BUILDING AND INDUSTRIAL STONES OF EASTERN CANADA

by

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PREFACE

The opportunity to carry out the present study of building stones was afforded by a substantial award granted for the period 1953-55 by the Vermont Marble Company, the receipt of which is hereby gratefully acknowledged.

Prior to beginning the field study, four weeks were spent in Vermont observing the quarrying of verde antique serpentine marble and white statuary marble from the quarries of the Vermont Marble Company. The diamond drilling programs were studied and visits were made to the foreign marble and granite division and finishing plants. Also, a study of the petrology of marbles and granites was made and some physical measurements of building stone performed under the direction of Doctor G.W. Bain at Amherst College, Amherst, Massachusetts.

The essence of this thesis is in two parts: a field study and a laboratory study. The field study aims to show what areas of Eastern Canada, for broad tectonic reasons are or are not potentially suitable for the occurrence of building or industrial stone.

The rocks dealt with include: (1) granites and related igneous rocks for building and industrial stone, (2) marble, polishable limestone and serpentine for building or decorative stone, and (3) marble and limestone for grinding into white pigment. The work has involved the gathering of geological information from the published literature and from direct field observation.

The area of field observation included that part of Eastern Canada as far west as longitude 80° and adjacent to economic transportation routes. Small prospects and abandoned quarries are ubiquitous in such a large and varied area of rock outcrop. It was soon learned that without detailed geological mapping, isolated and undeveloped properties revealed little information other than that obtainable in the literature. This made it necessary to exercise discretion in the selection of localities worthy of examination. It is thought that the important districts are represented and have received due consideration.

In conjunction with the field work, the second part represents a study of some laboratory methods designed to show the relationship between measured properties of a stone and its performance in a structure. The topics studied include: elasticity studies and the relation of pore space to flexibility; moisture effects and warping measurements; the effect of salt solutions; loss of strength in the presence of water, and a petrological study of the stones tested.

The writer wishes to express his indebtedness to Doctor Bain for his friendly encouragement and valuable advice.

As for the laboratory work, Mr. H. Dehn, chemist, of the department of Geological Sciences, McGill University, assisted with profitable discussions and with some of the experimental work.

The writer is also indebted to Doctor E.H.Kranck under whose direction this thesis was written.

Finally, managers of the numerous quarries and plants visited have been most cooperative in furnishing information and test pieces for laboratory study.

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INTRODUCTION

General Statement

Many rocks have such architectural appeal in both new and aged structures that they are desirable for construction and decoration. Likewise, rocks with unique chemical and physical properties are valuable for the production of manufactured items. Bodies of rock large enough to give sustained production of dimension pieces required by architects constitute an important resource. Sedimentary, igneous, metamorphic and hydrothermal rocks have been used for these purposes.

Rocks having architectural appeal require a desirable color pattern or fabric and must be available in size and quantity to finish a structure. Many large building structures therefore require quantities of stock on hand or from immediate production. In addition the stone must withstand normal abuse if an industry based on it is to maintain longevity. Sales are frequently based on appeal alone, but sustained production depends on the durability of the stone and adequate deposit to supply similar material. Appeal, size of deposit, and durability are essential features of any rock body that is to become the basis of a building stone industry.

Any attempt to outline the requirements for building stone should show the importance of selecting material for its proper use. A stone may require such properties as low warping under high moisture conditions or high elasticity for unsupported structures. The correlation of laboratory measurements with performance in a structure provides a useful means of determining such qualities of good building stone.

The recognition of deleterious components is important for estimating rock qualities. Some affect the permanence of appearance; others restrict the processing during finishing or polishing. Some of the deleterious minerals easily disappear on a weathered surface but leave their marks as cavities or pits. Many minerals known to cause such trouble can be observed in a cursory field examination. Others can be detected only by a microscopic examination.

Marbles, serpentines and granites may have deleterious components that can be expected to cause difficulty either in the processing of a stone or its future performance. Some minerals are common to each group, others are not. Quartz, for example is a troublesome mineral in the finishing procedure of marble but a necessary constituent in granites. Pyrite and other iron-bearing sulphides occurring in both marble and granite may cause discoloration. The minerals fluorite, apatite and nepheline occur in some building stones and may be removed in solution by rain water having dissolved atmospheric gases.

The deuteric stage minerals give the greatest difficulty in granites and mafic rocks. These synantectic minerals result from the reaction of early formed minerals with late magmatic residues. Reaction borders weather early, softening the rock and loosening the grains.

Concentrically zoned crystals of plagioclase feldspar often have alteration rims or centers with sericite or sausserite. Potash is made available for lichen growth to promote decay. Unless the feldspars are altered they are generally highly resistant to normal weathering. It is important to determine the extent to which feldspar alteration may have proceeded.

Strides toward solving technical difficulties are being made by the industry in many fields. Important problems include workability, adaptability to mass production methods, and heavy weight. The possibility of quarrying along certain easy planes can determine the success or failure of a quarry operation. New methods of quarrying can effect economies which place the building stone industry in a more favorable position in relation to competition from other materials. A new jet channeling flame process is now being introduced into granite quarrying operations, and substitutes for the mechanical method of drilling and broaching with greater economy. Research and laboratory studies by the industry have resulted in the reduction of weight by the development of panel veneers, and through-the-wall building units, new finishes, and methods of shipping and packing.

Microscopic studies have shown details in interlocking crystal structures. By cutting marble slabs having a preferred orientation of the calcite grains so that the surface is parallel with the c - axis, maximum transmission and minimum refraction of light are attained. Such attention to detail has led to the development of a new product, "Lumar".(Bain, 1936) . Some approaches to the problems of the building stone industry have been geological in nature, others chemical and physical. The role of the geologist in the study of and search for new deposits of building stone demands not only personnal judgement and the application of scientific knowledge but also an understanding of particular needs of the industry. The work of the geologist embraces both realms.

HISTORICAL REVIEW AND PREVIOUS INVESTIGATIONS

The principal investigations dealing with building stones have been made largely by geologists who have been concerned with the descriptions of various deposits and their chief purpose was to acquaint architects, building contractors and quarry operators with the types of stone available. This literature provides valuable technical information concerning the rock quarried in such particulars as the geological characteristics, and engineering qualities. Such investigations in Canada have been largely the work of government agencies.

A broader aspect of the published material on building stones is the account of research on factors causing weathering and failure in a building structure as well as of durability studies and measurements on the physical and chemical properties of various stones.

Between the years (1912 - 1917) the Canada Department of Mines published in 5 volumes a report by Parks (1912, 1914, 1914, 1916, 1917) on the natural "Building and Ornamental Stones of Canada". The first three volumes deal with the economic and technical aspects of the building and ornamental stones of Eastern Canada. Volume I is in two parts. The first deals with the chemical, physical and geological features of building stone and the methods of quarrying, testing, and preparing stone for the market. The second part is a systematic description of the building and ornamental stones of Ontario lying south of the Ottawa and French rivers. Volumes II and III of this report deal with the systematic description of the building stones in the Maritime Provinces and the Province of Quebec, respectively.

A systematic survey of the limestone resources of Canada was begun in 1925 by Goudge and in the succeeding years (1926-1929) preliminary reports were issued by the Mines Branch, Department of Mines, Ottawa. The same department published a report by Goudge (1933) on Canadian Limestones for Building Purposes, that was followed by separate reports by the same author on "Limestones of Canada", Part II Maritime Provinces (1934); Part III Quebec (1935) and Part IV Ontario (1938). A great deal of information regarding the occurrences, chemical and physical characteristics of marble and limestone was brought together. Although small quantities are ubiquitous, descriptions of the polishable limestones and marbles used for building stone have been included as part of the reports.

The Province of Quebec takes a prominent position among the granite producers for building stone in Canada and has received descriptive coverage in the reports of Burton (1931) and Osborne (1932-1933). Many of the granites here described are not found in Parks' work (1914) referred to previously. Other literature on the granites of Canada include those by Mailhiot (1913), Cole (1938), Bourrett (1946) and Mattinson (1953). Mattinson (1953) has made a most complete microscopic study of a number of granites that have been used for building stone in Eastern Canada. The most recent descriptive report is that by Carr (1955).

The contributions on granites that have been used for building stone in the Atlantic Provinces are found in the reports by Messervy (1925), Douglas (1942), Longard (1947), Wright (1934), Fletcher (1948) and Snelgrove (1953).

The other aspect on the literature of building stones are the works relating to the physical and chemical properties and durability studies.

The ancients recognized that building stones were susceptible to weathering. By direct experiments and possibly by examining the condition of stone in old buildings they were able to select more durable material. Vitruvius (about 25.B.C.) wrote about the durability of building stones and the selection of material prior to its use in a building.

He writes:

> "two years before the commencement of building the stones should be extracted from the quarries in the summer season, by no means in the winter, and they should then be exposed to the vicissitudes and action of the weather. Those which after two years exposure are injured, may be used in the foundations, but those which continue sound after this ordeal, will endure in the parts above the ground."
>
> (Vitrius M. - Architecture. Translated by J. Gwilt Book II Chapter VII London (1880).

Another early experiment performed by Alberti, and described in De re aedificatoria (The Architects Guide, London 1894) was to soak a piece of stone in water and if it increased much in weight it would be "apt to be rotted by moisture" or when a stone became broken in fire it would "bear neither sun or heat".

In the ninenteenth century more serious attempts were made to evaluate the durability of building materials. Schaffer (1932) considered that Daniel and Wheatstone were pioneers in the testing of building materials on a scientific basis, as described in their Report of the Commissioners appointed to inquire into the qualities of stone used in building the Houses of Parliament in London (1839). Merrill however, writing in (1891), cites the fact that this notable structure was so badly scaled and disintegrated in certain portions as to necessitate repairing before it was actually finished.

Earlier, Brard (1828) had proposed a rapid method of testing stones for frost resistance in which the crystallization of sodium sulphate was used to simulate the effects of frost action on a stone. The work was continued by numerous investigators and has been discredited and revived a number of times in a somewhat different form. Duquer (1895) investigated both methods, the effects of frost and the effect of sodium sulphate. The most recent work by Russell (1839), Kessler (1940) and Quervain (1946) indicates that salts, notably sodium sulphate and calcium sulphate, crystallizing in a stone, are the cause of damage in many building stones.

The literature relating to the physical and chemical studies of building stones is very extensive, but the most elaborate investigations on the subject are attributed to Hirschwald who devoted almost a lifetime to study and testing in this field. Hirschwald (1912) made the first systematic study of the properties of building stone. He presented planned methods of predicting durability and weathering qualities by laboratory tests. By recording and classifying the structural and physical properties of a large number of building stones from old buildings he established a method of testing and evaluating samples of unknown durability.

Structure was an important factor in his system of evaluation which was first established by a microscopic examination. By this means an unknown sample was given a tentative quality index prior to measurements of the physical properties. This method depended largely on personal judgement when assessing microscopic observations. A large supply of material and elaborate apparatus are required to make the combined measure of structural and physical measurements.

Hirschwald also observed that the size, character and distribution of the pores or voids would determine the frost-resisting properties of a stone. He determined a saturation coefficient which is the ratio of the weight of water taken up by capillary forces in 24 hours when the material is slowly immersed, to the weight of the water taken up when the pores are completely filled. For a large number of determinations he found that a stone should not be higher than 0.8 for a stone to be immune to frost action.

Kreüger (1923) made investigations on climatic action on the exterior of buildings. He utilized essentially Hirschwalds method to determine frost-resisting properties.

Stradling (1928) was not in complete agreement, citing that material strength is a factor not accounted for by Kreüger, regardless of the pore space fillings. Nevertheless a suprisingly large number of tests showed that materials were generally immune to frost damage when the absorbed water did not occupy more than 80 percent of the pore space.

Experiments made to measure the durability of building stone at increasing temperatures up to 1000° F. were made by Cutting (1881), and Humphrey (1809) applied drastic tests to various building materials by heating building stones to high temperatures and quenching with water.

Baldwin-Wiseman and Griffith (1809) recorded physical measurements on building material that included linear coefficients of heat expansion, permanent elongation and specific heats.

Wheeler (1910) performed experiments on the linear thermal expansion of several rocks at high temperatures and observed that in all cases there was a considerable permanent expansion produced by the first heating. Tarr (1915) made some heating tests related to the disaggregation of granite. He concluded that the principal cause of shattering was due to the unequal expansion of the constituent minerals with the molecular structure in the cleavage and twinning controlling the direction of cracks. The disruption of granite was considered to be aided by strains set up during cooling; the outer portion cooling faster than the inner.

Sosman (1916) recognized that the essential cause of shattering in granite by heat to be separable into two parts; the wedging and straining effect due to the fact that minerals originally close in contact possess different coefficients of thermal expansion and the similar effect produced by the rapid volume increase of quartz as its 575° C inversion point is approached and by the final sudden increase in volume at 575° C.

Shad (1917) found by experiment a permanent increase in the length of marble after heating; the magnitude of permanent increase was dependent on the temperature to which the specimen was heated.

Stress-strain curves for Aberdeen granite after being subjected to various temperatures up to 500° C., published by the Building Research Board (1926), shows that with increased temperatures, there is a large deformation under small loads during the first loading. The large initial deformation was explained by the separation of crystal groups that have first to be brought into closer contact before any appreciable load can be carried by the specimen. The explanation was believed to be confirmed since the material showed a permanent elongation after cooling.

The experiments recorded by Blackwelder (1927) indicated that most igneous rocks will withstand repeated heating and cooling up to 200° C. without damage, and begin to fail between 300° and 375° C. Most were found to endure slow heating and cooling through a range of 400° to 600° C., with the more resistant acidic granitic rocks enduring slow temperature changes of about 800° C.

Griggs (1936) subjected a coarse grained granite to temperature changes every 15 minutes from 32° to 142° C. to test the effectiveness of fatigue in rock exfoliation by insolation. Photomicrographs taken of the rock showed no change resulting from the experiments, suggesting that fatigue was not a recognizable factor of rock exfoliation.

Rosenholtz and Smith (1950) determined the linear thermal expansion of marble and Maxwell and Verral (1953) observed that marbles, limestones and travertines showed a permanent expansion on heating even at high pressures. Specimens tested also showed a marked increase in permeability.

The literature on the effects of moisture changes in building stone has not received as much attention as that of other physical measurements. As early as 1881, Schumann (1881) published results showing that some types of natural stones possessed the property of swelling when they were immersed in water. Hirschwald (1912), Matsumato (1921), Stradling (1928) and Bain (1940) drew attention to the same phenomenon.

Stradling's experiments (1928) showed that with materials showing evidence of moisture expansion there was quite definitely a large change in the value of the breaking strength. Although the natural building stones dealt with were mainly sandstones, he observed a change in the stress-strain ratio with varying moisture content.

The ratio of the wet to dry strength is a property used by Hirschwald (1912) who considered water to have a softening effect on stone. He found that there was an expansion of building stones in water.

The importance of moisture effects was further emphasized by Bain (1940) who has shown that uneven wetting will effect warping of marble slabs. The water absorbed on the crystals was interpreted to exert a pressure on the capillary walls resulting in an expansion of the capillary openings on the wetted side that caused warping. The published material on weathering of rocks, and rocks used as building stone, is very extensive. Often weathering problems have been studied and have frequently been discontinued before reaching a stage at which they could be of practical utility.

Merrill (1891) and Reiche (1950) made a survey of weathering processes and products, and Schaffer (1932) as a result of careful studies outlined a systematic analysis of weathering in natural building stones; work which included an accumulation of the knowledge and processes of weathering as applied to limestones and sandstones of Great Britain.

A study of rock weathering by Goldrich (1938) included mineralogical data and presented 14 chemical analyses showing the chemical changes in the stages of rock weathering.

Several papers have been presented on the bending and plastic deformation of stone. Notable are those by Raleigh (1934), Kovelman (1937) and Drewes (1956).

Juravlew's work (1937) contains a summary of descriptive and test data concerning acid-proof stones of the U.S.S.R.

Through the literature are found values for short term crushing strengths. Parks (1912, 1914a, 1914b) recorded a number of tests on Canadian building stones. Most measurements are largely in excess of all ordinary requirements, so that only in extreme cases are such values required. Further, despite precautions, duplicate results have not always been obtained particularly at high pressures and by using different size test pieces.

Summary:

Many of the natural properties of building stone have been measured. Some of the laboratory tests are complicated and time-consuming and fail to yield any definite information. Many of the older measurements and views are only of historical interest. Some practices which are definitely harmful are used without full knowledge of their damaging effects and are sometimes recommended in the periodical literature. Certain rules relating to durability have come down through experience and the observation of aged structures which have tended to validate them.

The method of judging durability by the examination of buildings and structures in which the material has been used has generally been regarded as indisputable. Such information obtained by actual performance in a structure involves much time and personal judgement, and may prove to be extravagant and unsuitable for present day needs. On the other hand, laboratory investigation based on reliable interpretations should provide a rapid means of evaluating a stone's adaptability to a building structure.

Part I. THE ROLE OF LABORATORY STUDIES

The laboratory studies have been made to investigate the relationship between measured properties of a stone and its performance in a structure. The investigations are by no means complete but are designed to show some of the problems of the stone industry in which there are useful and profitable fields for the application of scientific knowledge.

There still remains in the study of building stones a large field to be covered in correlating the behavior of a stone with the physical and chemical properties. New materials of yet unknown behavior are coming more and more into use and some means must be found to estimate their properties. A greater number of studies of this type will give important information for the selection of stone for its proper use and place in a building structure.

ELASTICITY STUDIES

Measurements of elasticity calculated from pure bending tests were made in the laboratory on some igneous building stones. All the tests listed in Table I were made on dry material and at room temperature. Loads were applied rapidly so that time was not a material factor in the test.

There is a considerable variation in the elasticity of the stones measured; not only between separate rock types but between separate specimens of the same rock, cut in different directions relative to the mineral foliation. This behavior of the crystalline aggregates is usually attributed to the initial porosity or intercrystalline spaces and to irregularity in outline of constituent grains. As the pore spaces are closed in compression or opened in tension, the effective cross section changes and this is believed to account for the variation in flexibility and non-linearity of stress with displacement.

Ancillary determinations of pore space, for the stones on which elasticity studies were made, were found to be characteristic for each individual stone. Measurements on a number of duplicate specimens show only small differences for a particular stone. The differences are sufficiently small so as not to have marked bearing on the elasticity of a single rock type.

Specimen Number	Pore Space Percent	Specific Gravity	Young's Modulus Pounds per Sq. in.		Deflection in Inches		Type and Source of Stone
			50 lb. load	70 lb. load	Total	Elastic	
9	0.0225	2.74	3.25×10^6	3.23×10^6	0.0087	0.0059	Anorthosite(New Glasgow)
2	0.0698	2.86	8.21×10^6	8.20×10^6	0.0053	0.0039	Essexite(Mt.Johnson)
4	0.0766	2.87	6.19×10^6	6.46×10^6	0.0056	0.0039	Essexite(Mt.Johnson)
3	0.0840	2.86	4.85×10^6	5.15×10^6	0.0050	0.0031	Essexite(Mt.Johnson)
13	0.1750	2.66	8.11×10^6	8.15×10^6	0.0067	0.0055	Nordmarkite(Mt.Megantic)
7	0.3350	2.76	1.24×10^6	1.20×10^6	0.0250	0.0181	Grey Granite(Riviere a Pierre)
11	0.3830	2.74	3.50×10^6	3.54×10^6	0.0073	0.0045	Rose Granite(Riviere a Pierre)
1	0.4990	2.68	5.25×10^6	5.38×10^6	0.0135	0.0098	Red Granite(Guenette)
5	0.5150	2.64	5.21×10^6	5.10×10^6	0.0152	0.0104	Red Granite(Guenette)
6	0.5250	2.65	2.89×10^6	2.76×10^6	0.0086	0.0065	Red Granite(Guenette)
10	0.6850	2.68	1.59×10^6	1.58×10^6	0.0154	0.00671	Grey Granite(Stanstead)
12	1.0450	2.64	5.68×10^6	5.67×10^6	0.0110	0.0070	Brown Syenite(Rawcliffe)

Table 1. Relation of pore space to flexibility for various igneous rocks.

In general, for igneous building stones, the amount of pore space between the grains shows little relation to Young's Modulus or elastic deflection. Such a comparison could hardly be expected; individual differences in composition, texture or irregularity of grain boundaries would be sufficient for a non-correlation. However for those stones taken from the same stone quarry, elasticity measurements indicate a dependency on the direction of the cut of the stone relative to it's foliation. Furthermore, reasonably good correlation has been found for changes in elasticity and the amount of pore space when dealing with the same material. (Table 2.)

The determination of elasticity is of value in the selection of material best suited for a specified type of structure and for placing the stone with regard to orientation.

The standard test for determining the strength of building stone is by compression to failure of a cube. The method is comparative by making necessary tests on cubes of the same size. Specimens cut in different sizes give widely varying results.

Griggs (1942) finds the shape of the specimen to be unfavourable to high-angle shearing. Stress concentration is produced by the square cross-section, and the effects of friction between the cube faces and the platens of the testing machine are not evaluated.

Kessler, Insley, and Sligh (1940) evaluated the crushing strength of 116 different granites from the principal producing districts of the United States. The deviation of crushing strength for duplicate samples of the same rock using cylindrical specimens was in three cases more than 20 percent, with an average of 7 percent for a total of 58 specimens.

It is frequently pointed out that most stones used for building structures will not fail by crushing, since the crushing strength far exceeds the requirements in a structure. It is sufficient to show that the determination of crushing strength is comparative only and values may be misleading without a knowledge of the conditions under which it was determined.

Specimen Number	Pore Space Percent	Specific Gravity	Young's Modulus Pounds per sq. in. 50 lb. load	Young's Modulus Pounds per sq. in. 70 lb. load	Deflection in inches Total	Deflection in inches Elastic	Type and Source of Stone
1	0.4490	2.68	5.25×10^{6}	5.38×10^{6}	0.0135	0.0098	Granite (Guenette) cut parallel to foliation
5	0.5150	2.64	5.21×10^{6}	5.10×10^{6}	0.0152	0.0104	"
6	0.5250	2.65	2.98×10^{6}	2.76×10^{6}	0.0086	0.0065	Granite (Guenette) cut normal to foliation
2	0.0698	2.86	8.21×10^{6}	8.20×10^{6}	0.0053	0.0039	Essexite (Mt. Johnson) cut parallel to foliation
4	0.0766	2.87	6.19×10^{6}	6.46×10^{6}	0.0056	0.0039	"
3	0.0840	2.86	4.85×10^{6}	5.15×10^{6}	0.0050	0.0031	Essexite (Mt. Johnson) cut normal to foliation

Table 2. Relation of pore space to flexibility for granite and essexite. Beam cut mutually at right angles to the mineral foliation.

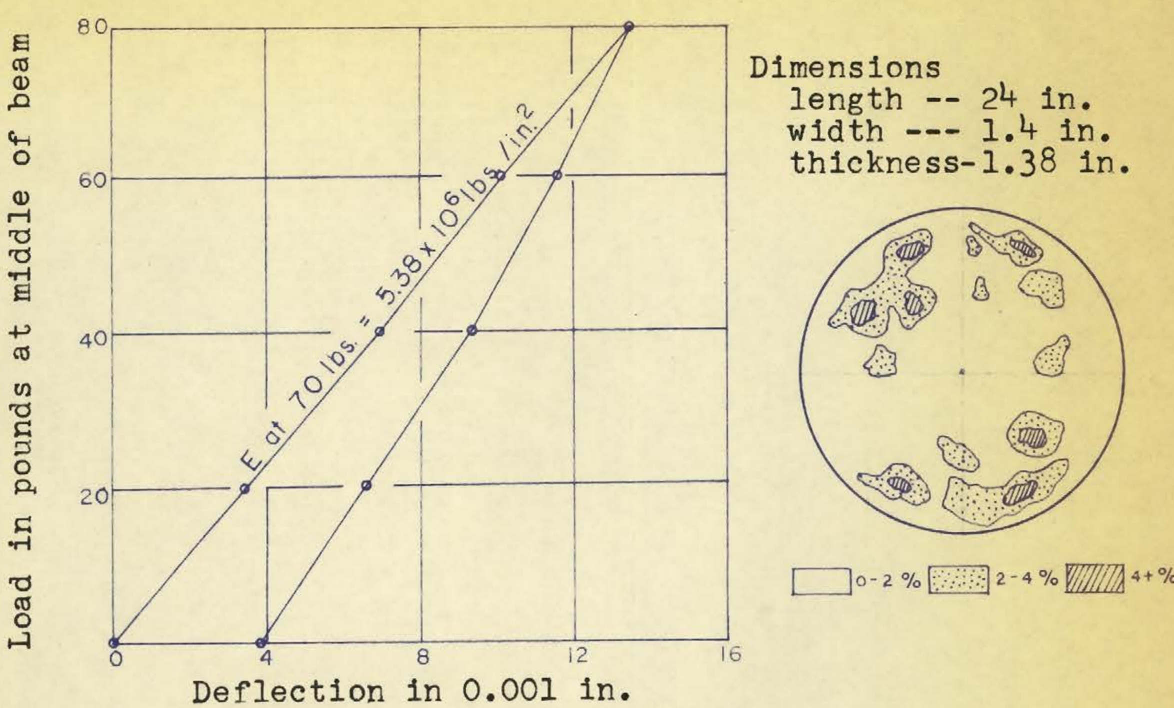


Fig. 1. Load deflection curve for test on Guenette granite in flexure. An orientation diagram for c-axis of quartz crystals, normal to length of bar is inset at upper right.

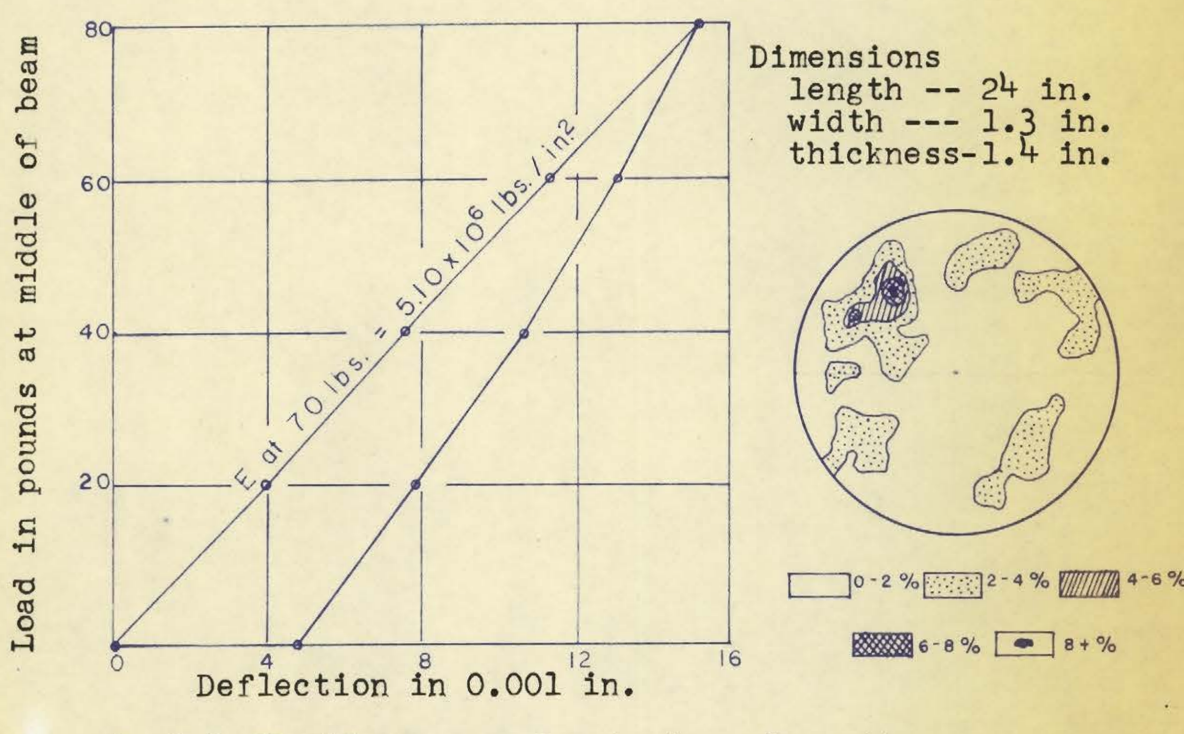


Fig. 2. Load deflection curve for test on Guenette granite in flexure. An orientation diagram for c-axis of quartz crystals, normal to length of bar is inset lower right.

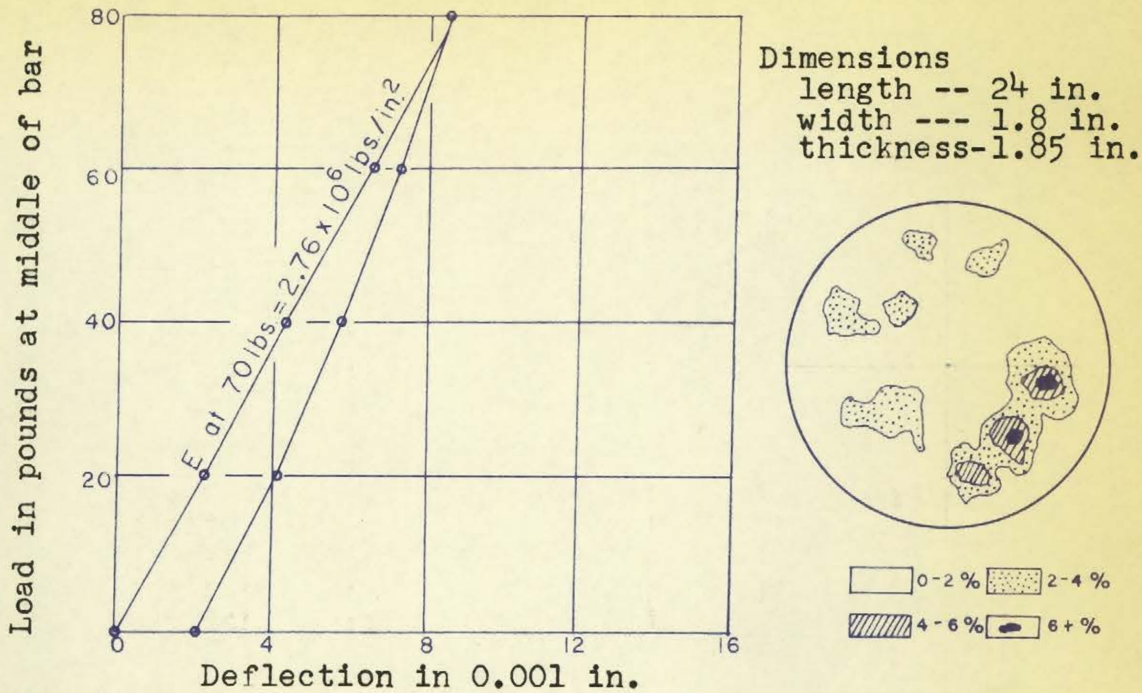


Fig. 3. Load deflection curve for test on Guenette granite in flexure. An orientation diagram for c-axis of quartz crystals, normal to length of bar is inset at upper right. Beam length normal to foliation.

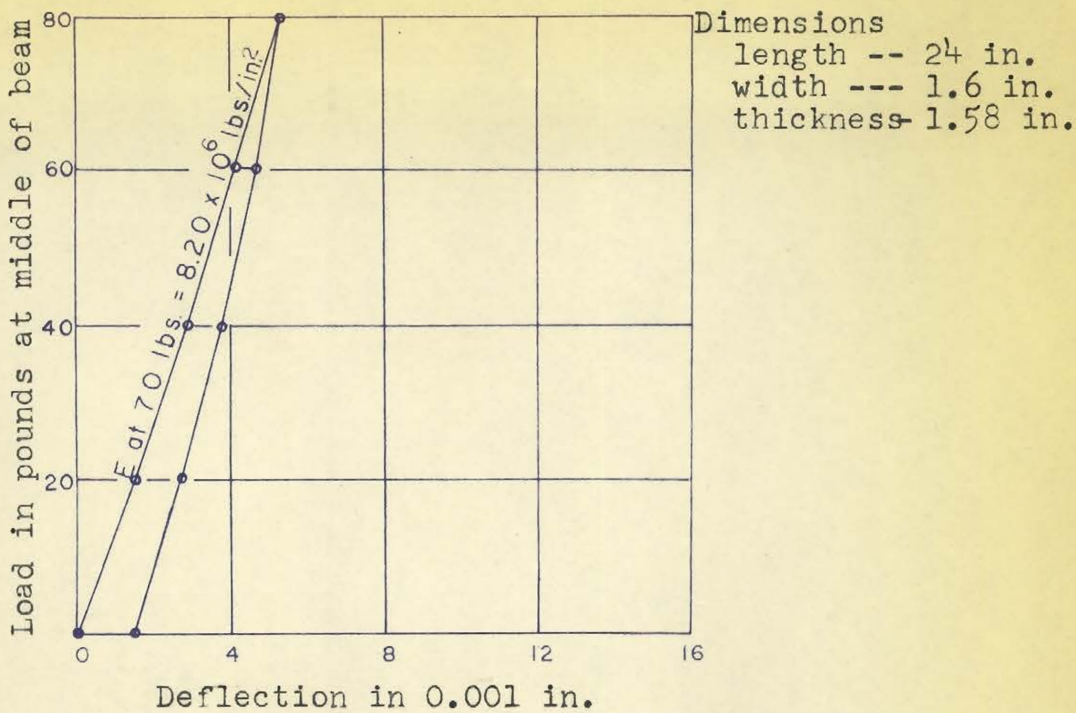


Fig. 4 Load deflection curve for test on Mount Johnson essexite in flexure.

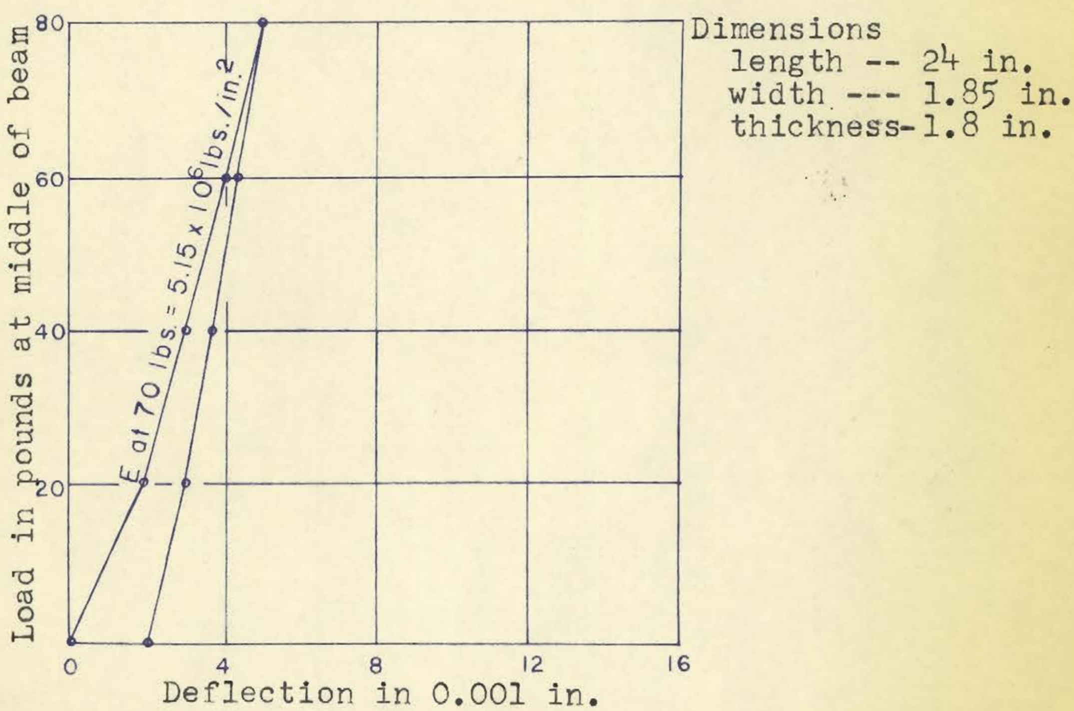
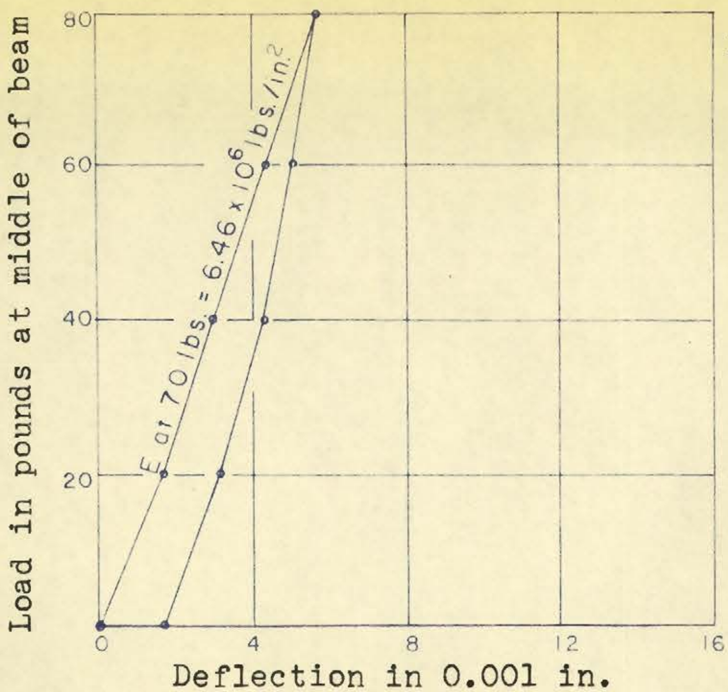
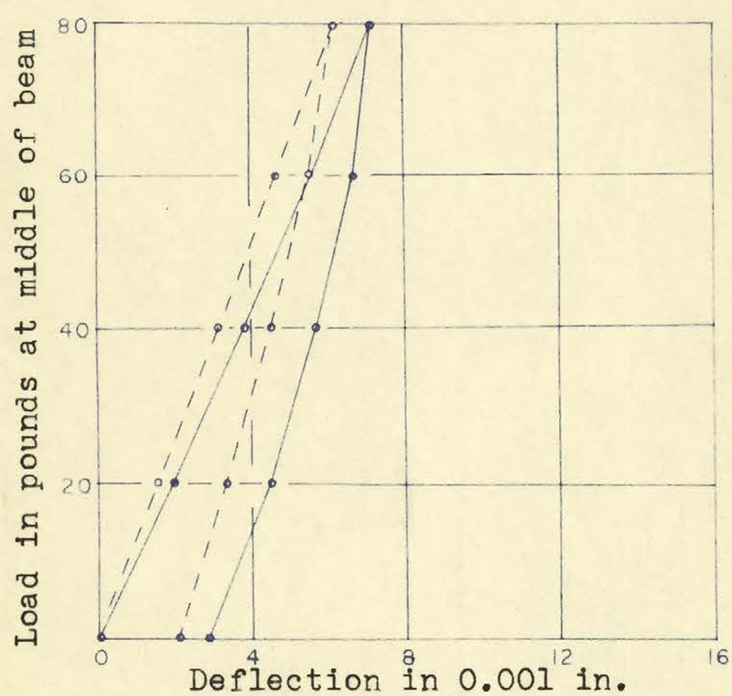


Fig. 5 Load deflection curve for test on Mount Johnson essexite in flexure.



Dimensions
length -- 24 in.
width --- 1.6 in.
thickness-1.68 in.

Fig. 6. Load deflection curve for test on Mount Johnson essexite in flexure.



Dimensions
length -- 24 in.
width --- 1.78 in.
thickness-1.8 in.

Initial bending ____
Beam inverted ----

Fig. 7. Load deflection curve for test on Riviere a Pierre (Dumas) granite in flexure. Inversion of the bar shows a decrease in the permanent distortion under load.

Effects of Salt Solutions on Building Stones

Tests using sodium sulphate solutions were initially proposed by Brard (1828) to simulate and augment the stresses believed to be produced by the action of frost on building stone.

The measuring of the effects of crystallization of salts in the pores of materials was assumed to give a measure of resistance to natural frost action. Gerber (1890), and Luquer (1895) investigated the relation between the sodium sulphate and the freezing method with a duplicate series of specimens. The measure of comparison of the tests was based on the loss of weight of the specimen. One specimen was boiled for one-half hour in saturated sodium sulphate solution and allowed to dry for 12 hours. A duplicate specimen was soaked in water and allowed to freeze at temperatures of 4° to 10° F. with thawing at 85°F. A comparison of the loss in weight of duplicate samples indicated the effect of sodium sulphate crystallizing in the rock pores to be most energetic in effecting a disintegration of the stone, while the effect of freezing was hardly noticeable.

Since the method was proposed to replace freezing tests, it was concluded that no definite relationship existed and that the sulphate method should be abandoned in favor of the actual freezing tests. Kessler, Insley and Sligh (1940) performed similar experiments. They subjected 14 different samples of granite to 5000 cycles of freezing at -12°C. for 6 hours, and thawing in water at 20°C. for 1 hour. Under this treatment the specimens showed no visible signs of disintegration. When 79 granite specimens were soaked 17 hours in saturated sodium sulphate and dried for 7 hours at 105° C. some granites were found to fail after 14 cycles. The average was 42 cycles.

The common philosophy held that frost was the most powerful agent in bringing about disintegration of building materials. Recent work by Russell (1929) and Quervain (1946) has indicated however, that in a number of cases, damage attributed to frost, was in fact believed to be caused by other agencies such as the crystallization of various salts, sodium sulphate and calcium sulphate producing the most vigorous results. Earlier, Lucas (1915) attributed much of the decay in building stones in Egypt to salts. The salts were found to consist largely of sodium chloride and sodium sulphate, though sodium carbonate and nitrates of the alkali metals were sometimes present.

Kessler, Insley and Sligh (1940) believed the cause of scaling of granites to be due to the action of acids of sulphur on calcite ingredients in the stone. They also suggested that sodium sulphate crystallization tests may give an indication of the relative resistance of different granites to weathering caused by the crystallization of water soluble salts in the pores.

The theories advanced to explain this form of scaly weathering in granites were: (1) Injury was presumed to have occurred during fabrication making the stone less resistant to frost action. (2) The formation of gypsum developed by the action of sulphurous or sulphuric acids on calcium carbonate originally present in the rock. The increase in volume required for gypsum could cause internal stress leading to scale weathering. (3) The sulphur dioxide in the air could form acids in the presence of moisture. A 10 percent solution of sulphuric acid leached through granite specimens would cause disintegration in 30 to 90 days producing an alteration in biotite. (4) Portland cements used as mortar had 4 percent of gypsum by weight and a 1.3 mortar would contain about 1 percent of gypsum, an amount sufficient to fill the pores of an average granite. A leaching and concentration on the surface might lead to or cause scaling.

The Department of Science and Industrial Research, Building Research Board (1927) (1936) have performed a number of laboratory experiments in which they have been able to reproduce surface skins and blisters on limestone and magnesian limestones such as occur on exposure to the atmosphere. They found that where stone was exposed to the washing action of rain water, the deposit forming the surface skin was washed away.

Surface skins have also been reproduced in the laboratory by Kaiser (1910), by exposing specimens to sulphur dioxide. Quervain (1946) performed experiments with alternate soaking of different rocks in a 10 percent solution of sodium sulphate and drying at 100° C. He observed surface scaling, and by chemical examination of the cube samples there was found to be an increase in sulphate content nearer the surface than towards the center of the cube. Prior to scaling, the content of the water-free sodium sulphate (Na_2SO_4) in the border zone was so great, that at the next soaking the volume of the water containing sulphate ($Na_2SO_4 \cdot 10H_2O$) exceeded the volume of the rock pores. The pressure apparently exceeded the tensile strength of the rock and produced sudden scaling on all sides of the cube.

Merrill (1910) gives an example in which prior crystallization tests revealed the relative durability of two stones used in actual buildings. They were found to bear a similar relative durability after exposure to the atmosphere. Since the two stones differed in density, and the most dense stone underwent the least disintegration, he regarded the more dense stones as having the greatest durability.

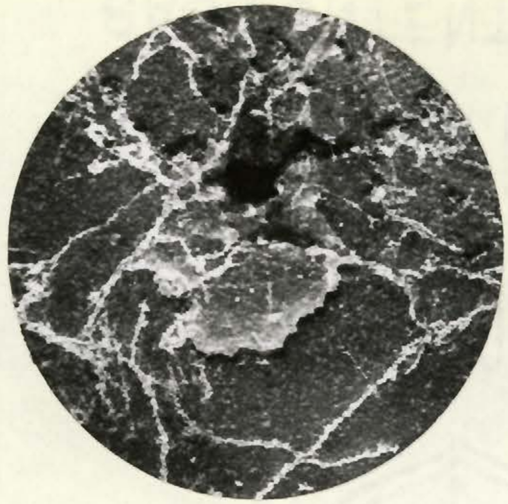
Observations and tests performed by the writer indicate that the porosity of a stone and the bonding of the grain contacts largely determine the degree of attack and resistance to the effects of salt solutions. A physical rather than chemical action is more in evidence where the lifting of fragments from the surface can be observed. One of the main difficulties in evaluating the damage due to salts is that the process is relatively slow but effective and continuous; in some cases it may result in the separation of small fragments but this can be detected only on close observation. Salt solutions do not effect all parts of a stone equally. In some cases roughing and scaling takes place along edges adjacent to mortar joints; in others it will occur as a central zone on the surface of a large block, or beneath lintels where efflorescence is not removed by rain water.

Observations show that roughing and scaling occur on both the exterior and interior of some Canadian buildings. The scaling appears on the surface of the stone as convex expansion shells or blisters with a thickness of about 2 to 5 millimeters and in some cases the diameter of the blister is as much as 3 centimeters across. The blisters have a hollow interior which indicates that the blistering is due to an expansion of the thin surface skin rather than to the growth of crystals beneath the skin. When the blister becomes loosened and is removed by the washing action of rain water it leaves a pitted and irregular surface with a roughened appearance compared to the original finished stone.

The tendency toward scales or blisters varies with different stones and appears to be somewhat selective. Roughing has been observed on different parts of a stone face, but is most apparent along the edges of a stone and adjacent to mortar joints. Studies show that those stones which become roughened by scaling of the outer surface have a greater available porosity while those stones which are more weather resistant have narrower intergranular spaces.

A number of granites used for building stone were alternately soaked for 12 hours in a 10 percent solution of the following salts: sodium sulphate, magnesium sulphate, calcium sulphate and potassium nitrate, and were dried for 12 hours at 80° C. The sodium sulphate solution produced the most noticeable effects on the stones. A minimum of 15 cycles of soaking and drying caused hydration and swelling of biotite mica and alteration to chlorite. Limonite appeared around olivine grains and pitting occurred surrounding some ferromagnesian minerals. The mechanical separation and removal of fine granular material around amphiboles represent initial stages in breaking the bonding of the crystal grains (Photo 3). The salts become concentrated along the borders of crystal grains or tiny discontinuous seams or fractures and widen the openings. When the stones are immersed in the solution, abundant small air bubbles emerge from the tiny fractures, indicating that the solution has penetrated the fractures to a greater depth and widened the openings. The actual lifting of feldspar flakes from the surface takes place; with each cycle the fragment is lifted an additional amount, until it becomes separated from the rock. (Photos 2a, b, c, d).

a.



58 Cycles

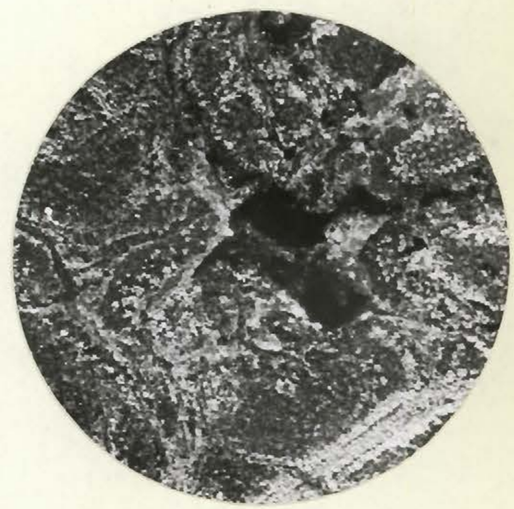
b.

59 Cycles

c.

60 Cycles

d.



61 Cycles

Photograph 1.(a,b,c,d.)

Rock specimen of syenite after treatment with a 10 percent sodium sulphate solution. Note stages in the removal of a feldspar fragment. With each additional cycle (wetting and drying) the fragment is separated by small increments until it is completely removed. (Mag. 15x).

Photo. 2 .

39 Cycles

Photo. 3 .

45 Cycles

Photo. 4 .

55 Cycles

Rock specimens immersed in a 10 percent solution of sodium sulphate and dried for a number of cycles.

Photograph 2. Widening of minute fractures across a feldspar grain in granite.

Photograph 3. Loosening of the fine grained aggregate surrounding amphibole crystal in granite.

Photograph 4. Concentration of hydrated salt along fractures and widening of openings in syenite.

The hydrous sodium sulphate ($Na_2SO_4 \cdot IOH_2O$) is stable up to 32.38° C. and above this temperature the stable form is Na_2SO_4. That is, above 32.38° C. the solid phase in water solution is the anhydrous form. Below 32.38° C. the decahydrate $Na_2SO_4 \cdot IOH_2O$ is present. The maximum solubility is at the 32.38° C. transition point where the salt melts in its water of crystallization. The two forms differ in physical properties, volume and density. The decahydrate ($Na_2SO_4 \cdot IOH_2O$) has a specific gravity of 1.46, while the anhydrous form has a specific gravity of 2.70.

In order for the salt to be an effective cause in disrupting mineral grains or surface skins, alterations should take place between dry air above 32.38° C. and moist air below 32.38° C. Theoretically a volume increase is expected when the anhydrous form of the salt becomes hydrated by the addition of moisture.

The method of alternate soaking and drying in a solution of salt is time-consuming and is somewhat drastic as a means of testing a stone. In addition, the temperature for drying is much in excess of that found under natural conditions.

The apparatus Fig. 8 was designed so that changing moist or dry air conditions could be circulated around test pieces that were saturated with the salt, sodium sulphate. To assure complete pore filling of salt solution it was introduced under vacuum at 38.38^{o}, the temperature of maximum solubility in water. The temperature within the specimen container could be alternated between 20^{o} and 50^{o} C.

Stone samples were subjected to alternate dry and moist circulating air with temperature changes between 20^{o} and 50^{o} C. for a period of 80 days. Each cycle continued for a 24 hour period. Those stones showing the greatest weight loss can be observed in actual buildings to have undergone serious scale weathering and roughing after a period of 30 years.

Table 3 shows the relation between the percent weight change and the percent available porosity on some igneous building stones treated with sodium sulphate. The relation is also shown in graphical form, Fig. 9. The samples of nordmarkite and essexite

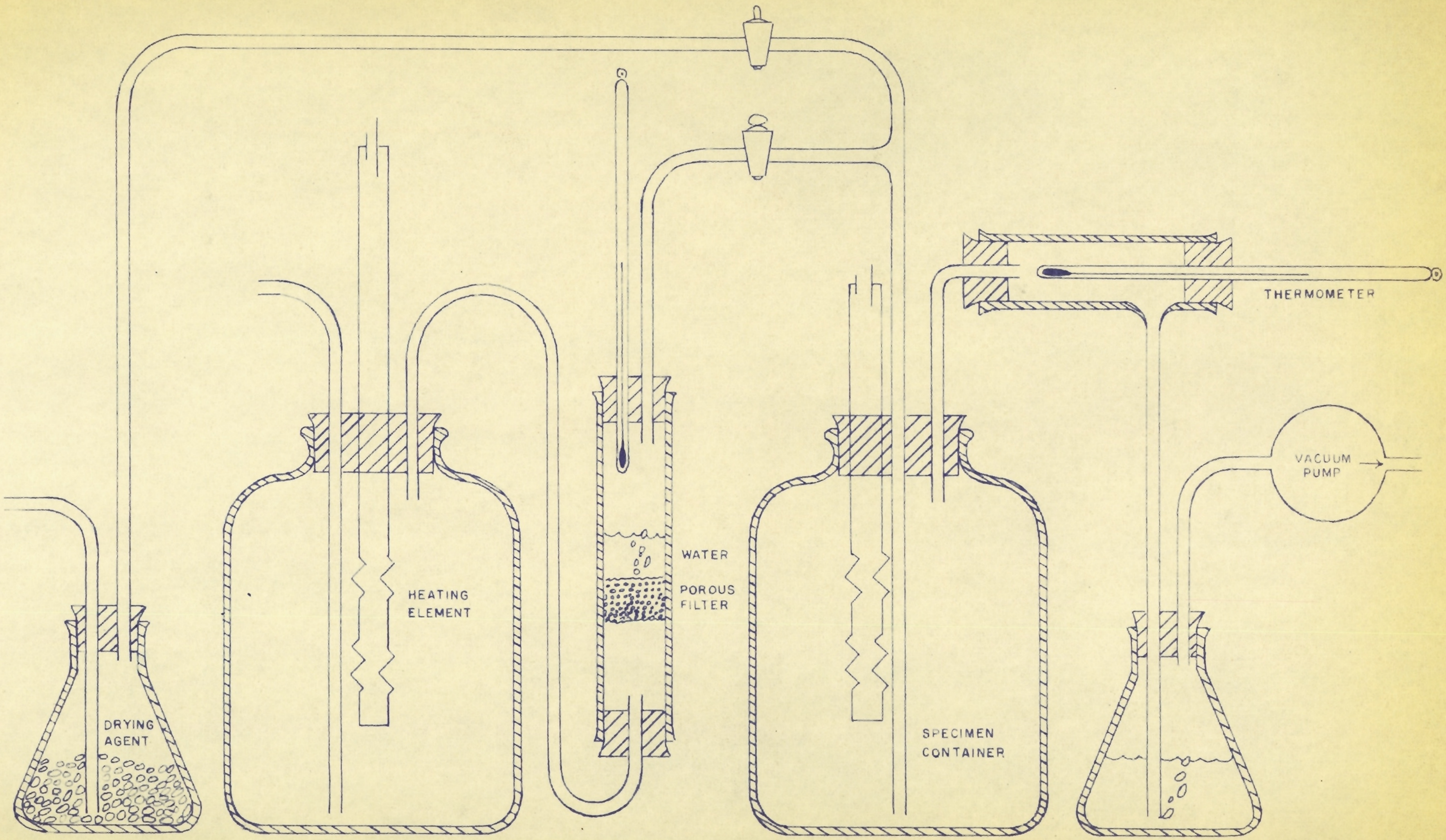


Fig. 8 Apparatus for changing moist or dry air conditions on test pieces.
(a) Specimens are first dried to constant weight to remove water from pores.
(b) Specimens placed in saturated sodium sulphate solution and evacuated to remove air from pores.
(c) Vacuum removed and normal air pressure forces saturated solution at 38.3°C. into pores.
(d) Rock specimen weighed to determine increase in weight due to sodium sulphate in pores.
(e) Rock specimen placed in container.

Type of Stone	Source of Stone	Percent Available Porosity	Percent Wt. Loss After Treatment With Na_2SO_4 and 80 Days in air Bath	Specific Gravity
Medium-grained dark gray biotite granite	Riviere a Pierre Scotstown Quarry	0.335	0.0374	2.76
Coarse-grained rose grey biotite granite	Riviere a Pierre Dumas Quarry	0.383	0.0968	2.74
Fine-grained pink biotite granite	Guenette Brodies Quarry	0.515	0.1141	2.68
Medium-grained light grey biotite granite	Stanstead	0.681	0.1681	2.68

Type of Stone	Source of Stone	Percent Available Porosity	Percent Wt. Gain After Treatment With Na_2SO_4 and 80 Days in air Bath	Specific Gravity
Medium grained green nordmarkite	Mount Megantic Scotstown Quarry	0.175	0.2280	2.66
Medium grained dark grey essexite	Mount Johnson Brodies Quarry	0.0840	0.0210	2.87

Table 3. Relation between the effect of the salt sodium sulphate, and the percent available porosity on some igneous building stones.

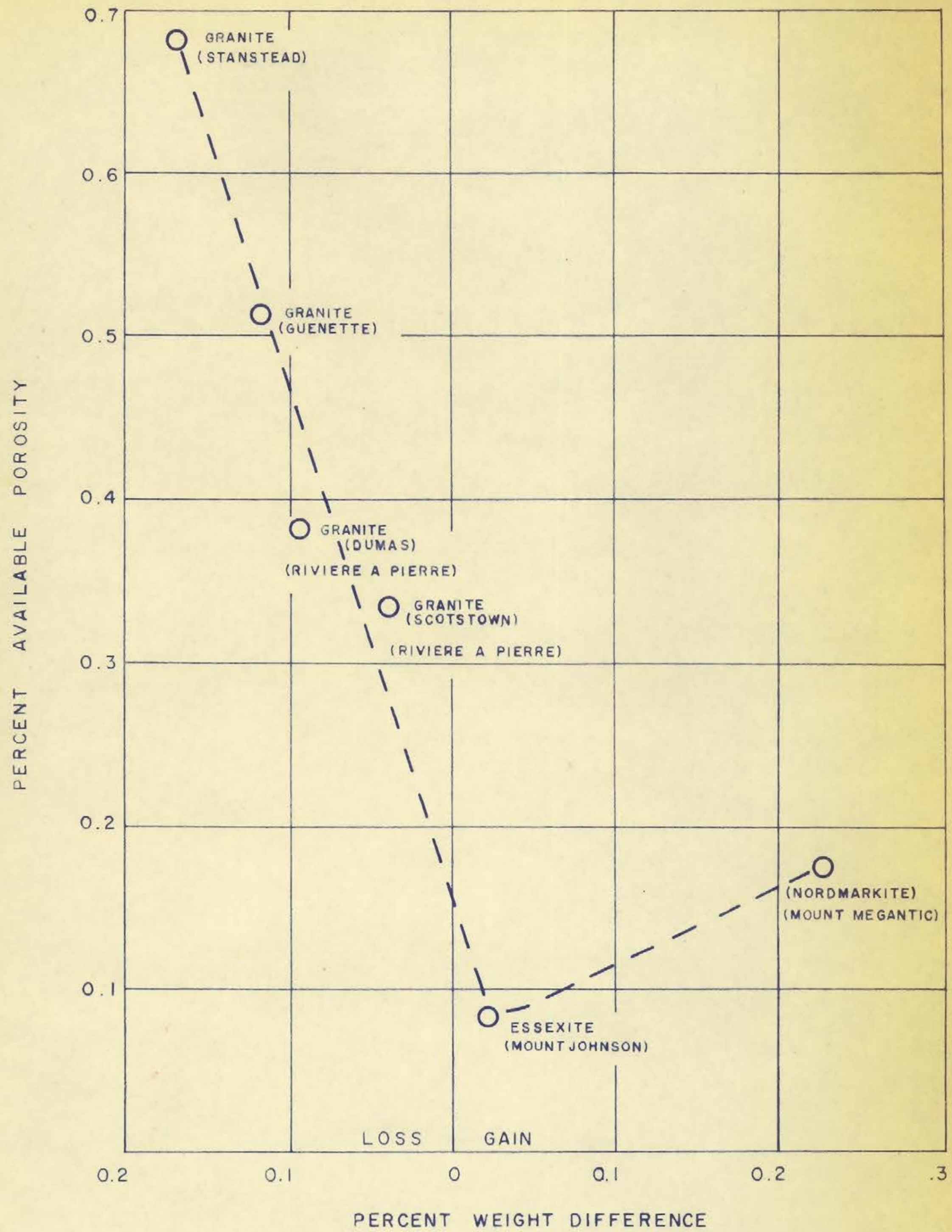


Fig. 9. Percent weight difference plotted against available pore space for some test blocks. The pores were filled with sodium sulphate and exposed to alternate dry and moist air in a constant air stream for 80 days.

show a gain in weight. This weight gain is attributed to oxidation of ferrous oxide to ferric oxide or hydrated ferric oxide and is believed to be in excess of a weight loss by mechanical fragmentation. A number of conclusions can be reached on the use of crystallization tests as a measure of durability of building materials. Sodium sulphate crystallization tests have been shown by Gerber (1890) Luquer (1895), and Kessler (1940), to have no direct correlation with actual freezing tests. The crystallization of sodium sulphate and freezing of water in the pores of a stone are not comparable in that they are entirely different medium. The method is then unsatisfactory as a means of testing the frost resisting properties of a stone. In addition, actual freezing tests on building stones are at present unsatisfactory due mainly to the different results found on freezing one face and the whole stone, and inability to assess the actual damage due to frost alone. As yet there has been no satisfactory explanation of the discrepancies that are observed between the effects of freezing under natural and artificial conditions or why some winters will produce more harmful effects than others.

Crystallization tests may show a correlation between laboratory tests and natural disintegration in building structures in that it may be possible to pick out poor material without differentiating between the moderate and the good.

The effect of salt solutions in a particular stone is due to a combination of circumstances which include, among others, the width and distribution of openings and the mechanical strength of the material.

A direct evaluation of the structural factors is difficult, yet any test which correlates significant factors in a general way is useful. The tests with salt solution of sodium sulphate seem to provide this correlation, and the test tends to reproduce in the laboratory a type of disintegration similar to that which occurs in natural exposure.

Moisture Effects on Building Stones

Schumann (1881) was one of the first to recognize that some types of natural stones possessed the property of swelling when they were immersed in water.

Such tests were noted later by Hirschwald (1912) in his comprehensive book on the testing of building stones. In 1921 Matsumato (1921) published a paper drawing attention to the same phenomenon. Although he made measurements on one or two building stones, his work applied mainly to plain and reinforced concrete. Stradling (1928) in somewhat more detail studied moisture effects on some building materials and performed some physical measurements on limestones and cements. In 1940, Bain (1940) described the warping effects caused when marble slabs are wetted on one side, and recommended using elastic marble to reduce warping.

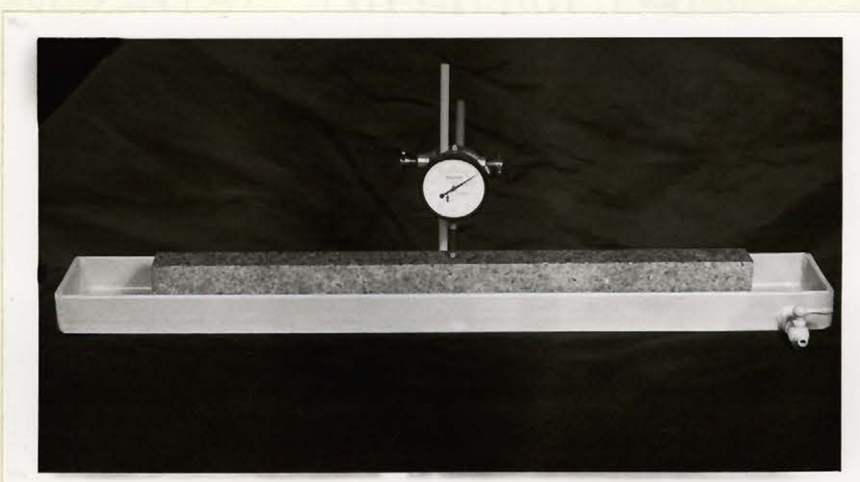
A study of the crystalline igneous stones used as building material in eastern Canada show that a variation of the moisture content within the pores produces important changes in the physical properties of the stone. Experiments have indicated that water alone produces physical changes and acts not merely as a transfer of corrosive solutions and a medium for frost action but involves a physical interaction between water and mineral solids of the rock.

Measurements of the effect of water have shown that (1) Unequal expansion occurs with unequal wetting. By wetting slabs of igneous rock on one side only, warping stresses are developed which result in a slow but continuous bending movement. The stone tends to maintain an equilibrium with water when saturation is nearly complete. (2) A permanency of warp occurs after evaporation of the water. Repeated wetting and drying of the same slab for a number of cycles show an increase in the amount of warp and permanency with each cycle. (3) When water wets one face of a stone slab, creep measurements increase sharply and the stone shows a marked decrease in strength.

Warping Measurements with Unequal Wetting

Measurements of warping with unequal wetting were carried out on various igneous rocks. Some typical curves are given in figure (13). The apparatus used for the wetting warping measurements is shown in photograph (2.).

In figure 10 a typical curve is plotted showing the warping of a granite beam supported at its ends and wetted at its base. Deflection is measured at the central part of the beam. Initial downwarping takes place rather rapidly to a maximum. At this point the water has reached, presumably, midway up the bar. The stone then warps upward as the stone nears saturation, and the movement ceases. Removal of the water results in a rapid but small upwarp, followed by a similar downwarp and levelling off to give a permanent warp to the stone. Movement of the beam is almost continuous during the stages when the water is either being absorbed or evaporated from the stone. Increasing the temperature of the water produces essentially a similar type of curve but with greater maximum bending.



Photograph 5. Wetting, warping apparatus.

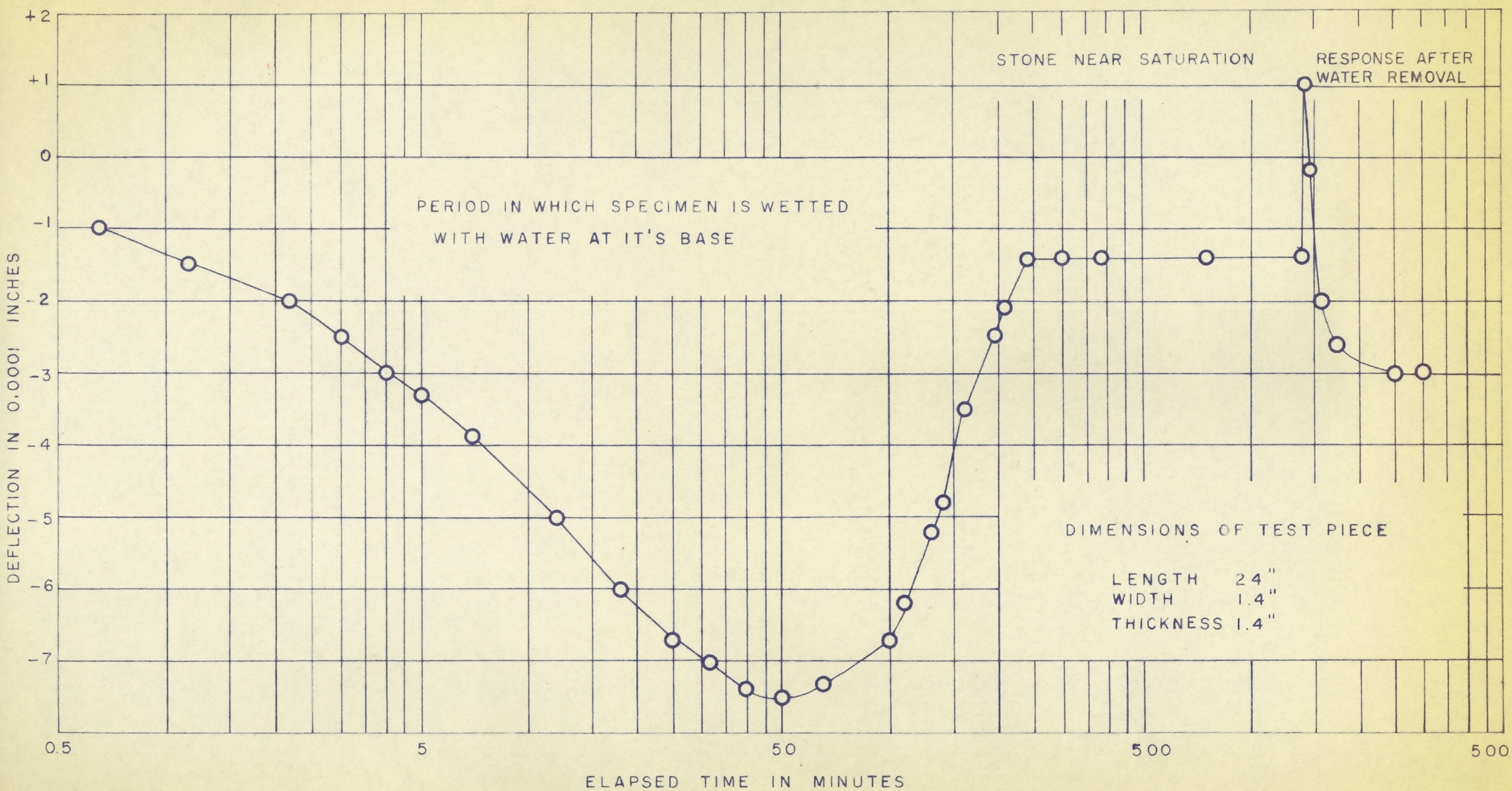


Fig. 10. Typical curve showing the warping of a granite beam supported at its ends and wetted at its base. Deflection is measured at the central part of the beam.

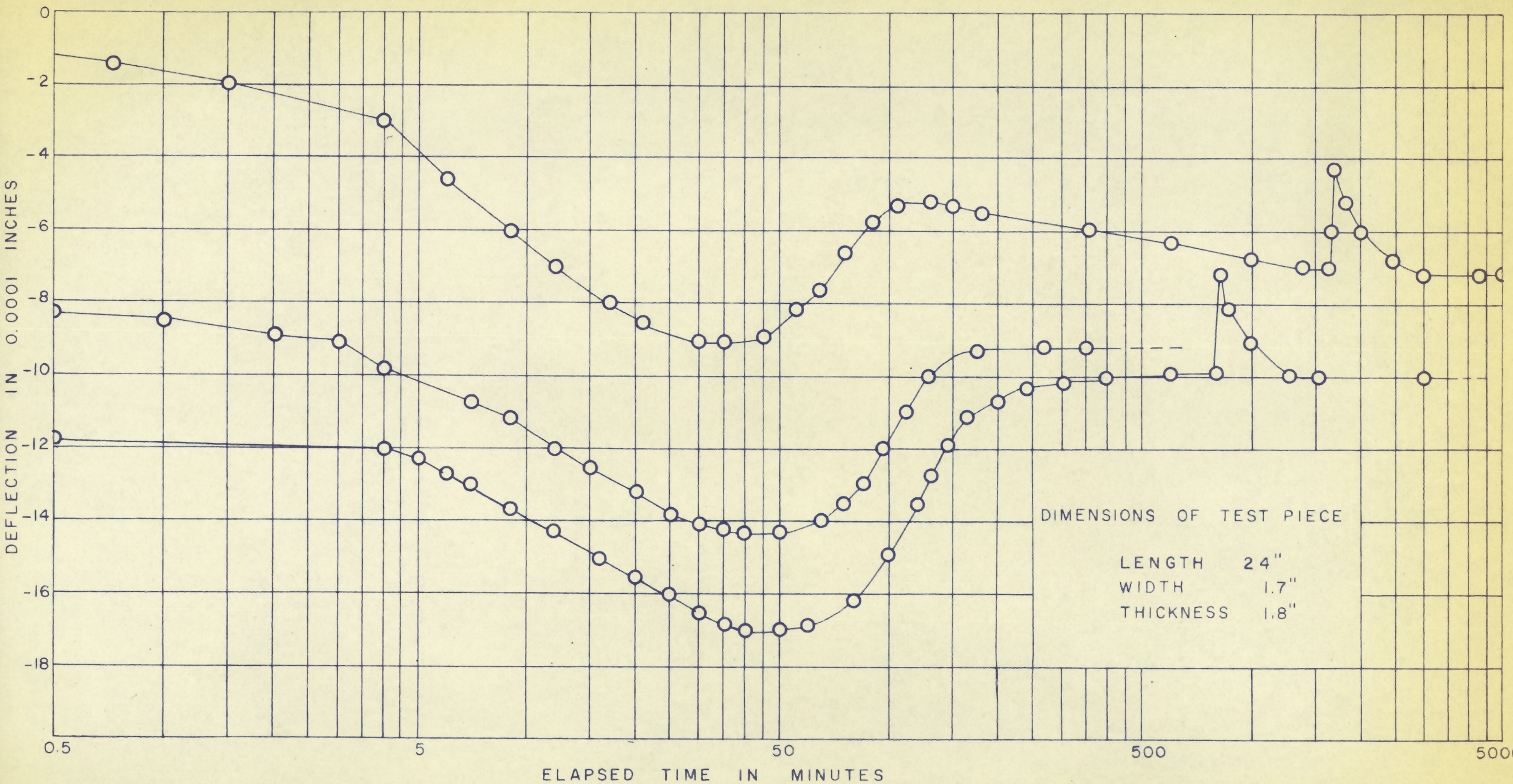


Fig. 11. Warping curves for repeated wetting and drying for three cycles of the same granite beam. Each cycle extended over a period of eighty hours.

Figure 11 illustrates curves for repeated wetting and drying for three cycles of the same granite beam, each cycle extended over a period of more than 80 hours.

With each cycle there is an increase in the amount and permanency of warp. Of all the rock specimens tested only one showed evidence of considerable creep under its own weight when supported at its ends. This specimen was a beam of essexite, cut so that its length was normal to the plane of foliation. Figure 12 shows the plotted values for this beam supported in a watertight tray. Deflection was measured at the mid-portion of the bar to the nearest 0.0001 inch. The specimen was allowed to creep under it's own weight for 11 days, after which there was no deflection for 19 hours. Wetting of the base to a height of 1/8 of an inch resulted in a small but rapid upwarp at the mid-section of the beam, followed by a rapid downwarp that decreased gradually for 40 hours after removal of the water from the base. The presence of water had the effect of increasing the amount of warp by at least 75 percent as compared to that of creep alone. The removal of the water did not result in a partial return of the warp as was found to occur in the other specimens tested.

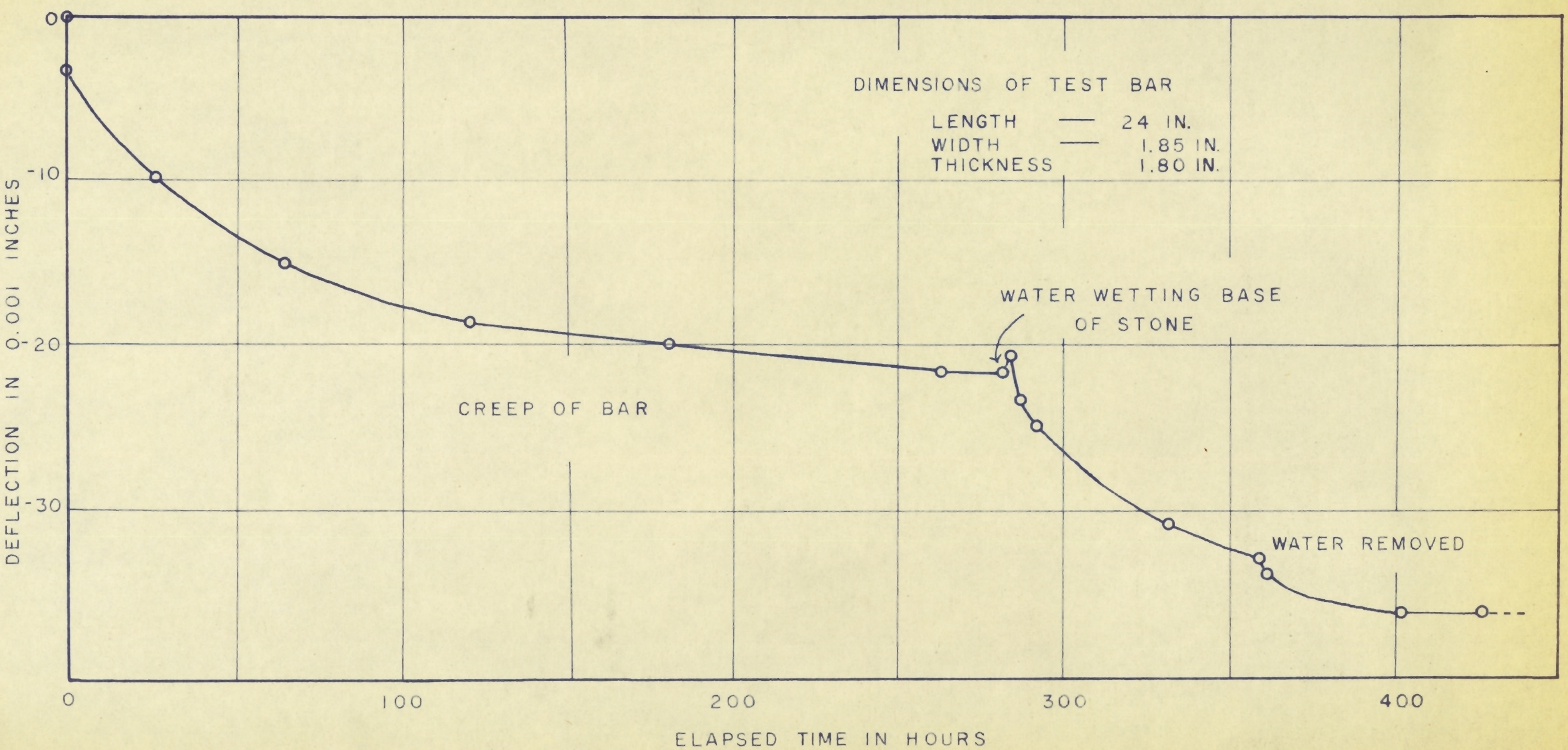


Fig. 12. Creep curve for beam of essexite under its' own weight when supported at its' ends. The length of the bar is normal to the plane of foliation. Water wetting the base shows rapid increase in the amount of creep.

Loss of Strength of Natural Building Stones in the Presence of Water

An experiment showing the decrease in strength of a granite beam in flexure is shown in Figure 14. A small load of 80 pounds applied to the mid-portion of a beam supported at its ends was allowed to creep until the bending movement measured at the mid-portion was small for a long duration. Water permitted to penetrate the stone along the base resulted in a notable decrease in the strength of the material and its ultimate rupture in an almost equivalent length of time as the creep tests. The experiment repeated with a beam of the same granite and of the same dimensions produced correlative results. These experiments demonstrate the dependence of strength of building materials on time and in the presence of water when under stress.

The part played by water in effecting a physical deformation in the experimental stone beams is believed to be due to adsorbed water that produces a swelling of the solid. Surface forces of absorbed water may have contributed to the deflection of the bar, particularly water adsorbed on the walls of cavities within the grains of the crystalline aggregate, or on the exteriors of grains.

A capillary force in the spaces within grains and in spaces between separate grains may also contribute to the bending movement. Such forces may explain the physical deformation when there is an absence of any marked temperature changes. A temperature increase in the water produces essentially a similar type of curve but with greater maximum bending. The bending in this case is attributed to a temperature expansion rather than to capillary or adsorption forces. Quite generally the adsorption and surface tension should decrease with a rise in temperature. Although the stones tested all have a low porosity, less than one percent, it is expected that there is a relatively free passage of water or water vapor through the interconnected pores for at least a thickness of 3 to 5 millimeters. Any rigid gels contained in the stone would absorb water vapor resulting in a swelling of the gel, effecting a considerable mechanical constraint on the water and the stone. The mechanical constraint would exert a hydrostatic pressure on the absorbed water effecting movement in the stone.

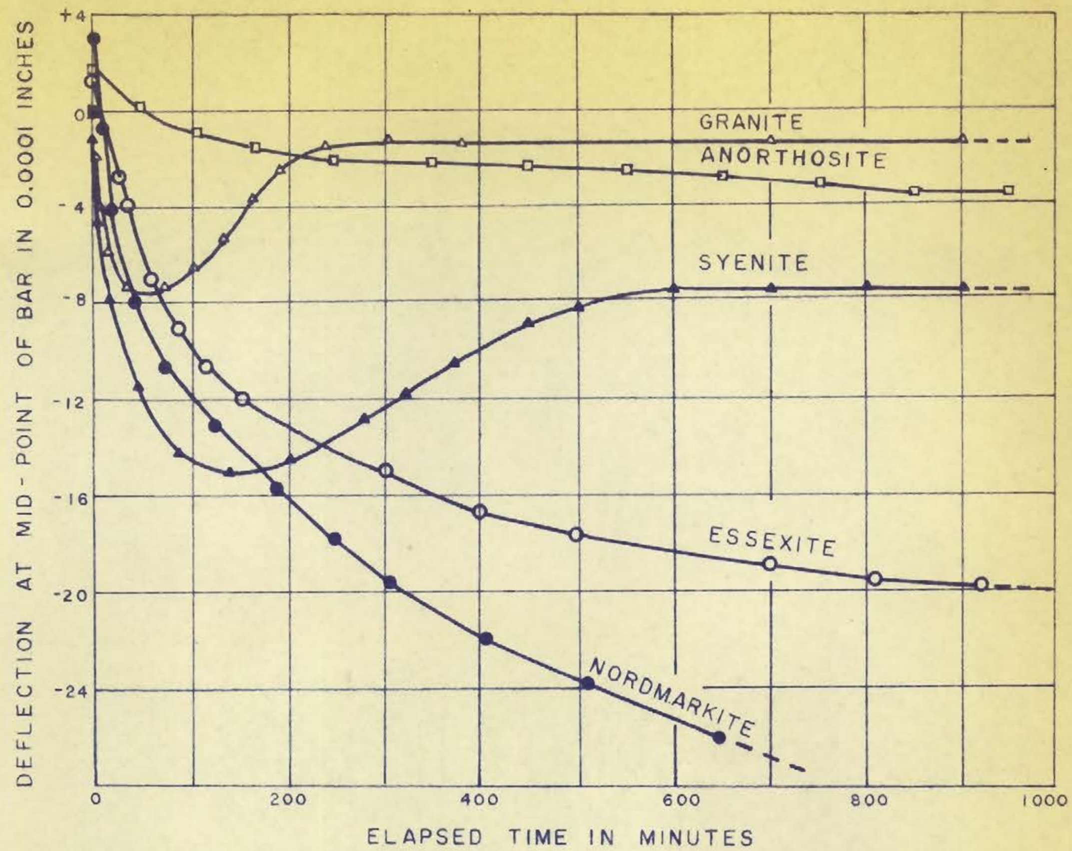


Fig. 13. Warping curves for various igneous rocks when wetted on one side only.

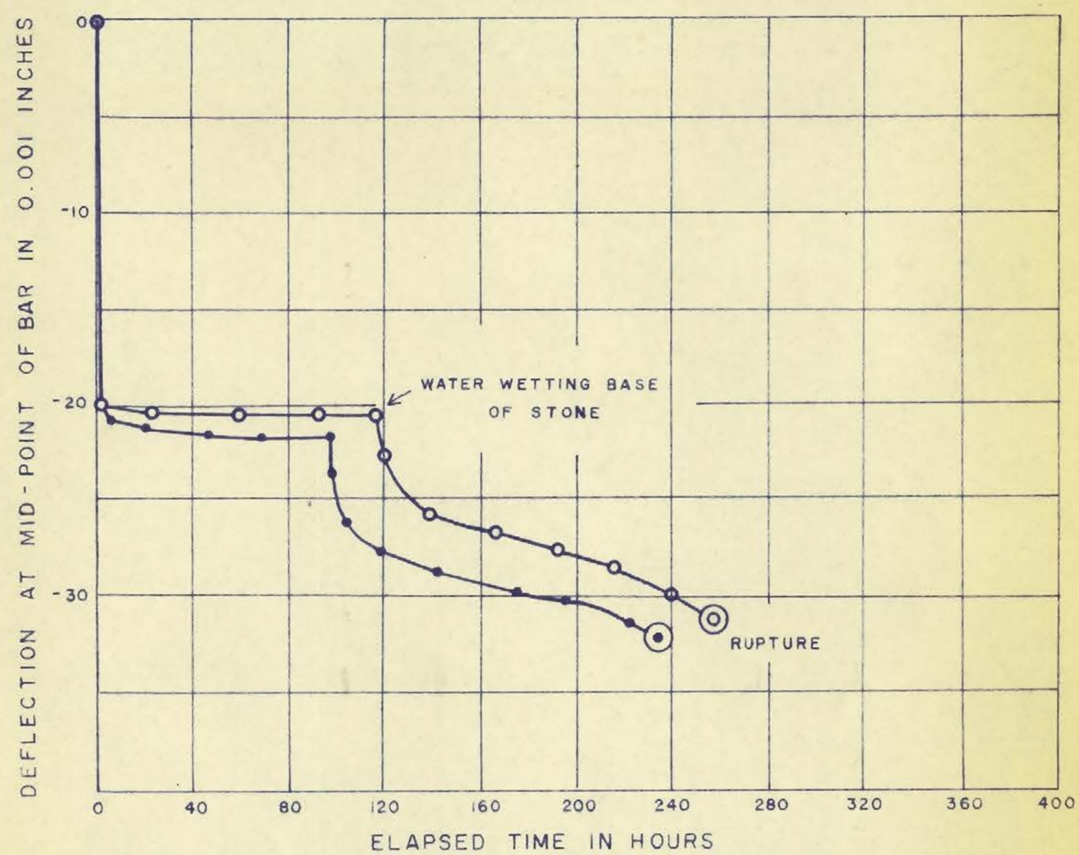


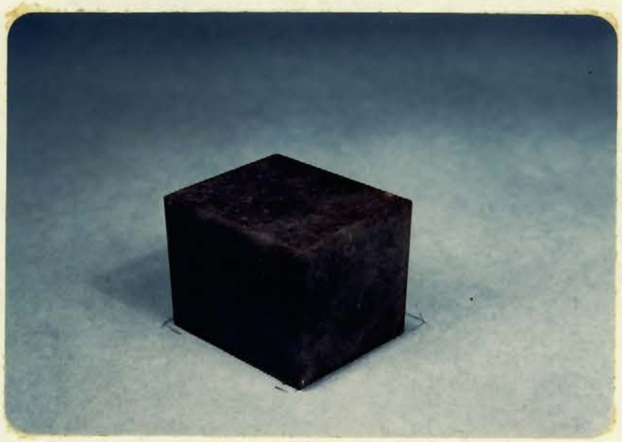
Fig. 14. Creep curves for duplicate granite bars supported at their ends and each under a load of 80 lbs. The abrupt change in the curves show the effect of wetting the base of the bar and resulting in the ultimate rupture of the stone.

Petrographic Description of Test Pieces

Rock Name: Anorthosite

Location: New Glasgow, L'Assomption, Quebec.

Contributor: Scotstown Granite Company Limited.



Macroscopic Description

The stone is a fine grained dark, greyish-green anorthosite. There is a fairly regular distribution of banded and elongated dark areas that alternate with the reflected green light from the felspar. Throughout the rock, tiny crystal faces of the felspar reflect a pleasing bluish opalescent color from beneath the polished surface. Observed at certain angles the polished surface shows silvery glints which are due to the reflection from magnetite grains. Other than the presence of the dark parallel bands that presents a certain clouded appearance to the rock, the mixture is fair. The stone takes a good polish. Only one small grain of pyrite was observed in the polished specimen examined. There is considerable magnetite and other ferromagnesium minerals present.

Microscopic

The stone is holocrystalline, allotriomorphic and equigranular. There is a predominance of nearly equidimensional plagioclase grains. The grain size measured across the grain averages 0.3 millimeters. There is a marked linear arrangement of dark minerals that include hypersthene, augite, hornblende and magnetite. These minerals too, are granulose. The rock is a cataclastic, a metamorphic structure resulting from crushing and granulation of the minerals. There seems to be no orientation attached to the felspars.

Minerals Present

Plagioclase felspars:

The plagioclase felspar exists in anhedral grains and make up over 90 percent of the rock. The felspar is ~~labradorite~~ oligoclase with an anorthite content of An (25-30). The crystals form a granulose mosaic in which the grains average 0.3 millimeters. The grains observed under the microscope are generally clear and show no alteration to sericite, clay minerals or carbonate.

Hypersthene

This mineral occurs as short, stubby and irregular shaped grains averaging 0.1 millimeters. It is easily recognized by the green to pale reddish pleochroism. The grains are commonly bordered along feathered and frayed edges by thin zones of hornblende. Magnetite is the only common inclusion.

Hornblende

Green hornblende occurs both as rounded, and somewhat elongated grains. The larger elongate grains average 0.6 millimeters and the smaller rounded dispersed grains less than .1 millimeter. The hornblende commonly encloses or lies adjacent to smaller magnetite grains.

Augite

Augite is present as colorless, irregular shaped grains of variable size but no larger than .2 millimeters. The augite shows alteration to hornblende and is in parallel position with it.

Magnetite

Magnetite exists as rounded grains of very fine size dispersed through the rock, and as larger grains of irregular shape associated with the hypersthene, hornblende and augite. The maximum size of the larger magnetite seldom exceeds 0.1 millimeter.

Alteration Products

There is very little alteration resulting from the breakdown of plagioclase to secondary white mica. As a rule, the felspars are notably clear. Along the grain borders and twin lamellae of some labradorite grains there is a slight incipient alteration to sericite but this is insufficient to cause trouble in the weathering of the stone. No carbonate or clay minerals were observed in thin section.

Volume Percentage of the Stone

Plagioclase	94.0
Hypersthene	2.3
Hornblende	1.8
Augite	.5
Magnetite	1.0
Others	0.4

History and Conclusions

The anorthosites are of pre-Cambrian age and are considered to be younger than the Grenville series. They have undergone a cataclastic metamorphism in which deformation has taken place. The rocks have been sheared and because of the peculiar mineralogical composition still remain massive and equigranular. The anorthosites in general, underlie a large area in the district north of Montreal and may be obtained in quantity, various colors and grain sizes. The colors obtainable are purple to black, deep green, bluish green, marble white and mottled bluish green, purple and rose.

The rock is composed almost entirely of labradorite felspar with small percentages of iron ores and dark ferromagnesian minerals. The high content of alumina and lime, and the low content of magnesia and iron suggest its suitability for chemical or industrial stone. The green anorthosite from New Glasgow and the coarse black anorthosite from the Lake St. John district are the only two that have been utilized commercially to any extent.

Previous investigations in the area have advocated the extended use of anorthosites in the building stone industry with which the author concurs. They are worthy of further study.

Medium Grained Anorthosites

Certain limitations have been placed on the testing of medium-grained anorthosites. They have not as yet been used commercially for building stone. Test pieces are most difficult to obtain without special equipment for extraction from the outcrop and cutting later into the required dimensions for tests. Elasticity and warping tests should provide valuable information on the physical properties of this rock and the extent to which it may be used in the building stone industry. There is no great limitation to the availibility and accessibility of the medium grained anorthosites. North of Montreal near Morin Heights, there are outcrops of a medium grained anorthosite with a variety of colors and some which are pleasingly mottled. They are available in quantity with easy means of transport to large centers.

The particular tests made on one anorthosite show that it has exceedingly low pore space, high elasticity, and a low warp factor when wetted, all of which recommend it for unsupported structures.

Brittleness of the plagioclase feldspars and absence of a marked easy-breaking plane have been attributed to the difficulties in quarrying of anorthosite. The stone is successfully quarried in the Lake St. John district of Quebec and has found a wide use in various parts of Canada and the United States.

Rock Name: Nordmarkite

Commercial Name: Scotstown Green Granite

Location: Mount Megantic, Hampden township, Compton County and Marston township, Frontenac County, Quebec.

Contributor: Scotstown Granite Company Limited

Macroscopic Description:

The nordmarkite from Mount Megantic is a medium grained dark green rock sold commercially as a dark green granite. The green background colors of the felspar are relieved by a fairly even distribution of the dark ferromagnesian minerals. The mixture of the various constituents is good and the color distribution is homogeneous. Observed at various angles a shimmering blue iridescence is reflected from the soda bearing felspar.

The stone takes an excellent polish and there is a good contrast between the various types of finish. The color is unusual and attractive for an igneous rock having this texture.

Microscopic Character

The rock is holocrystalline, allotriomorphic with intergrowth textures occurring between the feldspars. The mineral grains are firmly bound having irregular grain borders with intergrowths of one felspar into the other adjacent to the boundaries.

This presents a strongly bound and intergrated rock texture. There is no definite orientation to the mineral grains and no sulphides are present.

Minerals

Microcline

There are irregular shaped grains and rectangular patches of gridiron microline contained within the untwinned microcline and microperthite. These patches also occur within the soda bearing potash felspar, anorthoclase. The intergrowths of microcline and albite occur in various stages of development from albite through to the well developed grid twinning of the microcline.

Albite

Albite occurs as separate crystal grains with polysynthetic twinning. There is no marked alteration to sericite along the twin lamellae.

Perthitic intergrowths

The most common minerals making up the rock are the felspars. They include albite, microcline and the soda bearing potash felspar, anorthoclase. Intergrowths of albite, microcline and anorthoclase occur forming microperthite and microcline microperthite.

Grains of untwinned microcline contain lamellae and small rectangular patches of albite which grade into the gridiron type microcline. More commonly the felspar is intergrown to form cryptoperthite with elongate streaks of plagioclase intergrown with the soda bearing anorthoclase. This mineral shows the shimmering iridescence observed in reflected light on the polished specimen.

Aegirine

The aegirine occurs as irregular and rounded shaped grains. The color is dark green. Some of the aegirine grains surround a core of augite with aegirine-augite occurring between the two minerals grading one into the other. Usually small rounded grains of magnetite are associated with these minerals, particularly in the central parts. In some grains the augite is missing and the aegirine occurs alone. Other grains enclose only augite. Apatite, zircon, monazite and allanite occur as small accessory grains within the aegirine.

Augite

The augite frequently occurs in the central part of the dark ferromagnesium minerals that are distributed through the rock. Within some grains of augite there are patches of green hornblende formed at the expense of the augite by alteration. Both are associated with magnetite and iddingsite and probably result from the alteration of an original olivine grain.

Hornblende

A green hornblende forms rims surrounding augite and as irregular patches within the augite grains.

Biotite

Brown and green biotite occurs in small clusters and shreds that appear to be intergrown with the microperthite. The grains are clear and surround larger magnetite grains. Parts of some biotite grains are bleached and altered to chlorite.

Olivine

The iron rich olivine, fayalite, is not too common among the ferromagnesium minerals. It is found as small anhedral grains surrounded by rims of green hornblende or lies adjacent to hornblende grains.

Quartz

Small grains of quartz occur in the interstices between the other mineral grains. The presence of quartz with alkaline felspars or soda bearing potash felspar is the criterion by which the name nordmarkite is applied. The percentage of quartz varies in different sections and may be present from several percent to ten percent of the rock.

Apatite

Small equant prismatic grains of apatite are found included in the larger grains of aegirine.

Allanite

Pale brown allanite occurs as small anhedral grains. They are found as inclusions within the aegirine surrounded by pleochroic haloes.

Magnetite

Magnetite is irregularly disposed in small grains averaging 0.6 millimeters. It appears to have crystallized contemporaneously with titanite and apatite.

Volume Percentages

Felspar perthitic intergrowths	89.3%
Microcline	1.5
Albite	0.5
Aegirine	2.0
Augite	1.5
Hornblende	1.5
Biotite	0.2
Olivine	0.5
Quartz	2.0
Magnetite	0.5
Others	0.5

History and Conclusions

According to the geological mapping of the Mount Megantic area by McGerrigle (1934), the alkaline nordmarkite intrusive is in the form of a ring dyke approximately one mile thick surrounding the north side of Mount Megantic. It has been observed to cut subalkaline rocks of Devonian age. Osborne (see McGerrigle, 1935, p. 80-81) believes that the nordmarkite may be as young as Tertiary, constituting a representative of the Monteregian intrusives found in other parts of Quebec.

The presence of olivine in any igneous rock is most susceptible to weathering. Surrounding rims of reddish brown iddingsite probably developed as a deuteric alteration of the olivine. It is one of the first minerals to show alteration to limonite. There is no conspicuous alteration of the plagioclase. Since they make up only a small part of the rock, their alteration would not be expected to be a serious factor in the weathering of the stone.

A similar green nordmarkite from Ascutney Mountain, in Vermont, has been used to advantage for the interior decoration of the old Sun Life Building in Montreal. This stone has retained its natural beauty without alteration after nearly thirty years in place.

Rock Name: Quartz Monzonite

Commercial Name: "Imperial Pink" Granite

Location: Guenette, Campbell township, Quebec.

Contributor: Brodies Limited

Macroscopic Description

The stone from near Guenette in Campbell township, Quebec is marketed under the name "Laurentian Rose" granite. It is a fine grained aplitic quartz monzonite in which the mineral grains form a closely knit mosaic-like texture with rounded and smooth crystal borders.

The slight variation in the pink to red background color contrasts with the fine flakes of black biotite and clear white quartz. The mixture and color distribution of the various minerals is fairly homogeneous although when subject to close inspection there is a fine mineral foliation prominent in the alignment of the biotite flakes.

The surface takes a mirror-like polish and has a good contrast with the several types of finish. Some fine equidimensional grains of magnetite are distributed through the stone but does not materially affect the polishing of the stone.

A few small grains of pyrite can be found in some specimens but it is rare and not a common constituent.

The stone is not normally stained by exposure, although some minute stains do occur after a few years due to alteration to limonite along the grain borders of magnetite. Scaling has been observed on the finished surface of some buildings along base courses. Thin flakes, one to two millimeters in thickness, have been removed by the penetration and crystallization of salt solutions.

When this stone becomes wetted, it takes up water quickly and becomes darkened, reducing the amount of reflected light, and when drying, the water evaporates unevenly so that the surface has unpleasant dark and lighter areas.

Fabric

The rock is holocrystalline, with an allotriomorphic equigranular texture and the grain size averages 0.8 millimeters across the grain. There is a slight dimensional orientation in the alignment of biotite flakes. A certain optical orientation can be found in the quartz grains. The minute fractures that cut across the quartz grains show a rude parallelism with the orientation of the biotite flakes.

The alignment of the darker minerals accentuates a fabric pattern to the felspar which also shows a distribution arrangement, resulting in a compact fine grained somewhat gneissic stone.

Minerals

Microcline

Microcline occurs as stubby and irregular shaped grains and the average size measured across the grain is about .7 millimeters. The microcline is easily recognized by the well developed polysynthetic "gridiron" twinning. The crystals are clear and are relatively unaltered except for some slight incipient alteration to sericite.

A section normal to the c-axis shows an extinction angle of 15° on (001).

Plagioclase

Thin-section examination shows scattered plagioclase felspar crystals with the composition of albite-oligoclase and forms roughly 25 percent of the rock. The sericite alteration of the plagioclase is slightly more advanced than that found in the microcline, but is not considered serious to the weathering of the stone. Some of the plagioclase crystals contain rounded blebs of vermicular quartz and are the typical myrmekite structures.

Perthite

Perthitic intergrowths of plagioclase in wormy streaks and patches are commonly found in the untwinned microcline. The microcline is relatively unaltered while the plagioclase intergrowths are altered to sericite and clay minerals.

Quartz

The quartz grains have smooth to irregular sutured grain boundaries and fill the interstices between the other grains of the rock. The size of the grain varies but the average dimension across the grain is 0.2 millimeters.

Some rounded blebs and rods occur as inclusions in the untwinned felspars and small rounded or stubby grains of both microcline and plagioclase occur within the larger quartz grains and are completely surrounded by them.

The anhedral grains of quartz, although appearing uniform in structure are slightly strained indicated by the wavy extinction. There is little real evidence for deformation otherwise, and this undulating extinction is common for quartz even in the freshest granites.

Biotite Mica

Short disseminated scales and elongated prismatic grains of biotite appear to have a rude banding in which the biotite flakes trend along certain parallel planes. The predominant color is brown or yellowish brown with some green occurring as rods or bands within the brown flakes.

The borders of some tabular grains have feathered edges leached to muscovite. None of the plates were observed to be bent. Common inclusions in the biotite are zircons with surrounding pleochroic haloes, fine magnetite and allanite grains.

Muscovite Mica

Muscovite is present both as primary and secondary constituents. The primary muscovite occurs as equal and tabular colorless grains with strong birefringence and upper second order interference colors. The secondary muscovite is found as ragged grains along the feathered edges and represent an alteration product from biotite.

Sphene (titanite)

Euhedral crystals of sphene with the rhombic cross section and irregular grains occur as a common minor constituent of the rock. The color is usually pale brown. It is usually associated with magnetite and biotite.

Allanite

Prismatic elongated grains of pale brown allanite are associated with biotite and grains of magnetite.

Apatite

Apatite is a minor constituent and is found in small six-sided crystals.

Volume Percentages

Microcline	36.5%
Plagioclase	24.5%
Quartz	28.5%
Biotite	5.3%

Volume Percentages (continued)

Muscovite	--------------------------	2.5%
Sphene	--------------------------	0.6%
Magnetite	--------------------------	1.1%
Others	--------------------------	1.0%

History and Conclusions

This rock from Guenette is known to intrude Grenville rocks and from observations on isolated outcrops the body probably occupies an area of nearly 4.5 square miles. Osborne (1932) regarded the intrusive as having the form of a dyke, possibly a large ring dyke, with a length of over 10 miles. Aubert de la Rue (1948) considered the intrusive to be less regular in outline and wider, with a maximum dimension of about 3 miles.

Only parts of the stone have markings produced by flow structure, narrow veinlets and clots of dark ferromagnesian minerals. Amphibolite dykes cut across some quarries but do not materially affect the quarrying of good quality stone. Aside from its application for monumental and building stone, it has found use in industry for press rolls in paper mills where it meets exacting requirements demanded by the industry.

Many of the plagioclase crystals show alteration to sericite and carbonate. Biotite has been transformed in part to chlorite and muscovite. There is also a tendency for the fine grains of magnetite to weather red, resulting in a slight discoloration.

The porosity is relatively high for this type of granitic rock and probably accounts for the disagreeable scaling observed on some buildings.

Otherwise the stone has desirable qualities in its fineness of grain, compactness and homogeneity of grain size and color. It has well defined breaking planes that result in ease and economy of quarrying.

Rock Name: Hornblende syenite

Commercial Name: "Sienna Red" granite

Location: Rawcliffe, Grenville township, Argenteuil County, Quebec.

Contributor: Scotstown Granite Company Limited

Macroscopic Description

The rock is a medium grained brownish-red syenite. The mineral distribution is somewhat uneven when subject to close inspection.

Dark colored hornblende, grey altered feldspar and red orthoclase feldspar combine to give a confused brownish mixture to the stone. Inclusions of a grey altered mineral with dark concentric bands tend to an occasional pale green to brown mottling.

The rock takes a fair polish with the dark minerals causing the greatest difficulty in finishing. Quartz is nearly always absent although occasional grains can be found in some specimens. There were no sulphides in the specimens studied.

The rock is holocrystalline,inequigranular and medium grained. The grain size of the orthoclase crystals measured across the grain averages about 3 mm. The pink feldspar makes up the major part of the rock and contains inclusions with rectangular outline that are altered to chlorite and epidote. The grain borders of the feldspar are generally smooth and the hornblende commonly has irregular and feathered borders that interpenetrate the feldspar. There is no apparent mineral alignment or preferred optical orientation.

Minerals

Orthoclase

The orthoclase occurs as clouded well-formed subhedral crystals. Carlsbad twinning is fairly common and many of the crystals have irregular perthitic intergrowths of plagioclase and potash feldspar. Alteration is limited to scattered sericite within the crystal grains and to chlorite and epidote resulting from the alteration of inclusions.

Hornblende

Green hornblende forms small six sided crystals but is commonly found as elongated prismatic crystals with feathered and ramifying edges and terminations. The brown colored variety is sometimes found surrounding magnetite grains. Much of the hornblende has been altered to a finely divided aggregate of sericite epidote and chlorite.

Magnetite

Magnetite usually occurs as rounded and irregular shaped grains with sutured grain boundaries. Many irregular shaped grains occur as inclusions in the hornblende. A few octahedral grains of magnetite occur along with many finely disseminated grains that commonly occur throughout the rock.

Calcite

Anhedral calcite crystals fill angular interstices between the grains of some felspars. Some grains as large as 1.8 millimeters measured across the grains were observed.

Quartz

Quartz is very uncommon. A few small grains occur between the felspar crystals.

Quartz-felspar intergrowths

Some grains of felspar were observed to contain tiny subhedral intergrowths of vermicular quartz. This is the myrmekite type of intergrowth and indicates the deuteric alteration of an earlier felspar.

Apatite

Apatite is found as small equant hexagonal and prismatic crystals. They occur within the feldspar grains.

Volume Percentage

Orthoclase	85.6
Hornblende	4.5
Magnetite	1.5
Quartz	4.0
Chlorite	1.2
Epidote	1.0
Carbonate	0.7
Others	1.5

History and Conclusions

This syenite is from the western part of the Chatham-Grenville stock that occupies an area of about 20 square miles on the southern border of the Canadian shield. It is believed to be of late Precambrian age. (Osborne, 1935). The intrusive is made up of four kinds of rock; syenite, syenite porphyry, quartz porphyry and granite. Only the granite and syenite have provided a source of building stone.

In the syenite late deuteric alterations are recognized by quartz replacing the feldspars and forming myrmekite intergrowth. Inclusions in the feldspar have been altered to chlorite epidote and sericite. There are no clear crystals and all show some degree of alteration. The stone has a higher porosity than all other stones tested and may be accounted for by the more than usual amount of tiny open fractures observed in sections.

Rock Name: Granite

Commercial Name: "Rose-Grey" Granite

Location: Rivière à Pierre, Portneuf Co. Quebec.

Contributor: Dumas Voyer, Riviere a Pierre.

Macroscopic Description

This rock is a massive coarse-grained rose-grey granite that lacks a uniform grain size. Some of the feldspars measure as much as 1.5 cm. across the grain. The dark ferromagnesian minerals are grouped in clusters but tend to give a fairly even distribution to the dark and light constituents.

Subject to close inspection there is a marked variation in the intensity of color between the white and rose colored feldspars and the colorless or faintly bluish, clear quartz. The rose or lavender colored potash feldspar is randomly distributed but gives a general rose tint to the stone. Dull red tinted hematite occurs in small amounts along some grain boundaries or along minute cleavage planes.

There is no clear foliation present but tiny cracks developed in the quartz and feldspar appear to have a slight degree of parallelism. The quartz is clear and colorless with a few grains that are tinted yellow or blue. There is a tendency for this stone to lose a certain degree of its original color after exposure. In some buildings the stone has undergone a slight bleaching to a lighter color resulting in a loss of contrast between the light and dark minerals.

Microscopic Character

The rock is holocrystalline, allotriomorphic and inequigranular. The grain size ranges from .3 mm. to

1.5 cm. The mineral distribution is notably irregular. Mosaics of quartz and feldspar are grouped in some areas whereas others consist of clusters of biotite magnetite and green hornblende. Cracks are developed in the quartz and extend through into the feldspar grains; many have a random orientation but some show a certain degree of parallelism. Magnetite sphene and apatite occur as accessory minerals.

Minerals

Plagioclase

Plagioclase exists as anhedral grains ranging in size up to 5.5 mm. Twinning according to the Albite and Pericline laws is common. Measurements of the extinction angles normal to (010) indicate a composition of An_{25}. In many, only parts of the crystal show the twin striations and along alternate twins of some grains, secondary sericite and clay minerals have developed. Many of the plagioclase crystals are entirely fresh looking and show no alteration.

Potash feldspar

Some orthoclase feldspar occurs in irregular shaped grains in which the centers have in part been altered to a finely divided aggregate of sericite and clay minerals. Most of the potash feldspar is microcline which has the characteristic grating structure in polarized light. A number of the microcline crystals have perthitic intergrowths of albite. The microcline shows little or no alteration.

Quartz

Some of the quartz appears as large grains traversed by minute cracks containing dusty inclusions. The cracks extend not only across the quartz grains but into adjacent feldspar crystals. Near the extinction position, the large-appearing quartz grains are found to be made up of a coarse mosaic structure of smaller grains with smooth grain borders. Each of the grains has a slightly different extinction position.

Evidence of deuteric alteration is found in the myrmekite structures and granophyric intergrowths of quartz and feldspar.

Biotite

Green and brown biotite is present as irregular shaped grains. Less commonly small tabular crystals occur. Near the extinction position the green and brown crinkly appearance is usually observed.

There are faint pleochroic halos surrounding some apatite inclusions in the biotite. Several biotite grains have been penetrated by wormy intergrowths of quartz and feldspar and in parts the biotite has been altered to muscovite. In the central parts of some plagioclase crystals there are inclusions of biotite that have been altered to chlorite and epidote. Some small shreds of biotite are found adjacent to hornblende grains. They are alterations from the hornblende and are in continuation with it.

Hornblende

Common green hornblende occurs along with biotite in roughly equal amounts. The grains vary in size and measure up to 1.5 mm. The extinction-direction makes an angle of 15° with the c-axis and the pleochroism is as follows: X = yellow green, Y = olive green and Z = dark green. Some small shreds which penetrate along grain borders have been converted to biotite. Tiny fractures traverse the cleavage cracks at small angles. The cracks are filled with a fine grained aggregate of epidote and chlorite.

Sphene

Sphene is found as anhedral crystals with rounded grain boundaries. They commonly surround magnetite and apatite grains. The color is a pale brown and the acute rhombic section is not present. In a number of cases the sphene occurs as inclusions within biotite and hornblende. The grain borders appear corroded particularly where they are adjacent to the green hornblende.

Apatite

Apatite occurs as small, equant and prismatic grains. Pleochroic halos occur around some of the apatite inclusions in biotite. Apatite is a common accessory mineral and is found as inclusions in all the ferromagnesian minerals.

Muscovite

Muscovite is not a common constituent but occurs as small ragged grains secondary after biotite.

Magnetite

Magnetite occurs in small irregular shaped grains with rounded, smooth borders. The magnetite is usually found as inclusions within the sphene and hornblende.

Volume Percentage

Microcline	42.3%
Oligoclase	21.5%
Quartz	23.0%
Biotite	6.5%
Hornblende	5.0%
Apatite	0.2%
Sphene	0.3%
Magnetite	0.5%
Others	0.7%

<u>History and Conclusions</u>

This granite intrudes rocks of the Grenville series and is presumed to have been introduced during the period of Grenville mountain building. Osborne (1934). The rock has not undergone shearing nor has it assumed any noticeable foliated structure, commonly found in the other granites of the area.

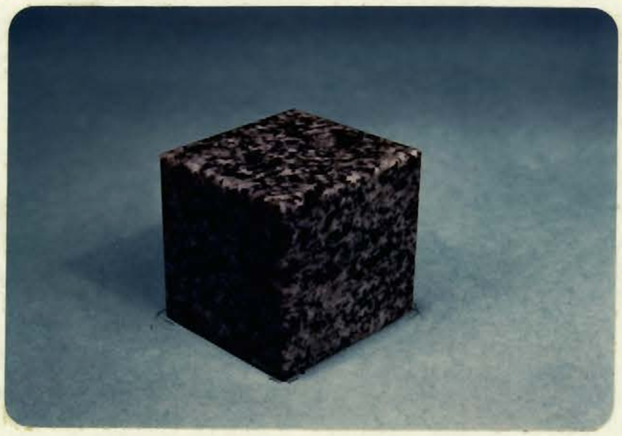
This rock is from one of the most important quarries in the district of Rivière à Pierre. Joints are sufficiently spaced and the ease of breaking along certain defined planes makes it a remarkable quarry for economical extraction of large size blocks. It is largely a structural stone, primarily because of its coarse grain. Although it has been used as a building stone, the texture is too coarse to be popular for surfaces subject to close inspection. Alteration within the minerals do not seem to be sufficiently advanced to impair seriously the durability of the stone.

Rock Name: Essexite

Commercial Name: "Ebony" Black Granite

Location: Mount Johnson, Iberville County, Quebec.

Contributor: Brodies Limited



Macroscopic Description

This essexite from Mount Johnson is a dark medium-grained rock known to the building stone trade as "Ebony". It is not too obviously porphyritic in parts, but it consists of some sporadic phenocrysts, up to an 2.5 cm. length of light bluish-grey plagioclase crystals. The bluish-grey groundmass of smaller grey feldspar is spotted black by fairly well distributed grains of hornblende biotite and augite. A polished slab, observed at certain angles, reflects a sprinkling of tiny silvery glints from magnetite. The magnetite is quite evenly distributed among the dark minerals. This variety of essexite from Mount Johnson has a parallel alignment of plagioclase laths and hornblende which is more obvious when the stone is cut parallel to the direction of alignment. The stone takes a good polish with a pleasing contrast between the polished and cut or hammered surface.

Microscopic Character

The rock is holocrystalline, allotriomorphic and porphyritic. The groundmass is made up of lath-shaped acicular feldspar crystals with a strong parallel arrangement of their long axes. Where the feldspars surround the rounded and irregular-shaped ferromagnesian minerals, the alignment diverges at slight angles.

The average width of the acicular crystals is about 0.8 mm. and the length varies from 1 to 6.5 mm. Occasional phenocrysts measure up to 2.5 cm. in length. There is a tendency for the ferromagnesian minerals to be grouped together in clusters but they combine with the lighter constituents to give a fairly even distribution to the rock. The fluidal arrangement is most apparent in the alignment of the feldspar crystals but is less conspicuous for the darker ferromagnesian minerals.

Minerals

Plagioclase

Prismoids of plagioclase average about 3 mm. in length and 0.8 mm. along the narrow dimension. Larger phenocrysts are partly rounded and some measure up to 2.5 cm. The grain borders of the crystals have irregular and sutured outlines with interpenetrating relationships. The composition, determined from the measurement of extinction angles in albite twins cut normal to (010), varies from An_{45} to An_{50}, The feldspars are fresh-looking and alteration to clay minerals and sericite is rare.

Nepheline

Nepheline is found in small euhedral grains between the feldspars. The forms are both rectangular and hexagonal. Staining tests show that the nepheline distribution parallels the alignment of the plagioclase.

Sodalite

The sodalite occurs in irregular-shaped grains with negative relief. It is dark between crossed nicols and a number of grains have regularly arranged inclusions.

Biotite

Brown biotite is a fairly common constituent. It occurs as short prismatic grains and irregular-shaped flakes with an average size of 0.7 mm. The mineral is fresh-looking and shows no marked alteration. It contains inclusions of apatite, magnetite, and plagioclase. Biotite and augite are closely associated and are partly intergrown with inclusions of one found within the other.

Augite

Augite occurs in irregular-shaped grains of variable size. Some grains measure 3.8 mm. in the largest dimension. The boundaries of the crystal are usually smooth and rounded but remnants of partly developed crystal faces appear in some sections. The augite is intergrown with the hornblende and is in parallel position with it. The augite is converted to hornblende and represents a late magmatic stage reaction.

Basaltic Hornblende

Brown basaltic hornblende occurs in grains that average less than 1 mm. in size. The grains have irregular shapes but the borders are usually clear and distinct. Pleochroism is strong with X = pale brown, Y = brown, and Z = dark red brown. The basaltic hornblende occurs as rounded inclusions with sharp grain borders within some biotite grains, and forms around augite, complexely interpenetrating it. Apatite, feldspar and magnetite are common inclusions found in the hornblende.

Magnetite

Rounded magnetite grains averaging 0.3 mm. are disseminated through the rock. Many grains are surrounded by basaltic hornblende where they occur near augite.

Volume Percentage

Plagioclase	71%
Augite	6%
Biotite	8%
Hornblende	3%
Magnetite	5%
Apatite	1%
Nepheline) Sodalite)	6%

History and Conclusions

This essexite is from one of several rock types having the form of vertical concentric cylinders surrounding the core of Mount Johnson. Osborne and Wilson (1934) found the alignment of the minerals to have a banding parallel to the outcrop of the concentric rings including a vertical alignment.

Accordingly this type of emplacement will imply a vertical continuation of the rock in depth rather than as horizontal sheets as found in other forms of intrusive rocks.

Larochelle (1959) summarized all the known data concerning the age of the Monteregian intrusives and made measurements on the paleomagnetism of rocks from Yamaska and Brome Mountains. Assuming the Monteregian hills are of the same age, there is a fair agreement for a post-Triassic age for the essexite of Mount Johnson.

The amount of alteration to sericite and clay minerals is negligibly small. Only a few minute wisps of sericite occur scattered in some feldspar grains. The porosity value of 0.076% is low and the rock shows no tendency to form scale weathering or discoloration after years of exposure in building structures.

Rock Name: Granodiorite

Commercial Name: "Stanstead Grey" Granite

Location: Stanstead County, Quebec

Contributor: Scotstown Granite Company Limited

Macroscopic Description

This rock specimen is a medium-grained grey granodiorite known in the building stone trade as "Stanstead Grey". It is composed of a fairly uniform mixture of white feldspar, quartz and biotite. The latter mineral appears to fill spaces around groups of quartz and feldspar grains. The stone takes a good polish but lacks a strong contrast between the polished and cut surfaces.

The finished surfaces of some specimens develop pale tints of yellow coloration which is due to the oxidation of pyrite. The pyrite occurs in grains less than .2 mm. in size and is commonly associated with the biotite grains.

Microscopic Character

The rock is holocrystalline, allotriomorphic and is characterized by fine narrow lathlike biotite arranged in a complex manner. The biotite shreds follow discontinuously around some feldspar grains and partially or completely surround groups of quartz and feldspar. There is no apparent mineral alignment or preferred optical orientation of the quartz grains. Nearly 25 percent of the rock is composed of quartz grains that have developed irregular, sutured grain contacts. This presents a strongly bound and integrated rock.

Plagioclase

Plagioclase feldspar occurs as prismatic and blocky grains. Many grains are zoned due to differences in composition. Albite twinning is common and pericline twinning occurs in a few grains.

Measurements of extinction angles on sections cut normal to (001) for albite twinning indicates a composition between An_{20} and An_{28}. Angular measurements of pericline twin lamallae with (001:010) edge indicate a composition of An_6.

The feldspar is generally fresh-appearing but some grains have slight alterations to sericite and clay minerals.

Microcline

Microcline is found as short stubby grains averaging 0.8 mm. in size and are smaller than the average grain size of the rock. The mineral is recognized by its well developed gridiron twinning, negative relief and negative optic sign.

The microcline is completely unaltered.

Quartz

Colorless quartz occurs in subrounded grain clusters that average about 3 mm. in size. The clusters are made up of individual grains with irregular sutured borders adjacent to each other and are smooth where they come in contact with other minerals. In some sections of the rock the quartz occurs in a fine granulated form and in others strain shadows are visible when observed near the extinction position. Minute cracks that appear roughly parallel extend across quartz grains and into the feldspars. These minute cracks possibly account for the relative ease of quarrying along certain defined planes.

Biotite

Green and brown biotite occurs in elongated tabular grains commonly joined end to end filling interstices between the quartz and feldspar grains. The trains of biotite are seen winding around large crystals and squeezed between them. Some appear slightly bent and partially or completely surround groups of quartz and feldspar grains. Inclusions of zircon and apatite appear in the biotite and some appear to have faintly developed pleochroic halos.

Muscovite is associated with some of the biotite flakes and is found in parallel position, generally forming the outer portion of a biotite grain.

<u>Augite</u>

Augite occurs rarely in distinct grains associated with biotite. The augite may be in part altered to biotite.

<u>Muscovite</u>

Muscovite is formed as a secondary mineral along cleavage planes in the plagioclase feldspar. It is also found associated with biotite.

<u>Apatite</u>

Apatite occurs in small equant, six-sided crystals with an average size of about 0.1 mm.

Zircon

Zircon appears as small rounded grains commonly found as inclusions in biotite. A few grains measure 0.4 mm. in diameter but normally they are less than 0.1 mm.

Pyrite

Pyrite appears in small rectangular grains less than 0.2 mm. in length. It is a rare constituent and constitutes less than 0.1% of the rock.

Volume Percentage

Oligoclase	-----------------------	61.4
Microcline	-----------------------	5.0
Quartz	-----------------------	25.0
Biotite	-----------------------	7.0
Muscovite	-----------------------	0.5
Apatite) Zircon)	-----------------------	0.2
Pyrite	----------------less than	0.1

History and Conclusions

The Stanstead "granite" is considered to have been intruded during the Acadian orogeny, in Devonian time (Cooke, 1950).

The presence of zoned plagioclase feldspar and interlocking igneous textures indicates that the granite has been formed from a melt. Deuteric effects have resulted in late stage quartz reactions with feldspar to form myrmekite structures. Early augite is replaced by biotite and biotite altered to muscovite. A slight dynamic effect is recognized from the occasional bent biotite flake and slight complication of the twinning in the plagioclase feldspars. The strain shadows and slight granulation in quartz, and squeezing of biotite around crystal groups, further indicate a slight post-crystallization stress. The minute parallel cracks found in the quartz grains may have developed at this time.

Pyrite is not present in sufficient amounts to cause disagreeable staining of the stone. A number of specimens however, show a slight yellow coloration due to the oxidation of pyrite. The stone has a relatively high percentage of available pore space (0.685%) and as a consequence is subject to the penetration of salt solutions into the pores. Advanced scale weathering and roughing appear where the stone has been exposed for a period of thirty years.

Summary

Descriptions of building stone seldom include detailed petrographic studies made in the laboratory. The microscopic study of the individual minerals composing the rock reveal good and inferior rock qualities. The recognition of deleterious components and the kind of grain fabric is important since they may limit the finishing qualities or affect the final appearance of a stone. It is desirable to know the state of alteration of the minerals or anomalous characters which may be of importance in selecting a stone so making it possible to avoid material that can be expected to cause trouble in a finished product. The methods of mineralogy and optical mineralogy furnish a basis for the study of new materials of yet unknown composition and behavior.

The physical measurements on building stone are largely related to the intended use. The method involves the measurement of a number of physical properties and requires specially cut test pieces and adequate apparatus. Measurements on the effect of moisture present an example of interesting and useful application in the selection of building material for specified uses. Very little attention seems to have been paid to the effect of moisture changes that occur in building stone. A warping occurs when stone is wetted unevenly, and quite definite changes in the breaking strength takes place. Considerable variations in the amount of warp occurs when different stones are wetted unevenly. Measurements on a large number of stones enable the selection of material that is best suited for specified moisture conditions. For example, a stone having low warping properties can be used to advantage in sections where moisture commonly condenses on stone walls.

Water which enters the interstices of a stone or water which acts on the surface alone is generally not pure water but contains dissolved gases and salts. The interstitial spaces are objectionable since they allow the penetration of water bearing salts and gases into the stone. Test specimens treated with salts show that minute cracks are widened and mineral particles are removed from the surface of a stone due to the action of the salt, and thus constitutes a loss to the surface structure of the material. The widening of minute cracks and mechanical removal of particles found on test specimens is more meaningful when the total accumulated losses over years of exposure are considered. The actual loss is small for individual specimens tested, but the values in a comparitive way shows the variation in resistance of different stones to the action of certain salts.

The elasticity of the igneous rocks measured under bending stress shows considerable variations in the values for different stones. Elasticity is related to differences of material, space between grains and to irregularity in outline of the individual grains. The elastic measurements indicate which stones are more suitable for supported or unsupported structures. The highly elastic stones are preferable for unsupported structures and the more flexible stones are better adapted to sections where settling can be expected.

Part II THE AREAL DISTRIBUTION OF QUARRIES AND BUILDING STONE OF EASTERN CANADA.

General Statment

Three geological regions may be cited as sources of building stone in eastern Canada, east of Lake Superior: the Canadian Shield, the St. Lawrence Lowlands and the Appalachian System. The southern part of the Canadian Shield is almost entirely a region of Precambrian rocks, predominantly crystalline in character, and is made up of many metamorphosed lithologic units of both sedimentary and igneous origin. It is in this region that coarse crystalline marbles, red granites, syenites and anorthosites occur and have found use in the building trade.

The St. Lawrence Lowlands are underlain by predominantly horizontal or gently dipping beds of shale, sandstone and limestone of Ordovician age. The limestones are the main source of building stone. The Monteregian igneous intrusives are a source of dark essexites and rare green nordmarkite for decorative building stone.

The broadly deformed belt of the Northern Appalachians, that comprises that part of the Province of Quebec southeast of the Logan fault, New Brunswick, Nova Scotia, Prince Edward Island and Newfoundland has provided some marbles. The main contribution to the building stone industry from this region, however, are the structural and variously colored decorative granites.

From the three geological regions of Eastern Canada, the stones most widely proven and adapted for use as dimension stone are the granites and non-polishable limestones. The marbles occupy a less promising position for the future production of building stone. Many presently known deposits have been neglected primarily because of structural and textural deficiencies. Excessive faulting has broken and jointed the beds, or there are other undesirable features, chief of which are coarseness of grain and presence of impurities. A building stone market demands large pieces, continuity of supply, and other desirable characteristics, such as color, texture and polishing features. Such demands have eliminated a large number of marble localities in Eastern Canada.

Many of the igneous rocks in eastern Canada may be somewhat diverse in character, but certain similarities of mineral or chemical composition persist to differentiate them from rocks of another region, or of the same region intruded at another period.

Thus in the Northeastern Appalachian System of Canada and of New England, isolated stocks and plugs occur showing a wide range of composition but with a general tendency to be rich in Na_2O. The igneous rocks of eastern Canada that provide a source of building stone present certain peculiarities connected with a definite tectonic process rather than a mere geographic extension.

In the Laurentian area the anorthosites have a considerable range in composition but have a distinct general tendency to be rich in CaO. The varieties of this rock in the different localities of the Grenville subprovince resemble similar structures and formations found in many places.

The ultrabasic intrusions which extend from central Massachusetts, through the Eastern Townships of Quebec to Mount Albert in Gaspé have a tectonic control rendered by the narrow elongated bodies of similar rock affinities that parallel the strike of the country rock. The "verde antique" marbles are limited to this similar group of rocks.

A knowledge of existing similarities and relationships in different localities is essential to a broad understanding of the position in depth and the lateral continuation of each rock.

THE GRANITE AREAS

General

Granites adapted for use as dimension stone are available in many parts of eastern Canada east of Lake Superior. From the standpoint of general distribution they are quarried in three main areas: (1) the north-eastern Townships of Quebec, New Brunswick, Nova Scotia and Newfoundland; (2) the St. Lawrence Lowlands in Quebec; and (3) along the southern border of the Canadian Shield, within 100 miles of the St. Lawrence and Ottawa rivers.

Granites of the Appalachian System

Newfoundland

There has been no production of granite for dimension stone for nearly forty years. Five areas, Petites (Rose Blanche), Indian Head, Quarry Station, Long Island and Benton have been judged worthy of producing building stone. (Carr, 1955). The syenite from the Petites (Rose Blanche) area seems to be the only stone of desirable color for a decorative building material. An even-grained texture is a quality valued in a deposit. The Petites area lacks this feature in having a coarse grained porphyritic texture.

Nova Scotia

In Nova Scotia attempts have been made without success to find a decorative red granite. Two black "granites", hornblende diorites have been quarried for local use but it is very doubtful whether such stone exists in sufficient quality and quantity to warrant export to other parts of Canada or the United States. The remainder of the granites in Middleton-Nictaux, Shelburne, Halifax and Queensport are of the grey variety. As a result the grey color in a stone is not so highly prized for export as the bright reds for decorative or ornemental applications. As a rule the grey granites are most often used only locally, other than those found near the large centers of population, such as Stanstead-Stanhope district in the eastern townships of Quebec.

New Brunswick

In New Brunswick there are a small number of granite masses east of a line joining Saint John, Fredericton and Bathurst. None east of this line possess the qualities for decorative building stone. Three large batholiths appear as a tectonic element trending northeast through the central part of the province, yet no special features have yet been attached to these granite masses as a source of building material.

A grey porphyritic pink-tinted granite is quarried intermittently from the Bathurst stock for local buildings and structural purposes. A small stock on the east side of Antinouri Lake, 20 miles northwest of Bathurst, is the source of a medium-grained salmon pink granite. Production is largely for rough faced ashlar used in the construction of buildings. The stone takes a good polish, but the feldspars are already in an advanced state of alteration to shreds of sericite and consequently cannot be expected to be highly weather resistant. Near Hamstead, in Queens county a grey granite is quarried largely for monumental purposes.

The St. George district in Charlotte county has supplied building and ornamental stone to all parts of Canada and the Eastern United States since 1872. Both red and black "granites" have been produced from the area. Wright (1934) records 51 quarries that have been opened in the St. George district of which 7 are black granites (diabase). The red "granite", a medium-grained quartz monzonite with an even-grained uniform texture, appears to possess all the desirable qualities of a good decorative building and monumental stone. The stone is generally unmarred by undesirable streaks or spots and shows a marked absence of deleterious minerals. The black "granites" show a considerable variation in texture and color, and imperfections are common. Despite the favorable location and quality of the stone, along with the adequate supply for sustained production, no quarries have operated for a number of years.

Parks (1914) and Wright (1934) examined the area in some detail. Based on observations of the companies operating at the time of their investigations they concluded that the reason for the decline in granite production was primarily due to the policy of the various companies. Many smaller quarries were operating with individual finishing plants; many quarry operations were carried out without the use of machinery of any kind and it was the practice of the owners not to ship rough stone.

Quebec

The largest single producing region for building stone in all Canada is in the Eastern Townships of Quebec in the northern Appalachians. The principal centers located at Stanstead-Stanhope, Scotstown, St. Gerard and St. Samuel- St. Sebastien all produce a grey granite. There are some variations in the texture and composition of the stone in the different areas although similarities exist for the color and wide spacing of joints.

The Monteregian alkaline intrusives provide a more unusual and rare variety of stone for the building trade in Eastern Canada.

The geographic distribution of the Monteregian intrusives in Quebec is partly in the St. Lawrence Lowland region and partly in the folded paleozoics of the northern Appalachians. They occur as a series of isolated hills within a fifteen mile wide zone southeastwardly from Mount Royal on the Island of Montreal to Brome and Shefford Mountains. Scattered dykes of alkaline types appear at various localities, with the most easterly appearing as a partial ring dyke of nordmarkite on the north and east sides of Big Megantic Mountain in Compton and Frontenac counties. Though a great variety of intrusive rocks are found in the Monteregian hills, the essexite quarried on Mount Johnson represents the only decorative building stone to find continued use in the building trade. Commercially, this is the only black "granite" quarried south of the St. Lawrence river in the province of Quebec.

The rare variety of green alkali syenite is quarried from Big Megantic Mountain and marketed commercially as a green "granite". This stone from Mount Megantic is similar in color and composition to the green syenite employed as veneer and in large fluted columns in the interior of the Sun Life building in Montreal, and quarried from Mount Ascutney near Windsor, Vermont.

Granites of the Canadian Shield

Province of Quebec

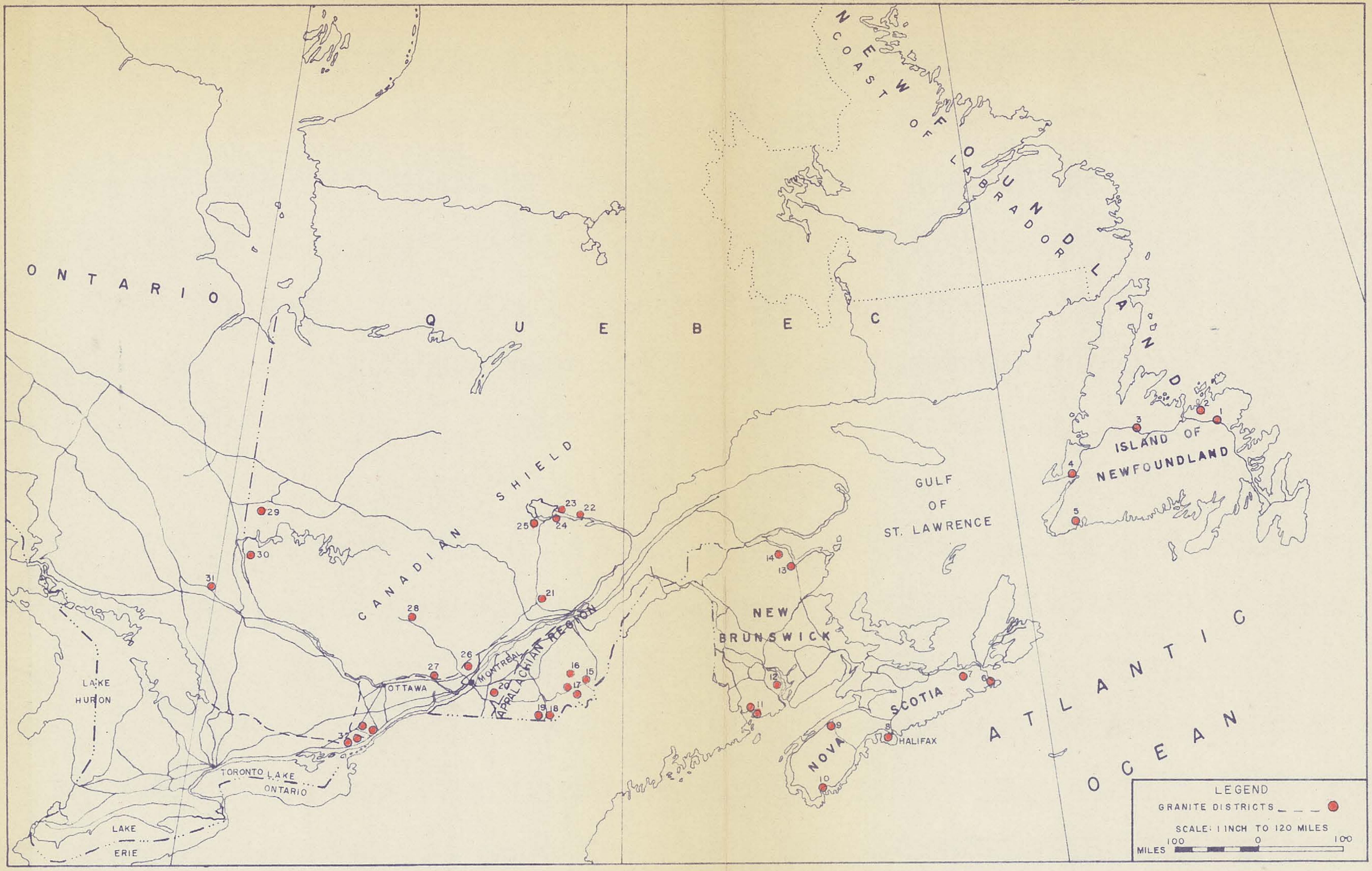
The southern part of the Canadian Shield represented by predominantly crystalline rocks is the source of a number of granites, syenites and anorthosites used for dimension stone. Other than a diabase (black granite) quarried in the Rouyn-Noranda district all the "granites" have been taken from the Grenville sub-province of the Laurentian Plateau. These rocks are much older than those in the more southern divisions. Most of the Precambrian formations in this part of the Laurentian Plateau have in general a characteristic foliation or gneissic banding, and for this reason are not auspicious sites for decorative building stone. It is the localities that have not developed extensive gneissic structures that offer potential sources of building material and where granites and syenites are commercially exploited. Those exceptions to the characteristic foliation include the late Precambrian Chatham-Grenville stock of Quebec where red syenite and various colored granites have been quarried; the dyke-like red granite of Guenette; the rose and grey granites of Rivière-à-Pierre, Roberval and Grand-Mère. The gneisses within the Laurentian Plateau have been exploited to a small extent but lack the popular appeal of the massive, uniform and attractive granites.

A potential source for building stone in Eastern Canada is to be found in the medium grained anorthosites. They are found North of Montreal in a variety of colors and are available in quantity with ease of transport to large centers.

Province of Ontario

Although sources for granite east of the head of Lake Superior appear in many localities, the quarrying of granite has contributed only a small part to the building stone industry in Ontario. In southeastern Ontario, along the south western extension of the Precambrian shield are the brownish augite syenites and red granites of the Gananoque area; the reddish brown granite from the Escott area, and the red granites of the Lyndhurst, Kingston and Brockville districts. Numerous areas of granitic rock offer potential sources for dimension stone and show a wide variety of type, texture and color. Two commercial building stones are produced: a medium-grained rich red granite from the Lyndhurst area, and a black granite (gabbro) from the River Valley area, 45 miles northwest of North Bay. Both these have desirable decorative and monumental qualities and have been exported to Vermont and New Hampshire in the United States.

Parks (1912), Baker (1916), Cole (1938) and Carr (1950) give valuable information concerning the stone quarries, production and potentials in the Province of Ontario.



NEWFOUNDLAND	NOVA SCOTIA	NEW BRUNSWICK	QUEBEC			ONTARIO
1 BENTON	6 QUEENSPORT	11 ST. GEORGE – BOCABEC	15 ST. SAMUEL – ST. SEBASTIEN	21 RIVIÈRE À PIERRE	27 RAWCLIFFE – BROWNSBURG	31 RIVER VALLEY
2 LONG ISLAND	7 ERINVILLE	12 HAMSTEAD	16 ST GERARD	22 CHICOUTIMI	28 GUENETTE	32 LYNDHURST – BROCKVILLE – KINGSTON – GANANOQUE
3 QUARRY STATION	8 HALIFAX	13 BATHURST	17 SCOTSTOWN – MEGANTIC	23 ISLE D'ALMA	29 ROUYN	
4 INDIAN HEAD	9 MIDDLETON – NICTAUX	14 ANTINOURI LAKE	18 STANHOPE	24 ST. GÉDÉON	30 VILLE MARIE	
5 PETITES (ROSE BLANCHE)	10 SHELBURNE		19 STANSTEAD	25 ROBERVAL		
			20 MOUNT JOHNSON	26 NEW GLASGOW		

FIGURE 15. SKETCH MAP OF EASTERN CANADA SHOWING LOCATION OF PRINCIPAL QUARRIES AND GRANITE DISTRICTS.

THE MARBLE AREAS

The Marbles of the Appalachian System

The Atlantic Provinces

Although there are a number of deposits of marble in the Atlantic Provinces exclusive of Prince Edward Island, very few have been quarried for dimension or structural purposes alone. There is a serious handicap, in that practically all the localities have a limitation as to the source and soundness of the material available.

Marble deposits of the crystalline variety occur in northern Newfoundland at a number of places on the east side of White Bay and in the vicinity of Canada Bay. These deposits are described in detail by Bain (1937), who considered that marble possibilities existed for the limestone, the crystalline limestone and silicate verde-antique types. He cautioned against excessive optimism since the white marbles at Canada Harbour and on Englee Island were found to be badly jointed on all exposures. Though there may be limitations to the area providing dimension stone, re-evaluation as a potential source of white extender pigment for industrial use cannot be overlooked. Changing demands of the industrial stones in many cases indicate potentials that were not formerly considered.

Marble deposits in Nova Scotia appear along the south side of the Cobequid Mountains in northern Nova Scotia and at Marble Mountain and George River in Cape Breton Island. In all the known deposits investigated the stone was so badly fractured and jointed that large pieces of good uniformity would be very difficult to obtain.

The marbles of New Brunswick are found as small lenses and belts that extend for nearly 20 miles both northeast and southwest of the city of St. John. North of St. John the largest deposits occur and are very much fractured.

Investigations of the marbles in both Nova Scotia and New Brunswick have shown that they lack the desirable combination of features that give particular localities a definite advantage over others.

The excessive faulting, the broken and jointed beds argue against their development as building stone.

Marbles of the Province of Quebec

Favorable geologic processes and conditions have existed for marble formation in the province of Quebec. In a small number of places the limestones have been altered to the crystalline marble variety such as in Mississquoi county, Marbleton, Wolfe county in the Eastern Townships and at Port Daniel in Bonaventure county, Gaspe penninsula.

Only those marbles at Phillipsburg in Mississquoi county are of marked importance. Marble as dimension stone has not been produced for a number of years although at one time was the largest producer of decorative building stone. The Phillipsburg unit from which the marble has been quarried is characterized by simple open folds between thrust faults that form part of the Phillipsburg (Clark, 1934). The marble is extremely fine-textured, almost glassy in appearance, with discontinuous irregular dolomitic veining.

Pre-Ordovician marbles appear in the Caldwell group as strong bands forming a separate unit in North and South Stukley. Cooke (1950).

Various attempts have been made to quarry dimension stone from this north trending marble belt. The Dominion Marble Company produced some variegated marbles for building stone in 1912 (Parks 1914) but has not operated since 1914. In 1951 the Vermont Marble Company core-drilled a small deposit occurring along the same band in North Stukley and found the stone to have soft sugary beds that make it unsuitable for dimension stone or grinding to white pigment.

Observations at different parts along this belt show the marble to have a considerable variation in grain size. In some localities the rock is dense and coarse grained; in others the grain size is fine and the rock becomes brittle. The marble has a pale blue color but at South Stukley yellow to green veining occurs and the stone is occasionally traversed by a coarse grained white calcite. Some of the cut blocks have small incipient seams and a marked fracturing appears in the southern part of the belt. Quartz veining is common and pyritè is conspicuous in many specimens.

Marble Areas of the St. Lawrence Lowland

Province of Quebec

Paleozoic limestones appear at numerous localities in the valleys of the St. Lawrence and Ottawa rivers, and the Lake St. John and Saguenay regions. Most of these ubiquitous deposits have been described by Parks (1914) and Goudge (1935). Those deposits suitable for building stones are of Ordovician age and are mainly from the Chazy and Trenton groups. St. Marc des Carrieres in Portneuf county is one of the largest quarry centers for high calcium limestones. The stone has a brownish grey color, will take a good polish and has found some use as an interior decorative stone in some instances, but is used primarily for exterior and rough sawn veneer.

The St. Marc limestone is from the northeast part of a continuous belt of Trenton limestone that appears along the north shore of the St. Lawrence and swings southward through the Montreal area to west of the city of St. Johns, Quebec. Limestones have been quarried extensively along this belt and from the adjacent Chazy formation in the Montreal area.

Province of Ontario

The Paleozoic limestones provide the greatest source of building stone in the province of Ontario. The Black River and Trenton formations of the Ordovician and the Lockport formation of the Silurian contain abundant limestones. They provide the main production for dimension stone. The largest quarry center is two miles west of Queenston on the Niagara escarpment where dimension stone is obtained from the Lockport dolomite formation. The building stone quarried along the Niagara escarpment is the unpolishable type.

From the Ordovician Black River formation, two marbles or polishable limestones have been produced. In Ontario county the Longford quarries have produced a buff and grey magnesian polishable limestone "Rama Buff" and "Roma Silver Grey".

The other polishable limestone is located at St. Albert, 30 miles southeast of Ottawa. The stone is a bitumenized uniformly fine grained and high calcium limestone sold commercially as "Silvertone Black" marble.

The limestones constitute one of the chief sources of building stone in Canada to day. Many do not have the pore space filled with reorganized calcite and consequently do not take a good polish. Exceptions are the Black River beds at Longford and St. Albert.

Marble Areas of the Canadian Shield

Province of Quebec

North of the St. Lawrence and Ottawa rivers, major belts of crystalline limestones or complex of marbles form part of the Precambrian Grenville series of highly metamorphosed rocks. The distribution of the marble bands is not fully known but a fair estimation from the contributions of individual investigators shows the maximum areal extent to be 100 miles west of the type locality, north of Grenville, Argenteuil county, and 100 miles northward of the Ottawa River. Continuations of the marble bands belonging to the Grenville series are found to the west near Bancroft and southwest into the Kingston-Brockville regions of Ontario.

In the counties of Pontiac, Hull, Labelle and Argenteuil marble bands appear, yet few if any offer potential marbles as decorative building stones. Most deposits are coarse grained, an undesirable feature in that such stones generally fail to take a good polish, and have a poor durability. Although some localities show a remarkable absence of jointing, the coarseness of grain size and presence of basic dark-colored inclusions render it unsuitable for dimension stone.

Province of Ontario

In Ontario, large marble deposits appear in the Precambrian Grenville and Hastings series. This is a region of at least 100 square miles in area, in which thick deposits of marble form a part in the Bancroft-Kingston-Brockville regions. Marble have been utilized particularly in the counties of Addington, Frontenac, Haliburton, Dungannon, Hastings, Lanark, Lennox and Renfrew. The deformation along this tectonic belt was accompanied by the invasion of large masses of granite and basic dykes. The marbles found are highly metamorphosed. Many of the marbles along this belt, both in Ontario and in Quebec have commonly developed a coarse grain that fails to take a high polish. In addition coarse grained varieties appear to disintegrate rapidly and to develop a granular condition on weathering.

Dolomites are common in this series. Based on a number of chemical analyses, Goudge (1938) has found that many calcite marbles have at least 3 percent of magnesium carbonate, although most deposits have 7 percent, which is remarkably uniform. The magnesium carbonate is due to the presence of individual grains of dolomite.

Many deposits of Grenville marble are rendered worthless as building stone due to the presence of deleterious minerals.

A number of small quarries have been opened for dimension stone in this marble region within the last 80 years but all have discontinued operations. No single reason can be attached to the discontinuation of quarrying, or as to why many deposits have not been explored more fully, but it is believed that the chief problems are: (1) coarseness of grain with loose bonding of grain borders; (2) very fine grain, producing a brittle stone; and (3) a continuous supply of uniform stone free from close fracturing and jointing. Deposits are now worked for the making of lime, terrazzo and agricultural limestone.

Two sources of marble, one located at Marmora and the other in Dungannon township formerly produced some marble for decorative building stone. A deposit located one mile north of Marmora occurs in beds of fine to coarse crystalline limestone. The marble band is 50 feet wide with a near vertical dip and can be traced for at least 600 feet. Horizontal fractures are common along the quarry face and the marble is traversed by a number of nearly vertical fine grained basic dykes that vary in width from 3 to 8 inches. Variations in color, fracturing and grain size argue against its use as a building stone or source of white pigment.

The marble occurrence in Dungannon township, 3½ miles south of Bancroft has been operated on a somewhat larger scale and produced variegated, brecciated and laminated marbles in a variety of colors. The stone is largely dolomitic and is relatively free from heavy fractures and jointing that is common for other localities in this region.

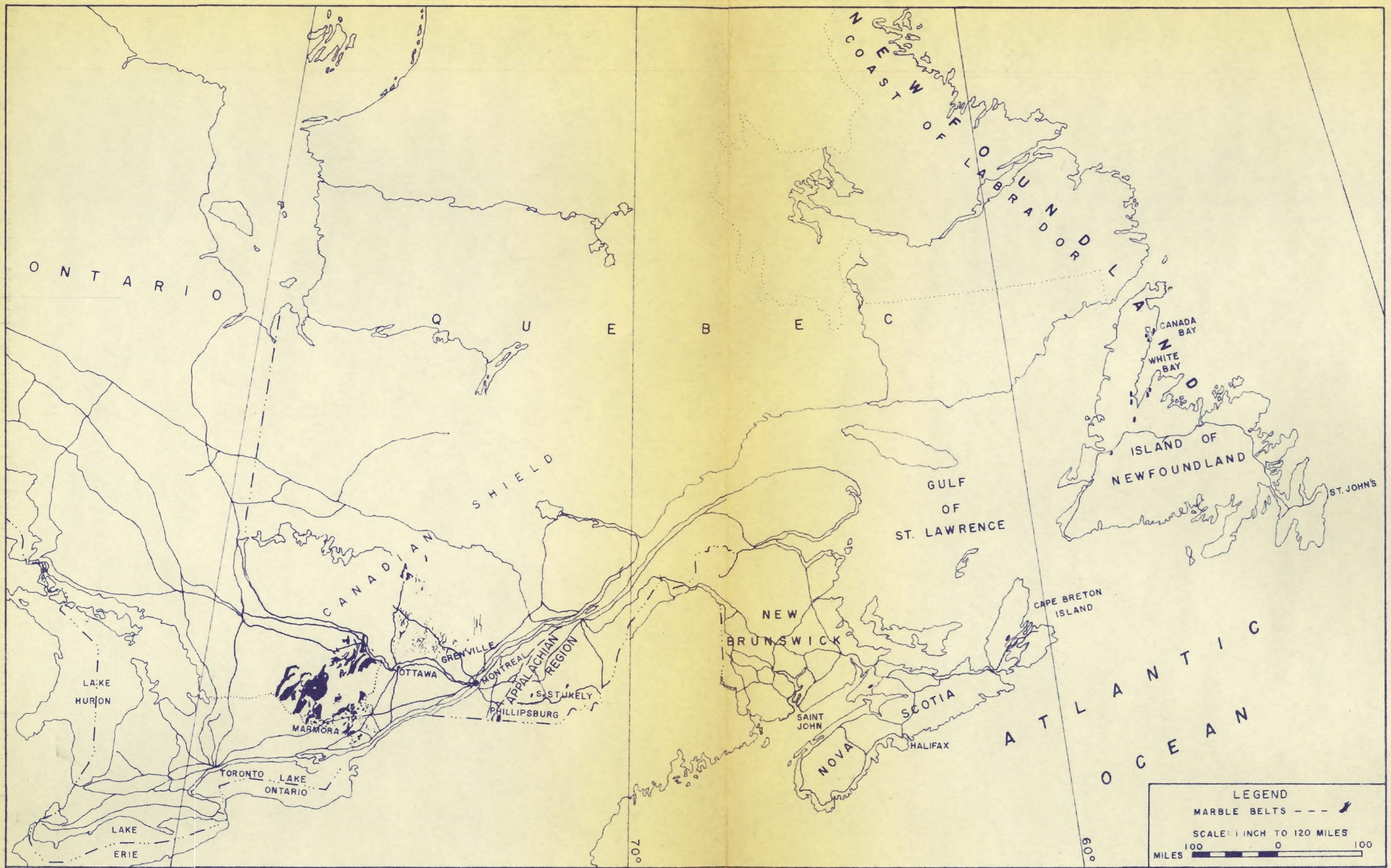


FIGURE 16. SKETCH MAP SHOWING THE LOCATION AND DISTRIBUTION OF MARBLE BELTS IN EASTERN CANADA.

The Serpentine Marbles

General Statement

The serpentines of the Eastern Townships belong to the class of rocks developed in consequence of special geological conditions thought to be present in the initial stages of an orogeny, where primary olivine-basalt magmas were intruded into sedimentary strata. The basic magnesian minerals such as olivine augite and hornblende were in special cases subsequently altered to the variety of serpentine, antigorite. The antigorite variety is utilized commercially as an attractive and valued decorative building stone. Some are readily carved and have beautiful and desirable colors when polished. The "verde antique" is an antigorite serpentine variety given to those green serpentine marbles by the ancient Romans and obtained originally from Italy, Greece or Egypt.

Deposits occur as altered lens-shaped intrusives in ultrabasic regions. With few exceptions, this rock

is badly jointed, allowing only small sized blocks to be obtained. Commercial "verde antique" quarries are developed in lenses where there has been in general a nicety of shearing and chemical change of the ultrabasic minerals, olivine and pyroxene to antigorite. Those that have joint planes widely spaced have only the bordering olivine and pyroxene minerals changed to antigorite. Where the smaller lenses have been crushed to a greater extent the action of hot solutions has more completely changed the olivine and pyroxene to antigorite. This more or less intermediate stage of alteration of the basic minerals has been found to produce the better varieties of "verde antique". Where shearing and alteration have advanced beyond this stage, the antigorite has been altered to talc, although even here the development of talc may have been only limited to parts of the lenticular body.
A distinction is made between a red weathering serpentine and a white weathering "verde antique" serpentine, each with a different mode of occurrence. (Bain, 1936). The former type of serpentinization

is ascribed to magmatic flow or autometamorphism, whereas the latter is considered to occur after complete crystallization of the ultrabasic and due to regional shearing forces and agencies.

There are a number of natural defects and other causes for unsatisfactory "verde antique" marbles. These include:

(1) Highly slickenslided surfaces that are not strongly bonded and tend to crumble in small pieces.

(2) Presence of talc or granite that introduces polishing difficulties.

(3) Presence of iron carbonate rhombohedrons that are dissolved by solution leaving a pitted surface.

(4) Minute fractures and openings that are not filled and so leads to structural weakening.

(5) Excessive iron present as magnetite that causes polishing difficulties, the hardness being greater than the serpentine and usually producing a dull polish.

(6) Incompleteness of serpentinization, leaving minerals that are harder and more difficult to polish.

(7) The presence of asbestos, chrysotile and slip fibre, generally incompletely attached to the walls of the fissures they fill, and more easily ground out during finishing and polishing.

(8) The presence of mica and uralite contaminating some "verde antique" marbles.

By careful selection some large masses may be found in which the veins are firmly cemented so as to produce a strong homogeneous marble.

The nearest sources of commercial "verde antique" serpentine type of marble are those quarries, in New England, at Roxbury, in Washington county and Rochester in Windsor county, Vermont. The deposits occur as lense-shaped intrusives in which the olivines and pyroxenes have been changed to minute flakes of antigorite arranged in an irregular mesh pattern. Fractures are marked by white carbonates as the dominant minerals.

The serpentine deposits in Eastern Canada that were considered worthy of study as a potential source of "verde antique" type of building stone are located: (1) along the Appalachian Upland extending from the Eastern Townships through to the Gaspe penninsula; (2) along the southern border of the Canadian shield in the Grenville subprovince.

Serpentines of the Appalachian System

The serpentine bodies of the Appalachian Highlands in Eastern Canada are located along a northeast trending belt of mafic and ultramafic intrusive rocks. The belt is made up of a series of irregular outcroppings found at intervals along the Appalachian front. The serpentine and serpentinized ultramafic rocks are often mapped as continuous between outcrops. Gaps occur between larger bodies and dykes. Variations in width are found along the strike and a number of the larger and smaller bodies tend to have a lens shape.

The same zone is considered to follow through as a narrow belt from central Massachusetts to the Green Mountains of Vermont, into the Eastern Townships of Canada and to continue beyond the Shickshock Mountains in Gaspe penninsula. These rocks have a tectonic control as shown by the relatively small and elongated bodies grouped into a belt that in general parallels the strike of the country rock.

A study of the literature and observations made on a large number of serpentine occurrences from Orford Mountain northeastward to the Gaspe penninsula revealed that "verde antique" serpentines in this part of the Serpentine belt are unsatisfactory. This conclusion is based primarily on the factors that have been shown to be unsatisfactory for other deposits in the same belt farther southwest. They include: (1) incompleteness of serpentinization. The dunites and peridotites have undergone a very general though partial alteration to serpentine, and the pyroxenites where they are not fresh and unaltered have been serpentinized like the peridotites or altered to chlorite and uralite. (2) Local intense shearing or fracturing has rendered the serpentines unsatisfactory. It would be difficult, if not improbable to obtain stone of the dimensions required for sustained production as a building or decorative stone. Although surface observations reveal this condition, insufficient evidence exists as to whether the fractures extend to depth. (3) The white weathering type of "verde antique" serpentine has not been found to occur in sufficiently large bodies. The predominant weathering colors are bright yellow browns and red browns that indicate the stones unsuitability as a source of "verde antique". (4) The color of the serpentinized peridotites and pyroxenites is dark green to dark brownish green and lacks the brighter greens and calcite veining. For this reason the stones offer little architectural appeal for decorative purposes.

Serpentines of the Eastern Townships

In 1930, Bain examined the serpentine deposits in the Eastern Townships from the International border to as far north as Eastman, Quebec. His conclusions were that the rocks of the serpentine belt in this part of Quebec were less schistose than in Vermont. The chlorite schists (which often border the serpentine lenses) were observed to remain as slightly changed volcanic ash and cinder deposits. The amphibolites appeared as lava flows and intrusive dykes and sheets of igneous rock. The fact that the rocks are sheared less argued against the region being suitable for "verde antique" serpentine deposits.

Orford Mountain - Brompton Lake Area

Small dyke - like masses of partly serpentinized peridotites and pyroxenites outcrop at the southwest end of Bowker Lake, and larger masses are found on both sides of Brompton Lake, the latter underlying an area of nearly 12 square miles. A number of small operations have been carried out in search of asbestos and chromite, exposing some of the serpentine rocks. In most places examined, the rock is very brittle and often intensely fractured, which prevents the extraction of blocks of the required dimensions for building stones. There are local alterations to talc or actinolite and in places fragments of serpentinized dunite, peridotite and pyroxenite lie in the matrix of the serpentine. The serpentine rock is mostly massive and of a dark green color, yet some varieties of a bluish-green color do occur that appear to represent parts of the imperfectly serpentinized rock.

Near the southwest end and one-half mile west of Stukely Lake, six small lenses of serpentine are found. The lenses have slickensided surfaces with many joint faces that have broken the stone into small fragments. Along the sheared surfaces picrolite has developed in widths up to three inches. The weathered surface has a pale green to brownish green color and in places has a rusty red weathered surface. The fresh stone has a deep green color and one specimen from the west side of Stukely Lake took a high polish but the color is of such a dark green as to render it undesirable as a decorative building stone. Between the southwest end of Stukely Lake and Eastman only one outcrop of a serpentine rock was found. This stone is much lighter in color with a few small disseminations of magnetite and pyrite. This rock is incompletely serpentinized as evidenced by the remnants of olivine scattered throughout the specimen.

Orford Marble Quarry

On lot 5, range XVI, and lot II, range F in Sherbrooke township, the Orford Marble Company quarries a serpentine marble. The quarry is located just south of a small pond about halfway between the most northerly of the Chain ponds and Bowker Lake. A sheared lens of serpentinized peridotite occurs with a red as well as white calcite veining. Thin sections show the stone to be predominantly antigorite and near the red alteration zones to be nearly all calcite with smaller amounts of disseminated magnetite. The calcite has been introduced along the small fractures. The stone does not polish well and consequently has not been used to any great extent for decorative building purposes. Most of the production is used for terrazzo.

Katevale Area

Some smaller masses of serpentinized ultramafic rocks are found about 6 miles east of Magog, near Katevale. Lenses or dykes cut across and are exposed along the highway to North Hatley. The serpentine has a soft light green color with abundant rhombohedrons of iron carbonate disseminated throughout the matrix. Shearing had taken place on the rock surfaces with the development of many tiny fractures that are in places filled with chrysotile asbestos.

Melbourne, Cleveland Townships

A narrow mass of peridotite representing the southwest extension of the Thetford Asbestos region extends through Melbourne and Cleveland townships. According to Cook (1950), throughout its distance it is only 600 to 1,200 feet wide except near Greenshields where it increases to 3/4 mile. Parks (1914) observed some narrow serpentine bands northwest of a slate band in Melbourne and Cleveland townships. The stone was very dark green, almost black in color and was composed of unaltered peridotite and was much fractured. Only museum specimens could be obtained.

At localities examined along this mass and also in a narrow dyke-like mass 2 miles west of St-François Xavier de Brompton, the serpentinized peridotites were found intensely fractured and in most cases the serpentinization not complete. Small veins of asbestos and development of picrolite generally mar the stone as a source of verde antique

Thetford Asbestos Region.

The dunites, peridotites and pyroxenites of the ultra-mafic rocks that extend from Asbestos, in Shipton township, northeastward through the Thetford asbestos region, have been described by many investigators and mapped in much detail.

The main mass of the peridotite has been estimated to be from 40 to 70 percent serpentinized throughout and the degree of serpentinization in the pyroxenite has been largely dependent on the relative abundance of olivine. Complete serpentinization has been found in minor zones but is associated with severe fracturing with alteration or replacement by iron or magnesium carbonate and development of talc. (Riordon, 1954)

The serpentines in this part of the Eastern Townships, aside from the development of intensely fractured surfaces and the presence of talc and chrysotile asbestos, have been found to lack the pleasing and desirable light green colors and contrasting carbonate veining for verde antique.

Matapedia-Chaudière River areas.

Beauceville area

MacKay (1921) mapped six small bodies of dunite, peridotite in which there has been an alteration in some degree into serpentine. The rock masses occur as isolated outcrops that extend northeastward as a belt from the mouth of Rivière des Plantes, about 3 miles north of Beauceville, Quebec. The weathered surface of the rock was observed to vary from brown to brick red and in places the rock was found to be cut by numerous veinlets of chrysotile asbestos. Boulder-like fragments occur in the crushed matrix of highly altered peridote and dunite, and where faulted and slickenslided surfaces were found, the rock broke up into numerous conchoidal fragments. The fresh rock varies in color from a pea green to a dark greenish black.

Cranbourne Township

In the Lake Etchemain Map Area, Tolman (1936) records dark colored, commonly fractured serpentine occurring in 8 small lenticular bodies. In trenches opened for the exploration of asbestos many rock surfaces show the presence of picrolite and some short, cross fibre abestos.

Roux, Rolette, Talon and Leverrier Townships.

Four small lenticular masses of partially serpentinized peridotite occur, one in each of the townships of Roux, Rolette, Talon and Leverrier. (Beland, 1952, 1954). There appears to be very little completely serpentinized rock and in places it is intruded by small masses and dykes of granite and syenite. On a fresh surface the rock is green or black and is rusty and grey on the weathered surface.

Awantjish Township

A lens of incompletely serpentinized peridotite and pyroxenite three miles in length and one-half mile across at its widest part has been mapped at a scale of 4,000 feet to an inch by Aubert de la Rue (1941). The serpentinized rock has disseminated grains of chromite in places, with accompanying minor amounts of talc. Most frequently the fibrous brittle picrolite was found along the slip planes in massive rock, and small amounts of chrysotile occur in small veins.

Serpentines of Gaspe Penninsula

Mount Albert

Serpentinized peridotite masses are known to occur on the Gaspe Penninsula in at least five localities. The largest is one that composes Mount Albert in Lapotardière township, and near the eastern end of the Shickshock range. This serpentinized peridotite mass according to Alcock (1926) "forms an oval area six miles long and nearly four miles at its widest part". The rock weathers to a buff color. On a freshly broken surface the rock is uniform in texture and consists largely of olivine which is in places partly or completely serpentinized. In parts of the serpentine rock picrolite has developed and occasionally the weathered surface has a banded appearance.

<u>South Mountain</u>

Two smaller separated bodies of serpentine occur 4 miles southwest of Mount Albert in Courcelette and Fairbault townships. One mass forms South Mountain and the other occurs one mile farther west. The serpentine is massive and has an overall length of 5 miles with an average width of half a mile (Mc Gerrigle, 1954). According to Ells (1883) the South Mountain serpentine shows the absence of asbestos or chromite and lacks the stratification observed on Mount Albert. The weathered surface was found to be exceedingly rough and ochreous.

<u>Mount Serpentine</u>

Mount Serpentine in Blanchet township extends for three miles with a maximum width of 2,000 feet and is composed of dense dark green to almost black serpentinized peridotite. The rock weathers to a brownish buff color and contains in places a little chromite and asbestos (Jones, 1934).

North Port Daniel River

A serpentinized peridotite mass which has a length of about one mile and a maximum width of 1,000 feet intrudes the MacQuereau sediments in Weir township along the upper waters of the North Port Daniel River. (Alcock, 1935). The freshly broken surface is dark green and the weathered surface is buff colored. The rock is largely serpentine traversed by small veins of chrysotile with chlorite present in considerable quantities.

Serpentine of the Grenville subprovince of the Canadian Shield.

The serpentines of the Grenville subprovince differ considerably from those found in the south in the Eastern townships. Much of it is contained in the carbonate rock of the Grenville series as massive transluscent olive green serpentine or as green aggregates. The quantities found are usually small and limited in extent. There are differences in color, mode of aggregation and origin. The serpentines are derived usually from diopside, but also from chrondrodite or other magnesian silicates. There are some in which darker green colors occur but brighter greens predominate. The serpentine may be disposed in rounded grains dispersed through crystalline limestone, giving a spotted appearance to the stone, or may be marked by cloudings of green or buff serpentine in white or various colored calcite marble.

There are no serpentine marbles quarried from the Grenville subprovince in Quebec or Ontario but there are numerous references in the geological literature to the occurrence of serpentine in this region. Regarding quarrying of serpentine marbles, Logan in "Geology of Canada", (1863),mentions a mill in operation for sawing serpentine marble from lot 16 Range 111 and a red variety from lot 13 Range V Grenville township, Argenteuil County, Quebec. These deposits are marked by many fractures and seams. They lack uniformity and are small and limited in extent. Only small pieces could be obtained.

Parks (1912) records "a serpentine marble consisting of a medium grained white or lavender colored calcite marked by cloudings of green or buff serpentine" located in the northwest quarter lot 7, concession IV; East quarter lot 7, concession III, Darling, Lanark County, Ontario. The deposit is marked by a great deal of irregular fracturing near the surface but at limited depth a strong series of joints appear parallel to the strike of the deposit.

The polished stone is marked by very light yellow and pale green serpentine bands and clouds intermixed with white to lavender shades of calcite marble. The deposit was traced for a distance of one-third of a mile with an average width of 500 feet. The deposit was worked prior to 1910 and according to Parks (1912) about 5,000 cubic feet were quarried during this period. There is no record of production since that time.

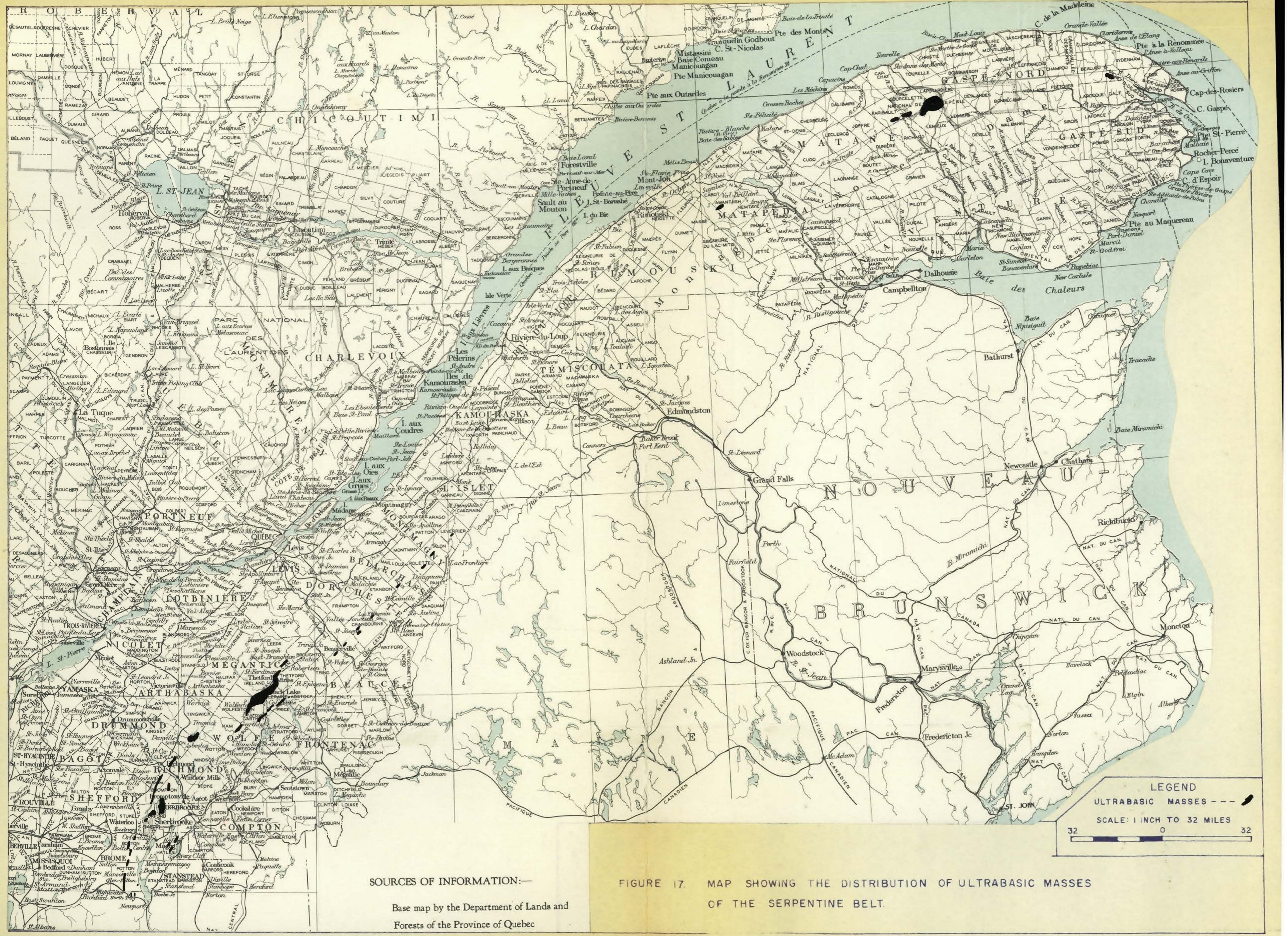


FIGURE 17. MAP SHOWING THE DISTRIBUTION OF ULTRABASIC MASSES OF THE SERPENTINE BELT.

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