "What About Deflection?", Lightweight Concrete Information Sheet No. 2, Expanded Shale Clay and Slate Institute, Washington, D.C. (1955).

(2) N.G. Zoldners, V.M. Malhotra and H.S. Wilson, "High-Temperature Behaviour of Aluminous Cement Concretes Containing Different Aggregates", Mines Branch Research Report R109, Department of Mines and Technical Surveys, Ottawa, p. 28 (1963).

(3) "Lightweight Aggregate Concretes", Housing and Home Finance Agency, Washington, D.C., August 1949.

(4) T.E. Jackson, discussion of the paper "Changes in Colour of Clays on Ignition in Clayware Kilns", by Arthur Hopwood, Trans. Ceram. Soc. (Engl.), pp. 37-43 (1903).

REFERENCES (cont'd)

(5) E. Orton and F.H. Staley, "Status of C, Fe, and S in Clays During Various Stages of Burning", 3rd Report, National Brick Manufacturers Association, 1908.

(6) A.V. Bleininger and E.T. Montgomery, "Effect of Overfiring upon the Structure of Clays", Trans. Am. Cer. Soc. 15, pp. 71-85 (1913).

(7) F.G. Jackson, "Oxidation of Ceramic Ware During Firing. II: The Decomposition of Various Compounds of Iron with Sulphur under Simulated Kiln Conditions", J. Am. Cer. Soc. 7, pp. 223-37, 382-96 (1924).

(8) Hewitt Wilson, "Ceramics - Clay Technology", McGraw-Hill Book Co., Inc., New York (1927).

(9) C.R. Austin, J.L. Nunes and J.D. Sullivan, "Basic Factors Involved in Bloating of Clays", Am. Inst. Mining & Met. Engrs. Tech. Pub. No. 1486, Mining Technology 6 (4) (1942).

(10) J.D. Sullivan, C.R. Austin and E.J. Rogers, "Expanded Clay Products", Am. Inst. Mining and Met. Engrs. Tech. Pub. No. 1485, Mining Technology 6 (4) (1942).

(11) C.M. Nicholson and G.A. Bole, "Cellulated Ceramics for the Structural Clay Products Industry", J. Am. Cer. Soc. 36(A), pp. 127-136 (1956).

(12) J.E. Conley, H. Wilson, T.A. Klinefelter and others, "Production of Lightweight Concrete Aggregates From Clays, Shales, Slates, and Other Materials", U.S. Bureau of Mines Report of Investigations No. 4401 (1948).

(13) C.M. Riley, "Relation of Chemical Properties to the Bloating of Clays", J. Am. Cer. Soc. 34(4), pp. 121-128 (1951).

(14) J.G. Matthews and H.S. Wilson, "Preliminary Report on Coated Lightweight Concrete Aggregate From Canadian Clays and Shales", Parts I-VI; Mines Branch, Department of Mines and Technical Surveys, Ottawa, Memorandum Series Reports Nos. 117, 120, 121 and 122, in 1952, by J.G. Matthews, and Nos. 126 in 1953 and 128 in 1954, by H. S. Wilson.

(15) W.A. Cole and J.D. Zetterstrom, "Investigation of Lightweight Aggregates of North and South Dakota", U.S. Bureau of Mines Report of Investigations No. 5065, July 1954.

REFERENCES (concluded)

(16) N. Prokopovich and G.M.Schwartz, "Preliminary Survey of Bloating Clays and Shales in Minnesota", University of Minnesota, Summary Report No. 10 (1957).

(17) J.O. Everhart, E.G. Ehlers, J.E. Johnson and J.H. Richardson, "A Study of Lightweight Aggregates", Ohio State University, Engineering Experiment Station Bulletin No. 169 (May 1958).

(18) L.M. Blyumen, "The Physicochemical Nature of Clay Bloating - The Formation of Keramzite", Glass and Ceramics 17 (2), Dec. 1960, pp. 89-94 (translated from Steklo i Keramika 17 (2), 1960, pp. 32-36).

(19) V.F. Pavlov, "The Effect of Viscosity Changes in the 800-1200° Range on the Vitrification and Bloating of Low Refractory Clays", Glass and Ceramics 17 (3), Dec. 1960, p. 133 (translated from Steklo i Keramika 17 (2), 1960, pp. 21-24).

(20) R.D. Hill and D.N. Crook, "Some Causes of Bloating in Expanded Clay and Shale Aggregates", Aust. J. of App. Sc. 11 (3), Sept. 1960, p. 374.

(21) Officers of the Geological Survey of Canada, "Geology and Economic Minerals of Canada", Economic Geology Series No. 1, Fourth Edition (1957).

—

HSW:(PES)EBM