Mines Branch Technical Bulletin TB 48

LIGHTWEIGHT CONCRETE AGGREGATES FROM CLAYS AND SHALES IN QUEBEC

by

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ABSTRACT

The first half of the report includes a description of the types of lightweight aggregates, the properties of lightweight concrete, the history of the expanded-clay and -shale industry, and the methods of production. Also, various theories on the causes of bloating are outlined and discussed. It is concluded that in most materials, the chemical analysis indicates whether the liquid phase formed on heating will be of the proper viscosity. The compounds that release bloating gases may be carbonates, organic material, 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 Quebec and Ontario is given.

In the second half of the report, the 68 locations from where 91 samples were taken are briefly described, and the results of the tests are given. Twenty-one samples from 18 locations show promise of being suitable for production by the rotary kiln. Some of the other materials might be used for sintering.

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(A French translation of this report will be published)

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 province of Quebec has received considerable attention in this investigation. This report is a consolidation of all phases of this investigation done by the Mines Branch on lightweight aggregate raw materials in Quebec to the present time and includes results of that part of the investigation published in Part V. It should be noted that some experimental work reported in Part V was completed by J. G. Matthews before he left the Government service. This work 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.

It should be noted that the section of this report describing geology refers to both Quebec and Ontario. 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 Quebec are marine and those of southern Ontario are lacustrine, they are both post-glacial and were deposited at approximately the same period.

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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, office and 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 lb/in.^{2}. Structural concrete should have a compressive strength of at least 2000 lb/in.^{2}. 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 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 struotural 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, caused 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 did not dissociate, but dissolved 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 increased 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 depended 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 believed the carbon dioxide was formed from elemental carbon being oxidized by the reduction of ferric oxide. They believed it was not from the carbonates, as these dissociate completely by 1900°F. The water was 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 claimed 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 varied inversely as the rate of heating, and directly with the rate of air flow. Oxygen and air atmospheres had 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 was slightly different to that 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 lowered the temperature at which maximum bloating occurred. 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.

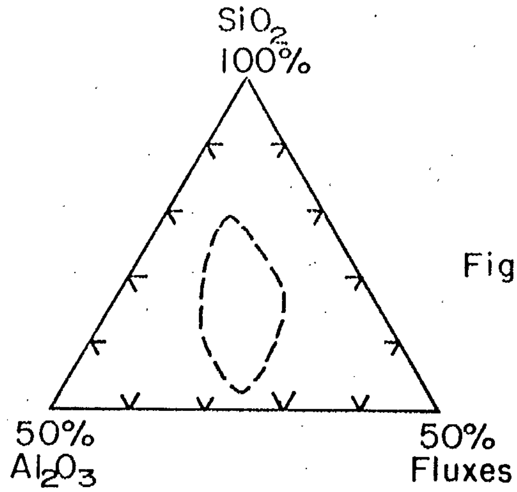

Figure : 1

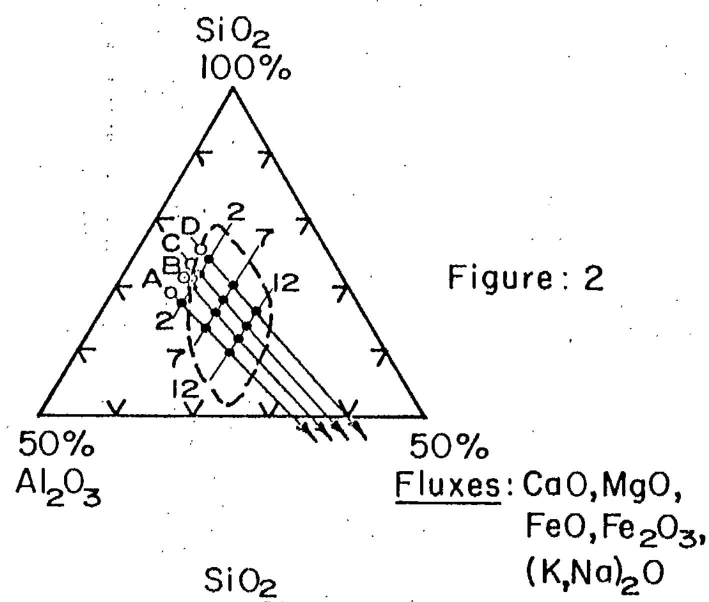

Figure : 2

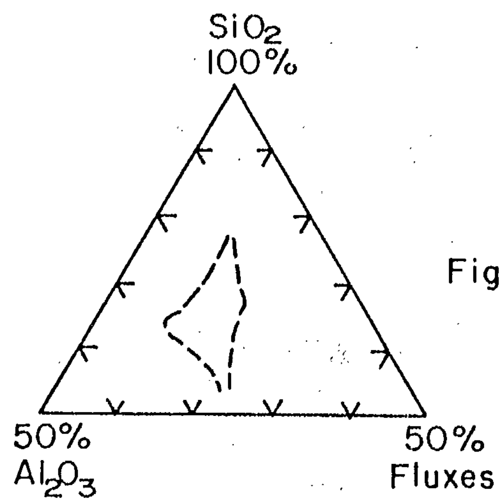

Figure : 3

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. Only 7 per cent additions of 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

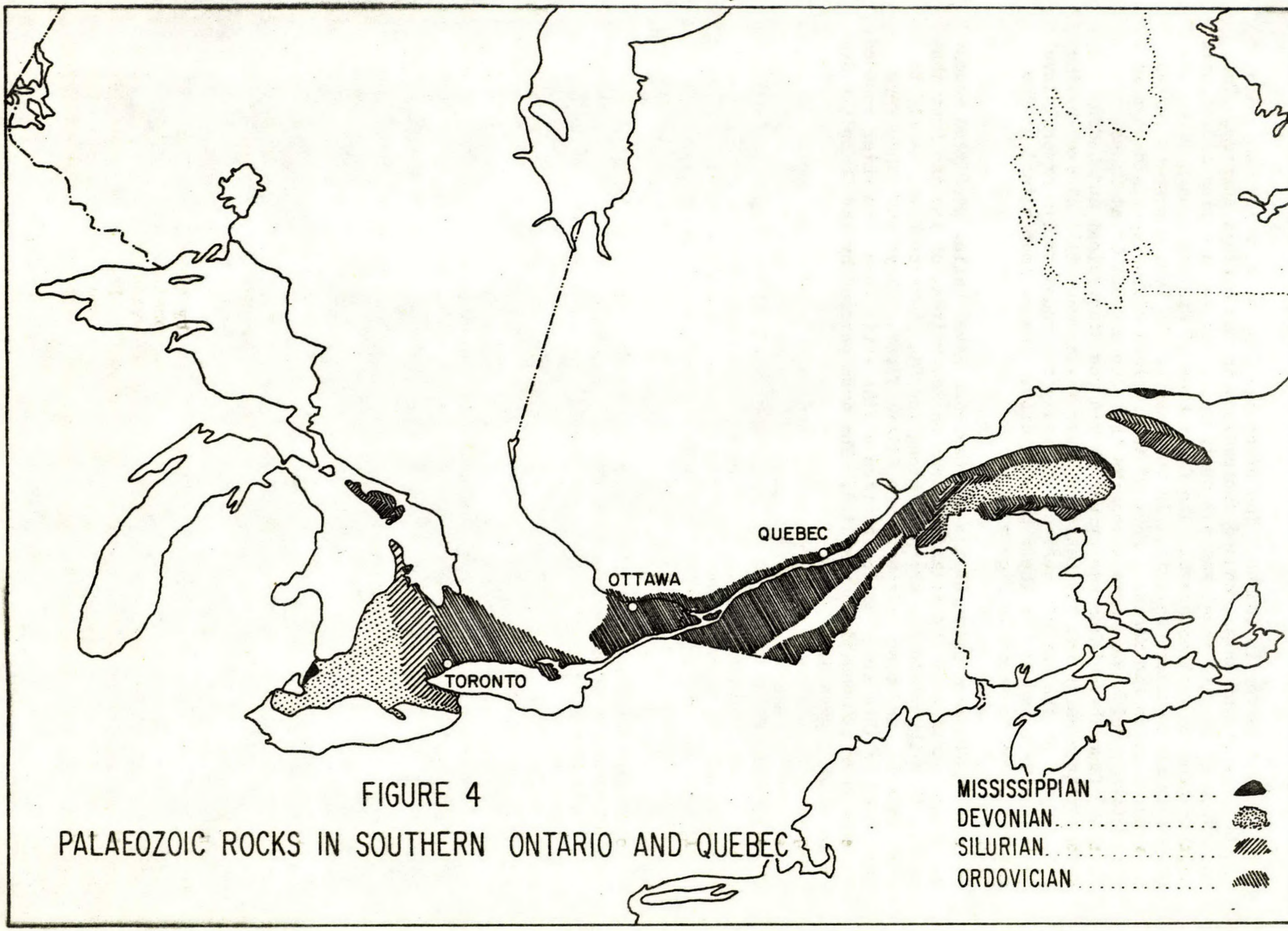

FIGURE 4

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.

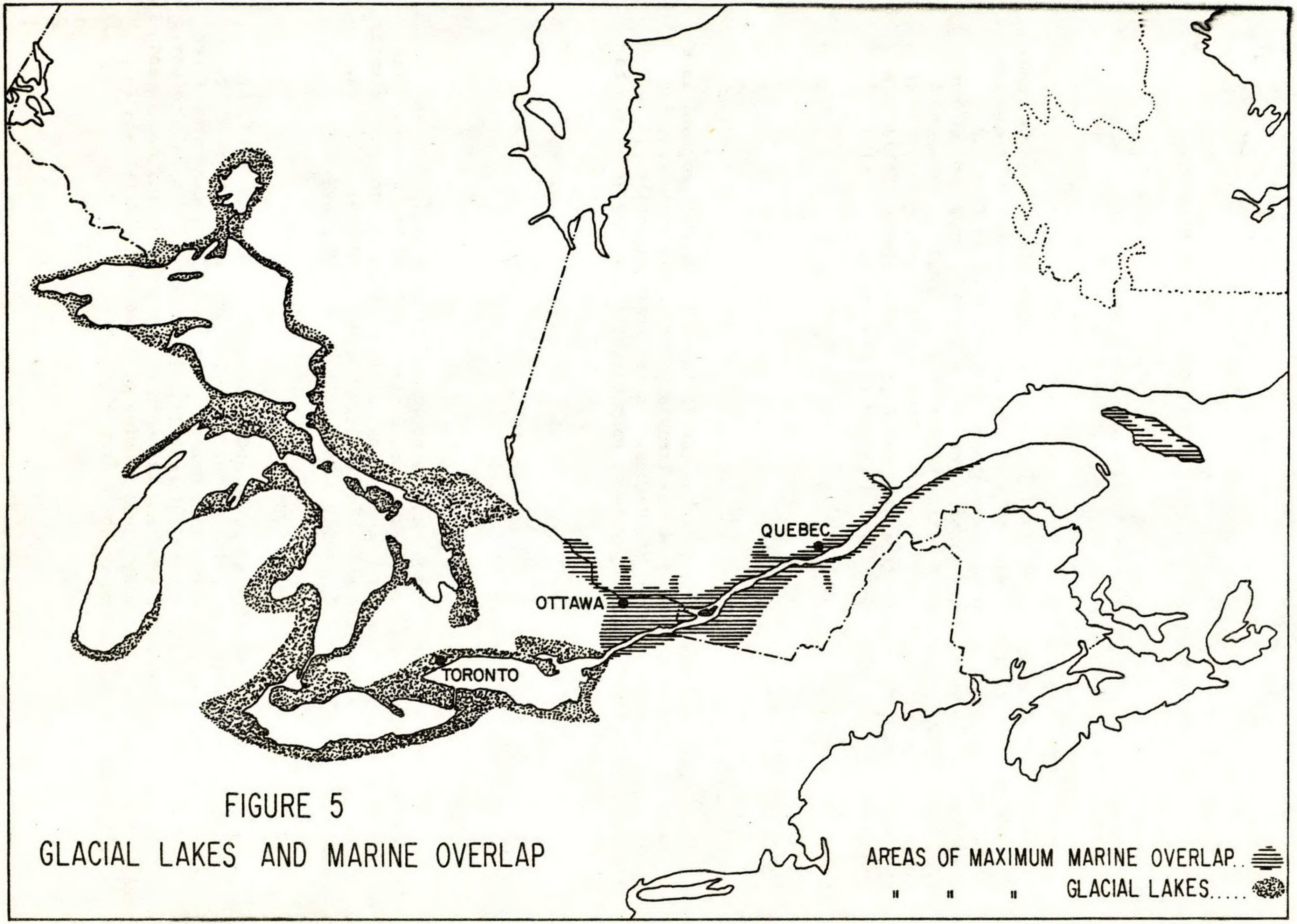

FIGURE 5

GLACIAL LAKES AND MARINE OVERLAP

EVALUATION OF CLAYS AND SHALES FROM THE PROVINCE OF QUEBEC

Arthabaska County

Victoriaville

A grey-brown clay is used by Brique Victoria Limitée in the manufacture of structural and drain tile at a plant 3/4 mile west of Victoriaville. The deposit, which had been opened to a depth of 12 feet, is situated 2 miles west of the plant. The clay (Sample 1) expanded 100 per cent when fired in the 5-foot rotary kiln at 1940 to 1980°F. The graded product had a unit weight of 33.0 lb/cu ft and had a crushing strength of 310 and 1070 psi for compactions of 1 and 2 inch respectively. This is a promising clay for production by the rotary kiln process.

Bagot County

St. Hugues

Sample 2 was taken from the top 25 feet of a deposit exposed to a depth of 40 feet in the banks of the Yamaska River at the ferry crossing about 1 mile downstream from St. Hugues. In the stationary kiln, it bloated, below the fusion temperature, only slightly and thus would not be a suitable material.

Beauce County

Beauce Junction*

Sample 3 was a black, highly compacted fissile slate from the Beauce County Quarry at Beauce Junction, 5 miles north of St. Joseph. This material was at one time used for roofing slate. Fusion was not sufficiently uniform to make this slate suitable for lightweight aggregate production. Some particles bloated well, while others were completely fused.

St. Georges

A deposit of grey clay, opened to a depth of about 20 feet, is used in the manufacture of brick on the southwest edge of the town of St. Georges. Sample 4, taken from this deposit, expanded 35 per cent when fired at 2030 to 2070°F in the 5-foot rotary kiln. The product had a unit weight of 38.9 lb/cu ft and had a crushing strength of 700 and 3570 psi for 1- and 2-inch compaction. This clay shows promise of being suitable for lightweight aggregate production in the rotary kiln.

St. Joseph de Beauce*

Samples of three clays from this locality were tested. Two (Samples 5 and 6) were red-burning clays used by Syndicat des Céramistes Paysans de la Beauce. Sample 5 did not bloat uniformly when fired in the stationary kiln. Sample 6 was found to be a poor bloater. Sample 7 was from an outcrop of oxidized Pleistocene clay 6 feet in thickness, on Highway 23 one mile south of the town. Stationary kiln tests showed this clay to be a good bloater, but only above the temperature where agglomeration commenced. Of the three samples, only Sample 7 shows any promise as a suitable raw material. It could not be used to produce a coated type of aggregate, but it might be used in the sintering process.

Bellechasse County

Beaumont

Samples 8 and 9 came from steeply dipping Sillery shale in a cut on Highway 2, 1/2 mile west of Beaumont, 7 miles east of Lauzon. The strata of this outcrop varied considerably in hardness. The outcrop extended for 20 feet along the highway, and was exposed to a depth of 8 feet.

Sample 8 was taken from the eastern half of this outcrop. In the stationary kiln tests, bloating was good only above the agglomerating temperature.

Sample 9 was from the western half of the outcrop. The bloating of this material was not sufficiently uniform when tested in the stationary kiln to warrant rotary kiln tests. This shale does not show much promise of being a suitable material.

One-half mile south of the junction of Highways 2 and 25A, 2 miles east of Beaumont, a mixture of weathered red shale, sand, and small pebbles was exposed to a depth of at least 5 feet in an open pit. A sample of this material (Sample 10) was passed over a 20-mesh screen prior to testing, to remove the sand. In the stationary kiln tests, the shale particles bloated well but the pebbles did not. The non-uniformity of this material did not warrant rotary kiln tests.

St. Charles de Bellechasse

Sample 11 was a grab sample of an unconsolidated red shale from a ditch along Highway 25A, just south of St. Charles. This material possessed almost no plasticity and consequently was difficult to pelletize. Only very slight bloating resulted from firing in the stationary kiln. No further tests were performed.

A sewer excavation on the south edge of St. Charles exposed a deposit of Lorraine shale, the extent of which is not known. Sample 12 was a grab sample of that shale. At best, only medium bloating was achieved in the stationary kiln tests, and the degree of bloating was not uniform. These poor bloating characteristics eliminated this shale from further consideration.

Chambly County

Chambly

An outcrop of Lorraine shale appears on the west bank of the Richelieu River close to the hydro dam at Chambly, 20 miles east of Montreal. There are 15 feet of shale above water level, topped by 3 feet of overburden. This shale (Sample 13) gave good results when fired in the rotary kiln. It expanded 80 per cent when fired at 2100 to 2130°F. The aggregate had a bulk density of 45 lb/cu ft and a crushing strength of 1510 psi for 1 inch compaction.

Chicoutimi County

Arvida

Highway 16 cuts through hills on the western edge of Arvida, exposing up to 30 feet of clay. The top 8 feet of the clay are brown (Sample 14) and the remainder is grey (Sample 15). Sample 14 bloated moderately, only at the temperature at which agglomeration took place. Sample 15 bloated only slightly, below the fusion temperature. Neither of these materials shows much promise of being suitable for the rotary kiln process.

Jonquiere

Sample 16 was taken from the top 8 feet of a deposit of clay exposed to a depth of about 25 feet in a quarry beside Highway 16 to the west of Jonquiere. The top 8 feet was the only part of the exposure that could be reached for sampling. This clay bloated moderately, but only through a narrow temperature range below the fusion temperature. This material would not be a suitable raw material.

Compton County

East Angus

Two samples (17 and 18) were taken from the property of East Angus Brick and Tile, Inc. Sample 17 was a grab sample of grey Pleistocene clay. When tested in the stationary kiln, it bloated poorly below the agglomerating temperature and above it, rather well. Sample 18, which was from the oxidized portion of the clay deposit, bloated well in the rotary kiln when fired at 2100 to 2150°F. The resulting aggregate had a bulk density of 33 lb/cu ft and a crushing strength for 1 inch compaction of 1590 psi. This oxidized material shows promise as a source of coated lightweight aggregate.

Dorchester County

Scott Junction

La Brique de Scott, Ltée., of Scott Junction, 25 miles south of Quebec, produces brick and tile from a deposit of Pleistocene clay. The pit has been opened to a depth of about 12 feet. The top 4 feet of the deposit is brown oxidized clay, the remainder is unaltered grey clay. Sample 19 was a grab sample of the brown and grey clays mixed in approximately equal proportions. It was fired in the rotary kiln at 2050 to 2100°F. Agglomeration began at 2100°F. Below that temperature, the expansion was 15 per cent, giving a product having a bulk density of 60 lb/cu ft and a crushing strength of 2460 psi. This aggregate has too high a bulk density, but if the clay were fired above the agglomerating temperature, the expansion would possibly be greater.

Gatineau County

Aylmer

A sample (Sample 20) was taken from an outcrop of a shaly limestone at Aylmer, 5 miles west of Hull. This material was high in lime. It was found to be non-uniform when tested in the stationary kiln; portions bloated well but with a high degree of surface fusion, while the remainder showed no bloating. This non-uniformity makes the material unsuitable as a raw material for lightweight aggregate.

Chelsea

A grey clay is exposed at intervals from Hull to Chelsea along Highway 11. Sample 21 was taken from a 4-foot exposure in the ditch beside the highway, about 2 miles south of Chelsea. When tested in the rotary kiln it bloated moderately, but in a narrow temperature range. When fired between 2020 and 2030°F, it bloated 5 per cent, resulting in aggregate having a unit weight of 51.9 lb/cu ft, and a crushing strength of 880 and 4140 psi for 1- and 2-inch compaction. It is doubtful whether this material could be used for production by the rotary kiln process, because of the narrow bloating range.

Deschenes

Green Rockcliffe shale is exposed beside the road between Deschenes and Aylmer, about 1/2 mile west of Deschenes. It is exposed to a depth of 4 feet, over a length of about 200 feet. Sample 22 did not bloat below the agglomerating temperature in the stationary kiln tests, and would not be suitable for the rotary kiln process.

Ironside

An excavation beside Highway 11, on the southern edge of Ironside, exposed a grey clay to a depth of 4 feet. A grab sample of the excavated material (Sample 23) bloated 95 per cent when fired in the rotary kiln at 1965 to 1990°F. The product had a unit weight of 31.2 lb/cu ft, and a crushing strength of 370 and 1200 psi for 1- and 2-inch compaction. This clay shows some promise of being a suitable material for the rotary kiln process, but the bloating range appears to be rather short.

Hull County

Hull*

Canada Cement Company Limited at Hull uses a blue Champlain clay in the manufacture of Portland cement, obtaining the clay from a deposit adjacent to the plant. A sample (Sample 24) from this deposit, when tested in the stationary kiln, showed too short a vitrification range to be used for coated lightweight aggregate. The bloating appeared to be fairly good above the agglomerating temperature, and the clay thus has possibilities as a raw material for a sinter process.

Jacques Cartier County

Lakeside

Montreal Terra Cotta Limited operates a structural tile plant at Lakeside (Pointe Claire). The raw material is a Pleistocene clay, a portion of which has been oxidized to a brownish colour. Both the unaltered grey clay (Sample 25) and the brown clay (Sample 26) were found to be poor bloaters with narrow vitrification ranges, when tested in the stationary kiln. Rotary kiln tests were considered unwarranted.

Ste. Geneviève de Pierrefonds

A brown clay containing some pebbles outcrops on the bank of the Rivière des Prairies, 1/2 mile east of the bridge from Ste. Geneviève to Ile Bizard. Sample 27 was taken from the 8-foot exposure. It did not bloat below the temperature at which fusion took place. The pebbles were limestone. This material would not be suitable for production of lightweight aggregate.

An excavation at the western end of Ste. Geneviève exposed a grey-brown clay to a depth of 5 feet. Sample 28, a grab sample of the material excavated, bloated fairly well, but over too narrow a temperature range to be a suitable raw material for the rotary kiln process.

Lake St. John County

Roberval

Samples 29 and 30 were taken from a 15-foot exposure of grey clay, about 2 miles southeast of Roberval beside Highway 55. Sample 29 was from the upper 8 feet and Sample 30 was from the lower 7 feet of the outcrop. The clay appeared uniform throughout the outcrop. Both samples bloated only slightly below the agglomerating temperature in the stationary kiln tests. This clay would not be suited to the rotary kiln process.

Laprairie County

Delson

Domtar Construction Materials Ltd. uses clay and Utica shale at Delson, in the manufacture of brick and structural tile. The top 1 to 3 feet of the deposit is brown clay (Sample 31). It bloated 70 per cent when fired in the rotary kiln at 2020 to 2055°F. The graded product had a unit weight of 42.0 lb/cu ft, and a crushing strength of 460 and 1920 psi, for 1- and 2-inch compaction. A blue clay (Sample 32), below the brown clay, is reported to have a thickness of at least 40 feet. It bloated only slightly, below the fusion temperature, when tested in the stationary kiln. Utica shale is exposed to a depth of about 20 feet, adjacent to the plant. When fired in the rotary kiln at 2005 to 2040°F, a sample of this shale (Sample 33) bloated 135 per cent. The graded product had a unit weight of 37.0 lb/cu ft, and a crushing strength of 590 and 2860 psi. Of the three materials, the shale (Sample 33) shows the most promise. The brown clay (Sample 31) bloated well, but is not abundant.

Laprairie

Domtar Construction Materials Ltd. also operates a brick plant at Laprairie, 20 miles southeast of Montreal. A large deposit of Lorraine shale is the source of the raw material used in the making of brick. This shale (Sample 34) has good bloating qualities, which seem to suit it for a coated type of aggregate. When fired at 2100 to 2150°F in the rotary kiln, it expanded 115 per cent, giving an aggregate having a bulk density of 37 lb/cu ft and a crushing strength of 1440 psi for 1-inch compaction.

L'Assomption County

L'Epiphanie

A deposit of grey calcareous clay (Sample 35) outcrops on the east bank of the L'Achigan River, 600 yards below the railway bridge near L'Epiphanie, 30 miles northeast of Montreal. The deposit does not appear to be extensive but has a visible thickness of 15 feet overlain by 10 feet of boulder clay. The clay when tested did not prove to be sufficiently uniform to be of much value as a raw material for lightweight aggregate.

St. Lin

A drainage canal under Highway 41, about 3-1/2 miles east of St. Lin, exposes 4 feet of grey-brown clay. This material (Sample 36) bloated moderately well, although through a rather narrow temperature range, when fired in the stationary kiln. It is doubtful whether this clay would be a suitable raw material for the rotary kiln process.

St. Roch de L'Achigan

A grey-brown clay similar to Sample 36 is exposed in a drainage ditch under Highway 18, about 1-1/2 miles south of the junction of Highways 18 and 41. Sample 37 was taken from a 6-foot exposure of the clay. This material proved to be a poor bloater.

Laviolette County

St. Tite

A clay deposit near a non-operating brick plant, 3/4 mile west of the railway station at St. Tite, had been opened to a depth of 6 feet. Sample 38 was taken over the 6-foot exposure of grey-brown clay. When tested in the stationary kiln, it bloated only slightly, below the temperature at which fusion occurred. It would not be a suitable raw material.

Levis County

Levis

Outcrops of Utica shale, which dip nearly vertically, occur in several locations east of Levis. The shale is flaky and brittle, and contains bands of limestone. Sample 39 was taken from an outcrop along Highway 2, 2-1/2 miles east of the Levis traffic circle. This shale did not bloat uniformly in the stationary kiln tests. The thin flakes did not bloat, whereas the thicker sections bloated fairly well. Rotary kiln tests were not warranted.

Lotbiniere County

Deschaillons

The Pleistocene clay along the south bank of the St. Lawrence River at Deschaillons is the material used by Montreal Terra Cotta Limited in the manufacture of structural tile. The deposit is about 25 ft thick and contains a blue-grey clay with a few bands of sand, principally in the lower portion. Sample 40 was a grab sample of this clay. In the stationary kiln tests, good bloating was achieved only above the temperature at which the particles began to agglomerate.

St. Antoine Lotbiniere

Lorraine shale is exposed to a depth of about 50 feet on the south bank of the St. Lawrence River in this area. Sample 41 was taken about half way up the exposure at the western end of the village. This was the highest point that could be reached at this outcrop. The shale bloated non-uniformly when tested in the stationary kiln, indicating it would not be suitable for production of lightweight aggregate.

St. Apollinaire

An excavation for a house on the northern edge of the village of St. Apollinaire exposed red shale to a depth of 6 feet. A grab sample (Sample 42) of the excavated material bloated only slightly below the agglomerating temperature, and would not be suited to the rotary kiln process.

Lotbiniere

Lorraine shale is exposed to a depth of 25 feet, 1-1/2 miles east of Lotbiniere, in a gully beside Highway 3. The bottom 6 feet of the outcrop were covered by talus. Sample 43 was taken from the interval 6 to 11 feet above the gully floor, and Sample 44 was taken from the interval 11 to 16 feet. The material above this level could not be reached. Both samples bloated well, when fired in the 5-foot rotary kiln. Sample 43 expanded 100 per cent when fired at 2010 to 2020°F, resulting in a product having a unit weight of 34.9 lb/cu ft and having a crushing strength of 560 and 2230 psi for 1- and 2-inch compaction. Sample 44 was fired at 1960 to 1990°F, and expanded 75 per cent. The product had a unit weight of 38.1 lb/cu ft and had a crushing strength of 620 and 2800 psi. This shale shows promise of being suitable for production of a lightweight aggregate by the rotary kiln process.

Missisquoi County

Cowansville

Interbedded grey-black shale and sandstone outcrop on the banks of a small stream, on Highway 40 one mile west of its junction with Highway 52. The deposit dips about 60 deg to the east. Sample 45 was taken from loose material at the surface of the deposit. The material bloated non-uniformly when tested in the stationary kiln, the bloating varying from none to good. This is not a promising raw material.

Dunham

A deposit similar to that near Cowansville outcrops on the banks of a stream, 1-1/2 miles north of Dunham, along Highway 52. Sample 46 was of loose material at the surface of the deposit. It reacted similarly to Sample 45 in the stationary kiln tests, and thus would not be a suitable raw material.

Farnham

Along the west bank of the Yamaska River, at the north edge of the town of Farnham, a light-coloured sandy clay (Sample 47) is exposed over a thickness of 12 feet. There is very little overburden. The clay bloated well when tested in the rotary kiln, although the strength of the product was low. It expanded 65 per cent when fired at 2100 to 2150°F, giving a product having a bulk density of 44 lb/cu ft and a crushing strength of 640 psi for 1-inch compaction. This is a promising material.

Montmorency County

Ste. Anne de Beaupré

The high bank about 3/4 mile from the north shore of the St. Lawrence River, east of Quebec, exposes shale up to 40 feet in thickness. Three samples were taken from an exposure 1-1/2 miles east of the shrine at Ste. Anne de Beaupré. The shale is grey, brown, and black, and is extensively folded. Sample 48 was from the top 6 feet, Sample 49 was from the middle 10 feet, and Sample 50 was from the bottom 10 feet of this 40-foot exposure. This material does not have much promise as a suitable raw material -- when tested in the stationary kiln, Samples 48 and 49 bloated non-uniformly and Sample 50 bloated only slightly.

Nicolet County

Becancour

Two samples, 51 and 52, were taken from deposits of red Queenston shale along the banks of the Becancour River, 2 miles south of the town of Becancour, 18 miles east of Nicolet. Sample 51, from the west bank of the river, was from 10 feet of shale covered by 5 feet of overburden. This shale gave fair results in the stationary kiln tests, but in the rotary kiln expanded only 5 per cent, which is insufficient to produce a good aggregate. Bloating above the temperature where agglomeration occurs might be sufficient to produce a good sintered aggregate.

The deposit on the east bank of the river varied up to 15 feet in thickness, with 3 feet of soil on top. This shale (Sample 52) was non-uniform below the agglomerating temperature, when tested in the stationary kiln. Above that temperature it seemed to be good. It may have possibilities as a sintered type of aggregate, but not as a coated type.

Mitchell

An abandoned brick plant, on the west side of the Nicolet River 1/4 mile south of the railway station at Mitchell, used a brownish-grey clay from a deposit that had been opened to a depth of 15 feet. Sample 53 was taken from the top 8 feet of the deposit. The remainder of the face was covered by talus. In the stationary kiln, this clay bloated moderately well, but over a very short temperature range. It is not a promising raw material.

Nicolet

Cuts through a series of low hills along Highway 3, west of Nicolet, expose Pleistocene clay. Sample 54 was taken from such a cut, 6-1/2 miles west of Nicolet. A trench one foot in depth showed the clay to be oxidized the full extent of the 12-foot face. Farther back in the deposit, the clay would probably be unaltered grey. The sample taken was an average of the 12-foot face of the outcrop. Stationary kiln tests showed that the clay did not bloat uniformly below the agglomerating temperature. At higher temperatures the bloating was good. As this clay would not be suitable for a coated type of aggregate, rotary kiln tests were not made.

A grey clay is exposed in the sides of a gully beside the road about 2 miles south of Nicolet, on the east side of the Nicolet River. Sample 55, taken from the middle 10 feet of a 20-foot depth of clay, bloated only slightly in the stationary kiln. This clay would not be a suitable material for the rotary kiln process.

St. Gregoire

A rise in ground about 1 mile south of Lake St. Paul, 1-1/2 miles east of St. Gregoire, consists of red Queenston shale. Sample 56 was of weathered material from the middle 8 feet of the 15-foot rise. When made into pellets by extrusion, this shale bloated well in the rotary kiln. When fired at 1980 to 2020°F, it expanded 130 per cent. The product had a unit weight of 27.8 lb/cu ft and had a crushing strength of 225 and 730 psi for 1- and 2-inch compaction. This is a promising material for the rotary kiln process.

Ste. Monique de Nicolet

A deposit of Queenston shale was exposed along the Nicolet River at Ste. Monique, 7 miles southeast of Nicolet. It is a moderately hard, plastic, red shale containing a few narrow bands of green shale. Sample 57 was taken near river level where 8 feet of sand overlie 6 feet of shale, 125 yards upstream from the highway bridge.

Sample 58 was taken from a 12-foot thickness of shale that is exposed for 200 yd along the river, 600 yd upstream from the bridge. The shale here is overlain by about 6 feet of sand. Both of these samples bloated only slightly when tested in the stationary kiln. This poor bloating quality eliminates them as possible raw materials for lightweight aggregate.

St. Pierre Les Becquets

A gully beside Highway 3, about 6-1/2 miles west of St. Pierre Les Becquets, exposes grey clay to a depth of 15 feet. Sample 59 was taken from a 5-foot outcrop near the bottom of the bank of the gully. This clay did not bloat below the fusion temperature, and would not be suited to the rotary kiln process.

Portneuf County

Cap Santé

The north shore of the St. Lawrence River between Cap Santé and Donnacona is made up of hard Utica shale, exposed to a depth of up to 30 feet. Sample 60 was taken from a point about 1/4 mile east of the railway station at Cap Santé. The deposit is made up of thin brittle bands and thicker bands.

A similar material outcrops beside Highway 2, west of Cap Santé. Sample 61 was taken from a 15-foot exposure about 2 miles west of the village.

Neither sample bloated when fired in the stationary kiln and does not show promise of being suitable raw material.

Neuville

Utica shale outcrops beside Highway 2 just west of the village of Neuville. In this outcrop the black shale is about 200 feet long and 10 feet thick, and is about 1/4 mile from the north shore of the St. Lawrence River. Sample 62 was taken over 8 feet of the exposure. It did not bloat in the stationary kiln tests, and thus would not be a suitable raw material.

Pont Rouge

A grey-brown clay is exposed beside the road between Highway 2 and St. Raymond, about 3 miles northwest of Pont Rouge. The clay outcrops on the south side of a valley beside the road. The clay is weathered to a depth of about 6 inches. Sample 63 was of the weathered material over a distance of 6 feet, and Sample 64 was of unweathered clay over a distance of 5 feet. Sample 63 bloated only slightly below the agglomerating temperature, and Sample 64 did not bloat below the fusion temperature, when they were tested in the stationary kiln. This clay does not show much promise of being a suitable raw material.

St. Augustin de Québec

A steeply-dipping black shale outcrops beside the road leading from the village of St. Augustin toward the St. Lawrence River about 1/2 mile from the river. The top 6 feet of the shale showed evidence of weathering. Sample 65 was taken from this weathered part of the outcrop. Sample 66 was taken over 15 feet of the unweathered part of the material.

Sample 65 bloated well when tested in the rotary kiln. When fired at 2005 to 2025°F, it expanded 100 per cent. The graded product had a unit weight of 32.8 lb/cu ft and had a crushing strength of 480 and 1830 psi. When tested in the stationary kiln, Sample 66 bloated non-uniformly and at best only slightly below the agglomerating temperature. The weathered portion of this deposit shows promise of being acceptable for the rotary kiln process.

Quebec County

Cap Rouge

A small outcrop of reddish and grey-brown shale occurs beside the road between the Quebec Bridge and Cap Rouge. The outcrop, which is 3 by 100 feet in extent, is reddish at the western end (Sample 67) and grey-brown at the eastern end (Sample 68). When tested in the rotary kiln at 2030 to 2055°F, Sample 67 expanded 100 per cent. The product had a unit weight of 45.0 lb/cu ft, and a crushing strength of 600 and 3710 psi. Sample 68 expanded 145 per cent when fired at 2010 to 2050°F, resulting in a product having a unit weight of 36.8 lb/cu ft and a crushing strength of 530 and 2490 psi. The material from this outcrop appears suited to the rotary kiln process.

Quebec*

At Wolfe's Cove, Utica shale is exposed for a considerable extent. This material (Sample 69) bloated only slightly when fired in the stationary kiln. No further tests were made.

Sample 70 was a Utica shale from Beauport, 5 miles east of Quebec. Tests in the rotary kiln showed that the shale has a short vitrification range since agglomeration was severe at the bloating temperature (1950 to 1960°F). This characteristic, which caused the material to stick to the kiln lining, indicates that the shale would not be suited to the rotary kiln process.

Rotary kiln tests on Sample 71, which was a Utica shale from Boischatel, 10 miles east of Quebec, gave results similar to those from tests on Sample 70.

Tests were performed on these two shales using a sintering machine with good results. Powdered coke was used as the fuel. Using 11.5 per cent coke and 3 per cent sawdust with Sample 70, a product having a bulk density of 38 lb/cu ft was obtained. Using 15 per cent coke and 3 per cent sawdust with Sample 71, the aggregate produced had a bulk density of 41 lb/cu ft. These were the best results obtained from several tests in which water, fuel, vacuum, depth of bed, and retention time were varied. These two shales appear to have good possibilities for the sintering process.

Richmond County

Richmond

At one time, a small brick plant at Richmond, 25 miles north of Sherbrooke, produced brick by the soft-mud process. The material used was dense, black, plastic clay. The deposit, which is covered by 4 feet of sandy-brown clay, had been opened to a depth of 4 feet. From the tests, the black clay (Sample 72) appears promising for a coated type of aggregate. The product from the rotary kiln test had a bulk density of 44 lb/cu ft, and a crushing strength of 1115 psi. The expansion was 30 per cent, and the firing temperature was 2000 to 2070°F.

Sample 73 came from a 3-foot outcrop of oxidized Pleistocene clay, 3 miles south of Richmond, along Highway 5. This clay, which was overlain by 2 feet of sand, appeared to cover a fairly extensive area. Sand was also found below the clay. The clay does not appear to be of much value, as it was non-uniform when tested in the stationary kiln.

Windsor Mills

Oxidized Pleistocene clay outcrops in several places in the vicinity of Windsor Mills, 15 miles north of Sherbrooke. Sample 74 was taken from an outcrop one mile north of the town, beside Highway 5. The clay is exposed to a depth of 10 feet and seems fairly extensive. Stationary kiln tests showed this clay to be a fairly good bloater. However, tests in the rotary kiln indicated that bloating below the agglomerating temperature is only slight. This eliminates it as a possible raw material for a coated type of aggregate.

Rouville County

St. Hilaire

Lorraine shale is exposed beside the road leading up the west side of Mont St. Hilaire, 3/4 mile from its junction with Highway 9. The shale is very hard and Sample 75 was a grab sample of loose material that had fallen from the 3-foot outcrop. In the rotary kiln this shale expanded 60 per cent, when fired at 1965 to 2010°F. The unit weight of the product was 53.3 lb/cu ft, and the crushing strength was 900 and 5200 psi. This material shows promise of being suitable for processing by the rotary kiln method.

St. Hyacinthe County

St. Denis

About 1 mile east of the village of St. Denis, along Highway 12, the banks of a drainage ditch expose grey-brown clay to a depth of 6 feet. Sample 76 bloated fairly well when tested in the stationary kiln, but not well in the rotary kiln. In the latter, the larger pellets bloated but the smaller ones did not. This appears to be a marginal material but not too promising for the rotary kiln process.

St. Johns County

Lacolle

A secondary road connecting Highways 9A and 9B, just north of Lacolle, passes through a small valley. About 10 feet of clay are exposed in the side of the valley. Sample 77 was taken from grey-brown clay in the upper 5 feet of the exposure, and Sample 78 was from the chocolate-brown clay in the lower 5 feet.

Sample 77 bloated well in the stationary kiln, but only marginally in the rotary kiln. When fired at 2000 to 2030°F, it expanded 5 per cent. The graded product had a unit weight of 55.8 lb/cu ft and a crushing strength of 770 and 3390 psi. Different firing conditions might improve the bloating. Sample 78 did not bloat below the fusion temperature in the stationary kiln. Of the two, only Sample 77 showed any promise of being suitable for the rotary kiln process.

St. Johns

Standard Clay Products Limited at St. Johns uses a Pleistocene clay in the manufacture of sewer pipe. The deposit, which covers several acres, is overlain by 2 feet of top soil and consists of 3 feet of oxidized clay (Sample 79) above the original grey clay (Sample 80).

Sample 79 exhibited good bloating characteristics when tested in the rotary kiln. The aggregate produced from this test had a bulk density of 49 lb/cu ft and a crushing strength of 2390 psi. The material expanded 35 per cent over a firing range of 2000 to 2050°F.

Sample 80 was found to be unsuitable for a coated type of aggregate as it expanded only 5 per cent before it began to agglomerate, when tested in the rotary kiln. Stationary kiln tests, however, showed it bloated very well above that temperature (2100°F).

Sherbrooke County

Ascot Corner

Extensive outcrops of Pleistocene clay occur at Ascot Corner, 7 miles east of Sherbrooke. Sample 81 was the brown oxidized clay used in a former brick plant. This clay bloated well when tested in the stationary kiln, but only at 2500°F, which is high for commercial production. Two samples (82 and 83) from an outcrop along the highway just west of the bridge over the St. Francois River might be suitable for a sintered type of aggregate. Both the brown and grey clays bloated only slightly below the agglomerating temperature, but above that temperature bloated well.

Deauville*

Sample 84 was argillite, or partially indurated slate-like material, from Deauville, 10 miles southwest of Sherbrooke. Only stationary kiln tests were performed, as the bloating was not sufficiently uniform to warrant rotary kiln tests.

Lennoxville

A deposit of clay about 1-1/2 miles southeast of Lennoxville was used in former years in the manufacture of brick. The deposit had been opened to a depth of about 20 feet. The upper 10 feet were brown (Sample 85), and the lower clay was grey (Sample 86). Both these clays bloated moderately well in the stationary kiln, but only about the temperature at which agglomeration began. These materials would not be suited to the rotary kiln process.

Stanstead County

Massawippi*

A sample of mudstone, or argillaceous sandstone, (Sample 87) was submitted from Massawippi, 25 miles wouthwest of Sherbrooke. When tested in the stationary kiln, this material had a fusion range that was not sufficiently uniform to make it of any value.

Vercheres County

Varennes

A gully beside Highway 3, about 3/4 mile east of the railway station at Varennes, exposes a grey-brown clay to a depth of about 15 feet. This clay (Sample 88) bloated well, but over a narrow temperature range, when tested in the stationary kiln.

Sample 89 was a grab sample of brown clay from an excavation 1/4 mile west of the railway station at Varennes. The clay had been exposed to a depth of 5 feet. This clay bloated well in the rotary kiln. It expanded 175 per cent when fired at 1930 to 1960°F. The graded product had a unit weight of 23.7 lb/cu ft and a crushing strength of 280 and 880 psi.

Of these two samples, only Sample 89 showed promise of being an acceptable raw material for rotary kiln production.

Yamaska County

Pierreville

Both banks of the St. Francois River, 1-1/2 miles south of Pierreville, 20 miles east of Sorel, show extensive deposits of Pleistocene clay. Sample 90 was taken from the west bank of the river, where only the oxidized clay was exposed. Grey Pleistocene clay would, no doubt, be found further down in the deposit. The river bank at that point was about 50 feet in height, and the clay appeared to extend the full height of the bank. It bloated well when tested in the rotary kiln at 2000 to 2050°F. The volume expansion was 45 per cent, giving an aggregate having a bulk density of 46 lb/cu ft and a crushing strength of 1250 psi.

Yamaska

The banks of a creek under the road leading south from the village of Yamaska expose grey-brown clay to a depth of 15 feet. Sample 91 was taken from the top 10 feet of the outcrop. It would not be a suitable raw material for the lightweight aggregate process, because, in the stationary kiln, it bloated only slightly, below the agglomerating temperature.

DISCUSSION OF RESULTS

Of the 91 samples of clays and shales from the province of Quebec, 21 showed promise of being suitable for the production of lightweight aggregate by the rotary kiln process. They bloated sufficiently in the rotary kiln that the unit weight of graded coarse aggregate did not exceed the maximum of 55 lb/cu ft specified by ASTM. The crushing strengths are 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 coated lightweight aggregates could probably be produced.

The 21 samples were:

Sample 1: Clay - Victoriaville, Arthabaska County
4: Clay - St. Georges, Beauce County
13: Shale - Chambly, Chambly County
18: Clay - East Angus, Compton County
23: Clay - Ironside, Gatineau County
31: Clay - Delson, Laprairie County
33: Shale - Delson, Laprairie County
34: Shale - Laprairie, Laprairie County
43: Shale - Lotbiniere, Lotbiniere County
44: Shale - Lotbiniere, Lotbiniere County
47: Clay - Farnham, Missisquoi County
56: Shale - St. Gregoire, Nicolet County
65: Shale - St. Augustin de Québec, Portneuf County
67: Shale - Cap Rouge, Quebec County
68: Shale - Cap Rouge, Quebec County
72: Clay - Richmond, Richmond County
75: Shale - St. Hilaire, Rouville County
77: Clay - Lacolle, St. Johns County
79: Clay - St. Johns, St. Johns County
89: Clay - Varennes, Vercheres County
90: Clay - Pierreville, Yamaska County

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

The latter group might be used to produce clinkered aggregate in a rotary kiln, although agglomeration might be too severe and cause difficulty in production. Many of the materials could probably be used to produce satisfactory aggregate by the sintering method, in 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.

Ninety-one samples from 68 locations in the province of Quebec were tested. Of these, 21 samples from 18 locations showed promise of being suitable for the production of coated lightweight aggregate by the rotary kiln process. The other materials either bloated through narrow temperature ranges or bloated poorly. Some of these might be used in the sintering process. Sintering tests were made on two shales, with promising results.

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.

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