

CERAMIC
INVESTIGATIONS
1926

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INVESTIGATIONS
IN
CERAMICS AND ROAD MATERIALS

(Testing and Research Laboratories)

1926

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MINES BRANCH INVESTIGATIONS IN
CERAMICS AND ROAD MATERIALS, 1926

INTRODUCTION

Howells Fréchette

Chief of Ceramics and Road Materials Division

Many investigations were carried on in the Division during the year, and though several months' time was lost by L. P. Collin and the writer, through illness, much progress can be reported.

During the summer months L. P. Collin visited a number of brick plants in Pennsylvania and Ohio. In Pennsylvania the methods of manufacture of grey face brick in connexion with proposed laboratory work on colour control of face brick were studied. In Ohio information on the methods used for the prevention of scumming was secured. He also visited thirteen brick plants in Ontario and Quebec, where scumming was being experienced. At these plants the cause of the scumming was studied and samples of raw materials were secured for laboratory testing. Unfortunately a prolonged illness prevented him from completing this work.

The research on the refractoriness of moulding sands has been carried to completion by J. F. McMahon. His complete report will be found on pages 9 to 24.

In connexion with his investigations on silica sand, L. H. Cole, of the Mineral Resources Division, had occasion to visit Punk island in lake Winnipeg. At the request of the Ceramics and Road Materials Division he undertook the examination of certain reported deposits of white-burning clay situated at the northwestern end of the island. The samples collected by him were later tested by J. F. McMahon. Their joint report is to be found on pages 25 to 35.

In co-operation with the Research Council of Canada an exhaustive laboratory investigation of the suitability of the magnesite from Grenville township, Quebec, for the manufacture of high-grade refractory brick, has been under way during the entire year. This work is being done by R. T. Watkins, and, while much remains to be done, the results so far obtained show good progress and prospects of success.

Seventy-one samples of clays and shales were tested to determine their physical properties and their suitability for the manufacture of ceramic wares. Other materials tested in the ceramic laboratories were five samples of mineral pigments, three samples of limestone, three samples of feldspar, one sample of magnesite, and five samples of moulding sand. Extended tests were made on a series of shales for a firm which is about to manufacture face brick.

Several samples of firebrick were tested and reported on for Government departments.

For the purpose of determining the quality of rock for road-building purposes, and securing other data regarding the crushed rock produced in Ontario and Quebec, R. H. Picher visited fifty active commercial crushed stone quarries as well as a number of quarries owned by various municipalities. His investigation could not take in all quarries in the sections of the provinces visited, but it probably embraces sufficient to serve as a guide to the character of the rock available in any district. This investigation will be continued in 1927.

During the year a considerable amount of time was devoted to the drafting and revision of specifications for broken stone roads by the writer who is chairman of the Broken Stone Roads Committee of the Canadian Engineering Standards Association, and who also acted as chairman of the Committee on Standardization of Sizes of Building Brick.

I

BRICK SIZES IN CANADA

Howells Fréchette

Modern industry has come to recognize as a well-established fact that much may be gained, both by producers and by consumers, through the standardization of size in many commodities.

This applies in no small degree to the size of brick and has been realized by a large part of the brick industry of Canada for many years. As long ago as 1893 an attempt was made to establish a standard size. Other attempts have been made since then, but in general they were local in scope, not widely supported, and the standard size adopted soon fell into disuse.

It was felt that to be effective and of real value to all concerned, the adoption of a standard size should be countrywide and have the unreserved endorsement of not only the brick manufacturers, but the brick users, and the manufacturers of materials used structurally in conjunction with brick. It was further felt that such endorsement from outside interests would tend to put the adopted sizes into practice more universally, more promptly, and would discourage departure from the standard.

A letter canvass of the Canadian brick manufacturers in April, 1926, revealed the fact that a very wide range of sizes of brick was being made within the country. As regards length alone there was a variation from $7\frac{1}{4}$ inches to 9 inches.

The accompanying table shows the sizes, as gauged by length alone, of the various types of brick, and shows the percentage of plants manufacturing each size and the percentage of the total production for each size.

Sizes of Brick Manufactured in 1926

Length, inches	Soft-mud		Wire-cut com- mon		Wire-cut face		Dry-pressed		All types	
	Per cent of plants	Per cent of pro- duction	Per cent of plants	Per cent of pro- duction	Per cent of plants	Per cent of pro- duction	Per cent of plants	Per cent of pro- duction	Per cent of plants	Per cent of pro- duction
$7\frac{1}{4}$			5	$3\frac{1}{2}$	3	2			2	2
$7\frac{3}{4}$										
8.....	29	28	25	70	15	8	5	7	20	29
$8\frac{1}{8}$	11	4	5	3	6	3	15	13	10	4
$8\frac{1}{4}$	19	9	16	2	34	8	28	20	23	9
$8\frac{1}{2}$	14	23	11	8	15	50	32	42	16	30
$8\frac{3}{4}$	21	29	29	10	27	29	15	12	24	21
$8\frac{7}{8}$	2	3	7	$3\frac{1}{2}$			5	6	3	3
$8\frac{7}{16}$	2	1							1	1
$8\frac{1}{2}$										
9.....	2	3	2	1					1	1

The writer placed these figures at the disposal of the Canadian National Clay Products Association which at the time was considering the adoption of a standard, and recommended that the services of the Canadian Engineering Standards Association be sought to aid in adopting and fixing a standard which would be acceptable to industry at large.

This suggestion was accepted and the Canadian Engineering Standards Association, agreeing to co-operate, empanelled a committee on which were represented the Canadian National Clay Products Association, Association of Canadian Building and Construction Industries, Bricklayers, Masons and Plasterers International Union, Tile Manufacturers Association, Ontario Association of Architects, Engineering Institute of Canada, and the Ceramics Division of the Mines Branch. At a fully attended meeting the representatives of the Canadian National Clay Products Association proposed the following sizes, and gave their reasons for advocating these:

Common brick, 8 by $2\frac{1}{4}$ by $3\frac{3}{4}$ inches.

Rough texture face brick, 8 by $2\frac{1}{4}$ by $3\frac{3}{4}$ inches.

Smooth texture face brick, 8 by $2\frac{1}{4}$ by $3\frac{7}{8}$ inches.

After a very thorough discussion they were tentatively adopted. The various members of the committee submitted their reports to their associations and in all cases the above sizes received endorsement.

No attempt was made to set deviation limits on these sizes since it is recognized that the difference of shrinkage between soft and hard burned bricks is very much greater with some clays than with others. It is to be hoped that all manufacturers, for their own and the common good, will adjust their moulds, dies, and cutters to a size that will make their output conform as nearly as possible to the above standards, and that such changes as may be necessary will be effected at once.

In the table of sizes made during 1926, it will be seen that the 8- and $8\frac{3}{8}$ -inch brick each represent about 30 per cent of the total output of brick made in Canada. By the selection of the smaller size as standard, the brick manufacturer will gain in several respects. This gain will not alone be represented by a lesser tonnage of clay per thousand bricks and a correspondingly greater number of bricks per kiln, but the drying time and the burning time may be cut down to some extent. This will be especially true where extra large sizes have been made in the past.

II

METHODS OF USING BARIUM CARBONATE FOR SCUM-PREVENTION IN STIFF-MUD BRICK

L. P. Collin

The increasing popularity of rough-textured brick has caused many manufacturers who formerly made soft-mud or dry-pressed brick to turn to the stiff-mud process. Because of this the problems in connexion with scumming and efflorescence have become quite important. Many plants which formerly produced mainly common or backing brick, on which a deposit of scum was no material detriment, are now making both smooth and rough-textured face brick. Unfortunately the stiff-mud brick, which should be clean and free from any scum or discoloration, are more likely to show scum than the soft-mud, and, therefore, scumming has become evident at many plants where it had not been noticed before. Scum from soft-mud brick often adheres to the sand used in moulding and as this sand falls off or is brushed off in handling after the brick are burned, it carries the scum with it. The body of soft-mud brick is more open and evaporation can take place below the surface to a greater extent, thus allowing a considerable portion of any soluble salts present to be deposited before reaching the surface of the brick. Many former manufacturers of dry-pressed brick, who have adopted the stiff-mud process, have encountered difficulties from scumming because materials containing a very small percentage of soluble salts may scum when stiff-mud brick are produced. This scumming would not occur in the dry-pressed process, because of the small amount of solution which could take place with the low percentage of water used.

It was pointed out in a previous article¹ on scumming and efflorescence that the commonest cause of the trouble is the formation of scum from the soluble sulphates and that this may be prevented by the use of various barium salts. It is generally recognized that barium carbonate is the best salt to use in most cases, but considerable discussion has arisen as to the respective merits of wet and dry addition. In order to learn more of the results accomplished by the two methods as well as to view the latest equipment, it was decided to visit a number of brick plants in Ohio where barium salts are regularly added to the clay.

Several plants in the vicinity of Canton, Ohio, are using barium carbonate. The Belden Brick Company, which manufacture stiff-mud red face brick, use a material containing soluble sulphates. About 300 pounds of barium carbonate are required for 26,000 brick, or slightly more than 3 pounds per ton of dry material. The barium carbonate is added by the wet method. Two cylindrical tanks equipped with revolving paddles as agitators are used alternately so that it is not necessary to shut down the plant to renew the supply of barium. The amount of barium carbonate

¹ Collin, L. P.: "Causes and Prevention of Scumming and Efflorescence." Invest. in Ceramics and Road Materials, 1925, p. 9, Mines Branch No. 072.

required for about a quarter of the day's run (75 pounds) is placed in a tank which contains about 150 gallons of water. A delivery pipe runs from the tanks to the pug-mill and the flow is controlled by the pug-mill operator.

The Stark Brick Company, of East Canton, which manufacture buff face brick and salt glazed brick, add barium carbonate dry very successfully. In the past, much trouble was experienced, particularly with the glazing of the brick, and this was traced to scum which appeared in drying. It was found necessary to use about 8 pounds of barium carbonate per 1,000 brick, or $2\frac{1}{4}$ pounds per ton of dry clay. The clay as it is brought in from the pits is ground in dry pans and the barium carbonate is added by shovelfuls at the pans, the amount being estimated by the operator. After being ground the clay is stored in a large shed. Any irregularity in feeding the barium carbonate is corrected to a great extent by the double handling to and from storage.

At the plant of the H. B. Camp Brick Company, Mogadore, Ohio, which is about 10 miles north of East Canton, the barium carbonate is added dry. From 7 to 8 pounds of the salt are required per 1,000 brick and this is added by the shovelful at the dry pan. The results are very good, as no scummed brick were seen on the yard.

The State Penitentiary brick plant at Junction City, near Columbus, has a great deal of trouble with scum which, as yet, has not been overcome. This plant is using the wet addition of barium carbonate by means of one tank. About 200 pounds of barium carbonate are used for 45,000 brick, which is a little over 4 pounds per 1,000, or about $1\frac{1}{4}$ pounds per ton of clay. The amount of barium carbonate needed had not been determined at the time the plant was visited. Brick are allowed to remain in the drier from four to seven days and exhaust gases apparently leak into several of the tunnels. Barium carbonate cannot prevent the formation of scum under these conditions.

The Claycraft Mining and Brick Company produce a very good quality of dark red face brick at one of their plants at Franklin, near Columbus, Ohio. They add barium carbonate at the dry pan with a considerable excess to make sure that all of the soluble salts are taken care of even if the mixing be not uniform. This company plans to install tanks for the wet mixing in the very near future.

The Stone Creek Brick Company, Stone Creek, Ohio, add dry barium carbonate to the clay in the pug-mills by means of a small screw feeder which is so placed that the barium carbonate falls at the extreme back of the pug-mill with the dry powdered clay and has the full working length of the mill for mixing. Very good results are obtained.

The Alliance Clay Products, Alliance, Ohio, also use dry barium carbonate. It is fed into the pug-mill by means of a feeder, which consists of a round-bottomed trough and two revolving blades which push the barium carbonate through a slot, extending from end to end near the bottom of the trough. The amount used is regulated by the speed of the blades and the width of the slot. Good results are obtained with this type of feeder, but evidently the company believe that wet-mixing would give better results as they are planning to install this process in a new plant which is under construction.

No definite opinion seems to exist as to the superiority of either the wet or dry process of mixing. Most of the manufacturers using the wet process seem to be quite satisfied and the same is true with those using the various methods of dry mixing, although two manufacturers who are adding the barium carbonate dry are planning to install tanks and use the wet addition. However, neither of them is sure that the wet addition will give better results. The factor of primary importance is the thoroughness with which the barium carbonate is mixed with the clay or shale. If this be true, then it only remains to ascertain which method results in the most uniform mixing. In using the wet addition it is a simple matter to have a constant amount of liquid containing a constant amount of barium carbonate flow into the pug-mill. It is a different matter, however, to maintain a constant flow of clay through the pug-mill unless a feeder is used. The flow of both the barium carbonate and the clay must be uniform and must synchronize if the proper mixing effect is to be obtained. If the feed of the clay be irregular the flow of barium carbonate slurry must be regulated by guesswork on the part of the pug-mill operator, and then the wet addition is no more accurate than dry addition at the pan with a shovel. The methods of controlling the wet addition vary but little in the plants visited. However, in the case of the dry addition totally different methods of control are practised. It would seem that the proper method of dry addition would be to control the amount of barium carbonate added by a feeder arranged to synchronize with a feeder controlling the amount of clay. Adding the barium carbonate at the dry pan, unless the clay or shale is fed mechanically as well as the barium carbonate, does not make for uniformity although it does the work satisfactorily in some cases.

The main factor to be considered in both the wet and dry methods of addition is a uniform flow of both the clay and the barium carbonate. It would appear that the best place to add the barium carbonate, in most cases, is at the pug-mill. When the wet addition is used the pug-mill is the only place the barium carbonate can be introduced, but in the case of the dry addition it can be mixed at other points such as the dry pan, pit cars, etc. Obviously, accurate additions and uniform mixing are very difficult to obtain except at the pug-mill or the dry pan; however, adding at the latter would require more expensive equipment at most plants for mechanical control of the clay and barium carbonate.

As there is no definite evidence as to the superiority of the wet or dry method of addition, local conditions must determine the method to be used. Either method should be equally satisfactory where dry powdered materials are used. Where a wet, unpulverized material is used, the wet addition should be more satisfactory, if sufficient water to introduce the barium carbonate is necessary for tempering, in addition to that already in the material. However, when the material requires very little or no additional water for tempering, the dry addition of barium carbonate must necessarily be used.

III

MANUFACTURE OF GREY BRICK

L. P. Collin

Grey brick are used in considerable numbers in some of the large centres of population in Canada, particularly in Montreal and Toronto. These brick have all been imported from the United States as Canadian manufacturers have been unable as yet to produce a satisfactory grey colour. As a result of the rather extensive use of these brick, several Canadian manufacturers wish to make a similar product and an investigation as to the possibility of utilizing Canadian raw materials for the production of grey brick is being carried on at present.

It was decided to visit plants at Ridgway, Daguseahonda, and Summerville, Pennsylvania, where grey brick are manufactured, while the writer was in the vicinity on other work. The methods used at all these plants are practically the same. In each case a second grade buff-burning fireclay is used. Manganese dioxide is added to these clays, and this black oxide imparts a grey colour to the burned brick. About 26 pounds of manganese dioxide ground to 80 mesh are used per 1,000 brick. This is added at the dry pan, and no great care is observed in using the proper amount as a little more or less than the given amount does not greatly influence the colour. The burning temperature is usually from cone 8 to cone 10. For a clear grey, oxidizing conditions are maintained, but at the Ridgway plant various shades of grey are obtained by using a strongly reducing atmosphere at the end of the burn.

IV

REFRACTORINESS OF MOULDING SAND

J. F. McMahon

The degree of refractoriness of a material is generally defined as a measure of the ability of that material to withstand heat. However, since the conditions under which the heat is applied have a marked effect upon the temperature at which certain heat reactions take place, it is necessary to consider the prevailing conditions in service, when studying the refractoriness of a material. More specifically, refractoriness has come to mean the ability of a material to withstand heat under definite conditions, such as atmosphere (oxidizing, neutral, reducing); slag action (acid, neutral, basic); heat application (sudden, gradual); and load (heavy, light).

In linking up refractoriness with a material for a specific type of service, the conditions under which the heat is applied and the characteristic change of state evidencing failure for that service must be recognized.

A moulding sand made up into a desired shape stands on the foundry floor at a temperature perhaps a little above that of the atmosphere. Then from the ladle to the sand is poured molten metal, the temperature of which varies up to 1,670° C. The conditions which prevail at the point of contact of the sand and molten metals are:—

1. Atmosphere—Highly reducing.
2. Slag action—Slight.
3. Heat application—Sudden.
4. Imposed load—Pounds to ton per square foot.
5. Temperature—Up to 1,670° C.

Therefore, it may be stated that the refractoriness of a moulding sand is the degree to which that sand will withstand heat with the prevailing conditions of reduction, thermal shock, and an imposed load, without any detrimental chemical or physical changes. The characteristic detrimental change may be regarded as that which causes the sand to fuse to the casting.

FACTORS AFFECTING THE REFRACTORINESS OF A MOULDING SAND

THE MINERAL AND CHEMICAL CONSTITUENTS OF THE SAND

This is the factor of primary importance in that upon it depends the reactions that take place in the sand upon the application of heat.

The following table, based on Boswell's list¹ of thirty-one moulding sands which he gives as being in use in the industry, shows the wide range of chemical composition together with comments:—

¹ Boswell, P. G. H.: "Moulding Sands for Non-ferrous Foundry Work."

—	Per cent	Comments
SiO ₂	95.86 to 46.67....	Very refractory and stable. Mostly in the form of quartz. Some in clay, feldspar, and mica.
Al ₂ O ₃	24.81 to 2.03....	In clay and feldspar. Very refractory in itself.
Fe ₂ O ₃	5.47 to 0.13....	Found coating the grains of quartz. In the clay and concretionary. Refractory in itself. Easily reduced.
FeO	0.56 to 0.15....	Found in various minerals. Not refractory. Fluxes easily with silica and alumina.
MgO	1.78 to 0.16....	Found mostly in mica and in clay substance. Refractory in itself but undesirable due to its basic properties.
CaO	4.55 to 0.14....	Found as carbonate and in feldspar and clay. Refractory in itself but an active flux when heated with SiO ₂ and Al ₂ O ₃ .
Na ₂ O	1.50 to 0.06....	Found in clay. Flux, not refractory.
K ₂ O	5.45 to 0.50....	Found in clay, but mostly in feldspars. Active flux, not refractory.
Loss Ign.	12.29 to 0.47....	Carbon dioxide. Carbonaceous matter. Aids in reduction.
H ₂ O	3.18 to 0.56....	} Not important as far as refractoriness is concerned.
H ₂ O	2.11 to 0.28....	
CO ₂	3.52 to None....	Found in magnesium and calcium carbonates. Has no effect upon refractoriness.
TiO ₂	0.97 to 0.06....	Found in clay matter and ilmenite. Negligible.
ZrO ₂	Trace to None....	} Unimportant as far as refractoriness is concerned.
P ₂ O ₅	0.15 to "	
SO ₃	0.42 to "	
Cl ₂	0.03 to "	
MnO ₂	0.06 to Trace....	
BaO	0.04 to None....	

The chemical analyses that are possible within the above limits give one an idea of the great diversity in the chemical and mineralogical compositions of various sands used in the industry. While the chemical analyses are very important, they do not give one a means whereby he can index the refractory value of the sand because of the various mixtures of minerals that are possible within such limits as noted above. Once a sand has been tested for refractoriness, additional chemical analysis should be an ideal guide to its constancy.

COMPOSITION OF MOULDING SAND

Moulding sands consist of two component parts, granular material and clay substance.

Granular Material. This consists principally of quartz grains which are very refractory. Mingled with the quartz grains may be many minerals, the most important of which are feldspar, magnetite, garnet, mica, and calcite. They represent that portion of the granular material which, due to ease of fusibility, ease of reduction, or fluxing action, fails first under heat. However, their effect upon the quartz grains is limited by the small amounts present and the restricted surface contact. In a sand the granular portion is usually the more refractory portion.

Clay Substance. The clay substance of a sand plays an important part in refractoriness because it usually carries with it most of the fluxing elements in a very finely divided and intimately mixed state. The surface contact produced by the finely divided clay substance and the reactions set up by the contained fluxes make the clay substance the weak factor in the sand under heat. The more important item in this consideration is quality rather than quantity present. The quality of clay

substance varies in the different sands and it is only when the quality is nearly the same that the quantity becomes important. The tests which follow show the importance of the clay substance and the part which it plays in refractoriness. The refractoriness of the clay substance alone might be used for a refractoriness determination of the sand for broad limits but not for one of close limits, because of the reactions that are set up between it and the granular material.

FINENESS OF GRAIN

Fineness of grain affects the refractoriness of a material inasmuch as upon it depends the surface contact and hence the ease of chemical reaction.

Screen analyses of the sands tested were made according to specifications of the A.F.A. The results obtained follow.

Screen Analyses of Sands Tested

Sand	On 6	On 10	On 20	On 35	On 65	On 100	On 150	On 200	On 270	Pan	Clay sub- stance	A.F.A. fineness factor
1.....			0.14	3.72	27.36	17.28	15.14	7.98	4.90	0.80	13.68	8 E
2.....			2.14	8.64	21.30	14.32	12.94	7.24	3.44	9.04	20.94	4 G
3.....		0.28	2.10	10.02	27.50	18.24	15.94	6.88	4.82	2.30	11.92	7 E
4.....			0.10	43.25	35.36	7.05	6.82	3.53	1.74	0.85	.....	6 A
5.....			1.40	38.68	48.76	7.90	2.64	0.29	0.03	0.05	.....	7 A
6.....		0.22	0.36	0.36	0.58	3.06	15.84	16.60	11.62	32.42	19.08	1 F
7.....		1.24	19.24	62.65	14.50	1.14	0.40	0.13	0.05	0.05	.....	8 A
8.....			13.05	68.96	15.78	1.22	0.50	0.15	.....	.....	.....	8 A
9.....		0.30	6.92	56.18	15.36	2.16	0.58	0.18	0.12	0.32	17.88	8 F
10.....			0.20	3.00	15.68	24.96	30.82	4.82	1.48	2.48	16.56	4 F
11.....	4.96	17.20	39.36	66.12	74.46	75.52	76.14	76.42	76.66	77.88	22.12	8 E
12.....		2.08	6.26	20.50	18.88	11.74	6.10	2.88	1.98	10.46	19.12	4 F
13.....			0.12	0.32	0.56	6.06	22.76	21.32	14.72	24.74	9.40	2 D
14.....			1.45	14.30	67.87	13.16	2.55	0.45	0.15	0.07	.....	6 A
15.....		0.04	0.12	1.44	11.68	11.56	14.72	7.92	5.14	17.76	29.62	2 G
16.....			0.02	0.05	4.61	6.46	5.87	4.49	6.46	13.88	16.32	2 F
17.....		7.54	19.14	24.74	16.36	4.74	0.46	0.30	0.28	3.42	23.02	7 G

The results of our tests show that there is no relation existing in the fineness test whereby we may be assisted in the determination of the refractoriness of a sand. This is easily understood when we consider the mineralogical and chemical composition of the sands in question which vary one from another to such an extent. The use of the fineness factor relative to refractoriness is limited to sands which vary one from the other only in this respect.

TESTS

The American Foundrymen's Association, for some time, has been working on the development of a series of tests whereby the various properties of sands used in the foundry may be determined. Among the several tests contemplated, that for the determination of refractoriness was referred to several research laboratories including the Ceramic Laboratories of the Mines Branch. While the property of refractoriness is of

decided importance in view of the high temperature to which moulding sands are subjected, very little investigational work has been done on it in the past and no method of determining it has been adopted.

While the specific refractoriness (that is the temperature at which the sand would fail under foundry conditions) could be determined by preparing moulds of the sand and pouring into them molten metal at increasingly higher temperatures until that at which the sand would sinter to the surface of the casting was reached, it would be a very expensive procedure and impossible to perform on a small scale in a laboratory.

The reactions that may be expected when a moulding sand is heated to increasing temperatures are as follows:—

The Removal of Mechanically-held and Chemically-combined Waters. These waters are all removed at temperatures below 500° C.

The Breaking Down of the Carbonates. At temperatures up to 900° C. the carbonates of magnesium, calcium, and iron break down, giving off CO₂ to form the oxides.

Shrinkage of the Bond. The temperatures at which bonds begin their shrinkage vary according to their natures. This amounts to a sintering and knitting together of the fine particles and occurs usually from 1000° C. upwards. In this reaction the bond tends to pull away from the non-shrinking sand grain.

Vitrification of the Bond. Upon the further application of heat, the bond approaches a liquid phase and as such reacts very readily with its impurities to develop a more stable compound, or mixture of stable compounds, depending upon the impurities and the percentages of same present. All the substances present in the bond, being in such a finely divided state, react very rapidly at this stage. The resulting products vary, not only in composition but also in viscosity. In certain instances the flow begins at the formation temperature, while in other instances flow does not begin until the temperature has advanced much higher. Between these two limits, there are varying degrees of viscosity.

Corrosion of Accessory Minerals. The condition of the bond at the previous state promotes its reaction with the materials in the sand, such as feldspars, mica, etc. At temperatures producing this reaction, the impurities just mentioned are very active themselves and unite easily with the slag to form various eutectics.

Corrosion of Sand Grains. The sand grains, being of such a stable nature (silica) and being so large grained (in comparison to the rest of the matter), are the last to be demolished. By continued heating these sand grains are gradually absorbed by the slag and enter into the liquid phase.

The methods that suggested themselves do not measure the specific refractoriness of the sands, since they do not reproduce the service conditions in every respect, but have been tried out on a series of seventeen samples of commercial foundry sands to learn whether they might be useful in determining the relative refractoriness of such sands.

These tests are as follows:

1. Softening point determination, entire sand.
2. Softening point determination, clay substance.
3. Sag test.
4. Draw trial.
5. Saeger's test.

SOFTENING POINT DETERMINATION, ENTIRE SAND

This method was chosen first because of its general use in the testing of refractoriness of materials which are similar to moulding sands. This test is one that is in every-day use in the ceramic industry for the testing of the refractoriness of the clays, etc., which are used in that industry.

Preparation of Sample. The material was quartered down to a 200-gramme sample. This sample was then ground in an agate mortar to pass a 60-mesh screen.

The material was then moistened sufficiently to allow it to be made into "cones" similar to standard pyrometric cones (tetrahedra 7 mm. along the edge of the base and 30 mm. high). They were moulded by hand in a steel mould. In the case of non-bonded sands (4, 5, 7, 8, and 14) sufficient gum tragacanth was added to furnish the necessary bond.

The cones when dry were embedded in a plaque of alundum to the depth of 2 mm. alternately about the periphery of the plaque with standard cones of successive numbers. The angle between the face of the cone and the plaque was approximately 75 degrees. The standard cones used were those of the Seger formulæ as manufactured by the Standard Pyrometric Cone Co., Columbus, Ohio.

The furnace was a carbon-resistance furnace which was capable of temperatures up to 1800°C. Strong reducing conditions were present. The temperature was raised to 1000° C. in one hour, and thereafter at the rate of 60 degrees per hour.

The softening point taken was that point at which the sand cone tipped and touched the plaque. The results of the test are given in standard cones with their accepted corresponding temperatures.

The results of the softening point test are as follows:

Sand Number	Softening point	Softening point
	Cone	°C.
1.....	14 $\frac{1}{2}$	1420
2.....	16	1450
3.....	17 $\frac{1}{2}$	1480
4.....	32 $\frac{1}{2}$	1713
5.....	32	1705
6.....	14	1410
7.....	33 $\frac{1}{2}$	1730
8.....	32	1705
9.....	26	1600
10.....	26	1600
11.....	26	1600
12.....	15	1430
13.....	20	1530
14.....	34	1740
15.....	15	1430
16.....	17	1470
17.....	14 $\frac{1}{2}$	1420

The above test is one which gives the ultimate heat-resisting qualities of the material. Undoubtedly its use would be of value in determining the refractoriness of a moulding sand. However, its results represent reactions which have gone to completion rather than the beginning of such reactions. It appears that in moulding sands, the desired factor is the beginning of failure rather than complete failure. A further discussion of the softening point test is given under the test of clay substance in the moulding sand.

SOFTENING POINT DETERMINATION, CLAY SUBSTANCE

Considerable stress has been laid, and justly so, upon the importance of the clay bond in the determination of the refractoriness of a moulding sand. In order to ascertain the degree to which this component of the sand affected its refractoriness the following experiments were run.

Washing. The clays were washed free from the sand grains by the method suggested in the fineness test of the A.F.A. standard tests.¹

The only deviation from this standard was the use of ammonium hydroxide in place of the sodium hydroxide as specified. This was done in order to keep away from any fluxing action which the sodium would impart to the clay.

Preparation of Test Pieces. The clay bonds were made into cones and tested in a similar manner to the entire sands.

The results obtained by this test were as follows:—

Clay Substance Number	Cone	Temp. °C.
1.....	10	1330
2.....	1	1150
3.....	03+	1099
6.....	10	1330
9.....	28	1635
10.....	14	1410
11.....	27	1620
12.....	16	1450
13.....	8	1290
15.....	10	1330
16.....	03+	1099
17.....	9	1310

SAG TEST

This test was carried on to determine at what temperature bending would take place in a bar of moulding sand, 4 by 1 by $\frac{1}{2}$ inches, when resting on the flat upon two supports 3 inches apart.

Preparation of Sample. The sand was quartered down to a 500-gramme sample. The sample was then passed through a 16-mesh screen and tempered with sufficient water to allow moulding. The oversize was rejected in this test.

¹ American Foundrymen's Association Tentatively Adopted Methods of Test, June 14, 1924.

Test Bars. In making the bars, the tempered sand was carefully fed through an elliptical funnel into a steel mould, 4 inches long, $1\frac{1}{2}$ inches deep, and $\frac{1}{2}$ inch wide. The sand was then consolidated by three blows centred on a wooden rammer, with the drop weight of the A.F.A. permeability apparatus. Sufficient sand was used to produce a finished bar 1 inch in width.

Furnaces. At the outset, these tests were run in a small, gas-fired, low air pressure Palo furnace; two tests being run at the same time. The results were very unsatisfactory. The sag bars in the second instance were burned in a gas-fired kiln of small dimensions and later put into the Palo furnace, the former kiln serving to preburn the pieces and the latter furnace to produce the sag. This also proved unsatisfactory due to the lack of strength in the preburned pieces. For the final test a kiln large enough to take care of all pieces at once was used. This was a gas-fired, down-draught kiln provided with a muffle.

Rate of Heating. This factor is probably the most important item to be contended with in running sag tests. The difficulty of maintaining a regular and definite rate of heating was the chief reason why the small Palo furnace was useless in this test. To overcome this difficulty, the Palo furnace was heated and held at 1000° C. until the pieces which had been burned in the above-mentioned gas kiln to that temperature were inserted upon their supports. This proved unsatisfactory. The rate chosen and used in the operation of the large kiln was 100 degrees per hour up to 1000° C. and thereafter at 35 degrees per hour.

The results of the sag tests run in the large down-draught, gas-fired kiln are given here, as determined by an optical pyrometer.

Sand Number	Water p.c.	Weight grms.	Temp. Sag °C.
1.....	15.0	72	1167
2.....	10.2	72	1417
3.....	6.8	60	1150
4 Too fragile to test.....			
5 " " ".....			
6.....	10.8	60	1220
7 Too fragile to test.....			
8 " " ".....			
9.....	12.0	72	1420+
10.....	10.0	60	1420+
11.....	9.8	60	1420+
12.....	10.4	70	1130
13.....	14.6	65	1205
14 Too fragile to test.....			
15.....	13.2	65	1215
16.....	10.0	65	1220
17.....	8.8	65	1250

The above test is one that is easily duplicated and lends itself to the problem at hand. This test comes a little closer to giving the initial point of failure, than does the softening point determination. This of course was to be expected since the effective bending moment was much greater and therefore less softening was required to cause distortion. The results of

the sag tests are lower than the softening points because the reactions had not progressed to the same extent by the time the index point had been reached. This method is not suitable for low bonded sands.

DRAW-TRIAL TEST

The purpose of this test was to determine whether it would be practical to determine the refractoriness of moulding sand by noting the effect of different temperatures upon the burned strengths and other properties of the sand.

Preparation of Sample.—The sand was quartered down to a 1000-gramme sample, passed through a No. 16-mesh screen, and tempered with sufficient water to allow moulding.

Test Pieces.—The sand was then carefully poured through a funnel into a steel mould, which was shaped to produce a hollowed cylinder $1\frac{1}{4}$ inches in diameter with a $\frac{3}{8}$ -inch hollowed centre. Sufficient sand was used to produce a finished cylinder 1 inch in height. The sand was then consolidated with three blows of the drop weight of the A.F.A. permeability apparatus on a steel rammer. The pieces were then allowed to dry slowly.

Furnace.—The furnace used for this test was the large gas furnace used in the sag tests.

Rate of Heating.—The temperature was raised to 600° C. at the rate of 100 degrees per hour, and thereafter at 30 degrees per hour.

Procedure.—The test pieces were placed upon fireclay trays, those to be drawn at the same temperature being placed on the same tray.

When predetermined temperatures, commencing at 1010° C., were reached the furnace was opened and a tray of test pieces was removed quickly to another muffle furnace which was maintained at a constant temperature of 900° C. When all of the test pieces had thus been transferred to the second furnace, it was allowed to cool slowly.

The test pieces, after slow cooling, were subjected to crushing tests on an Olsen machine. Before breaking and again after breaking they were examined under a microscope and the observations recorded.

For the purpose of recording the observations under the microscope, the following terms were chosen indicative of the effect produced by the heat.

1. Little effect.
2. Bond shrunk (which signifies the shrinking of the bond away from the sand grain).
3. Bond vitrified (the formation of the bond into vitreous (not fluid) material).
4. Little glass (the beginning of flow of bond and corrosion of grains).
5. Considerable glass.
6. Much glass.
7. Bond fusion progressed far (all bond in a glassy state).
8. Few grains fused (melted independently of corrosion).
9. Many grains fused (partial fluxing of the sand grain).
10. Fused (complete fluxing of sand grains by the glassy bond).

The results of the test were as follows:—

Results of Draw-trial Test

Cone	Temperature	Strength	Microscopic observation	Remarks
<i>Sand No. 1</i>				
07	°C. 1010	lb. No load	Bond shrunk.....	} Grains fused.
05	1050	61	Bond vitrified.....	
02	1110	275	Very little glass.....	
1	1150	178	Considerable glass.....	
4	1210	1264	Much glass.....	
6	1250	3100	Much glass.....	
9	1310	4700	Much glass.....	
11	1350	4600	Much glass.....	
<i>Sand No. 2</i>				
07	1010	190	Bond shrunk.....	} Few grains of sand fused.
05	1050	192	Bond vitrified.....	
02	1110	404	Very little glass.....	
1	1150	352	Very little glass.....	
4	1210	850	Considerable glass.....	
6	1250	2107	Much glass.....	
9	1310	3100	Much glass.....	
11	1350	3200	Much glass.....	
14	1410	Bond fusion progressed far...	
<i>Sand No. 3</i>				
07	1010	35	Bond vitrified.....	} Few grains of sand fused.
05	1050	38	Very little glass.....	
02	1110	125	Very little glass.....	
1	1150	112	Bond vitrified.....	
4	1210	224	Considerable glass.....	
6	1250	988	Much glass.....	
9	1310	1080	Much glass.....	
11	1350	1531	Much glass.....	
14	Bond fusion progressed far....	
<i>Sand No. 6</i>				
07	1010	106	Bond shrunk.....	} Few grains of sand fused.
05	1050	460	Bond vitrified.....	
02	1110	1311	Very little glass.....	
1	1150	754	Bond vitrified.....	
4	1210	2000	Considerable glass.....	
6	1250	9100	Much glass.....	
9	1310	8700	Much glass.....	
Very hard sand to judge due to light coating of bond.				
<i>Sand No. 9</i>				
07	1010	256	Little effect.....	
05	1050	101	Bond shrunk.....	
02	1110	60	Bond shrunk.....	
1	1150	60	Bond shrunk.....	
4	1210	74	Bond shrunk.....	
6	1250	16	Bond shrunk.....	
9	1310	26	Bond shrunk.....	
11	1350	Broken	Bond vitrified.....	
14	1410	128	Very little glass.....	
16	1450	191	Very little glass.....	

Results of Draw-trial Test—Continued

Cone	Temperature	Strength	Microscopic observation	Remarks
Sand No. 10				
07	1010	118	Little effect.....	} Few sand grains fused.
05	1050	63	Bond shrunk.....	
02	1110	141	Bond shrunk.....	
1	1150	Broken	Bond shrunk.....	
4	1210	Broken	Bond shrunk.....	
6	1250	58	Bond vitrified.....	
9	1310	164	Very little glass.....	
11	1350	121	Very little glass.....	
14	1410	886	Much glass.....	
16	1450	986	Bond fusion progressed far....	
Sand No. 11				
07	1010	163	Bond shrunk.....	
05	1050	Broken	Bond shrunk.....	
02	1110	43	Bond shrunk.....	
1	1150	44	Bond shrunk.....	
4	1210	16	Bond shrunk.....	
6	1250	24	Bond shrunk.....	
9	1310	41	Slight vitrification.....	
11	1350	41	Slight vitrification.....	
14	1410	42	Much glass.....	
16	1450	80	Bond fusion progressed far....	
Sand No. 12				
07	1010	136	Bond shrunk.....	} Many sand grains fused.
05	1050	167	Bond shrunk.....	
02	1110	194	Slight vitrification.....	
1	1150	149	Slight vitrification.....	
4	1210	270	Very little glass.....	
6	1250	1312	Very little glass.....	
9	1310	1031	Considerable glass.....	
11	1350	1640	Considerable glass.....	
Sand No. 13				
07	1010	No load		
05	1050	58	Bond vitrified.....	
02	1110	618	Bond vitrified.....	
1	1150	95	Very little glass.....	
4	1210	1025	Bond vitrified.....	
6	1250	3300	Considerable glass.....	
9	1310	4200	Considerable glass.....	
11	1350	7900	Considerable glass.....	
14	1410	.....	Fused.....
16	1450	.....	Fused.....
Sand No. 15				
07	1010	347	Bond shrunk.....	} Few sand grains fused.
05	1050	287	Bond shrunk.....	
02	1110	510	Bond vitrified.....	
1	1150	245	Bond vitrified.....	
4	1210	548	Bond vitrified.....	
6	1250	1772	Very little glass.....	
9	1310	1705	Very little glass.....	
11	1350	3800	Bond fusion progressed far, much glass.....	

Results of Draw-trial Test—Concluded

Cone	Temperature	Strength	Microscopic observation	Remarks
Sand No. 16				
07	°C. 1010	lb. 109	Bond shrunk.....	} Few sand grains fused.
05	1050	257	Bond vitrified.....	
02	1110	1130	Very little glass.....	
1	1150	199	Bond vitrified.....	
4	1210	944	Bond vitrified, very little glass.....	
6	1250	3300	Very little glass.....	
9	1310	2650	Very little glass.....	
11	1350	4300	Bond fusion progressed far....	
Sand No. 17				
07	1010	233	Little effect.....	} Few sand grains fused.
05	1050	254	Bond shrunk.....	
02	1110	553	Bond shrunk.....	
1	1150	230	Bond shrunk.....	
4	1210	308	Very little glass.....	
6	1250	1133	Considerable glass.....	} Many sand grains fused.
9	1310	877	Considerable glass.....	
11	1350	1863	Bond fusion progressed far....	

The figures given for strength in the above are important inasmuch as they link well with the observation under the microscope. Together they show the temperature at which the sands fail. It is not considered important that in sand 1, the cone 02 burn has greater strength than the cone 1 burn, because the differences are too small to suggest any particular change. However, in the same instance, when the strength of the cone 1 burn differs so greatly from the strength of the cone 4 burn, it suggests a radical change in the condition of the material. Between cone 1 and cone 4, this sand has undergone a change, and that change as seen by the microscope was the formation of much glass as a matrix to the sand grains. This is the point at which this sand fails. Figuring likewise from the figures on all the sands, the following initial failures of the sands are taken:—

Sand	Cone	Temperature
1.....	4	°C. 1210
2.....	4	1210
3.....	6	1250
4.....	4	1210
9.....	.....	1470+
10.....	14	1410
11.....	.....	1470+
12.....	6	1250.
13.....	4	1210
15.....	6	1250
16.....	4	1210
17.....	6	1250

In the particular instances of sands 9 and 11, while there seems to be much glass under the microscope, there is no fusion of the sand grains (the glass formed being such that it is not a flux to the sand grains), resulting in a weak bond. Then, too, there must be taken into consideration the low percentages of clay bond in the two samples.

The above test is considered to be of value in that one can, with a simple furnace arrangement and a magnifying glass or microscope, determine such points at which a sand can be expected to cause trouble from failure under heat.

SAEGER'S METHOD

This method was originally suggested to the Committee on Moulding Sands of the A. F. A. by J. M. Saeger, Jr., of the U.S. Bureau of Standards, at Washington.

In this test a sample of moulding sand in the shape of a bar is locally heated by an electrically heated platinum ribbon to increasingly higher temperatures. The temperature at which the sand sinters and adheres to the platinum is taken as the index of the refractoriness of the sand.

Preparation of Sample. The sand was quartered to a 1000-gramme sample by the usual method and then carefully tempered with sufficient water to permit moulding. The entire sample was passed through a coarse riddle and the procedure was followed of preparing the bar for cohesion test as outlined in A.F.A. Tentatively Adopted Methods of Test (June 14, 1924).

Heating Apparatus. The apparatus, while the same in principle as Saeger's, was somewhat different in detail of construction. It consists of a pair of brass bars, $\frac{1}{4}$ inch by $\frac{3}{8}$ inch by 12 inches, spaced $3\frac{1}{2}$ inches apart, firmly held parallel by a piece of fibreboard, $2\frac{1}{2}$ inches by 4 inches by $\frac{1}{4}$ inch, attached by screws near one end of the bars. At the opposite end, a platinum ribbon, $\frac{1}{2}$ inch wide and $\frac{3}{1000}$ inch thick, extends between the two brass bars. This framework is so mounted, on low standards to a baseboard, that the platinum ribbon may be raised or lowered at will.

The platinum ribbon may be heated to any desired temperature up to 1650° C. by means of an electric current supplied to it through the standards to which the brass bars are pivoted. A rheostat is provided for controlling the current and thus regulating the temperature of the platinum ribbon.

Procedure. The bar of sand is thoroughly dried and placed on the base of the heating apparatus. The current is turned on and the platinum ribbon heated to a predetermined temperature, observed by means of an optical pyrometer. The ribbon is then lowered so as to lie across the sand test bar near one end of it and allowed to remain in this position for five minutes. At the end of this time the temperature of the ribbon is read and the ribbon is raised from the test bar. That part of the sand which had been subjected to the heat is examined under the microscope for signs of sintering. These operations are repeated at increasingly higher temperatures upon fresh surfaces of the sand until marked sintering takes place as evidenced by the sand sticking to the platinum.

Results of Saeger's Test

Trial	Temperature	Remarks
<i>Sand No. 1</i>		
	°C.	
1.....	975	No glass.
2.....	1055	No glass.
3.....	1097	No glass.
4.....	1118	No glass.
5.....	1187	No glass.
6.....	1217	No glass.
7.....	1242	No glass.
8.....	1291	No glass.
9.....	1365	Traces of glass.
10.....	1503	Stuck to strip.
<i>Sand No. 2</i>		
	°C.	
1.....	975	No glass.
2.....	1035	No glass.
3.....	1058	No glass.
4.....	1118	No glass.
5.....	1173	No glass.
6.....	1210	No glass.
7.....	1223	No glass.
8.....	1258	No glass.
9.....	1375	Traces of glass.
10.....	1478	Stuck.
<i>Sand No. 3</i>		
	°C.	
1.....	975	No glass.
2.....	1055	No glass.
3.....	1072	No glass.
4.....	1118	No glass.
5.....	1167	No glass.
6.....	1223	First sign of glass.
7.....	1250	Glass.
8.....	1288	Glass.
9.....	1380	Stuck.
<i>Sand No. 6</i>		
	°C.	
1.....	1062	No glass.
2.....	1097	No glass.
3.....	1158	No glass.
4.....	1158	No glass.
5.....	1288	First sign of glass.
6.....	1268	Glass.
7.....	1300	Glass.
8.....	1410	Stuck.

Results of Saeger's Test—Continued

Trial	Temperature	Remarks
<i>Sand No. 9</i>		
1.....	°C. 1035	No glass.
2.....	1035	No glass.
3.....	1104	No glass.
4.....	1143	No glass.
5.....	1173	No glass.
6.....	1215	No glass.
7.....	1340	No glass.
8.....	1458	Traces of glass.
9.....	1433	Traces of glass.
10.....	1428	Traces of glass. Fusion started.
<i>Sand No. 10</i>		
1.....	°C. 1035	No glass.
2.....	1035	No glass.
3.....	1118	No glass.
4.....	1097	No glass.
5.....	1173	No glass.
6.....	1230	No glass.
7.....	1360	No glass.
8.....	1482	Stuck.
<i>Sand No. 11</i>		
1.....	°C. 960	No glass.
2.....	1055	No glass.
3.....	1143	No glass.
4.....	1135	No glass.
5.....	1202	No glass.
6.....	1198	No glass.
7.....	1345	No glass.
8.....	1474	Much glass.
<i>Sand No. 12</i>		
1.....	°C. 1020	No glass.
2.....	1010	No glass.
3.....	1097	No glass.
4.....	1150	No glass.
5.....	1210	No glass.
6.....	1237	No glass.
7.....	1261	No glass.
8.....	1385	Stuck.
<i>Sand No. 13</i>		
1.....	°C. 1097	No glass.
2.....	1104	No glass.
3.....	1143	No glass.
4.....	1173	No glass.
5.....	1223	Slightly stuck.
6.....	1275	Slightly stuck.
7.....	1328	Stuck badly.

Results of Saeger's Test—Concluded

Trial	Temperature	Remarks
<i>Sand No. 15</i>		
1.....	983	No glass.
2.....	1055	No glass.
3.....	1104	No glass.
4.....	1104	No glass.
5.....	1173	No glass.
6.....	1213	No glass.
7.....	1261	No glass.
8.....	1335	Traces of glass.
9.....	1488	Much glass.

<i>Sand No. 16</i>		
1.....	1045	No glass.
2.....	1080	No glass.
3.....	1158	No glass.
4.....	1150	No glass.
5.....	1190	No glass.
6.....	1250	Traces of glass.
7.....	1300	Traces of glass.
8.....	1410	Stuck.

<i>Sand No. 17</i>		
1.....	975	No glass.
2.....	1045	No glass.
3.....	1088	No glass.
4.....	1135	No glass.
5.....	1158	No glass.
6.....	1205	No glass.
7.....	1250	No glass.
8.....	1390	Slightly stuck.

Summary of Tests

No.	Beginning bond shrinkage	Bond vitrified	Tendency to distort. Sag test	Strong matrix. Crushing test	Softening point of bond. Cone test	Softening point of sand. Cone test	Failure. Saeger's test
	°C	°C	°C	°C	°C	°C	°C
1	1010	1050	1167	1210	1330	1420	1503
2	1010	1050	1417	1210	1150	1450	1478
3	Below	1010	1150	1250	1099	1480	1380
6	1010	1050	1220	1210	1330	1410	1410
9	1050	1350	1420+	1470+	1635	1600	1428
10	1050	1250	1420+	1410	1410	1600	1482
11	1010	1310	1420+	1470+	1620	1600	1474
12	1010	1110	1130	1250	1450	1430	1385
13	1010	1050	1205	1210	1290	1530	1328
15	1010	1110	1215	1250	1330	1430	1488
16	1010	1050	1220	1210	1099	1470	1410
17	1050	1150	1250	1250	1310	1420	1390

It will be noted that a general relationship exists in the above figures. To begin with, the shrinkage of the bond away from the grain occurs in all instances at temperatures below 1050° C. Most of the bonds have a very short shrinkage period before becoming vitrified. In the cases of Nos. 9, 10, and 11, the bonding substances are of a much more refractory character and the longer shrinkage period is evidence of this fact. The temperature of sag, or tendency to distort, links, as one might expect, with the temperature at which a strong matrix is present in the cooled trial test. The differences in temperatures between the vitrification of the bond and the softening point of the bond represent the range of reaction before the bond has entered an entire liquid phase and has lost its viscosity sufficiently to cause the cone to bend over. In all but two instances (Nos. 9 and 10) the bond softens before the whole sand.

The figures given as results of Saeger's test have not any definite relationship with the other tests. This is not surprising since the processes of heat application are so widely different. The Saeger test consists of the application of heat to the surface of the sand while all others consist of a soaking heat throughout the specimen. It will be noted (as would be expected) that the temperatures of failure as determined by the Saeger method are all higher than in previous tests. The important point is that while the other tests are very interesting, it does not seem that they reproduce as nearly as does the Saeger test, the conditions met in the foundry. While the test may be improved upon in several details, it is felt that it is the best method as yet suggested for a fair test of the refractoriness of a moulding sand.

V

KAOLIN AND ASSOCIATED CLAYS OF PUNK ISLAND

L. H. Cole and J. F. McMahon

The presence of kaolin and highly refractory clays on Punk island in lake Winnipeg has been reported from time to time during the past 15 years, but no detailed or extensive study of the deposits has been undertaken. The present report is the result of a four-day examination of the clay on the northeastern shore of the island by L. H. Cole. This examination consisted of surveying and mapping the area, drilling test holes, digging test pits and taking representative samples for testing in the laboratory. The tests on the samples were made by J. F. McMahon, and the section of the report dealing with tests has been written by him.

Location

Punk island is situated in lake Winnipeg, 3 miles southeast of Grindstone point on the west shore of the lake. The island, when subdivided, will be in portions of townships 26 and 27, range 7, east of the Principal Meridian. The length of the island in a northeasterly direction is approximately 7 miles, and its greatest width is a little over 2 miles. Its total area is nearly 9 square miles.

Transportation

Transportation from the island is entirely by motor boat or steamer. From the deposit of clay on the northeast shore to the nearest rail transportation at Riverton, the terminal of the Winnipeg Beach line of the Canadian Pacific railway, the distance is 40 miles; and the distance by water to Selkirk, on the Red river, is approximately 90 miles.

Topography

The whole island is low-lying and, with the possible exception of along the north shore where sandstone cliffs occur, no point rises 100 feet above the level of the lake. A heavy growth of timber consisting mostly of spruce covers the island and in some places the trees are of considerable size. Along the northeastern shore the elevation of the bank is only a few feet above the water-level, but the escarpment rises gradually towards the northwest. In places, back from the shore, the island is heavily covered with underbrush and the soil is very sandy underneath the loamy top covering. Blueberry patches and swampy flats are frequent.

Description of Clay Deposits

Geological maps of this area classify the rocks, which consist of limestone, weathered shales, and sandstones, as Ordovician. Wright,¹ who examined and sampled the clay on the northwestern shore of the island,

¹ Geol. Surv., Canada, Sum. Rept. 1922, pt. C, pp. 76-79.

reports kaolin particles in the clays interbedded with the sandstones and particularly coating what apparently were concretions. He did not, however, appear to have examined that part of the island covered by this report.

While, undoubtedly, the rock formations on the island are of Ordovician age, there are a number of points along the northeastern shore, exposed only at low water in the lake, where the rocks are of Precambrian age. The rock is greenish grey in colour and has a schistose structure. The presence of this rock has a direct bearing on the occurrence of the white and green clays since there is little doubt that such clays are the result of weathering in place of these rocks.

Along the section of the shore examined are found three types of clay, namely, a white clay, a green clay, and a brownish blue clay, the latter probably of Pleistocene age. Figure 1 shows the area underlain by each type.

The White Clay. The so-called white clay is cream-coloured when first excavated, but becomes whiter on drying; it is quite sticky and fairly plastic. It extends as a thin layer on top of a green clay in the shallow bay to the northwest of the sand bar shown in Figure 1. Outcrops of this clay, above the water-level, are quite hard and the clay cracks with a conchoidal fracture. Another area of this white clay lies underneath one foot of white sand $\frac{3}{4}$ mile to the northwest of the first area. Green clay lies underneath this area also.

The Green Clay. Underlying the white clay is a greenish to greenish white clay of varying thickness. There is no definite line of demarcation between it and the white clay, the latter gradually passing from a greyish clay to a greyish green and into the green clay. Hard particles of a greenish rock, partly decomposed, are found in the clay, especially as it nears the underlying rock. When excavated the clay is smooth and plastic. This clay passes with no definite line of change into a highly altered schistose-structured rock very similar in appearance to the green rocks outcropping near the shore at low water.

The Brownish Blue Stoneless Clay. A highly plastic smooth-working brownish blue, stoneless clay occurs over a considerable area of the shore examined. This is, in all probability, a Pleistocene clay, and it overlaps the white and green clays in places. Its extent and distribution are shown on Figure 1. This clay should not be confused with the clays examined by Wright on the northwest shore of the island since the latter were clays stated to be interbedded with sandstone, and most likely represent an argillaceous phase of the Winnipeg sandstone. In places this brown clay is overlain by reddish sands of recent origin and where it occurs in the bank its overburden is still sand and loam. At one place in the bank there is a face of brown laminated clay 6 feet in thickness above water-level, while only a few feet farther west the bank is composed of consolidated iron-stained sandstone. There is a vertical line of demarcation between the clay and sandstone as if this had been at one time an escarpment in the sandstone and the clay had been deposited in the depression.

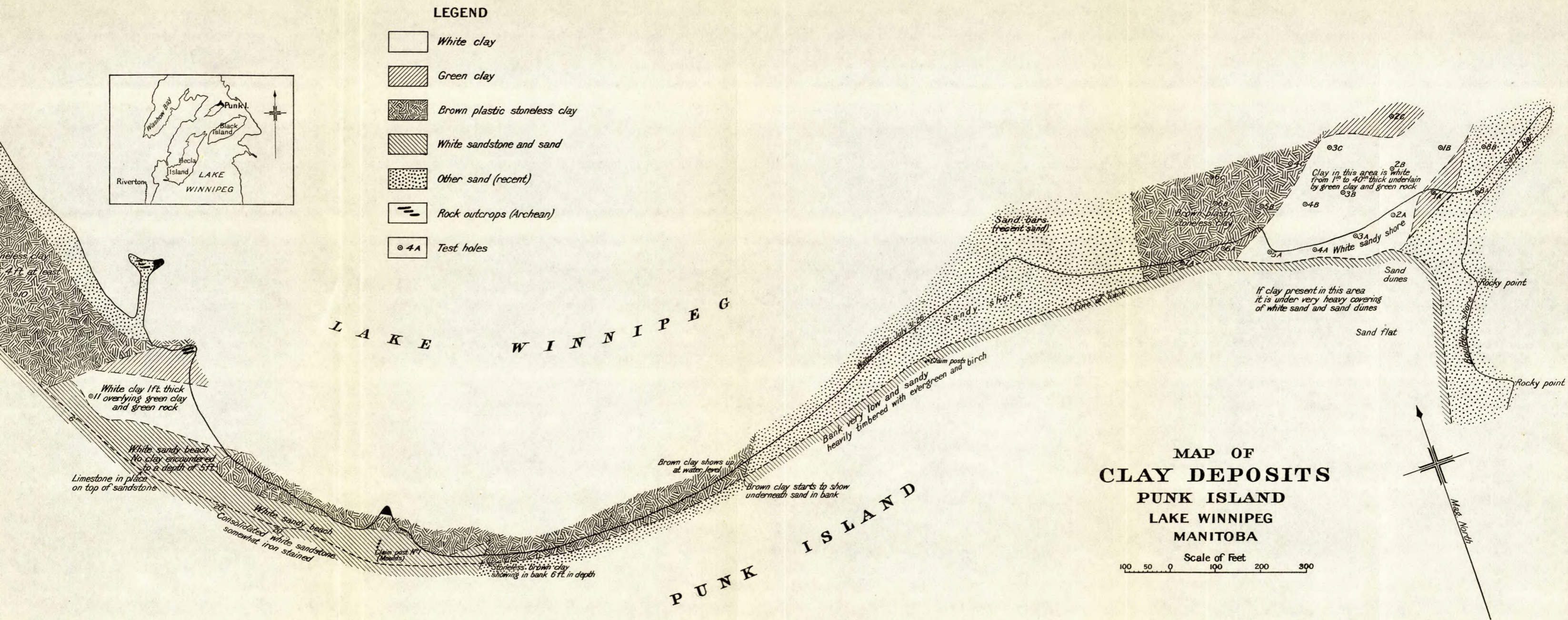


Figure 1

DRILLING TESTS

Test holes were drilled with a 6-inch post-hole auger in a number of places (see Figure 1), and a number of test pits were dug to supplement the data obtained from the drill holes. The information obtained from the drilling has been tabulated as follows:—

Drilling Records

Hole No.	Water	Sand-gravel	Brown clay	White clay	Green clay	Rock	Remarks
	inches	inches	inches	inches	inches	inches	
1A	.....	3	.....	.....	53	6+	Stopped in hard material.
1B	12	12	.....	39	8+	.....	" green clay.
2A	.....	8	.....	10	2	6+	" hard material.
2B	15	6	.....	29	22	6+	" "
2C	20	3	.....	.....	32	6+	" "
3A	.....	12	.....	2	25	6+	" "
3B	15	10	.....	40	6+	.....	" green clay.
3C	27	10	.....	2	36+	.....	" "
4A	.....	4	.....	8	23	6+	" hard material.
4B	13	15	.....	18	8	6+	" "
4C	17	21	11	.....	10+	.....	" green clay.
5A	.....	28	.....	3	23	6+	" hard material.
5B	14	1	38+	.....	.....	.....	Bottom in brown clay, very sandy with occasional bands of green and yellow.
6A	.....	6	27	1	38	6+	Stopped in hard material.
6B	12	24	4+	.....	.....	.....	" brown clay.
6C	25	21	5+	.....	.....	.....	" "
7A	.....	8	106	24+	.....	.....	The white clay is streaked with green and yellow bands. It is coarse in texture, not gritty but very short.
8A	.....	48+	.....	.....	.....	.....	Bottom in sand.
8B	18	42+	.....	.....	.....	.....	Stopped in sand.
9A	.....	8	38	.....	3	6+	Three inches of sand and gravel between brown and green clay.
10A	.....	.....	84+	.....	.....	.....	Stopped in brown clay.
11A	.....	12	.....	12	37	6+	" hard material.

Samples were taken for testing as follows:—

- No. 2A. White clay, 10 inches in thickness, taken from material from drill hole No. 2A, on shore.
- No. 4A. Green clay, 23 inches in thickness, taken from material from drill hole No. 4A, on shore.
- No. 10A. Brown clay, 7 feet in thickness, taken from material from drill hole No. 10.
- No. 11-1. White clay, 12 inches in thickness, from test pit No. 11. This clay underlies 12 inches of white sand.
- No. 11-4. Green clay, 37 inches in thickness, from test pit No. 11. This clay underlies sample No. 11-1.
- No. 11-5. Green rock from bottom of test pit No. 11. This hard material underlies sample No. 11-4.
- No. 13. Hardened white clay. This sample is similar to that in No. 2A, but was exposed above water-level and had become partly dried and showed conchoidal fracture.

CHEMICAL ANALYSES

Representative portions of a number of the samples were submitted for chemical analysis. The following are the results obtained:—

Results of Analyses Made upon Air-dried Material

	2A	4A		11-1		11-4	
	Crude	Crude	Washed	Crude	Washed	Crude	Washed
SiO ₂	65.60	54.57	53.22	63.30	59.22	58.06	53.46
Total iron as Fe ₂ O ₃ ...	0.97	6.07	6.07	1.08	1.08	6.02	5.50
Al ₂ O ₃	23.93	23.97	25.13	24.76	27.38	20.90	24.50
CaO.....	0.09	none	none	trace	none	none	none
MgO.....	0.49	5.10	4.74	0.89	0.95	6.26	6.84
K ₂ O.....	n.d.	n.d.	n.d.	1.33	1.43	n.d.	n.d.
Na ₂ O.....	n.d.	n.d.	n.d.	0.19	0.41	n.d.	n.d.
Loss on ignition.....	8.79	9.99	10.47	8.56	9.71	8.63	9.53
Total.....	99.87	99.70	99.63	100.11	100.18	99.87	99.83

A. Sadler—Chemist.

LABORATORY TESTS ON CLAY SAMPLES

Each sample was reduced to 2,000 grammes by quartering, and ground to pass 12-mesh. After drying at 100° C for one hour, they were tempered with sufficient water to develop the best working consistency, and made into briquettes. The briquettes were burned to a series of temperatures (the maximum temperatures selected in each case depending upon the softening point of the material). Measures of shrinkage, absorption, colour, and hardness were made on the burned briquettes.

The softening point of each sample was determined by making the material up into cones, placing them on an alundum base together with standard cones, and heating in a carbon resistance furnace until the cone tipped over to meet the base.

In several cases the clays were washed to ascertain the effect washing would have upon them. For this purpose 1,000 grammes of the material were taken and added to 3,000 c.c. water to which had been added 0.8 gramme of sodium hydroxide to aid deflocculation. The material was then blunged for one hour. After blunging, the sodium hydroxide was neutralized with sulphuric acid, and the clay, after screening through a 150-mesh lawn, was poured into a plaster bat and allowed to stand until it had reached a good plastic consistency. The material remaining on the screen was saved for weighing and examination. The screened material was then made into briquettes and burned to the same temperatures as the corresponding crude material. Shrinkage, absorption, colour, and hardness tests were run on these briquettes.

The burning tests were run in a large, down-draught, gas-fired muffle kiln. Sets of test pieces were withdrawn at predetermined temperatures and quickly transferred to an electric kiln, the temperature of which was maintained at about 1500° F. When the last draw had been made this kiln was allowed to cool slowly to atmospheric temperature before removing the test pieces for examination.

Clay No. 2A

Colour: white.

Non-calcareous.

Contaminated with hard particles.

Water of plasticity, 23 per cent. (Very plastic).

Air shrinkage: unwashed, 5.6 per cent; washed, 7.7 per cent.

Softening point, cone 30 (3038° F.). (Unwashed).

Residue (on 150-mesh screen) after washing, 19.2 per cent.

Unwashed

Cone	Fire shrinkage	Absorption	Colour	Hardness
	Per cent	Per cent		
2 (2138° F.).....	1.0	16.0	White	Hard
4 (2210° F.).....	2.0	14.8	"	"
6 (2282° F.).....	2.0	14.4	"	"
8 (2354° F.).....	2.0	13.7	"	"
10 (2426° F.).....	2.0	12.7	"	"
12 (2498° F.).....	2.5	12.3	"	Very hard

Iron spots were present on test pieces burned at cones 10 and 12.

Yellowish green efflorescence appeared on all pieces after absorption tests.

Washed

Cone	Fire shrinkage	Absorption	Colour	Hardness
	Per cent	Per cent		
2 (2138° F.).....	1.5	18.0	White	Soft
4 (2210° F.).....	2.5	15.8	"	"
6 (2282° F.).....		15.4	"	"
8 (2354° F.).....	4.0	14.5	"	"
10 (2426° F.).....	4.0	13.7	"	Hard
12 (2498° F.).....	4.0	13.3	"	"

Iron spots were present on the cone 10 and cone 12 test pieces.

Yellowish green efflorescence appeared on all test pieces after absorption tests.

Clay No. 4A

Colour: green.

Non-calcareous.

Contaminated with hard particles.

Water of plasticity, 26.5 per cent. (Very plastic).

Air shrinkage: unwashed, 6 per cent; washed, 7.9 per cent.

Softening point: cone 15 (2606° F.). (Unwashed).

Residue (on 150-mesh screen) after washing, 21.7 per cent.

Unwashed

Cone	Fire shrinkage	Absorption	Colour	Hardness
	Per cent	Per cent		
2 (2138° F.).....	3.0	15.5	Drab green	Hard
4 (2210° F.).....	3.5	15.0	"	"
6 (2282° F.).....	3.5	14.6	Deeper green	"
8 (2354° F.).....	3.5	14.5	"	"
10 (2426° F.).....	3.5	12.7	Reddish buff	Very hard
12 (2498° F.).....	3.5	11.3	Reddish brown	"

Yellowish green efflorescence appeared on briquettes after absorption tests.

Washed

Cone	Fire shrinkage	Absorption	Colour	Hardness
	Per cent	Per cent		
2 (2138° F.).....	4.5	15.9	Dirty buff	Hard
4 (2210° F.).....	5.0	14.2	Drab green	"
6 (2282° F.).....	5.5	14.7	"	"
8 (2354° F.).....	5.5	14.6	"	"
10 (2426° F.).....	5.5	12.3	Brownish buff	Very hard
12 (2498° F.).....	5.5	11.3	Light brick red	"

Yellowish green efflorescence appeared on briquettes after absorption tests.

Clay No. 10A

Colour: greyish brown.

Highly calcareous.

Water of plasticity, 47 per cent.

Air shrinkage, 10 per cent.

Softening point, cone 2 (2138° F.).

Unwashed

Cone	Fire shrinkage	Absorption	Colour	Hardness
	Per cent	Per cent		
010.....	0	15.6	Salmon	Hard
06.....	6	2.0	Dirty red	Steel hard
03.....	8	0.8	"	"

A white scum appeared on the briquettes burned to cones 06 and 03.

Clay No. 11-1

Colour: white.

Non-calcareous.

Water of plasticity, 26 per cent. (Very plastic and nice working.)

Air shrinkage: unwashed, 6.2 per cent; washed, 7.4 per cent.

Softening point, cone 32 (3101° F.). (Unwashed).

Residue (on 150-mesh screen) after washing, 21.7 per cent.

Unwashed

Cone	Fire shrinkage	Absorption	Colour	Hardness
	Per cent	Per cent		
2 (2138° F.).....	1.5	17.0	White	Soft
4 (2210° F.).....	1.5	15.9	"	Hard
6 (2282° F.).....	2.0	15.3	"	"
8 (2354° F.).....	3.0	14.1	"	Very hard
10 (2426° F.).....	3.0	11.5	"	"
12 (2498° F.).....	3.0	10.7	"	"

Iron spots were present on the pieces burned at cones 10 and 12.

All pieces showed yellowish green efflorescence after absorption tests.

Washed

Cone	Fire shrinkage	Absorption	Colour	Hardness
	Per cent	Per cent		
2 (2138° F.).....	2.0	17.6	White	Soft
4 (2210° F.).....	3.0	14.7	"	Hard
6 (2282° F.).....	3.0	15.0	"	"
8 (2354° F.).....	4.0	13.7	"	Very hard
10 (2426° F.).....	5.0	10.5	"	"
12 (2498° F.).....	6.0	8.6	"	"

Yellowish green efflorescence appeared on pieces after absorption tests.

Clay No. 11-4

Colour: green.

Non-calcareous.

Water of plasticity, 31 per cent. (Poor working).

Air shrinkage: unwashed, 4.4 per cent; washed, 5.7 per cent.

Softening point, cone 13 (2534° F.). (Unwashed).

Residue (on 150-mesh screen) after washing, 19.1 per cent.

Unwashed

Cone	Fire shrinkage	Absorption	Colour	Hardness
	Per cent	Per cent		
2 (2138° F.).....	2.0	24.5	Drab green	Soft
4 (2210° F.).....	3.0	23.3	"	"
6 (2282° F.).....	2.5	22.9	"	"
8 (2354° F.).....	2.5	23.2	Green	
10 (2426° F.).....	2.5	21.6	Brown	Very hard
12 (2498° F.).....	2.5	20.1	"	"

Yellowish green efflorescence on pieces after absorption tests.

Washed

Cone	Fire shrinkage	Absorption	Colour	Hardness
	Per cent	Per cent		
2 (2138° F.).....	3.0	23.0	Dirty buff	Hard
4 (2210° F.).....	3.5	22.4	Drab green	"
6 (2282° F.).....	2.5	21.6	"	"
8 (2354° F.).....	2.5	22.2	"	"
10 (2426° F.).....	2.5	20.6	Brownish buff	Very hard
12 (2498° F.).....	2.5	19.4	Light brick red	"

Yellowish green efflorescence on pieces after absorption tests.

Clay No. 11.5 Crude

Colour: green.

Non-calcareous.

Water of plasticity, 22½ per cent. (Rather short).

Air shrinkage, 2.2 per cent.

Softening point, cone 11+ (2462° F.+).

Unwashed

Cone	Fire shrinkage	Absorption	Colour	Hardness
	Per cent	Per cent		
010 (1742° F.).....	0.0	20.2	Pale salmon	Soft
06 (1886° F.).....	0.5	16.7	"	Hard
03 (1994° F.).....	1.0	16.1	"	"
01 (2066° F.).....	2.5	13.3	"	"
2 (2138° F.).....	3.5	11.5	Dark grey	Very hard
4 (2210° F.).....	4.0	8.9	"	"

Clay No. 13

Colour: white.

Non-calcareous.

Water of plasticity, 22 per cent. (Very plastic and nice working).

Air shrinkage: unwashed, 5.3 per cent; washed, 7.4 per cent.

Softening point, cone 28½ (2985° F. +). (Unwashed).

Residue (on 150-mesh screen) after washing, 38.7 per cent.

Unwashed

Cone	Fire shrinkage	Absorption	Colour	Hardness
	Per cent	Per cent		
2 (2138° F.).....	0.0	18.0	White	Soft
4 (2210° F.).....	0.5	17.2	"	Hard
6 (2282° F.).....	1.0	16.9	"	"
8 (2354° F.).....	1.5	16.1	"	"
10 (2426° F.).....	1.5	15.6	"	Very hard
12 (2498° F.).....	2.0	15.2	"	"

All samples after making absorption tests showed a yellowish green efflorescence.

Washed

Cone	Fire shrinkage	Absorption	Colour	Hardness
	Per cent	Per cent		
4 (2210° F.).....	1.5	21.0	White	Soft
6 (2282° F.).....	2.0	19.7	"	Hard
8 (2354° F.).....	2.0	18.9	"	"
10 (2426° F.).....	2.5	17.4	"	"
12 (2498° F.).....	2.5	15.5	"	Very hard

Yellowish green efflorescence present after the absorption test.
Briquettes burned to cones 10 and 12 showed iron spots.

CONCLUSIONS

1. *Type of Clays.* Judging from the field examination and the laboratory tests the white clay is a residual clay resulting from the alteration of the underlying green Archæan rocks.

Various phases of this alteration can be seen in the field, for example in test pit No. 11, there were five distinct phases, in descending order, as follows: white clay, light grey clay, dark grey clay, green clay and green rock. The line of division between these several phases was not distinct but one gradually graded into the next phase adjoining it. The chemical analyses of the white clays are characteristic of kaolins, and although the plasticity is a little higher than the average, some kaolins are known which are just as plastic. Even the material washed out of the white clay, although it contains a certain proportion of silica sand, has undergone complete kaolinization and, when finely ground and well-tempered with water, has good working qualities. The fusibility also of these white clays as well as their chemical composition, places them in the kaolin class.

The fusibility of the samples examined strengthens the evidence that these clays are derived from the underlying rocks. The underlying rock fuses at cone 11 (2462° F.), but with the partial removal of the alkalis

and iron the fusion temperature of the green clay rises to cone 13 (2534° F.). With the further removal of these materials as represented by the white clay the fusion temperature is increased to cone 32 (3101° F.).

The green clay is really an intermediate stage between the altered rock and the white kaolin. The alteration has not gone far enough to place this clay in the kaolin class or even in the class of a semi-refractory clay as the presence of iron and magnesia keeps the fusion temperature of the clay lower than the ordinary refractory clays.

The brown clay is a stoneless transported clay and has no relation to the white and green clays above mentioned. It is a considerably younger clay and overlies the other clays. It is probably of Pleistocene age and can be classed as a red-burning, highly calcareous clay.

2. Area and Extent of the Clays. In the section of the shore examined the extent of the white and green clays exposed is small. In no place was the thickness of the white clay over 40 inches, and one foot would be nearer the average; and the green clay was only slightly thicker than that of the white. It is true that white and green clays were found under the brown clay, but to determine whether any considerable body of these clays existed, would entail an extensive drilling campaign with a power core-drill. Only by such an examination can the true extent of the white clays be determined. The extent of the white clay as shown on Figure 1 would not warrant its operation.

The brown clay is more extensive in area and the thickness would indicate a large available tonnage.

3. The Economic Value of the Clays. The white clays can be used for such purposes as kaolins are used. Their high plasticity gives them an even greater range of uses than the average kaolin, as it allows the use of dies. Ware made from this clay would possess fair strength when dried. A chemical analysis of the green efflorescence appearing on the briquettes showed that it was due to soluble titanium and vanadium salts which the test water had carried to the surface. Had the clay been brought to the point of vitrification this efflorescence would not have appeared. Washing the material greatly improved the colour of the burned product.

The green clays have no outstanding feature that would recommend them for commercial enterprise. The only features which are of any particular interest are the burned colours, the workability, and the low shrinkages. With proper grinding and tempering, these clays might be used in the manufacture of building brick either by the stiff-mud or dry-press methods, and would give a product of rather pleasing colour. However, the temperature necessary to bring the material to the required absorption and strength would probably be too costly to be economic. These clays have practically no vitrification range; that is to say, the material upon reaching its vitrification point changes from a porous mass to a liquid of very little viscosity. Referring to the test on sample No. 11-4 it will be seen that at cone 12 (2498° F.) the material has an absorption of 19.4 per cent and at cone 13 (2534° F.) the material is fused. Hence, taking into consideration these factors, it does not seem advisable to recommend these green clays for the manufacture of clay products.

The brown clay as represented by sample No. 10A could be used in the manufacture of building brick. The colour, while not very pleasing to the eye, could be improved by special burning. The white scum appearing at the higher temperatures can be eliminated if proper precautions are taken. The clay has a very narrow vitrification range due to the high lime content. While fairly good brick might be made from the material, the difficulties of transportation to the nearest market (Winnipeg) is too great to warrant its use.

VI

COMMERCIAL CRUSHED STONE

R. H. Picher

A number of commercial quarries operated for the production of crushed stone in Ontario and Quebec were visited and sampled during the field season of 1926, in order to obtain information on the character of the stone quarried, sizes of crushed product, plant equipment and capacity, transportation facilities, and uses of the stone. At the same time county road superintendents were consulted with regard to the sources of supply for the material used in surfacing county highways, and an inspection was made of a number of roads so as to study the wearing quality of the material under various traffic conditions. Several highway quarries were sampled, the samples being selected so as to be representative of the rock formation most commonly found in each district visited. Samples were also taken from a few rock deposits which, although local in distribution, looked particularly suitable for road purposes. The inspecting and sampling was done as a continuation of an investigation on rocks of eastern Canada, with a view to determining their suitability for road purposes.

DESCRIPTION OF DEPOSITS

Ontario

1. *One mile southwest of Perth.* Small quarry in gneissic granite, operated intermittently for highway purposes only. Over 10,000 cubic yards are easily available without stripping or provision for drainage. The stone is suitable for use in bituminous pavements but lacks cementing power for waterbound macadam. Owner: Adam McKinley, Perth, R.R. 3.

3. *Lanark.* Quarry just opened in coarse crystalline limestone. The amount available is very large, but the stone is too soft for road purposes. Owner: William Stead, Lanark P.O.

4. *Three miles south of Arnprior.* Several small quarries in very fine-grained, thick-bedded limestone. The quarries are operated intermittently for highway purposes only. A very large amount of stone is available. It is suitable only for very light-trafficked roads. Owner: William Duncan, Arnprior, P.O. Box 443.

5. *Pakenham.* Very fine- and close-grained, thick-bedded limestone. Quarry operated intermittently for highway purposes only. Extensive quarrying would be hampered by thickness of overburden which varies from 3 to 6 feet at the quarry face and apparently more away from the face.

6. *Two miles northeast of Almonte.* Quarry just opened in medium to fine-grained, thin-bedded limestone. The stone is being crushed and

screened in a small portable plant at the quarry and used for surfacing the road nearby. The overburden is thin and outcrops plentiful in the slope of a ridge.

9. *Two and a half miles west of Prospect.* Shallow quarry just opened in fine-grained, very thin-bedded, siliceous dolomite. The stone is being quarried preparatory to surfacing the county road nearby. Outcrops are few but the rock is close to the surface over a large area. Deep quarrying would necessitate providing for drainage. Owner: Neil Stewart, Prospect P.O.

12. *Two miles west of Merrickville.* Very fine-grained, thick-bedded dolomite. Outcrops are numerous in the steep slopes of a flat-topped knoll. No quarry has been opened but it is intended to open a road cut through the knoll, so as to reduce the steepness of the grade, and use the stone from the cut for road surfacing.

13. *Easton Corner.* Very fine-grained dolomite; beds 2 to 8 inches in thickness. The quarry is operated intermittently for road purposes only. The overburden is very thin but upper 3 feet of stone partly weathered and less suitable than the fresh stone found under it. Results of test (see table) are for fresh stone only. Owner: William James King, Easton Corner.

15. *Deeks, five miles northeast of Merrickville,* beside the Toronto-Montreal main line of the Canadian Pacific railway. Large quarry in fine-grained, thin-bedded, siliceous dolomite, operated almost exclusively for the production of railway ballast. The rock is blasted with dynamite placed in holes 5 and 5½ inches in diameter and as much as 35 feet in depth. A series of holes are fired simultaneously loosening from 8,000 to 10,000 tons of rock. One blast is shot every other day, on the average, when working full capacity which is 4,000 tons per day. On account of the thinness of the beds, very little secondary drilling is necessary. The loosened rock is loaded by steam shovel on narrow gauge, dump cars which are hauled by a steam locomotive to the foot of an incline, and from there hauled to the top of the primary crusher by cable, operated by steam power. About 90 per cent of the output is sold to the Canadian Pacific Railway for use as ballast. The crushers and screens are set so as to produce crushed stone not over 2½ inches and as little as possible under ¼ inch in size, these being the limits of the specifications for ballast stone. All crushers are of the gyratory type and the primary one will admit stone 27 inches maximum thickness. The crushing and screening plant is electrically driven. Owner: The Grenville Crushed Rock Co., Merrickville.

16. *One mile northeast of Shanly.* Small quarry in very fine-grained, rather thin-bedded dolomite, operated intermittently for road purposes only. About 1,000 cubic yards have already been quarried, and there is ten times as much available with but little stripping. Owner: James Ault, Spencerville, R.R. 4.

17. *Maitland.* Quarry in rather thin-bedded dolomite. Texture varies from very fine to fairly coarse. All stone recently quarried has been exclusively used for road purposes. The quarry is at present idle, partly

filled with water, about 10 feet of rock being exposed above water-level, but could be easily drained as it is situated on top of an elevation. The quarry covers about 2,000 square yards and could probably be extended to double its present size. The rock is covered with 1 to 1½ feet of clayey loam. Owner: John Stacey, Maitland.

18. *Two and a quarter miles north of Lansdowne.* Small quarry just opened for road purposes in slightly foliated granite-gneiss, carrying but few ferro-magnesian minerals. The crystalline texture varies from fine to fairly coarse. The rock forms a low ridge with a very steep, cliff-like southern slope, and is regularly jointed. Over 10,000 cubic yards are easily available with little stripping. For waterbound macadam surfacing, it is to be preferred to local granite, on account of its better cementing power. Owner: W. Ross Smith, Lansdowne, R.R. 4.

19. *Two and a half miles west of Sweet Corner.* Large quarry in the side of a hill; shows rather coarsely crystalline granite, of regular texture, and with but few biotite or other ferro-magnesian minerals. The rock joints are rather irregular in distribution and direction. There is a large amount of easily available granite throughout this district. This quarry and several others in the vicinity are at present idle, and the machinery and other equipment have been removed. All quarries were operated chiefly for monumental stone. Owner: A. C. Brown Granite Works Co., Lyndhurst.

22. *One and a half miles west of Hartington.* Small quarry in very fine-grained, compact limestone. The quarry face which is 5 feet high shows better stone than that exposed in the quarry floor. The latter holds numerous shale partings, and for that reason is not so desirable for road purposes. The sample tested represents only the stone from the quarry face. Owner: Allen Ferris, Hartington.

Throughout this district, which includes parts of Loughborough, Kingston, Portland, Ernestown, and Camden townships, the rock is exposed on all slight elevations and there are numerous small quarries opened. There appears to be an appreciable variation in the quality of the stone in the different beds. The very fine-grained, compact rocks are inferior to the medium fine-grained, and those holding films or partings of shale are inferior to those which are free from them.

23. *Three-quarter mile southwest of Oates.* Small quarry in thin-bedded, very fine-grained, compact limestone. A few very thin beds show a slightly coarser and much harder stone than the average. Numerous outcrops in the steep slope of a bluff facing east, and conditions favourable for extensive quarrying. This is the eastern limit of the district referred to under No. 22. Owner: D. Carey, Sydenham, R.R. 1.

24. *One mile west of Waupoos.* Quarry just opened in fine-grained, very thin-bedded limestone, with shale partings. Rock apparently close to the surface for several acres with about 1 foot of clayey loam as overburden. Owner: Prince Edward County Council.

25. *Bloomfield.* Very much the same as No. 24.

26. Two miles east of Mountain View. Fine-grained, very thin-bedded limestone. Most of the stone from this quarry (about 10,000 cubic yards) has been used for surfacing the Provincial highway between Belleville and Picton, with surface-treated macadam. The quarry is on top of a high, very steep bluff with many outcrops on the slope. Owner: Ontario Department of Public Highways.

27. One mile northwest of Consecon. Fine- to medium coarse-grained, thick-bedded limestone. Rock runs close to the surface for a distance of several hundred yards along the top of a slight elevation. Owner: Prince Edward County Council.

Quarries Nos. 24, 25, 26, and 27 are operated exclusively for the production of road metal. Other quarries in this county (Prince Edward), which were visited but not sampled, had been opened for the same purpose, but were abandoned because of the poor quality of the stone.

28. One mile east of Strathcona. Medium- to very fine-grained, thin-bedded limestone, under an overburden of 1 to 2 feet of clayey loam. No outcrop in this neighbourhood, with the exception of this quarry, compares in quality with the stone near Napanee and Kingston. For 20 miles to the east outcrops are plentiful, but the rock as a rule is of poorer quality. This quarry is about at the western end of the district referred to under No. 22. Owner: Frank Tompkins, Napanee, R.R. 7.

29. South of Yarker. Fine-grained, compact, thin-bedded limestone, with a few thin beds of rusty, rather coarse-grained limestone. The rock is only thinly drift-covered and outcrops are numerous. Owner: Wilfred Connolly, Yarker.

31. Half mile south of Moscow. Very fine-grained, compact, thin-bedded limestone with shale partings in some beds. Rock very thinly covered by drift. Numerous outcrops. Owner: James S. Bell, Moscow.

33. One mile north of Foxboro. Fine-grained, thick-bedded limestone. The stone from this quarry has been largely used for surfacing the Belleville-Foxboro road with surface-treated macadam and another stretch north of Foxboro with waterbound macadam. Both surfaces are in good condition; but the latter shows signs of wear, although carrying less traffic than the surface-treated stretch. Over 4,000 cubic yards of stone have been taken from the quarry, and a large amount is still available with but little stripping. Owner: Stanley Sherry, Foxboro, R.R. 1.

35. Marmora. Very fine-grained, compact limestone. The quarry which is in the flank of a bluff, has a 30-foot face, the upper 10 feet being thick-bedded and the lower 20 feet thin-bedded. Stone can be quarried on an extensive scale with little stripping. Owner: Pearce Co., Ltd., Marmora.

36. Two and a half miles north of Madoc. Finely crystalline trap (andesite) with biotite phenocrysts. There is no quarry and the sample was taken from outcrops. The rock is relatively fresh at the surface and appears to be a very good road material. It should be easy to quarry as it is traversed by many joints, occurs in steep-sloped knolls or ridges, and is but thinly drift-covered.

37. Four miles north of Madoc. Very finely crystalline trap (and-site). This rock looks much the same as No. 36, but is more weathered at the surface and is not so tough. There is no quarry and the sample was taken from outcrops.

38. Preneveau. Very fine-grained, thin-bedded limestone. There is no quarry and the sample was taken from outcrops, which are numerous in the slope of a bluff. Conditions are very favourable for extensive quarrying. As judged by the results of the test, the rock is softer than the average limestone found in these parts, but, as already mentioned, the sample represents only surface rock. Owner: The Ontario Rock Co., 410 Crown Office Building, Toronto.

39. Preneveau. Dark green, finely crystalline diabase, slightly foliated in places.¹

43. Half mile west of Burnt River. In a large quarry, about 9 acres in extent, about 20 feet of limestone are exposed. The thickness of the individual beds varies from a few to 20 inches. In the upper 12 feet of the quarry face the stone is light brownish grey, very fine-grained and compact. In the next 6 feet the stone is red, fine-grained and of open texture. In the lower 2 feet the stone is red, fine-grained, hard and tough. Below the quarry floor the stone is similar to that shown in the upper part of the quarry. The quarry is in the slope of a bluff and the rock is covered with 2 feet of loam. Outcrops are plentiful on top of the bluff. The amount of stone available is very large. For many years the quarry was operated for the production of building stone, and during the last few years, for crushed stone. This has been idle for a year. The stone is highly regarded as road metal. In the table of the results of tests, test A refers to the brownish grey stone in the upper 12 feet of the quarry, and test B to the reddish stone in the lower 2 feet. The intermediate red stone, which was not tested, is softer than the two others. Owner: John E. Russell Construction Co., corner Bay and Wellington Sts., Toronto.

44. Two miles northeast of Kirkfield. This quarry which is approximately 20 acres in extent has been worked to a depth of 20 feet and is now being deepened to 40 feet. The stone is a thin-bedded limestone, generally rather coarse in grain, with occasionally thin layers of fine-grained stone, but on the whole very uniform in texture. The rock is covered with about 2 feet of clayey loam. There are no outcrops, but the rock lies close to surface over a wide area.

A crushing and screening plant is located at the quarry. The rock is first loosened by sinking well-drill holes to a depth of 20 feet and blasting with dynamite. Owing to the thinness of the beds, no secondary drilling and blasting is necessary. The loosened rock is loaded by steam shovel into narrow-gauge dump cars which are hauled to the foot of an incline by a steam locomotive. A stationary steam engine hauls the cars up the incline by cable to the top of the primary crusher, which is of the gyratory type and will admit stone up to 20 inches in size. The stone is crushed and screened into several sizes from 4 inches down to screenings,

¹ For description of quarry and equipment see: "Investigations in Ceramics and Road Materials, 1925, pp. 23-24.

and the various sizes and the relative proportion of each size are regulated according to the demand. The screenings are reduced to dust in a grinder. The stone is either stored in bins or piles. From the bins it can be directly loaded by gravity into standard-gauge, railway gondolas. The piled stone is loaded by a steam, orange-peel bucket crane. The quarry is connected by a spur line to the Canadian National railway. The maximum daily capacity of the crushing and screening plant is 1,000 tons and that of the grinding mill, 50 tons. The larger part of the stone is shipped to Toronto and used as aggregate in pavements and concrete. The limestone dust is used as filler in asphalt pavements. Owner: Kirkfield Crushed Stone, Ltd., 136 Confederation Life Building, Toronto.

45. North of Longford. Very fine-grained, compact, rather thick-bedded limestone. The stone is exposed in the slope of a bluff facing lake St. John. It has been quarried for many years, and now the excavation extends for over half a mile along the edge of the bluff, with a width up to 100 yards and a depth of from 15 to 25 feet. The stone is covered with about 2 feet of clayey loam. Quarrying can not proceed any farther into the face of the bluff, as the land is largely built over with private residences. The floor of the excavation is now at lake level at several places. A very large amount of stone can be obtained by pumping and quarrying below lake level. The stone in the upper 4 feet is harder and coarser than the average. In the table, sample A is from the upper 10 feet and sample B from the lower 15 feet of the quarry. The crushing and screening plant, which is installed at the quarry, has a maximum capacity of 300 tons per day. The stone is crushed and screened into the usual sizes, that is from 4 inches down to screenings, and stored in bins, from which it can be loaded directly by gravity into railway cars. The quarry is situated right along the Canadian National railway and connected to it by a spur. Most of the product is shipped to Toronto where it is largely used as aggregate in concrete. Owner: Longford Crushed Stone, Ltd., Orillia.

47. Three miles southeast of Gravenhurst. Finely crystalline granite-gneiss, with much biotite. Although showing a decided zoned structure, the rock does not break readily into flat pieces. All rock quarried has been used for building fills where the road passes through depressions, and none used in the wearing course of the road. On account of the irregularity in size and distribution of the feldspar zones through the rock, the latter is not strictly homogeneous and does not make a desirable material for waterbound macadam surfacing, but would apparently be quite suitable for bituminous macadam or surface-treated broken stone roads. For miles throughout the Muskoka Lake district, it is the only kind of rock available for road metal. It is exposed at many places in the form of steep-sloped ridges, and can be easily quarried in any amount with hardly any stripping. Owner: Muskoka County Council.

48. Uhthoff. Very fine-grained, compact, rather thick-bedded limestone. There is a 20-foot section of stone exposed in a large quarry, the upper 2 feet of which show a harder and slightly coarser stone than average. The quarry is in a slight elevation of the ground which extends over

many acres. Outcrops are few and the overburden at the quarry is about 2 feet thick. There is a crushing and screening plant at the quarry and the crushed stone is stored in bins from which it can be loaded directly by gravity into railroad cars. The quarry is situated close to the Canadian Pacific railway and connected to it by a spur. Most of the product is shipped to Toronto. Owner: Ontario Stone Corporation, 611 Excelsior Life Building, Toronto.

49. Medonte Station. There is a 38-foot face of fairly thick-bedded limestone exposed in this quarry. The stone in the upper 30 feet is similar to that of Nos. 45 and 48, that is, very fine-grained, compact, approaching lithographic stone in character, with the upper 7 feet slightly coarser and harder than that immediately below it. In the lower 7 feet of the quarry face the stone is fine-grained, less compact but harder than the lithographic type, and is traversed by many partings of green shale parallel to the bedding-plane. Between this stone and the compact stone above there is a 1 foot bed of fine- and open-grained, very soft, greenish limestone. In the table, sample A is from the lower 8 feet and sample B from the upper 30 feet. The quarry is situated in the lower slope of a hill and the overburden at the quarry face varies from 1 to 2 feet in thickness. There are but few outcrops. The stone is quarried by sinking vertical holes with well-drills and blasting it with dynamite. It is loaded by hand into narrow-gauge, side-dump cars, which are hauled by horses to the foot of an incline and up the incline by steam hoist to the crusher. The stone is crushed and screened into various sizes from 6 inches down, the size being regulated according to the demand. The crushed stone is stored in bins, from which it can be directly loaded by gravity into railway cars. The quarry is beside the Canadian Pacific railway and connected to it by a spur. At present most of the product is shipped to the Mond Nickel Co., Coniston, for use as flux. Owner: Langton Stone Quarry, Medonte.

51. One and a half miles southeast of Mount Nemo. The quarry, which is situated in the steep slope of a high escarpment, has a face about 50 feet high and shows fine-grained, thick-bedded dolomite with many minute cavities. A few thin beds of dark-coloured, fine- and close-grained dolomite are to be seen in the bottom of the quarry. This stone, which was not included in the sample, is harder than the lighter-coloured dolomite. There are numerous joints, and the surface stone is much weathered along the joints. The stone is used for surfacing county roads with waterbound macadam. Owner: Raymond Miller, Milton, R.R. 2.

52. Two miles east of Campbellville. The quarry, which produces stone for lime-burning exclusively, is in the steep slope of a high escarpment, and has in places a face 75 feet high. The stone is a very light-coloured, fine-grained, thick-bedded dolomite with many minute cavities. The upper beds, seen only at the central and highest part of the face, are very fossiliferous. The stone is quarried by sinking well-drill holes and blasting with dynamite. It is then loaded by hand into horse-drawn carts and hauled on the horizontal floor of the quarry to the top of a lime kiln which has been built at a point farther down the slope, so that its top is at

the same level as the quarry floor. All stone smaller than 2 or 3 inches is hauled and dumped in a waste pile. The fossiliferous stone from the upper beds in the central face of the quarry is blasted separately and hauled to the waste pile, as it is claimed that it burns at a quicker rate than the stone from the other beds. The maximum amount of stone quarried is 150 tons per 10-hour day. The thickness of the overburden varies from a few inches in the centre of the quarry to 5 feet at either end. Outcrops are plentiful in the slope of the escarpment, which can be followed for miles. Owner: Christie, Henderson and Co., Ltd., 201 Crown Office Building, Toronto.

53. *East of Hannon.* Dark-coloured, fine-grained, thin-bedded dolomite, with quartz- and calcite-lined cavities. The stone which is used for surfacing county roads is quarried by drilling and blasting, and is crushed and screened in a portable plant installed in the quarry. From the screen the stone falls into separate bins according to its size, and from the bins it is loaded by gravity into motor trucks. The thickness of overburden, from 2 to 8 feet of clayey soil, renders stripping expensive. There are several other places in this district where stone is more easily available than here, but it is highly argillaceous, and, it is said, disintegrates on exposure. Owner: Wentworth County Council.

54. *Two miles southeast of Vinemount.* Dark grey, fine-grained, thin-bedded dolomite. Some beds are highly argillaceous in places, but on the whole the stone is fairly uniform both in composition and texture. The excavation is 15 acres in extent and 20 feet deep. On account of shaly beds encountered, the stone is not quarried deeper, but the excavation could be much enlarged horizontally without excessive stripping. The stone is quarried by sinking holes with well-drills to the full depth of the face and blasting with dynamite. The stone is loaded by steam shovel into small side-dump cars which are hauled up an incline by hoist to the top of the crusher. In the crushing and screening plant, the stone is broken and separated into several sizes from 4 inches down to screenings. Any size can be produced or several sizes combined, according to the demand. The quarry is close to the Toronto, Hamilton and Buffalo railway and connected to it by a spur. Owner: Wentworth Quarries, Ltd., Hamilton.

55. *Dundas.* The quarry is in the upper slope of a high bluff. It covers 30 acres and the rock has been extracted to a depth of 75 feet. The stone is a fine-grained, thick-bedded dolomite. In the lower 52 feet it is dark steel grey, very fine-grained and tough. In the upper 24 feet it is lighter in colour, slightly coarser and not quite so tough. The rock is covered with soil up to 20 feet thick. The quarry is worked in a series of three steps, thus permitting of three working faces. The rock face at the upper level is 24 feet high, not including the overburden, which has been previously removed by steam shovel. The middle and lower levels have working faces 24 and 28 feet in height respectively. In quarrying, holes are sunk with well-drills 12 feet back from the face to the full depth of the level. The progress of the drills is, on the average, 4 feet per hour. After the rock is blasted by dynamite it is loaded by steam shovel into narrow-gauge, dump cars, hauled by steam locomotive to the top of the primary crusher. The primary crusher can take stone up to 42 inches in

size and crush it to 8 inches. The crushing and screening plant which is placed against the face of the escarpment and below the quarry level is so arranged that the stone moves by gravity from where it enters the primary crusher to bins from which it is loaded into railway cars. The stone is crushed and screened into several sizes from 4 inches down to screenings, and sizes can be recombined at will. On large contracts the machinery is adjusted to produce the maximum percentage of the size required. The stone is stored in different sizes in bins, from which it is loaded by gravity into railway cars or is piled. From the piles it is loaded by steam bucket either into railway cars or motor trucks. The maximum capacity of the plant is 4,000 tons per 10-hour day. The plant is situated along the Canadian National railway and connected to it by a spur. Part of the stone is sold as flux for blast furnaces, and the remainder largely used for concrete and road work. Owner: Canada Crushed Stone Corporation, Hamilton.

56. *North of Campden.* Light-coloured, fine-grained, semi-crystal-line dolomite with many small cavities. The quarry face is 12 feet high and the overburden is very thin. Except for the top bed which is several feet thick, all other beds are not over 10 inches. The stone is much jointed throughout and is largely quarried with crowbars and sledge. It is broken to road metal sizes in a small, portable, crushing and screening plant, and used for waterbound macadam surfacing of the county roads. Owner: N. G. Ismond, Campden.

57. *Two miles south of St. Catharines.* Dark-coloured, fine-grained, thin-bedded dolomite and magnesian limestone, with 2 to 2½ feet of soil overburden. The quarry is situated on top of a high bluff, known as the Niagara escarpment. The quarry face is 15 feet in height. Quarrying is done by sinking holes with well-drills to the full depth of the face and blasting with dynamite. The blasted stone is loaded by hand into boxes on narrow-gauge cars which are pushed to that part of the quarry immediately below the crushing and screening plant. The boxes are lifted by derrick to the primary crusher, which is of the jaw type, has an opening of 8 by 20 inches, and crushes the stone to 4 inches maximum size. The several sizes of stone are stored in separate bins, loaded by gravity into motor trucks, and used for road and concrete purposes. The maximum capacity of the plant is 150 tons per 10 hours and it is operated by steam power. Owner: Frank Staggs, St. Catharines.

58. *Half a mile east of St. David.* The quarry is situated on top and near the edge of the Niagara escarpment and is 25 feet deep, including 10 feet of clay overburden. The stone is a thick-bedded dolomite. In the upper part of the face it is brown, medium coarse-grained and of rather open texture. In the lower part it is light grey, and coarse-grained. Below the dolomite there are 6 feet of argillaceous limestone, part of which was taken out years ago by another company, before the quarry was opened, and used for the manufacture of natural cement. This stone was obtained by driving tunnels from the edge of the escarpment and mining by the room and pillar method. The stone in one part of the quarry is at present quarried for building purposes only and shipped to Toronto, where it is used in the extension of the Parliament Buildings. From another part of the quarry the stone is crushed and screened to sizes suitable for concrete

and road purposes. The crushing and screening plant, which has a maximum capacity of 250 to 300 tons per 10 hours, is so situated on the slope of the escarpment that the stone moves entirely by gravity from where it enters the primary crusher to where it is loaded on trucks. Owner: Queens-ton Quarries, Ltd., St. David.

59. One mile northeast of Thorold. The quarry is in the upper slope of the Niagara escarpment, covers 10 acres and has a maximum depth of 45 feet. The stone is light-coloured, rather coarse-grained, thick-bedded magnesian limestone and dolomite. In the lower part of the quarry there are a few thin beds of dark, fine-grained dolomite with shale partings, and below these, several feet of argillaceous limestone, similar to that found in quarry No. 58, and which are not quarried. The results of the tests in the table refer only to the coarse-grained, thick-bedded stone. The stone is quarried by sinking deep holes with well-drills and blasting with dynamite. Secondary blasting of blocks too large to be handled is done with jack-hammer drills and dynamite. The stone is hand-loaded into skips which are lifted by derrick to the crushing and screening plant. Part of the large size stone is loaded on railway cars and sold to the manufacturers of sulphite pulp. The remainder is crushed and screened to sizes from 3 inches down to screenings, stored in bins according to size, and loaded by gravity on railway cars and motor trucks. The crushed stone is sold for road and concrete purposes. The maximum capacity of the plant is 200 tons of crushed stone and 100 tons of rubble per 10 hours. A spur connects the quarry to the Canadian National railway. Owner: Walker Bros., Thorold.

60. Windmill Point. Close to the Canadian National railway, between Fort Erie and Port Colborne. Large quarry covering about 10 acres, and 20 feet in depth. In the upper 8 to 14 feet the stone is a dark brown, fine-grained, cherty and fossiliferous limestone with shale partings. Underlying this is a light grey, coarse-grained, semi-crystalline limestone, less cherty and softer than the darker stone above. Both stones are thin-bedded. Sample A in the table refers to the dark, and B to the light stone. The stone is quarried by blasting with dynamite placed in well-drill holes 20 feet deep. It is loaded by electric shovel into narrow-gauge, side-dump cars which are pushed by hand to the foot of an incline and hauled by hoist to the top of the primary crusher which has an opening of 36 by 28 inches. The stone is crushed and screened to the usual sizes, 4, 2, 1, $\frac{3}{4}$, $\frac{3}{8}$ inches and screenings, and each size stored in bins from which it can be loaded by gravity into railway cars or motor trucks. The maximum capacity of the plant is 700 tons per 10-hour day. Electrical power is used throughout the plant, except for the drills, which are operated by portable gasoline engines. At the quarry, which is situated on a slight elevation, the rock is covered with about 1 foot of light clayey soil, with outcrops plentiful over a large area. The stone is largely sold for concrete and road purposes. So far the dark, fine stone has been quarried in much larger amount than the light, coarse stone, and the company, which owns 78 acres of land, intends to extend the excavation so as to quarry the dark stone exclusively, as it is a better material for road purposes. The quarry is connected by spur line to the Canadian National railway. Owner: Windmill Point Crushed Stone, Ltd., Ridgeway.

61. Two miles northeast of Humberstone. Dolomite, magnesian limestone and argillaceous limestone. There is considerable variation in the texture and character of the stone of the different beds. As may be seen by the results of the tests in the table, the stone from this quarry is rather soft and suitable, at best, for light-trafficked roads. The quarry is on a low ridge and is 30 feet deep. A portable, crushing and screening plant, with storage bins, has been installed near the quarry. The stone is hoisted by derrick from the quarry floor to the crusher. From the bins it is loaded into motor trucks and used for surfacing county roads. Owner: Welland County Council.

62. Three miles west of Port Colborne. Light grey, coarse-grained, thick-bedded limestone, fossiliferous in places. The rock is covered with 3 to 7 feet of clay, and both stone and clay are used in the manufacture of Portland cement. The quarry, which covers several acres, is from 9 to 14 feet deep, not including overburden. The bed forming the quarry floor belongs to an older formation and contains much magnesia, so that it is unsuitable for use in the manufacture of cement. Quarrying is done by blasting with dynamite placed in holes drilled to the full depth of the quarry. The stone is loaded by electric shovel into standard-gauge, dump cars which are pulled out of the quarry by cable on inclined track and hauled by steam engine to the cement plant at Port Colborne. All quarried stone is crushed and ground at the plant and used exclusively for cement manufacture. The company is now opening a new quarry just west of the one described. Several other quarries are on the company's property, but they have been worked out. Owner: Canada Cement Co., Montreal.

63. Hagersville. Large quarry 34 feet in depth and covering over 20 acres. The quarry face shows:

1 to 2½ feet.	Overburden of clay and stone;
10 "	Very fossiliferous, very thin-bedded limestone of variable texture but generally fine-grained;
8 "	Fine-grained, rather thin-bedded limestone of uniform texture;
14 "	Fine-grained, thick-bedded, cherty limestone.

In the lower beds are lenses of stone so siliceous in places as to be more nearly calcareous sandstone. Quarrying is done by drilling and blasting. The rock is loaded by hand into narrow-gauge, dump cars, which are hauled by horses to the foot of an incline, and pulled by hoist to the crushing and screening plant. The stone is crushed and screened to several sizes, from 4 inches down to screenings, and stored in separate bins, from which it can be loaded by gravity into standard-gauge, railway cars or motor trucks. The maximum capacity of the plant is 3,000 tons per 24 hours. About 50 per cent of the product is sold to the Michigan Central Railroad for ballast, which includes only stone between 2 and ¾ inches in size. The remainder is sold largely for concrete and road purposes. The quarry is along the Michigan Central railway and connected to it by a siding. Owner: Hagersville Quarries, Ltd., St. Thomas.

64. Hagersville. Large quarry, from 16 to 30 feet in depth, and extending over 20 acres. The quarry face shows:

- | | |
|----------------|--|
| 6 to 8 inches. | Overburden of clay and stone; |
| 11 feet. | Very fossiliferous, very thin-bedded limestone of variable texture but generally fine-grained; |
| 6 " | Fine-grained, rather thin-bedded limestone of uniform texture; |
| 12 " | Fine-grained, thick-bedded cherty limestone with, in the lower beds, sandy inclusions. |

The stone is crushed and screened to several sizes from 4 inches down to screenings, and the different sizes stored in separate bins, from which it can be loaded directly on standard-gauge, railway cars or motor trucks. All crushers are of the gyratory type. The product is sold as rubble, or for road and concrete purposes. The maximum capacity of the plant is 850 tons per 10 hours. The quarry is along the Michigan Central railway and connected to it by siding. Owner: Hagersville Contracting Co., Hamilton.

65. Hagersville. Large quarry, 25 feet in depth, and covering over 20 acres. The stone is a very thin-bedded, fossiliferous limestone, with large amount of chert. The texture is variable, but generally fine-grained. Overburden, 1½ feet of sandy loam. Quarrying is done by blasting with dynamite placed in deep holes. The stone is loaded by hand into narrow-gauge cars, which are drawn by horses to the foot of an incline, and hoisted by cable to the crushing and screening plant. All crushers are of the gyratory type. After being crushed and screened to several sizes, from 4 inches down to screenings, the stone is stored in bins, from which it can be loaded directly into standard-gauge, railway cars or motor trucks. The maximum capacity of the plant is 900 to 1,000 tons per 10 hours. About 50 per cent of the product is sold to the Michigan Central Railroad for ballast, including stone between ¾ and 2 inches only. The other 50 per cent is sold for various purposes. The quarry is along the Michigan Central railway with which it is connected by siding. Owner: Gordon Crushed Stone Co., Ltd., 239 Confederation Life Building, Toronto.

66. Nelles Corners. Old quarry partly filled with water, about 3 acres in extent, with 6 feet of stone exposed above the water which is at least 6 feet in depth. The 6 feet of stone above water consists of dark, rather fine-grained, thin-bedded limestone containing much chert and many fossils. In a pile near a storage bin are seen fragments of light-coloured, fine-grained, siliceous and argillaceous limestone, which were quarried from beds now under water and which represent an older formation. Sample A in the table refers to the stock pile, and sample B to the dark stone exposed above water. Overburden, 1 foot of clayey soil. Comparatively few outcrops are to be seen, but the rock is apparently close to the surface over a wide area. Another old quarry nearby, also partly filled with water, shows similar stone. Owner: Haldimand County Council.

67. One mile southwest of Beachville. Two large quarries from 35 to 50 feet in depth and covering over 20 acres, in light buff, very fine-grained, compact, rather thick-bedded limestone, of very uniform texture.

The quarry floor is in places 40 feet below the level of the river, and in normal weather a small pump is sufficient to keep the excavation dry. The overburden, which consists of from 6 to 8 feet of sand and gravel, is removed by steam shovel, loaded into side-dump cars, and hauled by steam engine to waste piles. The stone is quarried by sinking deep holes with well-drills and blasting with dynamite. The drill progress is 7 to 8 feet per hour on the average. The stone is loaded by hand into boxes drawn by horses on narrow-gauge, flat cars. A hoist lifts the boxes from the cars to the primary crusher, which is of the gyratory type, and will take stone up to 15 inches in size and crush it to 4 inches. The maximum capacity is 600 to 700 tons per 10 hours. Most of the product (larger fragments) is burned for lime in several kilns installed near the quarry, part is sold for flux to the Steel Company of Canada at Hamilton, and a small part used for road purposes. On account of its purity (98 per cent calcium carbonate) the stone is more valuable for lime and other chemical uses than as road metal. The quarry is along the Canadian National railway, to which it is connected by siding, and the stone can be directly loaded by gravity from the storage bins to the railway cars. Owner: Standard White Lime Co., Ltd., Guelph.

68. *Two miles southwest of Beachville.* Large quarry, 32 feet in depth and covering over 5 acres. Stone looks much the same as No. 67. The course of Thames river was diverted, so as to make room for a large excavation and at the same time take advantage of the thin overburden covering the stone in the river bed. The bottom of the quarry is now 25 feet below the level of the river, and is kept dry by pumping. The overburden which is up to 6 feet in thickness and consists of fine clayey gravel and sand, is removed by steam shovel, loaded into narrow-gauge dump cars, and hauled by steam locomotive to waste piles. The stone is quarried by drilling holes to the full depth of the quarry and blasting with dynamite. It is loaded by steam shovel into boxes carried on narrow-gauge, flat cars which are drawn by horses. A hoist lifts the boxes from the cars to the crushing and screening plant. The larger fragments are burned for lime in several kilns installed near the quarry. The 3-to 4-inch stone, which is the maximum size from the crusher, is sold for flux to the Steel Company of Canada at Hamilton. The $\frac{3}{4}$ - to 2-inch stone is exported to the United States for use in the chemical industries. The stone screenings, that is, from $\frac{3}{4}$ inch to dust, are sold to the Canada Cement Company at Port Colborne. The maximum amount of stone extracted is now 1,500 tons per 20 hours, and the plant is being enlarged to obtain the same amount in 10 hours. It is the intention of the company to extract stone to an additional depth of 32 feet. The quarry is along the Canadian National railway to which it is connected by siding, and the stone can be loaded directly from storage bin to railway car. Owner: The Beachville White Lime Co., Ltd., Beachville.

69. *Innerkip.* Very thin-bedded, fossiliferous limestone, with large amount of chert, and many shale films or partings. Except for the thinner beds, this stone looks much the same as No. 65. Overburden: 1 foot of clayey soil. No outcrops are to be seen but the rock is said to lie close to the surface over several acres. Owner: Zorra Township Council.

70. *St. Marys.* Large quarry covering about 10 acres and from 20 to 38 feet in depth, in light earth-grey, fine-grained, rather thick-bedded limestone. The excavation is soon to be deepened to 58 feet. Overburden is 6 feet of sandy clay. The stone is quarried by deep drilling and blasted with dynamite. It is loaded by steam shovel into narrow-gauge dump cars, which are hauled by gas engine to the foot of an incline, from where they are hoisted by cable to the crushers, the primary one being a large jaw crusher with an opening 48 by 60 inches. All stone is ground and used in the manufacture of Portland cement. The other ingredient used with the limestone is clay, which is dug by steam shovel from a pit near the quarry. The maximum capacity of the plant is 300 barrels of cement per 10 hours. The quarry is connected by siding to both Canadian National and Canadian Pacific railways. Owner: St. Mary's Cement Co., Ltd., St. Marys.

71. Large quarry, in two excavations, covering together about 10 acres. The depth varies in different points, with a maximum of 40 feet, which is several feet below the level of the river Thames. In normal weather a small pump is sufficient to keep the excavation dry. The stone looks similar to No. 70, except that it separates more readily into thin beds. Most of the stone is quarried and crushed for road and concrete purposes, with a small proportion quarried specially for building purposes. The stone intended for crushing is quarried by deep drilling and dynamite blasting. The primary crusher, which is a No. 7½ Gates gyratory, will take stone up to 15 inches in size. The stone is crushed and screened to the usual commercial sizes, that is from 4 inches down to screenings, and each size stored in a separate bin, from which it can be loaded directly by gravity into standard-gauge railway cars. The quarry is connected by siding to both Canadian National and Canadian Pacific railways. The maximum capacity of the crushing and screening plant is 500 tons per 10 hours. Owner: St. Mary's Crushed Stone Ltd., St. Marys.

72. *One mile north of Amherstburg.* Large quarry, covering over 20 acres and varying in depth from 30 to 60 feet, exclusive of the overburden which is over 10 feet thick. In the upper 30 feet the stone is fine-grained, rather thick-bedded magnesian limestone and dolomite of loose texture. The lower 30 feet is rather thin-bedded limestone, the texture varying from coarse and semi-crystalline to very fine and compact. The colour of the stone is very light throughout, and varies from buff to grey. In the table, sample A refers to upper part and sample B to lower part. The pure limestone from the lower half of the quarry is broken to a maximum size of 5 inches and used for the manufacture of alkalis in a plant situated near the quarry. The impure limestone of the upper part is crushed and screened to sizes suitable for road and concrete purposes. Owing to the softness of the stone, the demand is limited and the crushing and screening plant is not in continuous operation. The maximum amount of stone that can be handled by both plants is 1,000 tons per 10 hours. The quarry is along the Michigan Central railway and connected to it by a spur. Owner: Brunner, Mond, Canada, Ltd., Amherstburg.

74. *Two miles east of Greenock.* Old quarry in the steep slope of a small hill, in very light grey, fossiliferous, massive limestone. The texture varies from very fine and compact to coarse and semi-crystalline, with

some layers holding many small cavities. The excavation is in the form of a side-hill cut, with a single face 450 feet long, and 25 feet high. The rock is covered with a few inches to 2 feet of clay and boulders, and outcrops are very common. The stone can easily be quarried in large quantity without much stripping. It is somewhat too soft for road surfacing purposes. Owner: Hydro Electric Commission, Toronto.

75. Two and three-quarter miles west of Wiarton. This quarry consists of three separate excavations, the largest of which is a little less than one acre. The stone is a light brown, fine-grained magnesian limestone or dolomite, very uniform in texture. In the larger excavation, it is thin-bedded, with thin, dark shale bands between the beds (sample A). In the two smaller openings, it is thick-bedded, and lighter in colour (sample B). The overburden, which consists of clayey or silty sand, is 2 feet thick at the two smaller quarries and 1 foot at the other one. The stone in the upper foot of the larger quarry is partly weathered and useless. The stone is quarried exclusively for the production of building stone. Because of the small demand the quarry is only intermittently operated. It is an excellent building material and more valuable as such than as road metal. Owner: J. S. Cook and Son, Wiarton.

77. East of Owen Sound. Several large excavations, from 15 to 25 feet deep, in dark brownish to bluish grey, fine to medium fine-grained, thin-bedded dolomite, with two directions of perfect jointing, at right angles to one another. The overburden consists of 18 to 20 inches of clayey soil. The stone is quarried by drilling holes with steam drills and blasting with dynamite. It is loaded by steam shovel into end-dump carts, hauled by horses to the foot of an incline, and dumped into a skip, which is pulled up the incline by cable and hoist to the crushing and screening plant. The stone is crushed and screened to several sizes, from 4 inches down to screenings, and stored separately in gravity bins. Most of the product is sold for road and concrete purposes. It makes a particularly good road metal. A small quantity of the bluish stone from the lower beds is also quarried with crowbars and sold as rubble. Owner: Oliver Rogers Stone Co., Owen Sound.

Several other important quarries are situated south and west of Owen Sound. The stone is a purer and lighter coloured dolomite than the one in the quarry just described, and is more suitable for building material or lime-burning than for road purposes.

78. Southwest of Gowrock. Quarry covering several acres and 41 feet in depth, in yellowish white, fine-grained, thick-bedded dolomite of loose texture, very uniform throughout. The quarry is in the slope of a high river bank, and the rock is covered with 6 feet of clayey soil, which becomes thicker farther up the slope and back from the quarry face. The bottom of the quarry is dry, although several feet below the river level. Quarrying to an additional depth of 20 feet is contemplated for the near future. The rock is quarried by deep drilling and blasting with dynamite. All the product is used for lime-burning in kilns installed near the quarry. As road metal the stone would be suitable only for surfacing roads carrying very light traffic. The maximum quantity of stone that can be burned is

100 tons per day. The quarry is along the Canadian National railway and connected to it by spur. Owner: Christie Henderson and Co., Ltd., 201 Crown Office Building, Toronto.

80. Elora. Quarry covering $1\frac{1}{2}$ acres and from 40 to 60 feet in depth. In the upper 40 feet the stone is a creamy white, fine-grained, vitreous dolomite, with many small cavities, particularly in the upper part (sample A). In the lower 20 feet it is a light bluish or ashy grey, fine-grained dolomite, without cavities (sample B). Except in the upper part, the stone is generally thick-bedded, with beds up to 4 feet thick. The overburden is very thin, and cliff-like exposures of the rock are numerous along the river bank between Elora and Fergus. The stone is quarried to a depth of 40 feet in one operation by deep drilling and blasting with dynamite and the lower 20 feet in another operation. Secondary blasting is often necessary for the thick beds near the bottom. The stone is loaded by hand into narrow-gauge, dump cars which are pulled up an incline by cable and hoist to the kilns, in which the stone is burned for lime. The stone which is too small for the kilns is crushed and screened to the following three sizes: 2 to 1 inch, 1 to $\frac{1}{2}$ inch, and screenings (less than $\frac{1}{2}$ inch), and sold for road or concrete purposes. The quarry is connected by siding to both Canadian National and Canadian Pacific railways. Owner: The Alabastine Company of Paris, Ltd., Paris.

81. Rockwood. Creamy to bluish white, fine-grained, thin-bedded, vitreous dolomite. Two large excavations are along the river bank. The overburden is 2 to 3 feet thick, and outcrops are numerous for several miles along the river bank. The stone is quarried by deep drilling and dynamite blasting. It is loaded by hand into end-dump carts which are hauled by horses and emptied into a kiln. The top of the kiln is about level with the quarry floor. The quarried product is used for lime-burning, except the smaller sized stone which is dumped into a waste pile. There are three lime kilns and the maximum quantity of stone that can be burned is 90 tons per day. There is only one kiln in operation at present. Owner: E. Harvey, Ltd., Guelph.

82. Pembroke. Dark bluish grey, fine-grained, thin-bedded limestone. The excavation covers about 4 acres and is 15 feet in depth including 3 feet of boulder clay as overburden. The stone is quarried with crowbars, and occasionally by drilling and blasting. Part of the stone is cut for building purposes, and part is crushed and screened to sizes suitable for road and concrete purposes. The equipment consists of a steam engine and boiler, air compressor, drill, small jaw crusher, rotary screen and storage bins. Owner: William Markus, Ltd., Pembroke.

83. Three miles southwest of Pembroke. Reddish and greenish grey granite-gneiss, of loose and irregular texture, and rich in quartz. Although the rock is as a rule but slightly foliated, in some places foliation is quite pronounced. The quarry, which has an approximate area of 1,500 square yards and a 20-foot face, is in the steep slope of a wide, low ridge. At the quarry the overburden is very thin, and outcrops are numerous over an area of several acres. On account of its loose texture, the granite-gneiss is not so suitable for road purposes as the local limestone, such as No. 82. Owner: Corporation of Pembroke.

Quebec

101. Rigaud. Pit opened in a very large boulder deposit in the upper slope of the Rigaud hill, 500 yards east of and at the same elevation as the "Devil's Garden." The boulders are largely composed of granite, syenite, syenite-porphry, with some gneiss, sandstone, and anorthosite, all hard rocks. They are loaded by hand into a car which, as it descends an inclined track by gravity to the crushing and screening plant, pulls up an empty car on a parallel track. The stone is crushed and screened to several sizes from 1½ inch to screenings, and stored in bins. From the bins it is loaded by gravity into standard-gauge dump cars, which are hauled down a slightly inclined track by a small steam engine. The lower end of the inclined track is on a trestle, so that the stone from the dump cars can be loaded directly by gravity into standard railway cars, which stand on a siding of the Canadian Pacific railway. The maximum capacity of the plant is 150 tons per 10 hours. The stone is suitable for use in all types of pavements and under all traffic conditions. Owner: Rigaud Granite Co., 11 Place d'Armes, Montreal.

102. One and one-quarter miles west of Brownsburg. Reddish and greenish grey, coarsely crystalline syenite, grading into granite in places. The colour and texture are not uniform throughout, although large blocks of uniform colour and texture can be obtained. The overburden is very thin and the amount of stone available is practically unlimited. The quarry is operated for the production of monumental and building stone, paving blocks, and curbing stones. At the time the quarry was visited, stone was being quarried for use as curbing in the city of Montreal. For that purpose the stone is drilled with jack hammers and loosened with plug and feather. The quarry machinery consists of air compressor, steam engine and boiler, large derrick operated by steam, and several smaller hand-derricks. The stone is hauled in horse-drawn wagons to a spur line of the Canadian Pacific railway at Brownsburg. Owner: Westmount Construction Co., 28 Royal Ave., Montreal.

103. Graniteville, 5 miles west of Stanstead. Medium-grained granite, made up of pure white feldspar, colourless quartz, and black mica. The sheeting and jointing are very regular, and blocks of large dimension can be obtained, the size being limited by the permissible load on railway cars. The quarry covers 3 acres in extent and is from 30 to 60 feet deep. Pumping is necessary to keep the excavation dry. The overburden is up to 12 feet in thickness in places but is as a rule quite thin. The stone is quarried in large blocks which are then reduced to blocks or slabs of the desired sizes by drilling and separating by plug and feather. There are several large electric derricks and smaller ones which are driven by compressed air. The air compressor is electrically operated. The quarry is operated for the production of paving blocks, monumental and building stone. The paving blocks are nearly all shipped to Toronto. For monumental bases, there is a large demand for the stone throughout Canada and the United States. Owner: S. B. Norton, Beebe.

There are several other large quarries in this area, the principal producers being The Stanstead Granite Quarries Co., Ltd., of Beebe, and Brodie's, Ltd., of Montreal. The Stanstead Granite Quarries Co., Ltd.,

which produces chiefly structural and monumental stone, has a large, electrically operated mill at Beebe, for cutting, sawing and polishing granite. All the quarries are connected with the Canadian National railway at Beebe by the same spur.

104. North of Beebe. Small quarry in granite similar to No. 103, but slightly coarser and containing less black mica, resulting in a lighter colour. The quarry is in the slope of a large round hill. The rock is but thinly covered with soil and outcrops at numerous places near the top of the hill. The stone is quarried chiefly for monumental purposes. A small amount is also cut into paving blocks. It is hauled in horse-drawn wagons to the railway siding at Beebe. The equipment consists of hand-derricks, hand-drills, etc. Owner: William Duncan, Beebe, R.R. 1.

Other small quarries in similar granite lie close to the one just described and are operated in the same manner and for the same purpose. A large amount of road metal could be obtained from the large piles of waste rock at all the quarries near Beebe and Graniteville.

105. Two miles southeast of Danville. Old quarry in the lower slope of a small knoll. The rock is a rather dark grey, finely crystalline quartz diorite or granite. The constituent minerals are not plainly discernible. The rock presents many fractures and can be quarried in large amount without much stripping. Judging from the results of the tests on a sample collected from waste pieces that had been exposed to the weather for several years, the rock should prove to be very satisfactory material for road metal. Owner: Danville Granite and Asbestos Co., Danville.

106. Lime Ridge. Light bluish grey, very fine and compact to fairly coarse and semi-crystalline, partly metamorphosed limestone or marble. The quarry covers several acres and is about 150 feet deep. The excavation is kept free from water by pumping. The stone is quarried by deep drilling and blasting with dynamite. It is loaded by hand into dump cars which are hoisted by cable on an inclined track to kilns in which the stone is burned for lime. The smaller size stone is crushed and screened to sizes suitable for road or concrete purposes. The quarry is connected by siding to the Maine Central railway. Owner: Dominion Lime Co., East Angus.

107. One mile northeast of St. Grégoire. Large quarry in the steep, southeast slope of mount Johnson, in greyish black essexite, which varies in texture from coarse to medium fine. The stone is quarried for monumental purposes. As a monumental stone it is justly famous, and known as the "Iberville black granite." A small quantity of the stone is also made into paving blocks. Only the high-grade, flawless stone is used for monumental work, so that there is a considerable amount of waste. The waste stone, if crushed and screened to suitable sizes, should make an excellent road metal, judging from the results of the tests. The quarry is one mile distant from the Quebec, Montreal and Southern Railway siding at St. Grégoire, and the product is hauled by horse-drawn wagons to the siding. The company owns an electrically operated mill at Iberville, 6 miles distant, for finishing the stone from their several quarries, which include, besides the one just described, one at Graniteville and one at Guenette. This mill not only finishes monumental stone, but also building stone, columns, etc. Owner: Brodie's, Ltd., 1070 Bleury St., Montreal.

Results of Tests upon Rock Samples

Sam- ple No.	Location	Rock type	Physical Properties							—
			Wear, per cent	French co-effi- cient of wear	Tough- ness	Hard- ness	Ce- ment- ing value	Speci- fic gravity	Water ab- sorbed, lb. per cu. ft.	
	Ontario									
1	1 m. S.W. of Perth..... McKinley's quarry.	Granite.....	2.31	17.3	14	19.1	15	2.63	0.15	See note.
3	Lanark..... Stead's quarry.	Crystalline limestone.....	7.06	5.7	4	12.3	29	2.73	0.29	
4	3 m. S. of Arnprior..... Duncan's quarry.	Limestone (Black River)...	4.50	8.9	4	16.9	43	2.70	0.35	
5	Pakenham.....	Limestone (Black River) ..A	4.26	9.4	7	16.8	51	2.68	0.38	See note.
6	2 m. N.E. of Almonte..... Cullan's quarry.	Limestone (Chazy).....	3.26	12.3	7	16.3	39	2.70	0.11	
9	2½ m. W. of Prospect..... Stewart's quarry.	Dolomite (Beekmantown) ..	5.00	8.0	7	16.7	60	2.70	0.28	
12	2 m. W. of Merrickville..... (No quarry.)	Dolomite (Beekmantown) ..	3.20	12.5	17	17.5	55	2.73	1.73	See note.
13	Easton Corner..... King's quarry.	Dolomite (Beekmantown) ..					91			
15	1½ m. N.E. of Burritt..... The Grenville Rock Co.	Dolomite (Beekmantown) ..	2.97	13.5	9	15.9	73	2.77	1.22	See note.
16	1 m. N.E. of Shanly..... Ault's quarry.	Dolomite (Beekmantown) ..	2.90	13.6	5	15.6	25	2.79	0.85	
17	Maitland..... Stacey's quarry.	Dolomite (Beekmantown) ..	3.37	11.9	9	16.1	21	2.80	0.79	
18	2½ m. N. of Lansdowne..... Smith's quarry.	Dolomite (Beekmantown) ..	3.37	11.9	12	16.3	47	2.78	0.96	
19	2½ m. W. of Sweet Corner..... A. C. Brown Granite Works Co.	Granite-gneiss.....	2.55	15.7	9	19.0	31	2.74	0.41	See note.
22	1½ m. W. of Hartington..... Ferris' quarry.	Granite.....	2.74	14.6	11	18.4	33	2.68	0.43	
23	¾ m. S.W. of Oates..... Carey's quarry.	Limestone (Black River) ..A	3.64	11.0	8	17.2	78	2.74	0.21	See note.
24	1 m. W. of Waupoos..... Prince Edward County Council.	Limestone (Black River) ..A	4.00	10.0	5	16.7	22	2.71	0.07	See note.
		B	2.74	14.6	9	17.2	28	2.77	0.52	
		Limestone (Trenton).....	4.10	9.8			32	2.70	0.37	

Results of Tests upon Rock Samples—Concluded

Sample No.	Location	Rock type	Physical Properties							—
			Wear, per cent	French co-efficient of wear	Toughness	Hardness	Cementing value	Specific gravity	Water absorbed, lb. per cu. ft.	
	Ontario—Concluded									
56	N. of Campden..... Ismond's quarry.	Dolomite (Lockport).....	6.26	6.4	5	13.0	36	2.52	2.59	
57	2 m. S. of St. Catharines..... Frank Stagg.	Dolomite (Lockport).....	3.30	12.1	12	14.8	50	2.69	2.81	
58	½ m. E. of St. David..... Queenston Quarries, Ltd.	Limestone (Lockport).....	4.96	8.1	7	13.0	68	2.67	1.60	See note.
		A	4.62	8.7	7	13.8	51	2.67	1.37	
59	1 m. N.E. of Thorold..... Walker Bros.	Dolomite (Lockport).....	4.22	9.5	9	16.2	139	2.68	1.25	
					6	10.8				
60	Windmill Point..... Windmill Point Crushed Stone, Ltd.	Limestone (Onondaga).....	3.34	12.0			94	2.67	0.23	See note.
		A	5.62	7.1	5	14.8	39	2.66	0.56	
61	2 m. N.E. of Humberstone..... Welland County Council.	Limestone.....	8.60	4.7			75	2.55	3.95	
62	3 m. W. of Port Colborne..... Canada Cement Co.	Limestone (Onondaga).....	3.84	10.4	6	14.9	34	2.69	0.35	
63	Hagersville..... Hagersville Quarries, Ltd.	Limestone (Onondaga).....	3.38	11.8	12	17.8	128	2.59	1.70	See note.
64	Hagersville..... Hagersville Contracting Co.	Limestone (Onondaga).....	3.12	12.8	14	19.4	68	2.63	1.04	See note.
65	Hagersville..... Gordon Crushed Stone Co., Ltd.	Limestone (Onondaga).....	2.93	13.7	11	17.3	85	2.58	1.96	See note.
					12	16.3				
66	Nelles Corners..... Haldimand County Council.	Limestone (Onondaga).....	3.79	10.6			59	2.56	1.86	See note.
		A	3.20	12.5	11	17.1	59	2.68	0.28	
67	1 m. S.W. of Beachville..... Standard White Lime Co.	Limestone (Detroit River).. <td>3.97</td> <td>10.1</td> <td>5</td> <td>13.9</td> <td>29</td> <td>2.59</td> <td>2.24</td> <td></td>	3.97	10.1	5	13.9	29	2.59	2.24	
					5	14.5				
68	2 m. S.W. of Beachville..... The Beachville White Lime Co., Ltd.	Limestone (Detroit River).. <td>3.58</td> <td>11.2</td> <td>3</td> <td></td> <td>35</td> <td>2.64</td> <td>1.12</td> <td></td>	3.58	11.2	3		35	2.64	1.12	
69	Innerkip..... Zorra Township Council.	Limestone (Onondaga).....	3.04	13.2			98	2.57	2.33	See note.
70	St. Marys..... St. Mary's Cement Co., Ltd.	Limestone (Delaware).....	3.40	11.8	7	15.7	40	2.66	0.94	

71	St. Marys.....	Limestone (Delaware).....	3.65	11.0	7	15.5	46	2.64	1.51	
	St. Mary's Crushed Stone, Ltd.									
72	1 m. N. of Amherstburg.....	Limestone (Detroit River)A	5.26	7.6	6	11.3	62	2.45	5.50	See note.
	Brunner, Mond Canada Ltd.	B	3.92	10.2	4	17.3	41	2.67	0.78	
74	2 m. E. of Greenock.....	Limestone (Alpena).....	5.13	7.8	4	10.8	63	2.58	1.17	See note.
	Hydro-Electric Commission.									
75	2½ m. W. of Warton.....	Dolomite (Lockport).....A	3.82	10.5	7	14.1	33	2.58	2.13	See note.
	J. S. Cook & Son.	B	4.25	9.4	5	13.3	22	2.53	2.47	
77	Owen Sound.....	Dolomite (Cataract).....	3.38	11.8	15	15.7	74	2.67	2.12	
	Oliver Rogers Stone Co.									
78	S.W. of Gourock.....	Dolomite (Guelph).....	6.38	6.3	5	6.8	33	2.56	3.63	See note.
	Christie, Henderson Co. Ltd.									
80	Elora.....	Dolomite (Guelph).....A	2.54	15.7	10	14.0	18	2.66	1.50	See note.
	The Alabastine Co. of Paris, Ltd.	B	4.06	9.9	6	14.9	26	2.63	2.35	
81	Rockwood.....	Dolomite (Guelph).....	4.82	8.3	7	14.6	53	2.68	1.14	
	E. Harvey, Ltd.									
82	Pembroke.....	Limestone (Chazy).....	3.42	11.7	8	15.5	63	2.72	0.61	
	William Markus, Ltd.									
83	3 m. S.W. of Pembroke.....	Granite-gneiss.....A	4.07	9.8	9	19.1	41	2.62	0.36	See note.
	Corporation of Pembroke.	B	5.28	7.6	7	19.0	36	2.64	0.38	
Quebec										
101	Rigaud.....	Granite.....	2.22	18.2	.....	.....	36	.....	.....
	Rigaud Granite Co.									
102	1½ m. W. of Brownsburg.....	Syenite.....	3.46	11.6	5	19.2	19	2.63	0.39	
	Westmount Construction Co.									
103	Graniteville.....	Granite.....	3.66	10.9	7	18.3	29	2.67	0.55	
	Norton's quarry.									
104	N. of Beebe.....	Granite.....	3.20	12.5	8	18.9	37	2.66	0.50	
	Duncan's quarry.									
105	2 m. S.E. of Danville.....	Diorite.....	2.30	17.4	13	18.9	62	2.67	0.27	See note.
	Danville Granite and Asbestos Co.									
106	Lime Ridge.....	Metamorphosed limestone..	4.54	8.8	5	11.9	55	2.70	0.27	
	Dominion Lime Co.		4.90	8.2	5	13.8	42	2.70	0.23	
107	1 m. N.E. of St. Grégoire.....	Essexite.....	2.06	19.4	14	18.3	44	2.83	0.16	
	Brodie's, Ltd.									

NOTES ON RESULTS OF TESTS

1. Stone slightly foliated.
5. Very fine-grained, A finer and more compact than B.
12. Sample of partly weathered stone.
15. Toughness varies widely between different beds.
18. Numerous checks in stone of lower toughness and hardness.
22. Numerous calcite-filled cracks in stone of lower toughness and hardness.
23. A is very fine-grained and compact; B is coarser and tougher than A.
26. Top bed shows slightly higher toughness and hardness than average.
27. Stone in upper foot coarser and harder than average.
28. Very fine-grained, A finer and more compact than B. Quarry face shows mostly A stone.
37. Sample of partly weathered stone.
38. Sample taken from outcrops.
39. Rock with toughness of 13 shows markedly schistose structure. The higher toughness of 22 is more representative of the average.
43. A is finer grained, more compact, and much more common than B.
45. Sample A from upper 10 feet and B from lower 15 feet of quarry.
49. Sample A from lower 7 feet and C from upper 30 feet of quarry. B is from a 1-foot bed between A and C. C is finer grained, more compact and softer than A; and B is much softer than either A or C. In the test for wear, A and B are included together.
55. Sample includes only the grey stone, which is tougher and harder than the brown stone above.
58. A, buff stone; B, grey stone.
60. A is fine-grained and cherty; B is coarse-grained and semi-crystalline. Toughness and hardness of A (not tested) should be higher than what the test indicates for B.
- 63, 64, 65. Low wear and high toughness and hardness are due to chert in limestone.
66. A is from lower part of quarry and B from upper part. B is very cherty and apparently of higher toughness and hardness than A.
69. Limestone very cherty.
72. A is from upper part of quarry and B from lower part.
74. Sample from stone that has been exposed to the weather for several years.
75. A is from the larger quarry and B from a smaller quarry farther west.
78. Stone of very light colour and loose texture.
80. A is from upper 40 feet of quarry and B from lower 20 feet.
83. B is coarser than A.
105. Sample from stone that has been exposed to the weather for several years.

VII

STONE AND ITS USE IN ROAD CONSTRUCTION

R. H. Picher

Eastern Canada has vast deposits of stone and gravel particularly suitable for road construction. As the gravels have already been dealt with in a previous article,¹ in the present article only the solid rocks, or bed-rocks, will be discussed, having reference to the qualities that they should possess as road material, the several kinds of rock most commonly used for road purposes, and the relative merits of each kind for the different types of road surfaces.

Gravels have been used in preference to broken stone on road surfaces because of their easier accessibility and cheapness, even where, owing to the amount of traffic, a more desirable type of surfacing should have been used. In eastern Canada waterbound macadam roads, the material for which was, in many cases, field boulders crushed in small portable plants, were regarded as an improvement over gravel roads. However, in many districts, the lack of suitable gravel has been a more important factor than traffic requirements in the selection of waterbound macadam as a road improvement. With the rapid development of suburban and interurban highway communications due to the motor vehicle, both gravel and waterbound macadam surfaces proved unsuitable for carrying the fast-moving traffic, and more durable types of pavements have become a necessity. The increased use of the so-called "permanent pavements," in which broken stone is the main constituent, created a large demand for this kind of material. The extensive building of improved roads together with the increased use of concrete in construction are the two principal factors responsible for a rapid development of the crushed stone industry. To-day the greater number of Canadian quarries are operated exclusively for the production of crushed stone, some of which have a daily output in excess of 3,000 tons.

QUALITIES A ROAD STONE SHOULD POSSESS

Before considering the various requisites of a good road stone, it is well to mention that these requisites will vary according to the type of pavement and the amount of traffic that the road will have to carry.

1. The stone should possess enough toughness and resistance to wear to withstand the pounding and grinding of traffic. Consequently the larger the amount and the greater the weight of traffic, the more resistant should the stone be. Exception to this is to be found in the case of concrete pavements, which are considered under No. 4.

2. The stone should break into sharply angular, chunky fragments. Such fragments, if properly graded as to size, will compact solidly into the road surface and will offer the maximum of resistance to disruption by traffic, on account of the strong interlocking of the angular pieces. The binding medium, the function of which is to hold firmly in place the individual pieces making up the road surface, is thus subjected to less strain.

¹ Picher, R. H.: "Gravel and Gravel Roads", Mines Branch, Dept. of Mines, Canada. Mem. Ser. No. 27.

A good instance of this interlocking of stone fragments was observed in an eastern Ontario town in which several streets had been surfaced with waterbound macadam. The stone used was a very hard, glassy quartzite, which broke into sharply angular fragments, but was absolutely devoid of cementing power. When visited the streets were in good condition and, although the top layer of fine material was completely worn out, the surface was surprisingly smooth, the stone particles apparently holding in place because of their strong interlocking. It is easily understood that only fairly hard rocks will break into such angular fragments. A soft rock will usually break into pieces with blunted edges, and in the process of compacting it on the road, the roller will further round off the edges. A laminated rock, even if fairly hard, will break into flat or elongated pieces which will not compact solidly on the road.

3. The faces of the fragments should not be too smooth. Rough faces prevent the fragments from slipping or rubbing against one another and are gripped better by the binding material. Laminated rocks, as a rule, break with smooth faces and are otherwise unsuitable.

4. The rock should not be too porous, or, more properly, should have a low water-absorption factor so as to prevent water from penetrating and softening the road structure. In eastern Canada few stones show an unduly high water-absorption factor. Those with a very high water-absorption are otherwise too soft for road purposes, but they may be suitable as concrete aggregate. Recent investigations in cement concrete structures show that some stone having a high water-absorption produced a stronger concrete than stone having a low water-absorption. In conducting mortar tests on gravels, the writer arrived at somewhat similar results. One of the highest results obtained was with well-graded, fine gravel (from $\frac{1}{4}$ inch down) composed largely of very soft and porous sandstone. Since a high water-absorption is generally found among soft stones it would seem advisable in drawing specifications for a stone which is to be used as aggregate in cement concrete structures, to put somewhat less stringent restrictions as to the hardness and toughness of the stone, and give more consideration to the water-absorption. However, before any definite conclusions can be arrived at, further investigations will be necessary. It is true that cement concrete pavements have to withstand the pounding and grinding of traffic, which is not the case with other concrete structures, such as culverts, walls, buildings, etc. It may be mentioned, however, that the stresses caused by traffic are not taken up by the individual stone particles of the concrete road surface, but by the concrete slab as a whole. In this regard the concrete pavement is very different from other types, such as the various bituminous pavements, in which the wear caused by traffic is largely taken up by the individual stone particles.

5. Another important quality which a stone should have in order to be used in waterbound macadam surfacing is good cementing power. On account of its inability to withstand the wear of fast motor traffic satisfactorily, waterbound macadam has been almost entirely discarded for main highways, and the cementing power requirements have been eliminated from the specifications for stone to be used on such highways. This type of construction will, however, continue to be in use as a first step towards the improvement of many of our secondary roads, particularly in districts devoid of suitable road gravel.

All the above requirements apply particularly to the wearing course of a road. While it is recommended that the same stone be used in all the courses, including the foundation course, this is sometimes found to be economically impracticable. Where it is necessary to ship high-grade crushed stone from outside points for the top course, owing to the local stone not being of a quality equal to the requirements of the wearing surface, the local stone may possibly be usable for the foundation. In no case, however, should a stone intended for use in the foundation be so soft as to be easily crushed by the roller in the process of compacting. In addition it should not be unduly porous, else it will absorb water and keep the substructure of the road in a damp condition.

LABORATORY TESTS

In order to determine with any degree of accuracy the suitability of a stone for road purposes, it is necessary in most cases to subject it to a test. The most reliable way is to use the stone in a certain stretch of road, and carefully observe its behaviour under actual service conditions. The objections to this method are that it is very expensive and it takes too long a time before definite conclusions can be drawn as to the value of the material. Laboratory tests, although they do not exactly duplicate conditions which exist in service tests, are much less expensive than the latter and quickly ascertain the suitability of the material by comparison with recognized standards based on extensive service tests. Tests are made to determine the resistance of the stone to the pounding and grinding action of traffic, water-absorption, and specific gravity, the latter usually expressed in pounds per cubic foot. Tests are also made, when specifically required, to determine the crushing strength and the cementing power of the rock. The Road Materials Laboratory, Mines Branch, Department of Mines, Sussex St., Ottawa, is fully equipped to conduct such tests, also all the standard tests on paving blocks and gravel, and is prepared to undertake such tests as time permits, arrangements for which should be made through the Director of the Mines Branch.

In collecting a sample for testing, great care should be taken to ascertain any variation in the characteristics of the rock from the different parts of a deposit, and the sample should be taken so as to represent the average of that part of the deposit which it is intended to work. A good guide for ascertaining variations in the quality of the rock is a close examination of its texture especially as regards coarseness or fineness of the grain. These variations are likely to occur between the different strata of sedimentary or bedded rocks. It is sometimes found, within the same deposit, that some beds make a very good road stone, whereas adjacent beds are absolutely worthless. The sampling of sedimentary rocks should proceed across the bedding, so as to include all the beds intended for use. If beds which are considered unsuitable for road purposes can be easily left out, either in the process of quarrying or crushing, they should not be included in the sample. However, since most of the large quarries operated for crushed stone, in quarrying, drill holes up to 35 feet in depth, and loosen with dynamite hundreds of tons of rock in one single blast, it is evident that a sample from such quarries should include all the layers.

Limiting Values of Per Cent of Wear and Toughness under Varying Traffic Conditions

Type of road surface		Light Traffic up to about 100 vehicles per day		Moderate Traffic 100 to 250 vehicles per day		Heavy Traffic 250 vehicles per day and over	
		Per cent of wear	Tough- ness	Per cent of wear	Tough- ness	Per cent of wear	Tough- ness
Waterbound macadam.....	a	5 to 8	5 to 9	2.7 to 5	10 to 18	0 to 2.7	over 18
	b	5.7-	6+				
	c	5 -	6+				
Bituminous broken stone with seal coat and broken stone with bituminous carpet....	a	8 -	5+	5.7-	10+	5.7-	10+
Bituminous concrete with or without seal coat.....	a	5.7-	7+	4 -	13+	4 -	13+
	b	3.5-	13+	3.5-	13+	3.5-	13+
	c	3.5-	13+	3.5-	13+	3.5-	13+

a. Recommended by the Office of Public Roads, Washington, 1916.

b. Recommended by the American Society of Municipal Improvements, 1914.

c. Recommended by the American Society of Civil Engineers, 1917.

+ = "and over," that is, the figure is a minimum value.

- = "and under," that is, the figure is a maximum value.

The recommendations b and c simply give minimum limits for toughness and maximum for per cent of wear for the type of road in question.

ROCK TYPES SUITABLE FOR ROADS

The various types of rock most commonly used for highways are known commercially as trap rock, granite, quartzite, limestone, and sandstone. Trap rock includes all the fine-grained, very hard igneous rocks, of which the best is diabase. Granite includes granite proper, syenite, diorite, gabbro, and some varieties of gneisses. Quartzite includes quartzite proper, quartz, chert, and flint. Limestone includes limestone proper, dolomite, marble, and crystalline limestone. In the following series the rocks are named in their respective order of merit from the road-making standpoint, commencing with the most desirable. As a rule the fine-grained or finely crystalline varieties of a given type are more durable than the coarser grained ones. The following is by no means a strict lithological classification.

Trap rock.. . . .	{ Diabase. Basalt. Porphyry. Felsite.
Granite.. . . .	{ Gabbro. Diorite. Syenite. Granite. Gneiss.
Quartzite.. . . .	{ Quartzite. Chert. Flint. Quartz.
Limestone.. . . .	{ Dolomite. Limestone. Marble. Crystalline limestone
Sandstone.. . . .	Sandstone.

Trap Rock. Under this name are included the true trappean rocks, which vary from pure black to greenish and bluish black in colour, and the felsites, which vary from almost pure white to light pink, red, purple, and, more rarely, light green. Trap rock forms large masses in parts of Nova Scotia and New Brunswick, but is less common in Quebec and Ontario. It possesses to a high degree all the qualities required in a road stone, and is the best road material known, especially the dark, fine-grained varieties. It is exclusively specified as the coarse aggregate for some of the high-grade, bituminous pavements. The dark traps have a high cementing power, which makes them particularly suitable for water-bound macadam roads. A waterbound macadam surface built with this rock is very durable, although when partly worn out it will be rougher, but less dusty, than that built with a softer stone. Except for bituminous concrete pavements in some of our large cities and towns, trap rock has been very little used for highway purposes, for several reasons. Although fairly easy to quarry, it is more expensive than other kinds of rock to crush because of its great toughness. As compared with other rocks it is relatively scarce and is usually found in thinly populated areas where cheaper material, such as gravel, granite, and limestone satisfactorily answer the needs of local road traffic. Montreal is more fortunate than any other large centre of population in having deposits of trap rock, locally called "banc rouge," within its limits.

Granite. Granite is scarcer and more local in distribution than other kinds of rock in the more thickly settled parts of southern Quebec and Ontario, however in the northern parts of these two provinces and in Nova Scotia and New Brunswick it covers considerable areas.

In the arbitrary classification of rocks given above, the difference between the so-called granites and trap rocks is mainly a matter of texture, or relative size of the crystals making up the rock, the granites being more coarsely crystalline than the traps. On that basis, it is evident that there can not be any sharp line of demarcation between the two classes. In other words, the one grades into the other. As shown by the table the granites, like the traps, include several types of rock. The darker types generally make better road materials than the lighter ones, but the colour is a less reliable guide than it is with the traps, and in neither case should it be regarded as infallible. Gabbro is best in point of road-making quality, with diorite a close second. Both possess the valuable properties of the trap rocks, but to a lesser degree on account of their coarser texture. Granite and syenite are about equal in durability. Granite has a greater resistance to wearing and grinding, and syenite a greater resistance to pounding, as well as a higher cementing power, which makes it more desirable than the granite for use in waterbound macadam pavements. For bituminous and cement concrete pavements, both are equally suitable. Granite and syenite, which contain a large amount of mica, generally black mica, or are made up of large crystals, should not be used in road work, as the crystal faces afford planes of weakness within the rock. Gneiss is generally considered unsuitable for roads, because of its banded or zoned structure and its strong tendency to break in thin slabs in a direction parallel with the bands. However, some gneisses show this weakness to a small degree only and are nearly

equivalent to the granite and syenite in their durability as road material. They should not, therefore, be rejected just because they exhibit a banded structure.

Granite is probably much better known as monumental, ornamental, or structural, than as road material. As a matter of fact, comparatively little granite has been used on roads and streets except for stone block pavements and curbing in some of the larger cities. However, of late, owing to the large increase in motor traffic, trap rock and granite have tended to displace softer stones as coarse aggregate, particularly in high-grade bituminous surfaces. This tendency probably will be more pronounced as time goes on, for large amounts of granite lie within reasonable haulage distance of all our large population centres, excepting, however, southwestern Ontario.

Quartzite. Of the several rock types included under this heading, quartzite proper is the only one of economic importance to the road builder. Chert, flint, and quartz are found mostly as inclusions in other rocks in the forms of nodules, lenses, veins, or dykes. Cherty limestone, which is extensively used for road purposes in southwestern Ontario, will be dealt with under "Limestone." Quartzite is fairly common throughout Nova Scotia, eastern and northern Quebec, and Ontario. Smaller occurrences of quartzite are also found in southern New Brunswick and southeastern Quebec. The qualities of quartzite as road material vary. Some quartzites are nearly equivalent to granite, whereas others are totally unfit for use. The two most usual defects that lower the value of this stone are a banded structure, which causes the stone to split into thin pieces, and vugs, or cavities within the rock, the effect of which is to decrease the resistance to impact. The average quartzite is light in colour and is somewhat glassy in texture. It has a very high resistance to wear, and breaks into very sharply angular fragments, which have a strong interlocking action when compacted on the road. On the other hand, it has a rather low resistance to the blows and pounding of traffic, and is almost entirely devoid of cementing power, so that it is unfit for use in top course of a waterbound macadam unless mixed with other rocks. The Nova Scotia quartzite is very different from that found elsewhere. It is a grey, granular stone, looking very much like a fine-grained sandstone, and is locally known under the name of "whin-rock." It also is deficient in binding power but, contrary to the usual glassy quartzite, it is very tough, a quality which makes it a particularly good aggregate for high-grade pavements. It has been extensively used in and around Halifax for bituminous pavements and waterbound macadam. A decided improvement has been effected in the case of the waterbound macadam by incorporating into the top course finely crushed black slate which is found in that district. The black slate is unsuitable for use alone as road stone, but makes an excellent binding material, on account of its iron content. The Ontario glassy quartzite has been successfully used in surfacing streets and roads in and around Brockville. It may be mentioned that the quartzite in the vicinity of Brockville is superior as a road stone to the average quartzite found farther west and north. Outside of Nova Scotia it is doubtful whether quartzite will ever be extensively used for road purposes because of its low degree of toughness.

Limestone. This is by far the most common rock throughout the older settled parts of Quebec and Ontario, and for that reason has been the first stone used in road metalling. To-day, it still holds first rank as regards quantity used for road purposes. Limestone is scarce in the Maritime Provinces, being found in isolated patches in eastern Nova Scotia, and southern and western New Brunswick, but it forms important deposits throughout the St. Lawrence valley in Quebec, and southern Ontario. Of the several rocks included under this name, magnesian limestones, better known as dolomites, and limestones proper only need to be considered here. Marble, besides being very scarce, is unsuitable for roads because of the readiness of the crystals constituting the rock to split along their cleavage-planes. Crystalline limestone, which is a very coarse marble, is still weaker than the latter, due to its coarse texture.

Dolomite is much less common than limestone proper. It is not found in the Maritime Provinces, and in Quebec occurs mostly between Montreal and the Ontario border. In Ontario two important areas are found, one between Ottawa and Prescott, and the other forms a wide belt which runs from Niagara Falls to Georgian bay. The essential constituents of dolomite are the carbonates of lime and magnesia, but foreign matter or so-called impurities are always present. From the results of tests it would appear that the impurities, more particularly silica, impart to the stone its road-making qualities. This probably explains why a certain type of impure dolomite is such a good road stone, being equivalent to granite in durability. On the other hand, it has a very poor cementing power, and several failures of waterbound macadam surfaces in western Quebec and eastern Ontario were chiefly imputed to this fact. Colour is usually a good criterion by which to judge the road-making quality of dolomite. Suitable dolomites vary in colour from dark bluish grey to light steel-grey, whereas the purer and softer grades vary from light buff to creamy white.

The Quebec dolomite is a sound, dark bluish grey, siliceous dolomite, eminently suitable for road purposes, except, as already mentioned, for waterbound macadam surfacing. Comparatively little has been used on roads in recent years, chiefly because the districts in which crushed stone is needed for road purposes are fairly close to Montreal, which can supply crushed limestone and trap at such a cost as to make local quarrying and crushing of dolomite unwarrantable. The eastern Ontario dolomite was formerly extensively quarried for building purposes, and lately much has been crushed to supply local road demands. Although on the average somewhat inferior to the Quebec stone, it has proved of good quality as aggregate in bituminous and concrete pavements. The road-making quality of the southwestern Ontario dolomite varies over a wide range. The steel-grey and brownish grey varieties are comparable in value to the eastern Ontario stone, but among the purer, lighter-coloured varieties, some make acceptable road metal, while others are totally unfit for use on roads, even in foundation work.

Limestone is the best known road stone in Quebec and Ontario, and the one which has been most useful in the improvement of our streets and roads. It is easy to quarry and crush to convenient sizes, wears very smoothly on the road, and has a good cementing power. Under our modern heavy road traffic, however, limestone will wear very fast and form much

fine, objectionable dust in waterbound macadam surfaces, and even where a bituminous binder is used, will not withstand, satisfactorily, the wear of heavy traffic. Limestone is essentially made up of calcium carbonate, but always contains a certain amount of foreign matter which, as in the case of dolomite, appears to improve the quality of the stone as road material.

Most of the limestone deposits in Nova Scotia and New Brunswick are so badly weathered as to be absolutely worthless for road purposes. In the few localities where fresh stone is available, however, it is found to be better than the average Quebec and Ontario limestone. The Quebec stone is almost everywhere fresh and does not vary much in its physical properties from place to place. It is a stone of medium durability, quite suitable for use as aggregate in bituminous pavements subjected to light traffic, but will not withstand the wear of heavy traffic. The Ontario stone is also generally found to be fresh, but varies in its road-making qualities over a wider range than the Quebec stone. If we draw a line from Toronto to Georgian bay, most of the stone east of this line is about equivalent to the Quebec stone with regard to its qualities as road material. Exception to this is found in the Kingston district and a few other limited areas, in which the limestone is much better than the average, and almost equal to the Quebec dolomite in durability. West of the line just mentioned, most of the limestone, which is comparatively free from foreign matter, is soft and unfit for use on roads, with the exception of the cherty limestone. This stone is very common along the eastern shore of lake Erie, and is particularly well developed at Hagersville, where it is extensively quarried for concrete, ballast, and road purposes. The stone possesses, to a high degree, all the qualities of a good road material. The chert is mainly responsible for this since the limestone, considered alone, is rather soft. Where the proportion of chert is quite high, the rock as a whole is sometimes referred to as quartzite.

Sandstone. There is no other rock the qualities of which, as road metal, vary over such a wide range as sandstone. Some are among the hardest and toughest rocks known, whereas others crumble readily to sand under the lightest traffic. It is a very common rock throughout eastern Canada, but most of it is unsuitable for road work, even foundation work, so only the suitable varieties will be mentioned here. Glassy sandstone closely resembling quartzite in texture is found in several parts of Nova Scotia, New Brunswick, and Quebec, but nowhere in large amount. It is a tougher rock than quartzite, but is nearly devoid of cementing power, and should not be used in waterbound macadam surfacing. Some fine- and close-grained sandstones, largely confined to parts of Nova Scotia, New Brunswick, and eastern Quebec, can advantageously replace limestone for light-trafficked roads. The ferruginous sandstone of New Brunswick is the most durable variety of this class, and can be safely used under very severe traffic conditions. Calcareous sandstone or, more properly, dolomitic sandstone, although not so durable as dolomite, makes a satisfactory material for surfacing roads where the traffic is not so heavy. The only deposits of dolomitic sandstone of any commercial importance are found between Ottawa and Prescott.

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GEOLOGICAL SURVEY PUBLICATIONS

Memoir No.

85. Road material surveys in 1914. By L. Reinecke.
99. Road material surveys in 1915. By L. Reinecke.
106. Road materials in a portion of Vaudreuil county, Quebec, and along the St. Lawrence river from the Quebec boundary to Cardinal, Ontario. By R. H. Picher.
107. Road materials in the vicinity of Regina, Saskatchewan. By L. Reinecke.
114. Road material surveys in the city and district of Montreal, Quebec. By L. Reinecke.

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