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

PART II

MANITOBA AND SASKATCHEWAN

by

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Industrial Minerals Division

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PREFACE

In 1949 the Mines Branch began an investigation into Canadian sources of clay and shale raw materials suitable for the production of light-weight aggregates. This report contains the results of test work on samples from what are considered the most important known deposits within a marketable distance of well populated areas. Most of these samples were collected by the Branch during the summer of 1950 while others were submitted by individuals or companies. The samples collected weighed from 5 to 10 pounds and were taken by trenching so as to represent a true average of the deposit. Laboratory tests were conducted during the winter of 1950-51.

The aim of the laboratory work has been to produce the highest grade of aggregate, namely a coated aggregate, at the lowest cost by using the raw materials in their natural state. In view of the number of samples covered and the limited amounts of each, no work has been done on the suitability of the materials for the production of sinter aggregates either in the rotary kiln or sintering machine.

It should be noted, however, that many of the materials classed in this report as being unsuited for coated aggregate manufacture might be found very satisfactory for the production of sinter aggregate. For anyone considering such production the work covered in this report on raw materials for coated aggregate manufacture will at least eliminate the decidely unfavourable materials and will indicate those upon which further work should be done.

The Branch wishes to thank A.S. Dawson and W.G. Cowie of the Industrial Development Department, Canadian Pacific Railway Company, for submitting numerous samples of clays and shales that helped fill in gaps in the area surveyed. Reports and maps of the Geological Survey of Canada were of great assistance in locating outcrops.

John Convey,
Director, Mines Branch.

COATED LIGHTWEIGHT CONCRETE AGGREGATE

FROM CANADIAN CLAYS AND SHALES

PART II

MANITOBA AND SASKATCHEWAN

INTRODUCTION

Definition of Lightweight Aggregate

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

Types of Clay and Shale Lightweight Aggregate

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

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

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

Desirable Properties of a Lightweight Aggregate

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

(a) High Strength to Weight Ratio

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

(b) Good Workability

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

(c) Low Absorption

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

(d) Uniform Size Gradation

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

(e) Chemical Inertness

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

TEST METHODS

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

Preparatory to testing, all samples were reduced in size to $-\frac{1}{2}" + \frac{1}{4}"$. Samples that were not coarse enough or were too soft to stand crushing were pelletized in a small cement mixer, dried, and screened to the above size range. Because of the shortness of the rotary kiln, all samples were dried overnight in an oven maintained at 100°C to drive off the mechanically held moisture and thus prevent decrepitation when subjected to rapid heat.

Stationary Furnace Tests

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

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

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

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

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

Rotary Kiln Tests

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

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

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

As a result of the stationary furnace and rotary kiln tests the materials were classified into five groups which are shown in a summary table for each province in Figures 4 and 5. These classifications are as follows:

1. Materials considered suitable for coated aggregate production.
2. Materials which are good bloaters but which are not considered suitable for coated aggregate production because of their relatively narrow vitrification ranges and resultant sticking and agglomerating characteristics.

3. Materials which are poor bloaters.

4. Materials which are too refractory.

5. Materials which are non-uniform and which are a combination of two or more of the above classifications.

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

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

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

Determination of Physical Properties

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

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

The test used to determine the crushing strength, was patterned on that carried out in other laboratories. The apparatus consisted of a steel cylinder, 2 inches inside diameter, and 6 inches deep, into which the aggregate crushed to -3/8 inch + 8-mesh was poured without any tamping, to a depth of $4\frac{1}{2}$ inches. A 1 31/32 inch diameter steel plunger applied the pressure to the aggregate in a Carver Hydraulic Press and the amount was noted to give a compaction of 1 inch. This was then converted to lb./sq. inch.

The true value of this test has not been determined. It should, however, provide a rough method of rating the various products but, to do so, it should be considered along with the weight of the product. Since the weight and strength vary directly, the crushing strength-to-weight ratio gives a better method of evaluating the various products.

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

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

RELATION OF CHEMICAL PROPERTIES TO THE BLOATING OF CLAYS AND SHALES

Review of Previous Work

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

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

Wilson[3] considered that the gases causing bloating when the clay or shale had reached the vitrified condition might consist of entrapped air, steam, sulphur dioxide and trioxide, carbon dioxide or monoxide, oxygen or hydrocarbons absorbed during firing. He treated bloating as an undesirable quality of some clays and shales, and observed that it took place to a greater degree in the fine-grained, dense materials. He divided the expansion caused by entrapped gases in a semiviscous body into two classes: bloating caused by improper oxidation due to insufficient heating time at temperatures below the vitrification period to allow the escape of gases chiefly formed from the carbon, sulphur and carbonates, and bloating due to gases formed during and above the vitrification temperature, the most common of which is sulphur dioxide or trioxide formed from the decomposition of calcium sulphate.

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

The United States Emergency Fleet Corporation[5] which developed lightweight aggregate during World War I for use in the construction of concrete ships found that the clay or shale should be rich in compounds of metallic oxides, carbon, sulphur, sodium, potassium, or other equivalent compounds, some of which, when the material is subjected to heat, will either act as a flux or give off gas.

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

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

Austin, Nunes and Sullivan[8] heated various clays in a tube furnace and determined quantitatively the gases evolved during bloating. They also determined the effects on bloating of varying the heating rates, rate of air flow and the atmosphere. These investigators found that carbon dioxide, sulphur dioxide, and water were evolved at the bloating temperature. They believed that, since most carbonates decompose at low temperatures, the carbon dioxide was formed by the oxidation of the elemental carbon that remained in the clay by reduction of the ferric oxide. They suggested that the sulphur dioxide might be evolved from the decomposition of residual calcium or magnesium sulphate or intermediate compounds formed during the firing. The water evolved was considered to have come from some mineral other than clay as clay loses its crystal lattice structure at a temperature below the bloating temperature. In general, the evolution of gases from clays varied inversely with the rate of heating, and directly with the air flow. It was shown that good bloating took place in a nitrogen atmosphere which indicated that the oxidation must come from within the clay rather than from a reaction with the atmosphere.

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

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

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

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

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

APPLICATION OF CHEMICAL ANALYSES TO PROBLEM OF PRODUCING COATED AGGREGATE

As this investigation was concerned only with the highest grade of aggregate i.e., coated aggregate, the differences between materials found suitable for coated aggregate production and those that were not, were of more interest than the differences between non-bloating and bloating clays. Many materials proved to be excellent bloaters yet were found to be unsuitable for coated aggregate because of their narrow vitrification ranges, and sticking and agglomerating qualities. Following stationary furnace and rotary kiln tests all materials tested were classified into one of the five groups previously mentioned under test methods.

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

Some of these materials classed as poor bloaters would very probably be good bloaters, or found suitable for coated aggregate manufacture if the heating time were long enough to remove some of the excess carbon. The effect on bloating of removing excess carbon by prolonged preheating before subjecting the materials to bloating tests is illustrated in Figure I.

The decided improvement in the interior structure of the particles is not shown on the graph. The product formed without preheating a material high in combustible carbon expands by the swelling of the combustibles rather than bloating. With prolonged preheat treatment and removal of carbon a bloated cellular structure and a lighter product are developed. For these reasons shales high in combustible carbon were not considered as representative of their classification of poor bloaters.

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

1. The material must contain a compound that will dissociate, or form intermediate compounds that will dissociate with the formation of a gas or gases at a temperature at which the material is in the pyroplastic condition.

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

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

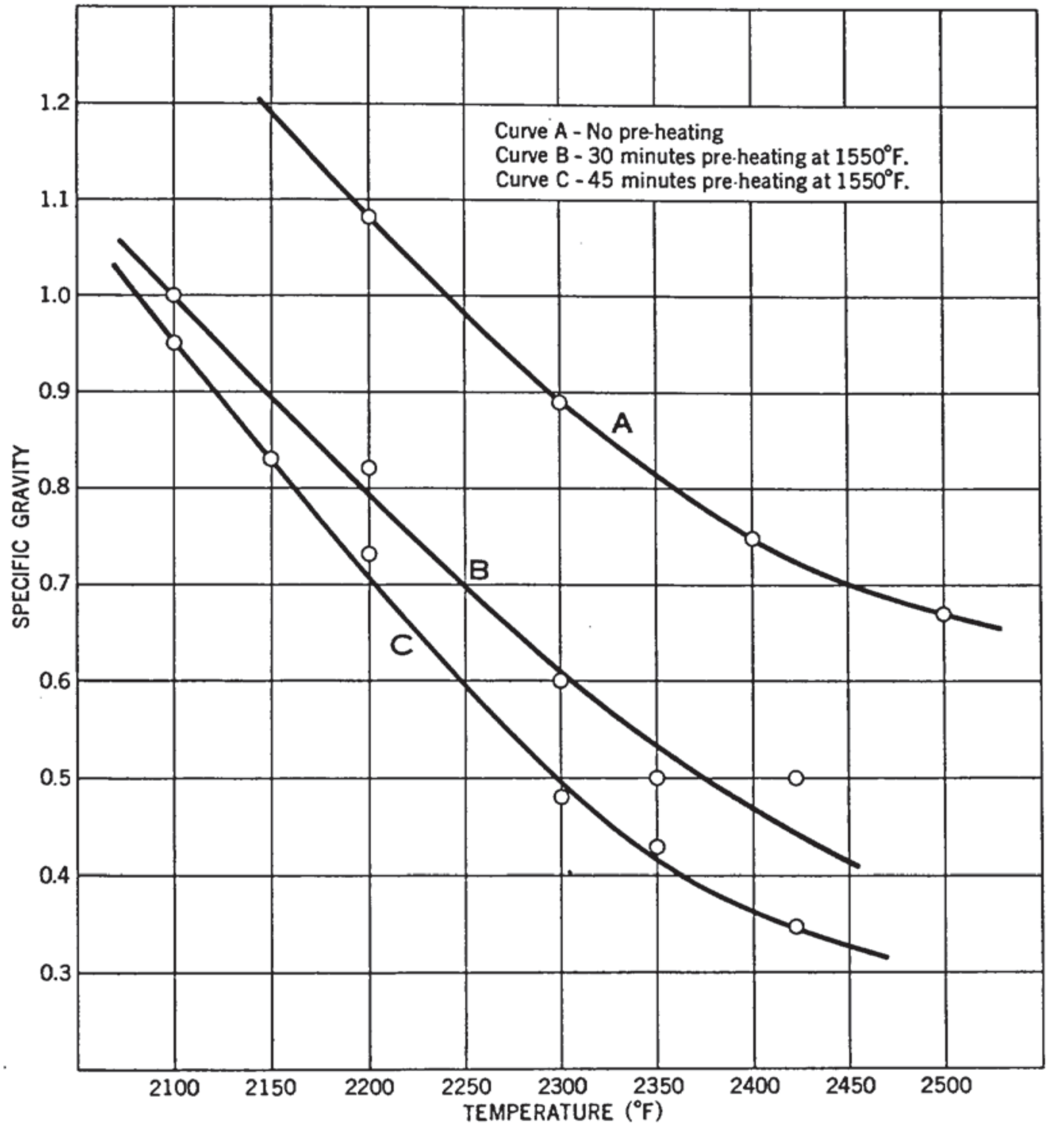

Figure 1 - Effect of preheating upon the specific gravity of bloated specimens of shale high in combustible carbon.

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

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

The vitrification range of a clay or shale for the purposes of lightweight aggregate manufacture covers the partially fused condition and is the range in temperature between the point of incipient fusion and the point at which the viscosity has decreased to impractical working conditions. The lower limit of the vitrification range is fixed by the temperatures at which the eutectic composition of the components begins to liquefy. The upper limit is fixed by the character and quantity of the fluxes present.

The fluxes containing sodium and potassium will give a wider vitrification range than those containing calcium and magnesium because their high viscosity retards their interaction with the surrounding clay grains. Fluxes containing calcium and magnesium have a low viscosity and shorten the

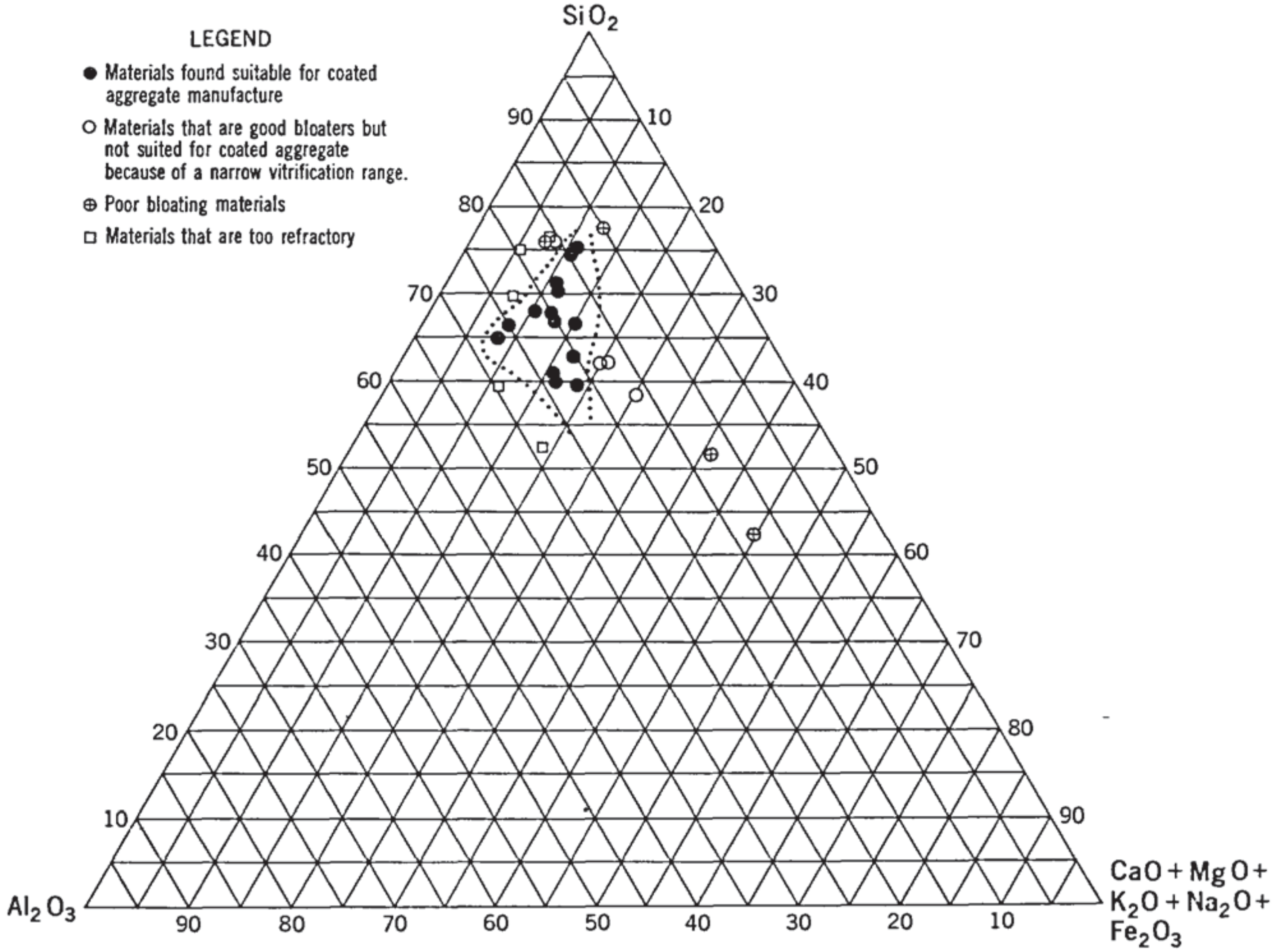

Figure 2 - Composition diagram of major oxides in clays and shales showing proportions required to produce coated aggregate. Dotted line represents approximate limits of materials suited for coated aggregate.

vitrification range. Ferric oxide is believed to be an intermediate flux. There seems reason to believe, therefore, that the vitrification range of a clay or shale should bear some relation to the proportions of the $K_2O + Na_2O$ and $CaO + MgO$ fluxes.

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

The vitrification range of a clay or shale coated aggregate raw material has an important bearing on the size range of the feed for the rotary kiln. In most materials the extreme fine sizes start to agglomerate at a temperature below that sufficient to cause good bloating of the coarse sizes. However, if the vitrification range is wide this temperature may still be high enough to allow good bloating of the coarse sizes. Otherwise, the feed has to be separated in at least two size ranges, and each fired separately. In actual practice the vitrification range should be wide enough to allow bloating over a range of at least 50°F below the temperature at which sticking becomes excessive.

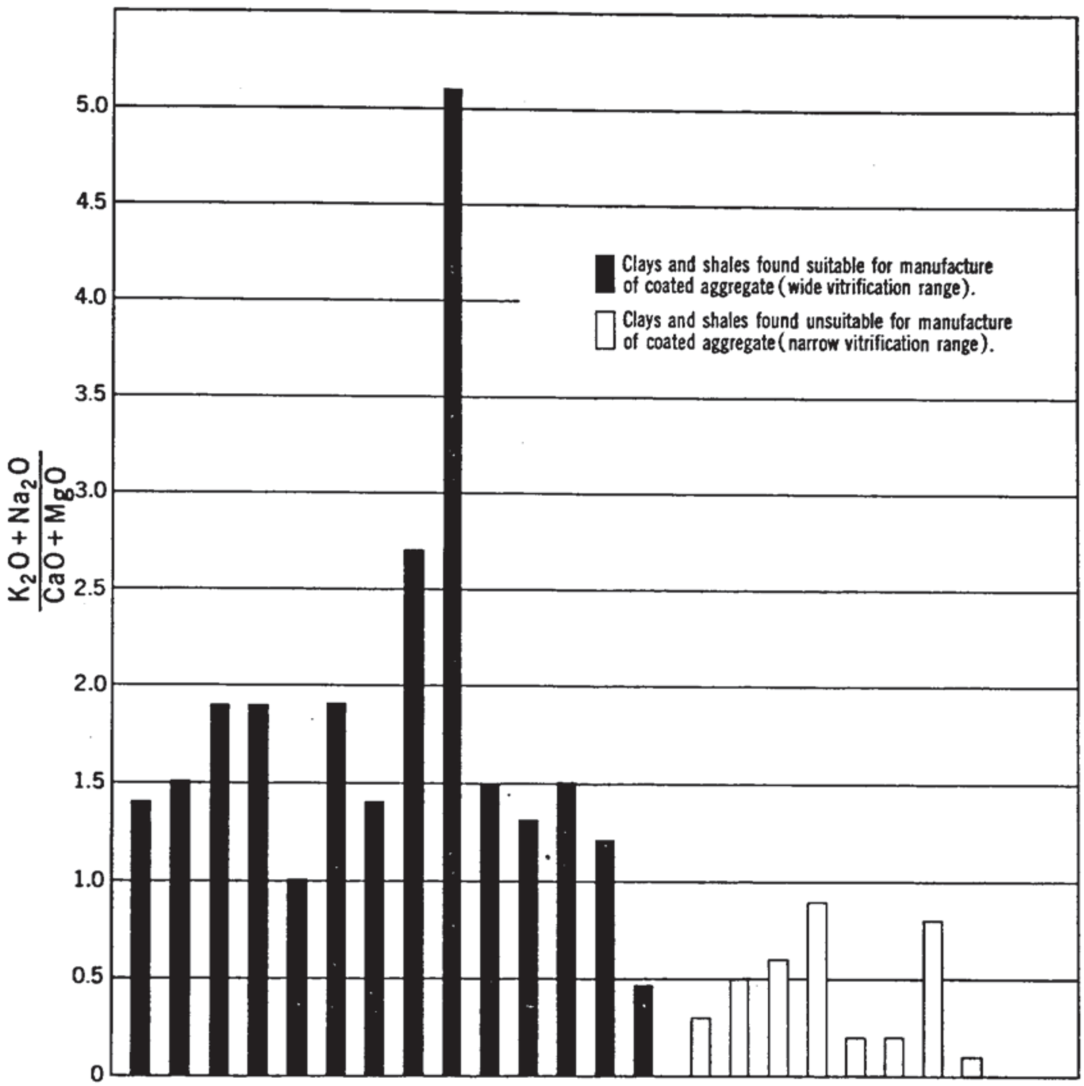

Figure 3 - Relationship of type of fluxes in clays and shales to width of vitrification range.

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

Materials having good possibilities for coated aggregate production		Materials that are good bloaters but are not considered suitable for coated aggregate because of sticking and agglomerating characteristics		Materials that are poor bloaters		Materials that are too refractory (showing no bloating or fusion when fired in stationary furnace at 2400 F for 5 minutes)		Materials that are too non-uniform in bloating qualities	
Locality	Sample No.	Locality	Sample No.	Locality	Sample No.	Locality	Sample No.	Locality	Sample No.
Winnipeg-clay	1	Miami-shale	33	Morden-shale	22-24	Souris-shale	9-11	Winnipeg-clay	2
Lac du Bonnet-clay	4-6			Miami-shale	29	Ninette-shale	12	Birds Hill-clay	3
Oak Lake-shale	8			Leary's-shale	34,35	La Riviere-shale	13-15	Edran's-clay	7
Morden-shale	18,19			Leary's-shale	39,40	Kaleida-shale	17	Kaleida-clay	16
Miami-bentonite	28					Rathwell-shale	41	Morden-bentonite	20
Miami-shale	31,32							Morden-shale	21
								Miami-shale	25-27
								Miami-shale	30
								Leary's-shale	36-38

Figure 4 - Summary of lightweight aggregate test results - Manitoba

LOCATIONS, DESCRIPTIONS AND TEST RESULTS OF CLAYS AND SHALES IN MANITOBA

The samples of shales and clays from Manitoba tested for the manufacture of coated lightweight aggregate gave quite good results. Of a total of 41 samples tested from 19 locations, 10 materials from six locations showed good possibilities, one material was a good bloater but had a narrow vitrification range, eight were classified as poor bloaters, nine were too refractory, and 13 were too non-uniform in firing qualities.

The potential market centre for a lightweight concrete aggregate in Manitoba is the city of Winnipeg. The most promising raw material nearest to Winnipeg was the Lake Agassiz gumbo clay underlying the city. This raw material should be investigated more fully by anyone contemplating the manufacture of lightweight aggregate in this province. All other materials that gave promising results in the laboratory are at locations involving a considerable rail haul to the Winnipeg market.

A description of the clays and shales tested and the results of the laboratory tests are given below.

WINNIPEG

The area around the city of Winnipeg is underlain by Palaeozoic limestones and dolomite. The shale bedrock nearest to Winnipeg occurs west of an approximate line drawn from Emerson in the south through Portage La Prairie to Dauphin.

Surface deposits in the area consist of a calcareous surface clay extending to a depth of about five feet underlain by a plastic, fine-grained, gumbo clay deposited from the waters of Lake Agassiz which formerly covered the area. This gumbo clay is of wide lateral extent and is reported to have a thickness of from 30 to 40 feet.

Two samples of the Lake Agassiz clay were tested for lightweight aggregate. One of these (Sample 1) was from the pit of the Alsip Brick, Tile and Lumber Company, Limited while the other (Sample 2), submitted by the Industrial Development Department, Canadian Pacific Railway Company, was from an excavation at the corner of River and Main Streets.

The gumbo clay from the Alsip Brick, Tile and Lumber Company, Limited (Sample 1) proved to be a good bloater with a wide vitrification range. The rotary kiln product showed a volume expansion of 30 per cent, a bulk density of 44 lb./cu. ft., and a crushing strength of 636 p.s.i. The average kiln temperature was 1925°F while agglomeration of the charge started when the temperature was increased beyond 1950°F.

The other clay (Sample 2) did not give favourable results. It was more highly calcareous than the previous sample and not as uniform. It bloated well in the stationary furnace but showed non-uniformity in width of vitrification range, some of it having a very narrow range. In the rotary kiln test the portion of the sample having the narrow vitrification range started agglomerating and sticking to the kiln at a temperature at which there was no bloating of the remainder of the sample. The product was poor and the physical properties were not measured. In view of its good bloating properties, as shown in the stationary furnace, a material such as this might respond to other methods of processing where sticking and agglomerating of the charge are not so important.

A sample of buff clay containing limestone pebbles (Sample 3) from Birds Hill, eight miles by rail from Winnipeg, was submitted for testing by the Industrial Development Department of the Canadian Pacific Railway Company. The clay proved to be quite refractory, showing no bloating and only slight fusion when fired at 2400°F for five minutes in the stationary furnace. Rotary kiln tests were not considered warranted in view of the poor bloating qualities and non-uniformity of the material.

LAC DU BONNET

Samples of clay were submitted for testing by the Industrial Development Department of the Canadian Pacific Railway Company from a large deposit underlying Lac du Bonnet on the Canadian Pacific Railway, 66 miles northeast of Winnipeg. The clay is fine-grained, highly plastic, and contains white specks of lime in varying amounts. Due to the extent of the deposit and its striking resemblance to the gumbo clay from the Alsip Brick, Tile and Lumber Company, Limited pit at Winnipeg, it is thought to have been deposited from the waters of glacial Lake Agazzis. The deposit is reported to have an exposed width of about 15 feet on the banks of the Winnipeg River on sec. 8, tp. 15, r. 11, E. 1.

Three samples from this deposit were tested. The first (Sample 4) was taken from the bank of the Winnipeg River, one-half mile south of Lac du Bonnet. In the stationary furnace this material showed excellent bloating properties and had a wide vitrification range. The rotary kiln product showed a volume expansion of 75 per cent, a bulk density of 28 lb./cu. ft. and a crushing strength of 636 p.s.i. The average kiln temperature was just below 1950°F at which temperature agglomeration started.

In view of the good results obtained with this sample two additional samples were submitted. One of these (Sample 5) was from the river bank near Minnewawa Street, Lac du Bonnet. The other (Sample 6) was taken in a water main excavation, one-eighth of a mile west of the river bank. Both materials were a fine-grained, plastic clay with scattered white specks of impure calcium carbonate, Sample 6 containing only a relatively small amount. In the stationary furnace both materials exhibited excellent bloating properties and each had a wide vitrification range. The samples were processed in the large 14' X $1\frac{1}{2}$' rotary kiln with excellent results. Both gave an over-expanded product when processed at an average temperature of 1975°F, which was 75°F below the temperature at which agglomeration began.

The product from Sample 5 showed a volume expansion of 100 per cent and a bulk density of 25 lb./cu. ft. while that from Sample 6 showed a volume expansion of 140 per cent and a bulk density of 20 lb./cu. ft. The crushing strengths were low as would be expected from the low bulk density values and could not be measured with the equipment on hand. The impure calcium carbonate present did not show any bloating in the firing treatment, merely burning hard.

The amount of calcium carbonate present in the three samples was variable and, before any development could be undertaken, it would be necessary to determine the amounts present and its effect on the resulting concrete if it could not be separated from the aggregate. The strengths of the products from the latter two samples could easily be increased at the expense of an increase in weight by reducing the kiln retention time.

The clay from Lac du Bonnet as represented by the above three samples is one of the very few materials tested that showed such a degree of volume expansion so far below the temperature at which agglomeration started. Kiln control would be a comparatively easy matter. Moreover, in contrast to most clays, this clay, when dry, is very hard and stands crushing as well as most shales thus eliminating the need for pelletizing in feed preparation. There were also indications that crusher run material including fines could be processed in one operation due to good bloating properties and the wide vitrification range possessed by the material.

EDRANS

A sample of calcareous surface clay (Sample 7) from Edrans was submitted for testing by Supercrete Limited, St. Boniface. The clay was of non-uniform composition with an abundance of tiny fossil shells.

In both the stationary furnace and rotary kiln tests this material proved to be a poor bloater, was non-uniform, and had a narrow vitrification range. Serious sticking and agglomeration were encountered in the rotary kiln without any expansion taking place.

OAK LAKE

Shale belonging to the Riding Mountain formation was observed in a road cut on the south side of the Assiniboine River directly north of the town of Oak Lake which is on the main southern line of the Canadian Pacific Railway, 165 miles west of Winnipeg, and 191 miles east of Regina. This shale is much softer than the Riding Mountain shales sampled at Ninette, Souris, and La Riviere. An eight-foot width of dark grey iron-stained shale (Sample 8) was visible, overlain by from two to ten feet of boulder clay and reworked shale.

In the stationary furnace this material showed good bloating qualities and a wide vitrification range. The rotary kiln product was also good showing a volume expansion of 25 per cent, a bulk density of 42 lb./cu. ft., and a crushing strength of 1600 p.s.i. The average kiln operating temperature was 2055°F with agglomeration of the charge starting at about 2075°F. The shale gave a product made up of light and strong, well-rounded particles and showed good possibilities as a raw material for making coated lightweight aggregate.

SOURIS

Shale belonging to the Riding Mountain formation is exposed in abundance on the south bank of the Souris River approximately one and one-half miles southeast of the town of Souris. A geological section of the exposure was noted as follows:

Top soil	3 feet
Brown, silty clay with scattered pebbles	3.5 feet
Light grey, weathered shale with some iron-stain (Sample 11)	5 feet
Greenish-grey, iron-stained, hard shale (Samples 9 and 10)	15 feet
Concealed to river level	50 feet

Stationary furnace tests made on this shale showed it to be too refractory. None of the samples showed any appreciable bloating or fusion when fired at 2400°F for five minutes.

NINETTE

Shales belonging to the Riding Mountain formation outcrop in abundance in the vicinity of Ninette. Overburden in most places is very light and, in some cases, the shale extends up to the grass roots. The weathered shale zone as found at Souris was not found in any of the outcrops examined. A geological section of an exposure on the E. ½ sec. 20, tp. 5, r. 16, W. 1, in a road cut was noted as follows:

Boulder clay	3 feet
Greenish-grey, iron-stained, well-compacted shale (Sample 12)	13 feet

Stationary furnace tests made on this shale indicated that it was too refractory with no bloating or fusion taking place when fired at 2400°F for five minutes.

LA RIVIERE

The low hills surrounding the town of La Riviere are composed almost entirely of Riding Mountain shale. Outcrops are numerous and overburden is light. A section as follows was measured on the eastern edge of the town in a pit formerly worked for the production of brick:

Top soil	3 feet
Uniform dark grey shale (Samples 13, 14, and 15)	55 feet
Concealed with talus to creek level	75 feet

Stationary furnace tests indicated that this shale was too refractory for consideration as a raw material for the manufacture of lightweight aggregate. There was no indication of bloating or fusion when fired at 2400°F for five minutes.

KALEIDA

Two samples from the Kaleida area were submitted for testing by the Industrial Development Department of the Canadian Pacific Railway Company. One of these was a buff-coloured clay (Sample 16) from the S.W. ¼ sec. 32, tp. 1, r. 8, W. 1. The other was a hard, light grey-coloured shale (Sample 17) taken on the Pembina River between Darlingford and Windygates.

The buff clay (Sample 16) proved to be non-uniform with the bulk of the sample showing poor bloating qualities and a narrow vitrification range. The shale (Sample 17) behaved similarly to the Riding Mountain shale from La Riviere, showing no bloating or fusion in the stationary furnace when fired at 2400°F for five minutes.

MORDEN

At the strip mine of Pembina Mountain Clays Limited, two miles west and three and one-half miles north of Thornhill, an average of about 10 feet of shale overburden is stripped in mining the bentonite. The shale belongs to the Pembina member of the Vermillion River formation. A section in one point of the pit was measured as follows:

Top soil and weathered shale	2 feet
Light grey, soft shale (Sample 19)	10 feet
Light grey, soft shale with a few narrow stringers of bentonite. (Bottom 6" gypsiferous)(Sample 18)	2.5 feet
Hard, black carboniferous shale	0.5 feet

Both samples proved to be fairly good bloaters with a wide vitrification range when tested in the stationary furnace. The rotary kiln product from Sample 18 had a bulk density of 40 lb./cu. ft., a crushing strength of 827 p.s.i. and a volume expansion of 30 per cent. Sample 19 gave a product with a bulk density of 44 lb./cu. ft., a crushing strength of 1511 p.s.i., and a volume expansion of 20 per cent. The average kiln temperature for both samples was 1925°F or just below the temperature at which agglomeration began. Both samples were good bloaters and possessed a sufficiently wide vitrification range for rotary kiln treatment.

Composite samples were secured of the various bentonite beds (Sample 20) and interbedded black shale beds (Sample 21) that lie beneath the above mentioned shale. The bentonite (Sample 20) proved to be an excellent bloating material in the stationary furnace producing a light fluffy product. In the rotary kiln test there appeared to be non-uniformity in the degree of bloating of portions of the sample. The bulk density of the product measured 45 lb./cu. ft. and the crushing strength, 318 p.s.i. The overall volume expansion was low at 20 per cent. The average kiln temperature was just below 1900°F at which temperature agglomeration started. The black carbonaceous shale (Sample 21) gave poor results in both the stationary furnace and rotary kiln. It proved to be extremely non-uniform in bloating qualities.

Shale belonging to the Morden member of the Vermillion River formation is exposed in a valley one and one-half miles southwest of Morden in the N.E. $\frac{1}{4}$ sec. 36, tp. 2, r. 6, W. 1. A 30-foot width of shale was exposed under 10 feet of glacial overburden at the northeast corner of section 36. The entire width of shale represented by Samples 22, 23 and 24 proved to be a poor bloating material.

MIAMI

Shale is well exposed in an outcrop in a road cut on the S.E. ¼ sec. 9, tp. 5, r. 7, W. 1., four and one-half miles east of Miami. A section of the exposure was noted as follows:

Boulder clay and reworked shale	10 feet
Vermillion River formation	
Pembina member	
Interbedded black shale and cream-coloured bentonite (Samples 28 and 29)	7.5 feet
Boyne member (?)	
Grey weathering, grey to buff shale with considerable iron-stain (Sample 27)	11 feet
Buff weathering, grey to buff shale with numerous narrow beds of iron-stained, cream-coloured, bentonite (Samples 25 and 26)	18 feet

All three samples of the grey to buff-coloured shale behaved alike when tested in the stationary furnace. Each showed the same non-uniformity. Portions of each sample showed slight bloating with a narrow vitrification range fusing quickly to a glass. The remainder showed no bloating nor fusion under the same firing conditions.

Composite samples were taken of the bentonite beds (Sample 28) and the black shale beds (Sample 29) of the Pembina member. In the stationary furnace the bentonite bloated well into a light, white-coloured, fluffy product. A good product was obtained in the rotary kiln operated at just under the agglomerating temperature of 1875°F. The product had a bulk density of 43 lb./cu. ft. and a crushing strength of 795 p.s.i. The black shale (Sample 29) proved to be a poor bloater due, in part at least, to the high carbon content which resulted in only surface bloating.

Although the bentonite appears suitable for the manufacture of a coated lightweight aggregate, its use, due to the interbedded black shale, does not appear promising from a practical point of view.

Large amounts of highly bentonitic shale believed to belong to the Pembina member of the Vermillion River formation occur in several isolated buttes on l.s.d. 4, sec. 25, tp. 4, r. 7, W. 1, about five miles south of Miami. A section measured on the side of one of the buttes was as follows:

Top soil	2 feet
Highly bentonitic grey shale	3 feet
Olive green bentonite	7 inches
Hard, greenish-grey, bentonitic shale (Sample 33)	4 feet
Hard, grey, bentonitic shale (Sample 32)	6 feet
Soft, grey, highly bentonitic shale with a few ironstone concretions (Samples 30 and 31)	45 feet

The bottom 20 feet of the soft, grey bentonitic shale represented by Sample 30 proved to be non-uniform in bloating qualities when tested in the stationary furnace. A portion of the sample had excellent bloating properties and a wide vitrification range. In view of this, more detailed sampling of this section is necessary to eliminate the portion having a narrow vitrification range. The overlying 25 feet of soft, grey bentonitic shale (Sample 31) was uniform in firing qualities, bloated well, and had a wide vitrification range.

A good product was obtained in the rotary kiln at an average temperature of 2000°F, while agglomeration started at about 2025°F. The product had a bulk density of 38 lb./cu. ft. and a crushing strength of 636 p.s.i. The volume expansion was low at 15 per cent. The hard, grey, bentonitic shale (Sample 32) bloated well and had a wide vitrification range. The rotary kiln product had a bulk density of 44 lb./cu. ft. and a crushing strength of 1034 p.s.i. The volume expansion measured 10 per cent but this could possibly be improved with a longer retention time. The average kiln temperature was 2020°F while agglomeration started at 2025°F. The four-foot width of greenish-grey shale (Sample 33) bloated quite well in the stationary furnace but had a narrow vitrification range. Rotary kiln tests were not made.

The tests on the shales from the above outcrop indicated a width of 31 feet of shale that has good possibilities as a raw material for coated lightweight aggregate. This width could probably be extended farther downward by more detailed sampling and testing of the bottom 20 feet of the section. The deposit is five miles by road to the railway at Miami, and 80 miles by rail from Winnipeg. Large amounts of the shale are available on several buttes and overburden appears to average about 10 feet.

LEARY'S

The upper part of the Morden member of the Vermillion River formation is exposed near Leary's station in a shale pit that is used to obtain material for making bricks. A sample (Sample 34) was secured of dark grey, almost black, hard,shale over a stratigraphic width of 10 feet. A grab sample (Sample 35) of the same material but lower stratigraphically was taken in the bank of the south branch of the Morris River below the pit.

On rapid firing in the stationary furnace both samples proved to be poor bloaters due largely to the high carbon content which resulted in only surface bloating.

Another exposure of shale was noted in a road cut one-half mile west of Leary's station in the S.W. ¼ sec. 13, tp. 6, r. 8, W. 1. Both the top of the Morden member and the bottom of the Boyne member are probably represented in the section which was noted as follows:

Glacial drift	8 feet
Buff to grey, soft shale (Sample 38)	6 feet
Dark grey shale with numerous brownish-grey beds of hard sandy or silty shale (Sample 37)	5.5 feet
Dark grey, fairly soft shale with a few sandy or silty beds (Sample 36)	19 feet

All three samples gave unfavourable results when subjected to a rapid heat treatment in the stationary furnace. All were extremely non-uniform and were poor bloaters while portions of each had narrow vitrification ranges fusing quickly to a glass.

Farther west of Leary's station near St. Lupcin (Babcock) shale belonging to the Boyne member of the Vermillion River formation is exposed in a road cut on the north side of the south branch of the Morris River. A section of the exposure was noted as follows:

Glacial drift	10 feet
Light grey, white speckled shale (Sample 40)	15 feet
Light grey, soft shale (Sample 39)	12 feet

Stationary furnace tests on both of these materials showed them to be poor bloaters. Moreover, each shale had a very narrow vitrification range and fused quickly to a glass.

RATHWELL

A sample of hard, dark grey shale (Sample 41) believed to belong to the Riding Mountain formation, was submitted for testing by the Industrial Development Department of the Canadian Pacific Railway Company. The sample came from a 15-foot exposure along the Rathwell-Notre Dame de Lourdes road, four and one-half miles south of Rathwell.

In the stationary furnace this shale behaved identical to the Riding Mountain shales tested from Ninette, Souris, and La Riviere in that it showed no bloating or fusion when fired at 2400°F for five minutes.

Materials having good possibilities for coated aggregate production		Materials that are good bloaters but are not considered suitable for coated aggregate because of sticking and agglomerating characteristics		Materials that are poor bloaters		Materials that are too refractory (show no bloating or fusion when fired in stationary furnace at 2400 F for 5 minutes)		Materials that are too non-uniform in bloating qualities	
Locality	Sample No.	Locality	Sample No.	Locality	Sample No.	Locality	Sample No.	Locality	Sample No.
Regina-shale	2	Regina-clay	1	Bruno-clay	8	Eastend-shale	15-18	Knollys-shale	13,14
Regina- "	3								
Chamberlain-shale	4	Swift Current-shale	23	Unity-shale	9,10	Tantallon-shale	27,28	Swift Current-shale	20,21
Elbow-shale	5-7								
Knollys-shale	12			Knollys-shale	11			Bertwell-shale	32
Swift Current-shale	19	Bertwell-clay ironstone	33						
Swift Current- "	22								
Bracken-shale	24								
Ponteix-shale	25								
Estevan-shale	26								
Kamsack-shale	29,30								
Kamsack-shale	31								

Figure 5 - Summary of lightweight aggregate test results - Saskatchewan

LOCATIONS, DESCRIPTIONS AND TEST RESULTS OF CLAYS AND SHALES IN SASKATCHEWAN

The shales from Saskatchewan in general gave good results in the laboratory. Of a total of 33 samples tested from 21 locations, 15 materials gave indications of being suitable for the manufacture of coated lightweight aggregate; three materials were good bloaters but had a narrow vitrification range; four were poor bloaters; six were too refractory, and five materials were too non-uniform in bloating qualities.

The most noticeable feature of the tests conducted was the excellent results obtained with the Bearpaw shale. The uniformity of this shale over large areas and its excellent bloating properties make it one of the best sources of raw material for the manufacture of coated lightweight aggregate in the province. Out of 12 samples of Bearpaw shale tested, 10 gave good results. The material in the remaining two samples, representing a sandy phase of the formation, was too non-uniform in bloating properties.

The potential market centres for a lightweight aggregate in Saskatchewan are the cities of Regina and Saskatoon, 162 miles apart by rail. These areas are both heavily covered with glacial drift but the Bearpaw shales lie close to the surface at various intermediate points. As neither centre presents a large aggregate market it is possible that a plant could be located to best advantage at some intermediate point. Fuel oil from west central Saskatchewan and coal from the southern part of the province are readily available for fuel.

A description of the shales and clays sampled and the results of the laboratory tests are given on the following pages.

REGINA

The area around Regina is heavily covered with glacial material and no bedrock is exposed in the immediate vicinity. Immediately underlying the surface is a highly plastic, fine-grained, dark grey clay, a sample of which (Sample 1) was submitted for testing by A.S. Dawson, geologist, Canadian Pacific Railway Company. The sample came from a sewer excavation at the intersection of Regina Avenue and Montague Street in the western part of the city.

This material proved to be a fairly good bloater in the stationary furnace but had a somewhat narrow vitrification range. In the rotary kiln, bloating took place at a temperature which was close to that at which agglomerating and sticking began and it was thus impossible to control the temperature to give a uniform product. Due to the narrow vitrification range of the clay, and the difficulty of temperature control most of the material showed no bloating and the overall volume expansion measured only 10 per cent. The product was light and weak with a bulk density and crushing strength of respectively 37 lb./cu. ft. and 477 p.s.i. On the basis of this test the clay would not be classed as having good possibilities for the manufacture of coated lightweight aggregate. However, because it is the only raw material within 30 miles of the city further work would be justified.

The nearest exposures of shale to Regina are believed to be at the south end of Last Mountain Lake. Two samples of Bearpaw shale from this area were submitted for testing by the Industrial Development Department, Canadian Pacific Railway Company. One of these (Sample 2) was from the west shore of Last Mountain Lake at Buena Vista Station, 31 miles by rail from Regina. This shale contained some gypsum, was dark grey in colour, highly weathered and soft.

It is exposed in numerous cuts along the Regina to Saskatoon branch of the Canadian Pacific Railway, some of the cuts representing a quarryable width of shale under light to moderate overburden. The other sample (Sample 3) from this area was taken in a railway cut 200 yards north of Regina Beach station approximately one mile north of the previous location. This shale was very similar to that from Buena Vista but possibly a little harder. It is reported that 15 feet of shale is exposed under light overburden at this location.

Both of these materials gave excellent results in the stationary furnace and rotary kiln, both expanding uniformly into light, strong, well-rounded pellets. Each had a wide vitrification range enabling easy kiln control. The shale (Sample 2) from Buena Vista station gave a product weighing 46 lb./cu. ft. with a crushing strength of 1200 p.s.i. The volume expansion measured 20 per cent and the average kiln temperature for the test was 1950°F. Slight agglomeration of the charge started at about 1960°F. The shale (Sample 3) from Regina Beach station gave a product weighing 34 lb./cu. ft. with a crushing strength of 1830 p.s.i. The volume expansion measured 70 per cent while the average kiln temperature was just below 2000°F at which temperature agglomeration of the particles started.

The shales from the Last Mountain Lake area believed to be the closest shale exposures to Regina, appeared to be well suited as raw materials for coated lightweight aggregate.

CHAMBERLAIN

Bearpaw shale outcrops along Highway 11 where it crosses the Arm River at Chamberlain, 56 miles by rail northeast of Regina on the Regina-Saskatoon line of the Canadian National Railway. Overburden consists of two to three feet of boulder clay but this amount increases rapidly up the side of the valley. The shale is gypsiferous and contains a few clay ironstone concretions which being large and in well defined bands can be separated easily from the shale. Sample 4 taken in a road cut on the north side of the river, was representative of three feet of shale.

In the stationary furnace this shale (Sample 4) proved to be a good bloater with a wide vitrification range. A good product was obtained in the rotary kiln showing a bulk density of 42 lb./cu. ft. and a crushing strength of 636 p.s.i. The volume expansion measured 35 per cent while the average kiln temperature for the test run was just below the agglomerating temperature of 2010°F.

ELBOW

Bearpaw shale is exposed in several road cuts within a short distance of the railway at South Elbow on the Canadian National Railway midway between Saskatoon and Moose Jaw. Moreover several buttes in the Saskatchewan River valley at this location appear to be composed of Bearpaw shale covered with a thin mantle of boulder clay.

Three samples were secured at two exposures between South Elbow and the railroad bridge. Sample 5 represented seven feet of shale overlain by one foot of boulder clay while Samples 6 and 7 represented a total of $7\frac{1}{2}$ feet of shale overlain by 25 feet of glacial material.

All three samples showed good bloating properties in the stationary furnace and had wide vitrification ranges. Good products were also obtained in the rotary kiln. The best product showed a volume expansion of 75 per cent, a bulk density of 35 lb./cu. ft., and a crushing strength of 1305 p.s.i. The average kiln operating temperature for this run was 2015°F while agglomeration tended to start at about 2030°F.

The Bearpaw shales at South Elbow are considered to be a potential source of a good raw material for coated lightweight aggregate. It is possible that a plant in this area could supply the Regina, Moose Jaw and Saskatoon areas should the demand warrant it. Careful prospecting in the area would be necessary to locate deposits more suitable to mining than those sampled.

BRUNO

A 32-foot width of light brown calcareous clay (Sample 8) is used for the manufacture of brick at Bruno, approximately 60 miles by rail east of Saskatoon.

Stationary furnace tests on this material showed a narrow vitrification range and poor bloating properties. Rotary kiln tests were not considered warranted.

UNITY

Two samples (9 and 10) of sandy shale from the Belly River formation were submitted for testing by the Saskatchewan Department of Natural Resources. The samples were taken near End Lake about seven miles by rail south of Unity, a town on both the Canadian Pacific and Canadian National Railways, 121 miles by rail west of Saskatoon. Both materials proved to be bloaters when fired in the stationary furnace but gave poor results in the rotary kiln. The shales showed no volume expansion when fired just below the temperature at which serious sticking began. Unity is served with local natural gas.

KNOLLYS

Beds belonging to the Whitemud, Battle, and Frenchman formations of Upper Cretaceous age and the Ravenscrag formation of Tertiary age are well exposed one-half mile south of Knolly's siding on the Canadian Pacific Railway, 212 miles southwest of Moose Jaw.

The Whitemud beds consisting of kaolinized clay and sandstone were not sampled but a sample was taken of six feet of dark brown shale (Sample 11) overlying the Whitemud formation and believed to belong to the Battle formation. Overburden where sampled amounted to three feet of sand. This material proved to be a poor bloater when tested in the stationary furnace and rotary kiln.

The Frenchman formation consisting essentially of grey and buff sandstone was not sampled. At a point five feet above what is believed to be the top of the Frenchman formation three samples were secured of 14½ feet of Ravenscrag shale. Overburden at this point amounted to 18 feet. A section of the shale bed was as follows:

Light grey sandy shale (Sample 14)	8 feet
Light grey shale (Sample 13)	3.5 feet
Dark grey shale (Sample 12)	3.0 feet

The bottom shale (Sample 12) proved to be a good bloater with a wide vitrification range. A good product was obtained in the rotary kiln showing a bulk density of 43 lb./cu. ft., and a crushing strength of 1273 p.s.i. The volume expansion was somewhat low at 15 per cent. The average kiln temperature was 2115°F and agglomeration of the charge started at about 2130°F. As to quality of product this material is classed as having good possibilities as a coated aggregate raw material. However, the small amount available, the location of the occurrence, and the large amount of overburden make its economic development doubtful.

The overlying shales (Sample 13 and 14) when tested in the stationary furnace proved to be too non-uniform in bloating qualities for consideration as materials for coated lightweight aggregate.

EASTEND

Clays have been mined in the Eastend area from the upper portion of the Whitemud beds for many years. The clay is shipped to Medicine Hat, Alberta where it is used for making sewer pipe. At the R. Dempster clay pit, on the N.W. $\frac{1}{4}$ sec. 36, tp. 6, r. 22, W. 3, from 30 to 60 feet of boulder clay and 13 feet of shale is stripped from above the Whitemud beds. A section of the shale which belongs to the Battle formation is as follows:

Soft, black carbonaceous shale (Sample 18)	3 feet
Massive, hard, carbonaceous, bentonitic shale (Sample 17)	2 feet
Light grey, highly bentonitic shale (Samples 15 and 16)	8 feet

The above materials proved to be too refractory for consideration as coated lightweight aggregate raw materials. When fired in the stationary furnace at 2400°F for five minutes none of the samples showed any indication of fusing or bloating.

SWIFT CURRENT

Several exposures of Bearpaw shale occur in the vicinity of Swift Current on the main southern line of the Canadian Pacific Railway, 152 miles west of Regina, and midway between Regina and Medicine Hat. A small exposure was noted in a road cut seven miles east of the city at the N.E. corner, N.E.$\frac{1}{4}$ sec. 19, tp. 15, r. 12, W. 3. A three-foot width of gypsiferous shale (Sample 19) was sampled. Overburden at this location consists of from 10 to 15 feet of glacial material. The shale proved to be a good bloater with a wide vitrification range in the stationary furnace. A good product was obtained in the rotary kiln showing a bulk density of 39 lb./cu. ft., and a crushing strength of 1432 p.s.i.

The volume expansion measured 20 per cent. The average kiln temperature was 2020°F while agglomeration of the charge started at about 2025°F.

Another exposure of Bearpaw shale was noted on the S.½ sec. 2, tp. 16, r. 14, W. 3, approximately two miles northwest of Swift Current. Here the shale is overlain by 28 feet of sandstone and 10 feet of additional overburden. However, most, if not all, of the sandstone has been eroded away over a large area lower in elevation and adjacent to the exposure. Here the shale does not appear to have more than 10 feet of overburden. A section of the exposure was noted as follows:

Concealed	10 feet
Thin-bedded, partially indurated, iron-stained, grey sandstone	20 feet
Concretionary, grey sandstone	1 foot
Partially indurated, iron-stained, grey sandstone	7 feet
Sandy, brownish-grey, iron-stained shale (Sample 21)	5 feet
Concealed	7 feet
Sandy, brownish-grey, iron-stained shale (Sample 20)	5 feet

Both of these materials (Samples 20 and 21) gave poor results in the stationary furnace and rotary kiln. Portions of the shales bloated well but the more sandy portions showed poor bloating qualities. Both were classed as being too non-uniform for consideration as raw material for coated lightweight aggregate.

A sample of Bearpaw shale (Sample 22) from an exposure on the west bank of Swift Current Creek in the northeast part of the city of Swift Current was submitted for testing by the Industrial Development Department of the Canadian

Pacific Railway Company. The shale is uniform, grey, soft and blocky and is exposed in a terrace along the creek bank. A total thickness of 15 to 20 feet of shale is exposed with practically no overburden. Sample 22 represented a five-foot thickness of the exposure. This material gave good results in both the stationary furnace and rotary kiln. The product from the rotary kiln had a bulk density of 44 lb./cu. ft. and a crushing strength of 1350 p.s.i. The vitrification range of the shale is wide allowing easy kiln control. The volume expansion measured 30 per cent. The average kiln temperature was 1975°F while agglomeration of the charge started at about 2000°F. Because of its wide vitrification range and good bloating properties this shale is considered to offer good possibilities as a raw material for coated lightweight aggregate.

North of Swift Current, the Belly River formation outcrops on both banks of the South Saskatchewan River. A sample of Belly River shale from the south side of the river at the Cabri ferry was submitted for testing by the Saskatchewan Department of Natural Resources. This shale (Sample 23) was very sandy and proved to be a poor bloater when tested in the stationary furnace. A poor product, showing no volume expansion below the temperature at which serious sticking began, was obtained in the rotary kiln.

BRACKEN

A sample of Bearpaw shale (Sample 24) from Frenchman Creek in sec.15, tp. 5, r. 14, W. 3 near Bracken on the Consul-Valmarie branch line of the Canadian Pacific Railway in the southwest corner of the province was submitted by the Saskatchewan Department of Natural Resources. This material proved to be an excellent bloater in the stationary furnace and possessed a wide vitrification range. In the rotary kiln a very good product was obtained showing a bulk density of 50 lb./cu. ft. and a crushing strength of 1591 p.s.i. The volume expansion measured 35 per cent. The average temperature of the kiln was 1985°F while agglomeration of the charge started at about 2000°F.

The main drawback to using this shale as a raw material for lightweight aggregate is its great distance from markets.

PONTEIX

A sample of Bearpaw shale from Notukeu Creek, three miles northeast of Ponteix, 134 miles southwest of Moose Jaw on the Moose Jaw-Shaunavon-Lethbridge branch of the Canadian Pacific Railway, was submitted for testing by the Saskatchewan Department of Natural Resources. This shale (Sample 25) proved to be a good bloater with a wide vitrification range. When tested in the rotary kiln the feed shattered somewhat due to insufficient drying. The presence of the fine material produced by shattering necessitated a lower than normal operating temperature with the result that an underbloated product was formed. The bulk density of the product measured 53 lb./cu.ft.; the crushing strength, 1909 p.s.i.; and the volume expansion 10 per cent. Because of its excellent bloating qualities and its wide vitrification range as shown in the stationary furnace, this material is considered of good quality and one that warrants further work should the demand arise. The location of this shale with respect to present markets is, however, unfavourable.

ESTEVAN

Samples of the Estevan "blue shale" were submitted for testing by the Saskatchewan Department of Natural Resources. Small scale tests were sufficiently encouraging to warrant testing a 1000-pound sample (Sample 26) in a 14' X $1\frac{1}{2}$' rotary kiln. These tests showed that the material possessed a somewhat narrow vitrification range resulting in sticking and agglomerating at a temperature of 2200°F for the $-\frac{1}{2}" + \frac{1}{4}"$ feed. The lightest product produced below this temperature showed a bulk density of 44 lb./cu. ft. and a crushing strength of 636 p.s.i. By adding small amounts of a refractory powder to the air stream the temperature was raised without difficulty to 2250°F and a well-rounded, better-bloated product was obtained. The product from a test run in which the refractory powder had been added showed a bulk density and crushing strength of 41 lb./cu. ft. and 477 p.s.i. respectively for the -3/8" to 8-mesh fraction. The maximum volume expansion was somewhat low at 25 per cent.

The tests indicated that the finer sizes of the shale would have to be fired separately to give a good product.

On the basis of these test results, the Estevan "blue shale" is considered to offer good possibilities as a raw material for coated lightweight aggregate. However, it does not have as good bloating properties as many other materials from Saskatchewan which were tested.

TANTALLON

Two samples of Riding Mountain shale from near Tantallon were submitted for testing by the Saskatchewan Department of Natural Resources. One of these (Sample 27) was from the north side of the Qu'Appelle valley near Tantallon and the other (Sample 28) from a road cut at Bear Creek.

Both materials proved to be too refractory, showing no bloating and only very slight fusion when fired for five minutes at 2400°F in the stationary furnace.

KAMSACK

The area around Kamsack in Eastern Saskatchewan is underlain by shale of the Riding Mountain formation. The town is provided with local natural gas fuel. From the number of shale exposures in road cuts it is evident that overburden is light in the area between Kamsack and Kamsack Creek to the south. Samples were secured in a road cut on the east side of Highway 8 approximately three miles south of Kamsack and one-quarter mile north of Kamsack Creek. A geological section of the exposure was noted as follows:

Top soil		1 to 2 feet
Very highly weathered shale (almost clay)	(Sample 30)	1.5 feet
Weathered shale	(Sample 30)	3.5 feet
Comparatively soft, grey shale (Sample 29)		4.9 feet

When tested in the stationary furnace both the weathered and unweathered shale proved to be good bloating materials with wide vitrification ranges. Both also gave excellent products in the rotary kiln. The upper weathered shale gave a product with a bulk density of 32 lb./cu. ft., a crushing strength of 1018 p.s.i., and a volume expansion of 50 per cent. The product from the lower shale (Sample 29) showed a bulk density of 37 lb./cu. ft., a crushing strength of 1193 p.s.i., and a volume expansion of 75 per cent. The average kiln temperature for both runs was 2040°F. Slight agglomeration of the charge tended to start at about 2050°F.

A sample of shale from the Riding Mountain formation exposed on the Whitesand River about one-half mile from Kamsack was submitted for testing by the Saskatchewan Department of Natural Resources. This shale (Sample 31) proved to be an excellent bloater and possessed a wide vitrification range. A good product was obtained in the rotary kiln showing a bulk density of 51 lb./cu. ft. and a crushing strength of 1304 p.s.i. The volume expansion of the shale measured 40 per cent. The average kiln temperature was 2070°F and slight sticking of the charge started at about 2080°F.

As to quality of product the shale from the Riding Mountain formation at Kamsack, represented by Samples 29, 30, and 31 is considered to offer excellent prospects as a raw material for coated lightweight aggregate. The location is somewhat distant from any one large market centre but it is possible that a plant on the site could serve an area bounded by the cities of Saskatoon, Regina and Winnipeg.

BERTWELL

A sample of black, carbonaceous shale (Sample 32), believed to belong to the Vermillion River formation, was submitted for testing by the Saskatchewan Department of Natural Resources from Bertwell, 225 miles by rail northeast of Regina on the Regina-Yorkton-Hudson Bay Junction branch of the Canadian National Railway. The shale is exposed on the west bank of the Etomani River, 10 miles northeast of Bertwell. A sample of clay ironstone (Sample 33) from the same location was also submitted.

The black carbonaceous shale (Sample 32) proved to be non-uniform in bloating properties when tested in both the stationary furnace and rotary kiln. The largest part of the sample showed no bloating.

The clay ironstone (Sample 33) bloated well in the stationary furnace but had a narrow vitrification range. Rotary kiln tests were not made.

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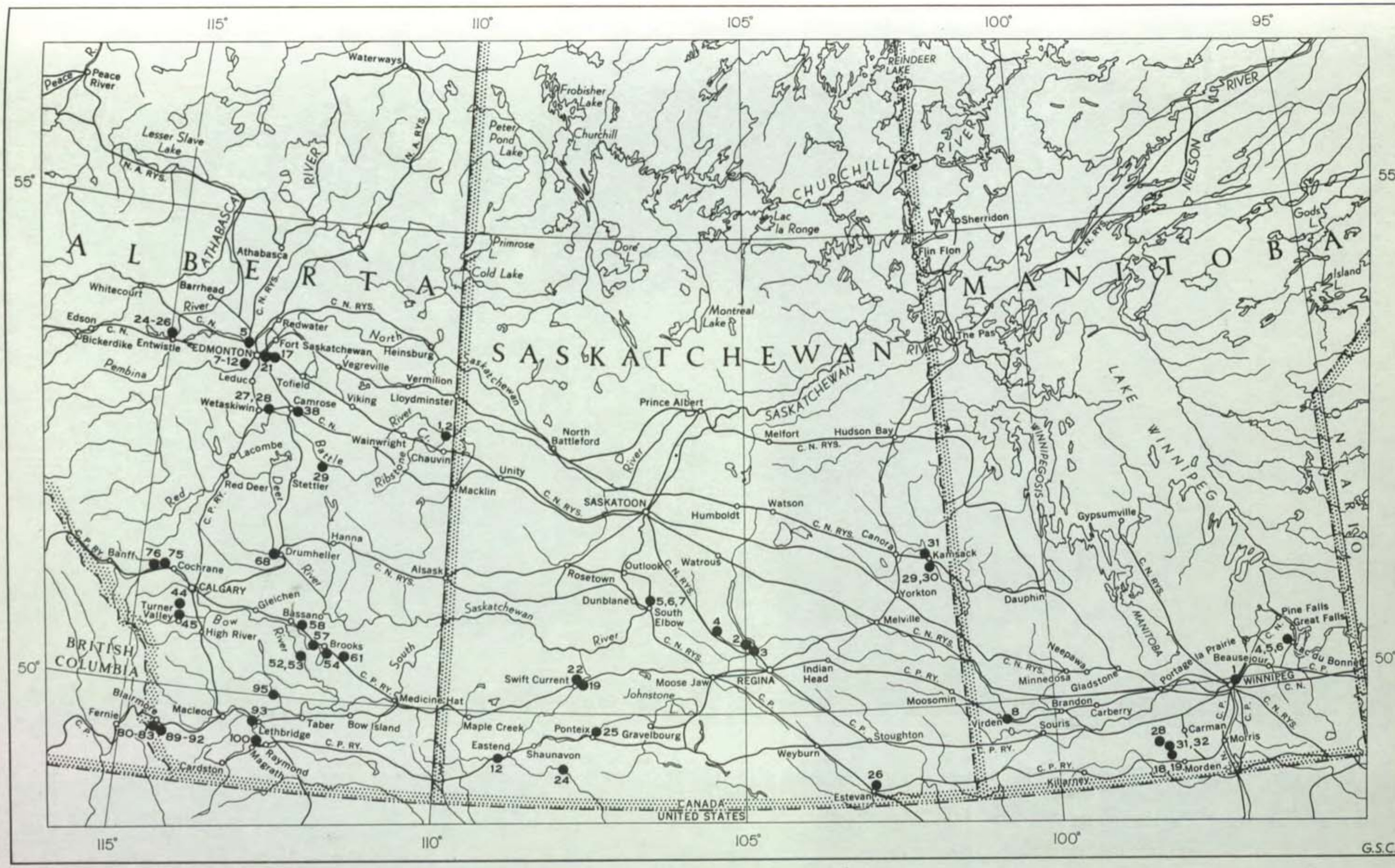

SCALE OF MILES

100 0 100 200 300

Map of southern areas of Alberta, Saskatchewan and Manitoba showing approximate locations of clays and shales with possibilities for making coated lightweight concrete aggregate.