ONTARIO

DEPARTMENT OF MINES

BUILDING STONES OF ONTARIO

PART I

INTRODUCTION

By

D. F. HEWITT

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BUILDING STONES OF ONTARIO

will be issued in five parts:

Part I	Introduction
II	Limestone
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BUILDING STONES OF ONTARIO

PART I: INTRODUCTION

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BUILDING STONES OF ONTARIO

By

D.F. Hewitt[1]

PART I: INTRODUCTION

The building stone industry has existed in Ontario since the early 1800's when local stone deposits were exploited for construction of homes, buildings, walls, dams and bridges. Great impetus was given to the stone quarrying industry by the construction of the Welland and Rideau Canals between 1824 and 1831. These canal construction jobs employed British stone masons to quarry limestone for the dams, locks and retaining walls. Many of these masons subsequently settled in Ontario and in the mid 1800's local skilled labour was available to quarry and lay stone. Many of the stone buildings and homes in Ottawa, Perth, Kingston, Napanee, Niagara Falls, St. Catharines, Fergus, St. Mary's and other Ontario cities and towns date from this period.

The stone quarrying industry began to flourish and many small local quarries, largely employing hand labour, were worked to supply stone locally. Adequate supplies of attractive building stone were available in most parts of southern Ontario and the extensive local use of stone has given character to the architecture of many areas. The examples of Perth and Kingston are typical. In Kingston medium-bedded Black River limestone,

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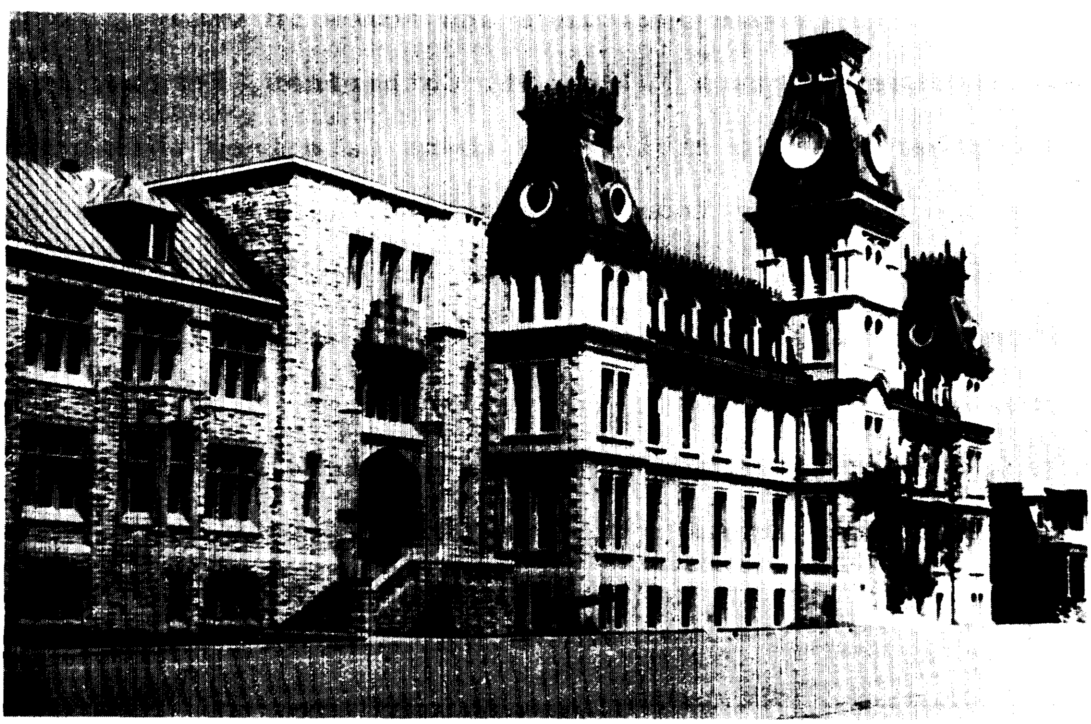
Perth town hall erected in 1863 using local grey and purple Potsdam sandstone.



Kingston's Black River limestone was used in the Mackenzie building at Royal Military College, Kingston; rock faced ashlar on the left, pointed faced ashlar on the right.

occurring in free beds 6 to 15 inches in thickness, was easily quarried and was used in so many early buildings that Kingston became known as the "Limestone City". In Perth the Potsdam sandstone is locally available in grey and mottled purple tones. Much of downtown Perth is built of this attractive stone and sandstone houses are enduring landmarks on many residential streets.

Stone buildings of this period were largely built of rock-faced ashlar consisting of rectangular blocks 4 to 15 inches in height with a natural rock face. This type of stone was quarried from free beds 4 to 15 inches thick and a massive stone construction was employed in which the stone walls were the load-bearing structural members. Even when other building materials such as brick or wood were used for the superstructure, the building foundations were stone. This widespread use of stone led to the development of stone quarries in favourable beds wherever these could be found and small quarries dotted southern Ontario.

In 1889 the Portland cement industry was introduced into Canada and concrete began to displace stone as a material for building foundations and engineering structures such as dams, walls, etc., due to its cheapness and ease of emplacement. Throughout the country barns can often be dated by observing whether the foundations are of stone or concrete construction. Typical of a local quarrying industry is the Winger quarry at Springvale, a village near Hagersville, which was operated in the late 1800's and supplied Springvale sandstone for many houses and barn foundations in the area. The Springvale quarries have now been idle for over 50 years.

At the turn of the century there was a radical new departure in architecture involving a change from massive stone construction to steel frame construction in which the steel formed the structural framework of the building; the stone was hung from the steel frame as an envelope to form the walls. For this purpose heavy stone blocks, which had formed the load-bearing stone walls supporting the floors and roof, were replaced by thin slabs of dimension stone from 2 to 6 inches thick cut from large mill blocks by sawing.

The first steel frame building in Toronto was the old Board of Trade building built in 1888 at Yonge and Front streets. This was followed in 1893 by the Robert Simpson building.

The trend away from massive blocks of ashlar to cut stone sliced in 2 to 6 inch slabs from a large mill block which might weigh 10 to 20 tons and measure several feet in rectangular dimensions, made a radical change in quarry operations. Many small local quarries ceased operation. Hand labour costs involved in quarrying, selecting and trimming stone became too high to compete favourably with other building materials, and only the highly mechanized dimension stone quarries were able to compete in most areas.

Later the reinforced concrete building frame came into popularity as a competitor for the steel framed building, and a thin curtain wall of dimension stone or brick was all that was required to keep out the weather. The first reinforced concrete building in Toronto was the Loft building erected in 1900 on Front Street east of the Royal York Hotel.

Cut dimension stone has had a steady popularity for large office and public buildings. Recently there has been serious competition by precast concrete slabs faced with mineral aggregates or crushed ceramic materials such as glass.

Limestone has retained its popularity as a high quality building material. However due to its high cost, granite is no longer widely used to face entire buildings, but is usually employed for the first and second storeys and entrances where it is readily seen by the passerby. Polished granite, limestone and marble are widely used in banks and store fronts. Marble is used extensively for interior trim. At the present time most of this marble is imported from foreign countries.

In the years since World War II there has been a marked trend back to the use of stone especially in houses of better quality in which limestone and sandstone ashlar are now widely used for stone fronts. Limestone and sandstone ashlar construction is used in churches and many school and university buildings. Queen's University traditionally uses limestone ashlar: recently the local Black River stone has been unavailable and Queenston limestone from the Niagara peninsula has been used instead. The University of Western Ontario traditionally uses sandstone and several new buildings of Medina sandstone have recently been erected.

There is now a good supply of sandstone ashlar coursing available from the Credit Valley Medina and Kingston Potsdam sandstone quarries. The supply of limestone ashlar is mainly limited to Queenston type limestone and Wiarton dolomite. It is unfortunate that the very pleasing white-weathering Black River limestone is no longer quarried as some of the most attractive buildings in Ontario are built of this stone.

In 1962 and 1963 exploration work has been carried out by several companies on marble deposits in eastern Ontario and three new marble quarries have been opened in that area.

REPORTS ON ONTARIO BUILDING STONE

A comprehensive study of building stones of Ontario was carried out by W.A. Parks and a report was issued by the Canada Department of Mines in 1912. This is the most complete and detailed report available on Ontario building stones and has unfortunately been out-of-print for many years. In 1933 the Mines Branch of the Canada Department of Mines published a report on "Canadian Limestones for Building Purposes" by M.F. Goudge, giving an excellent account of Ontario limestone quarries. In 1955 the Canada Department of Mines and Technical Surveys published a report by G.F. Carr on "The Granite Industry of Canada" which includes 18 pages on the granite industry of Ontario and covers the principal granite quarries.

TYPES OF BUILDING STONE

The five principal types of building stone which have been produced in Ontario are granite and gneiss, limestone, marble, sandstone and slate. Granite mill blocks suitable for sawing into building and monumental stone have been produced in several quarries in Ontario on an intermittent basis. Recently the Vermilion Bay quarry of Scotstown Granite Company and the Nipissing Black Granite quarry of Industrial Garnet Company have been active.

Granite gneiss and paragneiss which readily split into 2- to 4-inch beds are quarried at Parry Sound, Minden, Huntsville and Kingston for the production of flagstone, drywall stone, steps and granite veneer. Granite boulders are common in glacial deposits all over Ontario and are used as a building material in fences, walls, houses, stores, etc. A large tonnage of various granitic and pegmatitic rocks are now used for aggregate for facing precast concrete slabs used in buildings.

Limestone mill blocks suitable for cut stone are produced by Queenston Quarries and Peninsula Stone Quarries near Queenston and Thorold. Mill blocks have been recently produced from time to time at various locations on the Bruce Peninsula. Thin-bedded limestone suitable for flagstone, copings, sills and ashlar coursing is quarried at six localities near Wiarton on the Bruce Peninsula.

Marble mill blocks have been taken out at several localities in eastern Ontario in the summers of 1962 and 1963. There has been production from the Tatlock quarry of Omega Marble Tile and Terrazzo Limited, from the Tatlock and Sharbot Lake quarries of Angelstone Limited, and from the Cashel township quarry of the Grenville Marble Company. This marble is suitable for cut stone. The principal production of marble in Ontario is from the Madoc area where it is mainly used for the production of terrazzo chips.

Sandstone millblocks for sawing are produced near Glen Williams from the Medina sandstone by Argo Block Company. Ashlar, flagstone, steps and copings are produced by several small Medina sandstone quarries near Limehouse, Glen Williams and Inglewood, and by several small Potsdam sandstone quarries near Kingston. Minor amounts of sandstone are quarried near Perth and Ottawa from the Potsdam (Nepean) formation.

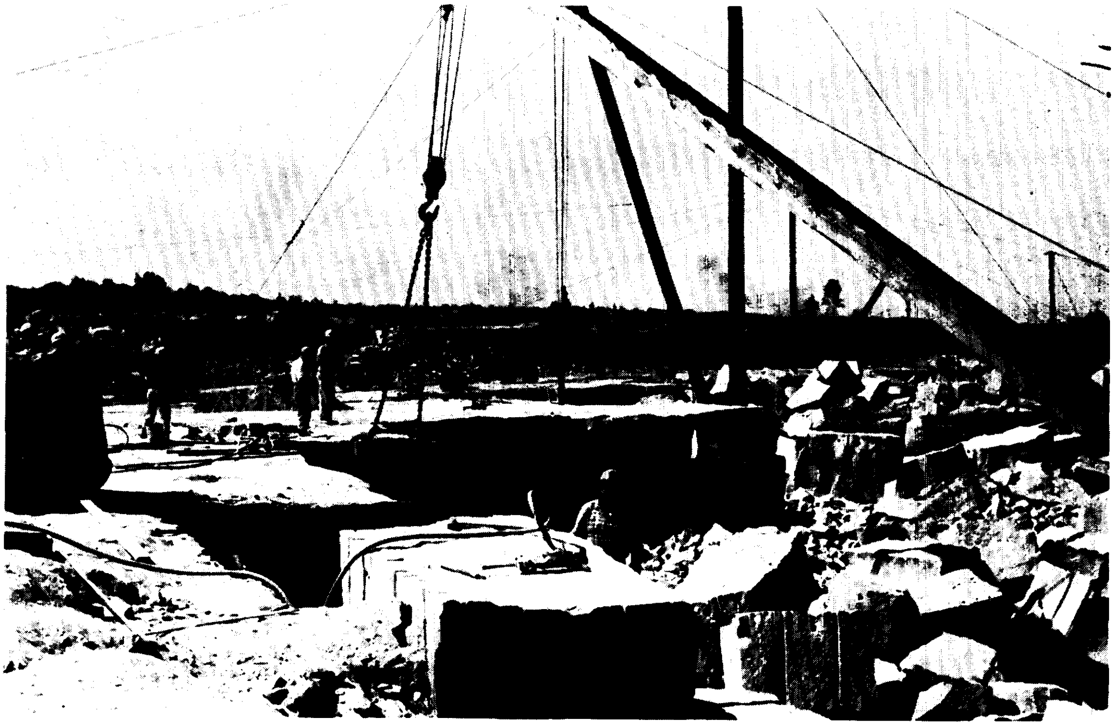
Slate has not been produced commercially in Ontario since 1939 when there was some slate quarried near Madoc.

Mill Blocks:

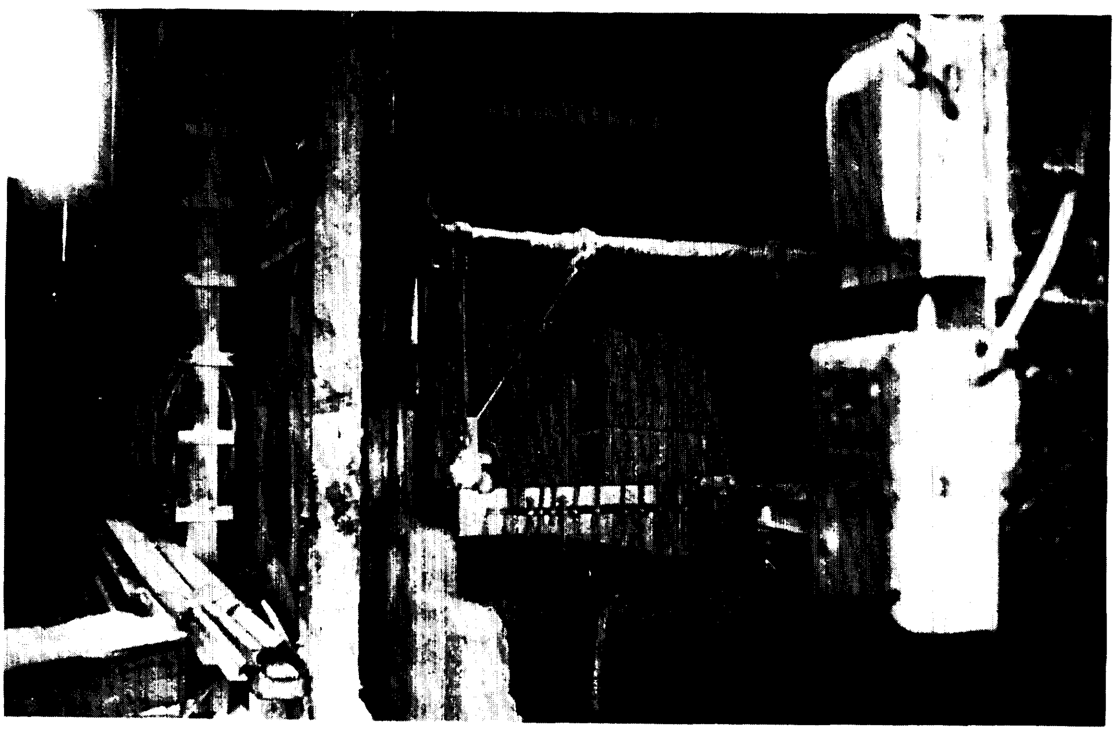
Most granite and marble quarries and many limestone and sandstone quarries produce and sell their stone in the form of mill blocks, which are large rectangular blocks of stone measuring several feet on the side and weighing up to 15 or 20 tons. The size of mill blocks quarried depends upon the thickness of bedding and frequency of jointing in the rock. A typical mill block of marble might measure 4 by 5 feet by 8 feet. If the mill blocks are to be shipped for long distances from the quarries to fabricating plants they should be trimmed to a rectangular shape to eliminate waste. This process of trimming is known as "scabbling", which may be accomplished either by hand tools, carborundum or diamond saws or wire saw.

Cut Stone:

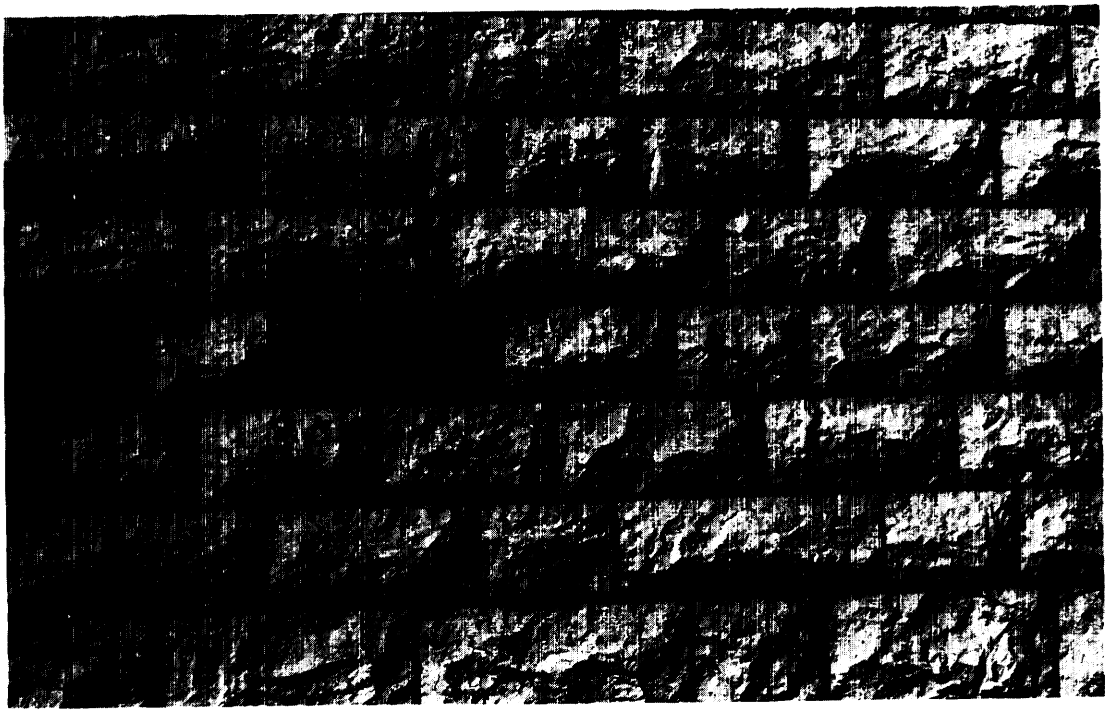
Cut or finished stone is sawn from mill blocks to specific size specifications. The cut stone panels are generally $\frac{3}{4}$ to 8 inches in thickness depending on their use for exterior or interior requirements. Cut stone is commonly employed for exterior walls where limestone or granite are mainly used. For interior use marble is more common. Cut stone may be cut or carved into special shapes for decorative purposes. Cut stone may also be used for sills, lintels, steps, coping, etc.



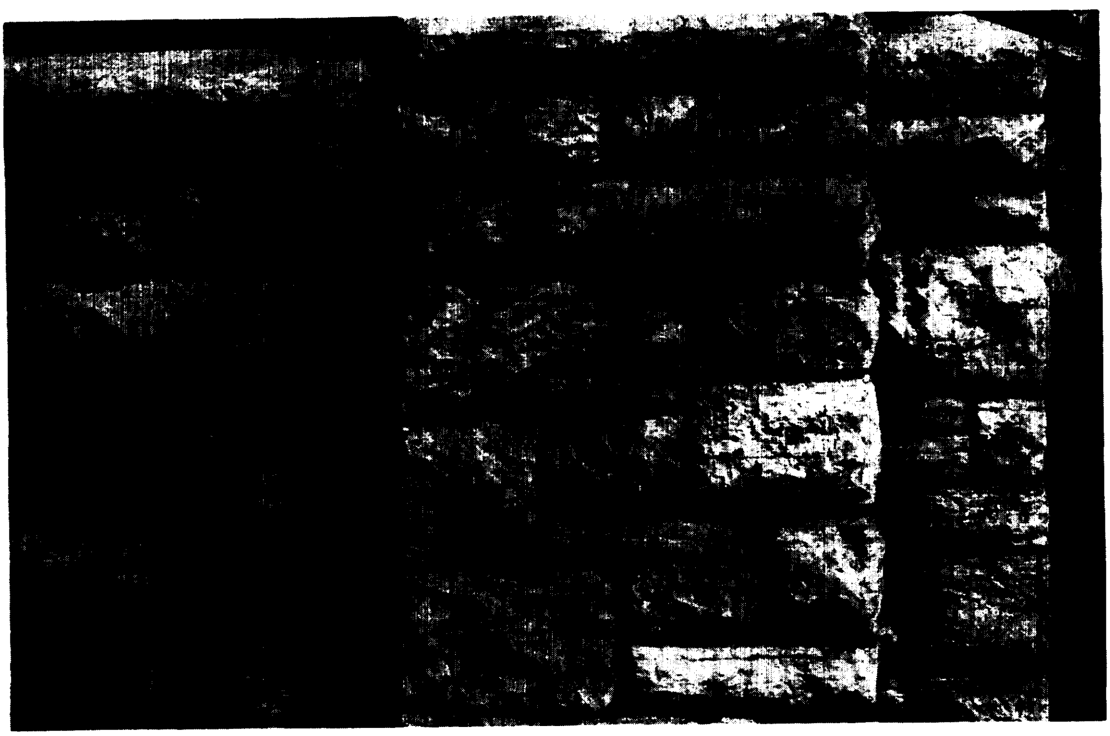
Handling mill blocks of limestone at Queenston Quarries.



Gang-sawing mill blocks of Queenston limestone at Queenston Quarries.



Rock faced even-coursed ashlar using Black River limestone.



Rock faced random coursed ashlar using Black River limestone.

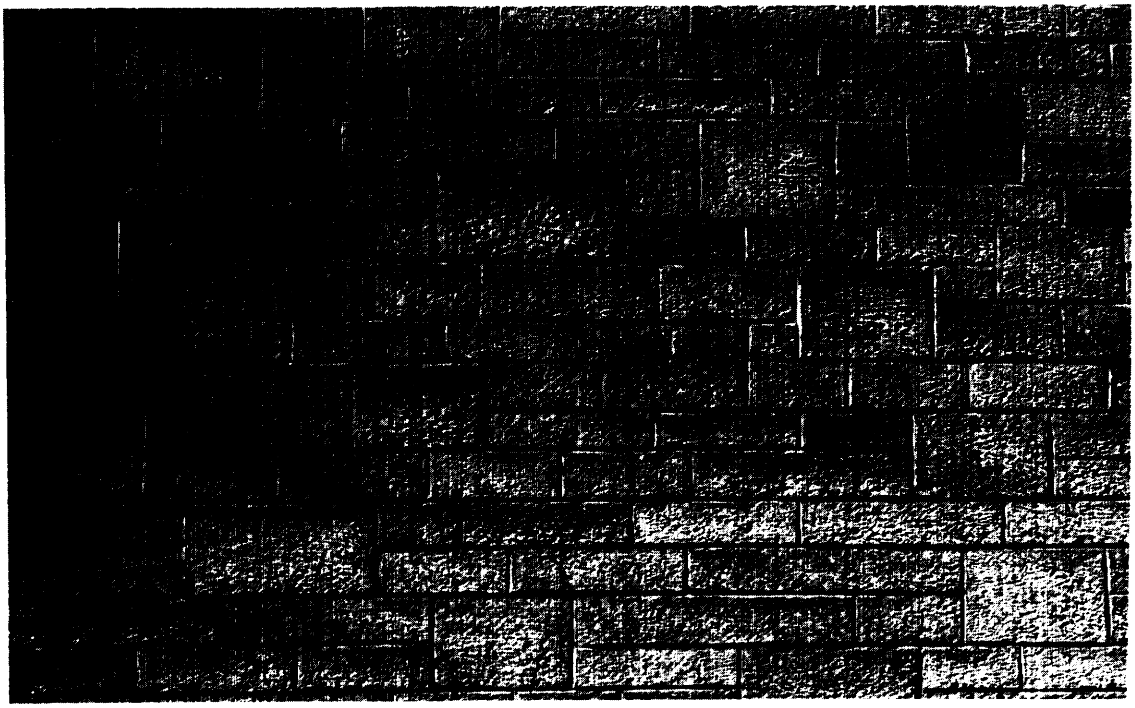
A variety of surface finishes are available for cut stone. Granite and marble are commonly polished. Granite may also have a sawn surface or a "hammered" or "axed" surface obtained by surfacing with a bush hammer. Granite may also have honed, rubbed, sanded or natural cleavage surfaces. Marble for exterior use is generally not polished but will have a sawn, rubbed or honed finish. Limestone is supplied with gang-sawn finish, chat or shot-sawn finish, smooth machine finish, wet rubbed or honed finish, depending on the fineness of finish required.

Ashlar or Coursing Stone:

Rectangular blocks of building stone up to one foot or more in length, bounded by sawn, planed or planar rock surfaces, used in walls or building facings are termed "ashlar" or "coursing stone". "Split-faced ashlar" has a natural rock face produced by splitting the rock by machine guillotine, by plug and feather, or by scoring with a hammer and chisel along the proposed line of fracture on both sides of the stone. "Rock-faced ashlar" has a natural rock face pitched by hand tooling.

"Even-coursed ashlar" uses blocks of equal height for each course, with the blocks in a single course being equal or unequal in length. "Random coursed ashlar" uses blocks of differing size and height usually in multiples of about 2½ inches.

Ashlar may also have finishes referred to as "pointed face", "hammered face" and "pick face". Pointed faced ashlar has a relatively smooth surface produced by the pointing chisel. In the hammered face finish, the surface is rendered planar by hammering. The degree of fineness of finish depends on the type of hammer



Pick faced random ashlar using Medina (Credit Valley) sandstone; Sigmund Samuel Library, University of Toronto.

Random ashlar showing a variety of finishes including sawn, chat-sawn, punch, pick face and rock face. Carr Hall, St. Michaels College, Toronto.

used. Pick faced ashlar has a series of irregular grooves in the surface produced by a mason's pick. A hand tooled margin may be added to any of the above styles.

While ashlar is most frequently laid up with a rock face or split face it may have a sawn surface. Some Ontario ashlar is laid up with the bedding surface exposed: this is termed "strataface ashlar" or "strataface coursing."

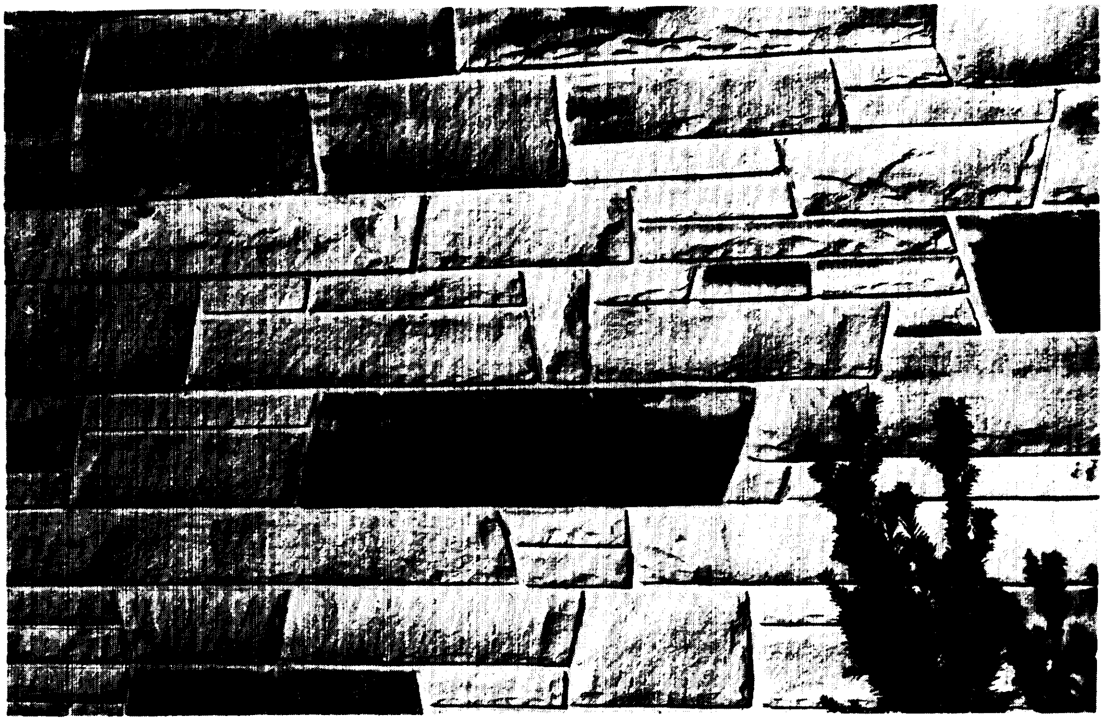
While ashlar is usually rectangular in shape, occasionally the ends of the ashlar blocks are inclined at an angle to the base. This is termed "mitred ashlar".

Rubble:

Blocks of building stone up to about one foot in length, not necessarily bounded by planar, parallel regular surfaces are termed "rubble". A very attractive appearance is given by rubble which differs from ashlar in that the individual blocks are not regularly rectangular and there is no even coursing.

Flagstone:

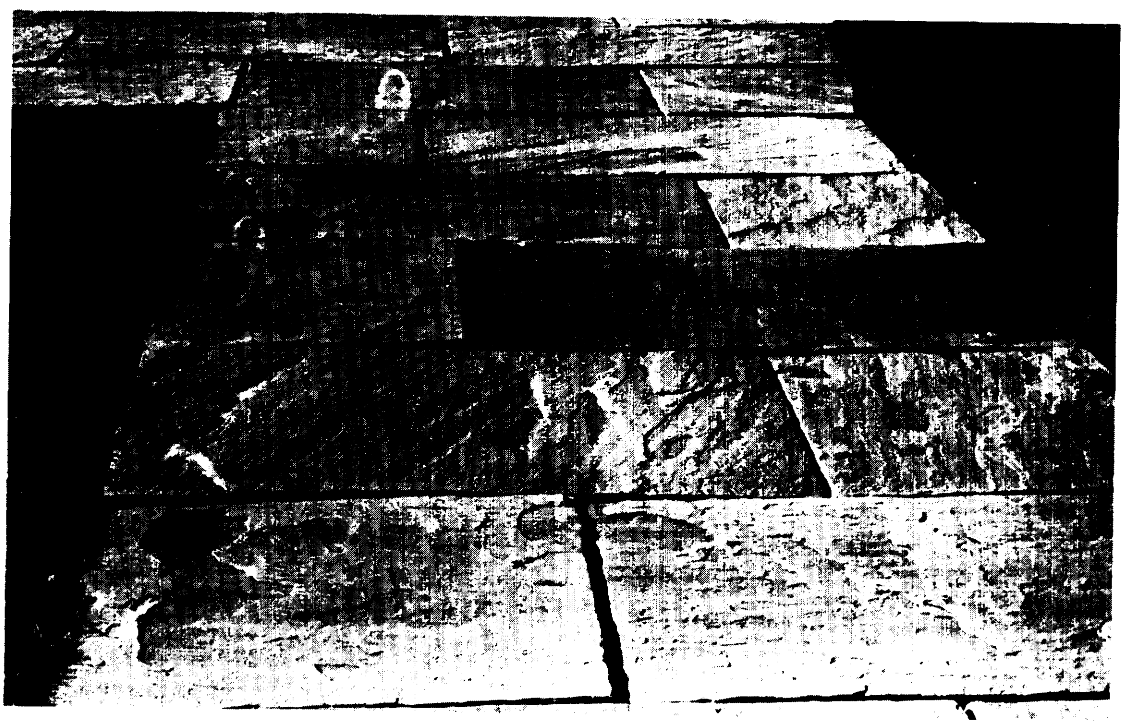
Flagstone consists of thin beds of stone $\frac{3}{4}$ to 3 inches in thickness, usually limestone or sandstone. "Regular" flagstone is rectangular in shape with sawn or rock face edges. These may be used for steps, flagstone paths, patios, etc. "Random flagstone" is of irregular shape with rock faces, and is commonly used for walks, patios, etc. "Wall flagstone" is thin ($\frac{1}{4}$ to 1 inch) natural random flagstone used for interior wall applications. It is a variety of veneer.



Split faced mitred ashlar using Medina (Credit Valley) sandstone.

Split faced mitred ashlar using Potsdam (Kingston Hue) sandstone.

Split faced Medina (Credit Valley) sandstone rubble used in St. Augustine of Canterbury Church, Bayview Avenue, Toronto.



Regular rectangular Medina (Credit Valley) sandstone flagstone used in a walk; showing bedding surfaces.

Veneer:

Thin slabs of stone from $\frac{1}{2}$ to 3 inches in thickness and of irregular shape are used as facing stone for buildings, walls, etc. These slabs are set on edge and present their large face to the viewer. They are generally of random shape and are sometimes termed "5-point" by the quarrymen. Granite gneiss, paragneiss, limestone and sandstone are used for veneering stone. "Mosaic veneer" is made of random 5-point slabs of stone of regular thickness laid as a facing stone.

Special Uses:

Stone is commonly used for copings, steps, sills, hearths, mantles and chimney caps.

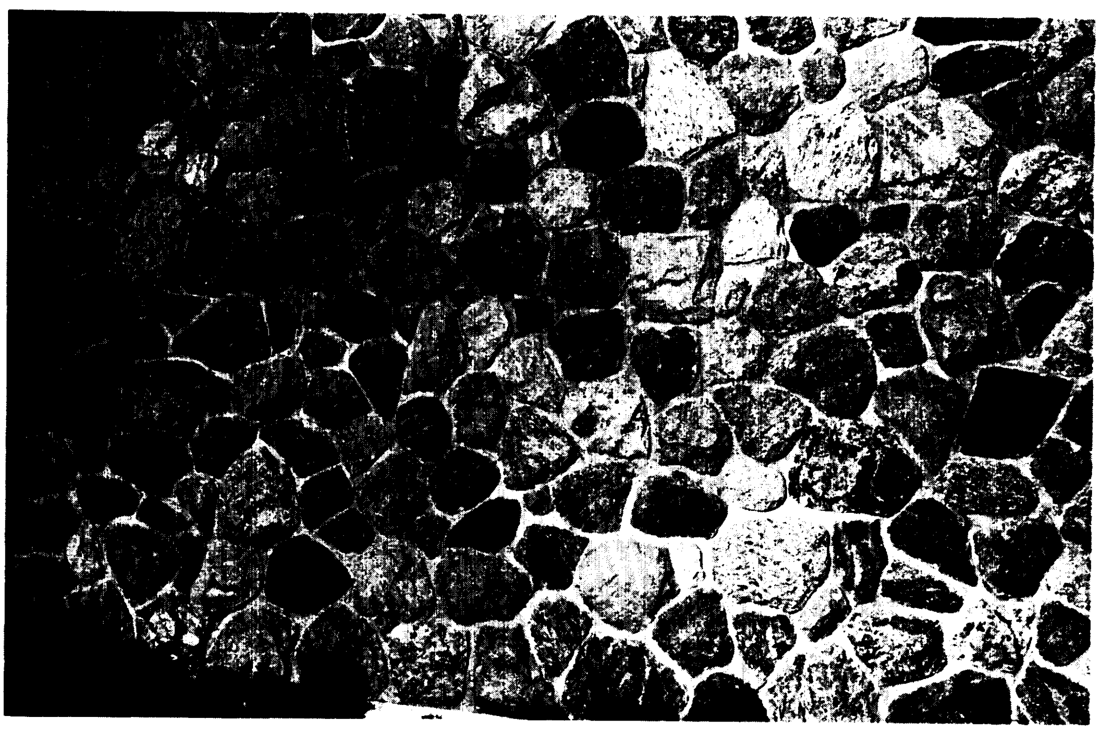
Rough Building Stone:

Rough building stone consists of irregular shaped rock-faced pieces of stone which may be laid up in walls having an irregular joint pattern. Split faced boulders could be classed in this category. This type of stone is frequently seen in chimneys, walls, store fronts, etc.

Riprap and Armour Stone:

These are large angular blocks of quarry stone from 1 cubic foot (about 200 pounds) up to 10 or 15 tons in size. When riprap is individually placed and fitted on the face of a revetment wall, dike or breakwater, it is often termed armour stone. Granite or limestone is commonly employed as armour stone.

Mosaic veneer ("five point") used for facing a wall.



Split faced granite field stone used in a wall.

Monumental Stone:

Granite is most frequently used as monumental stone and only the stone of highest quality is used for this purpose. It should be free of flaws, inclusions, cracks, discolouration and other imperfections and should be of uniform colour. Production of monumental stone in Ontario is limited.

Paving and Curbstone:

The use of paving and curbstone has largely given way to the use of concrete and macadam.

PHYSICAL PROPERTIES OF BUILDING STONE

The physical properties of building stone are important in evaluating the quality of a building stone deposit. The tests described in the following sections give useful information for architects or contractors using stone. Some idea of the weathering characteristics and durability of a building stone can be ascertained from careful observation of weathered outcrops of the rock in place. The best test of a building stone is its durability under actual service conditions in buildings over a period of years, and most of the widely used stones have a service record well known to architects.

Geological Features:

Geological features which are important in evaluating a building stone deposit include character of jointing, bedding, uniformity of stone, uniformity of colour and freedom from intrusions, shear zones, alteration zones and deleterious materials. Jointing should be uniform and widely enough spaced not to interfere with quarrying of mill blocks. In many granite and marble deposits close jointing renders the deposit valueless as a building stone. A uniform, widely spaced set of vertical joints may be of assistance in quarrying stone.

The character of bedding is important particularly in limestone and sandstone deposits. Where mill blocks are desired, a thick massive-bedded deposit is desirable. Where ashlar, flagstone and veneering stone are the principal products, the deposit should have thin to medium bedding. Granite gneiss and paragneiss deposits producing flagstone and veneering stone should have a well-developed stratiform foliation and "bedding" cleavage.

Uniformity of texture and colour are generally desirable in a stone deposit, although adjacent beds may produce acceptable stone of different colour or texture.

The presence of intrusive dikes or sills is a common feature in some granite and marble deposits. These features may seriously interfere with quarrying operations, and alteration along dike contacts may spoil the adjacent stone. Shear zones and zones of hydrothermal alteration are likewise undesirable and should not be present.

The rift and grain of the stone should be ascertained. The rift is the direction of easiest breaking, and the grain is the second direction of breaking. Rift and grain are commonly present in Ontario granite and marble deposits and sometimes present in sandstone and limestone deposits.

The depth of unconsolidated overburden and overlying waste rock strata are important features to be determined in examining a commercial building stone deposit. Several sandstone deposits in the Credit Forks and Inglewood areas are covered by such a thick section of overlying rock in the face of the Niagara escarpment that they cannot be worked by open pit methods. The Gasport member of the Lockport formation which is quarried commercially at Queenston Quarries is overlain by a thick section of waste rock which is quarried for crushed stone.

Chemical Composition:

It is sometimes desirable to determine the chemical composition of the potential building stone. From the chemical composition of a marble, for example, the percentage of silicate minerals which may affect the stone's weathering properties can be calculated, and the percentage of iron which will allow calculation of the percentage of iron-bearing minerals likely to cause rusty discolouration. The percentage of magnesium carbonate in limestone or marble appears to have little effect on its durability (Goudge 1933, pp.178-181). In the case of most granite, limestone and sandstone used for building purposes, the chemical composition is of minor significance compared to other physical properties and is not necessarily determined, except where specific problems may require it. The percentage of shale in a limestone, which will affect the durability, can be determined by chemical analysis. If efflorescence is a problem, a chemical analysis will furnish data on the presence of soluble sulphates in the rock.

Petrographic Examination:

A petrographic examination is made to give the mineralogical composition of the building stone, its texture, grain size, alteration and type and character of cementation. The mineralogical composition will give information on likely weathering characteristics and hardness of the building stone, and on percentages of deleterious minerals such as sulphides which may be present. The texture, grain size and type of cementation will influence the polishing qualities of granite or marble and the durability, friability and workability as a building stone. A poorly cemented friable sandstone or limestone is likely to be too soft for building stone.

Petrofabric analyses to determine the presence or absence of preferred mineral orientation may be carried out on marbles, as grain orientation has an effect on durability. The measurement of the coefficient of irregularity of a marble, which measures the regularity of grain boundaries, gives an indication of the durability of a marble under weathering (Bain 1940, pp.3-9).

The coefficient of irregularity is obtained by dividing the length of grain contacts per square centimetre by the square root of the number of grains per square centimetre. Bain's experiments with marbles indicates that an average coefficient of irregularity is about 1.8 and this may rise to 2.1 in the case of marbles with irregular grain boundaries. Marbles having a high coefficient of irregularity are likely to weather better than those with a lower coefficient of irregularity.

Colour:

Colour and uniformity of colour are important in a building stone. In fabricating stone for a large building it is essential that colour tone be maintained throughout the job. The beds of stone being quarried should be sufficiently uniform to fulfil this requirement.

Colour tones and light reflectivity of building stones, for example white marble, can be measured by differential colorimeter and compared with known standards. Black knots and inclusions present occasionally in granite will affect uniformity of colour. Some stones change colour with age, the colour sometimes depending on the nature of the fumes present in the air where the building is erected. Practical experience under conditions of use is the main guide to expected colour changes with weathering. The microcrystalline "birdseye" limestone of Black River age formerly quarried at Longford Mills is grey on fresh surfaces and turns an attractive silver-white on weathering.

Grey magnesian limestones which contain some iron carbonate may turn buff to brownish in colour on weathered surfaces. Rama stone formerly quarried at Longford Mills shows this weathering peculiarity. Magnesian limestones and dolomites are more prone to this type of discolouration.

While uniformity of colour is generally desirable, mottled sandstones of pleasing appearance are produced from the Medina sandstone quarries of the Inglewood areas in tones of red and grey. In the Kingston area much of the Potsdam sandstone produced is banded or mottled buff and brown or red.

Staining and Efflorescence:

The presence of deleterious minerals, such as pyrite or marcasite which may weather to produce rusty iron stains, is generally detected in petrographic examination. Tendency to discolour on weathering can sometimes be detected by weatherometer tests which subject the surface of the stone to alternate cycles of heat, light and water.

Efflorescence can be detected by partially submerging a block of stone in water for a period of several weeks. Soluble salts will appear as a white or coloured scum on the rock surface.

Specific Gravity, Absorption and Porosity:

The specific gravity or density of a stone is a measure of its relative weight or heaviness compared to water. True specific gravity of a stone is its weight, compared with the weight of a volume of water equal to the volume of the stone exclusive of pore space.

True specific gravity is determined by grinding the stone to a powder in which the pore space is eliminated, and measuring the specific gravity of the powder using a specific gravity bottle which has a small hole in the glass stopper. The bottle is first weighed, then filled with distilled water and weighed again. The bottle is emptied, dried, the ground stone sample is added and it is again weighed. The bottle with the powdered stone sample is filled with water and again weighed. The weight of the dry bottle with the powdered stone, minus the weight of the dry bottle gives the weight of the powdered stone, W. The weight of the bottle with powdered stone and water minus the weight of the powdered stone, W, gives the weight of the bottle plus enough water to fill it after the stone is put in = Y. The weight of the bottle full of water minus Y gives the weight of the water displaced by the stone = Z. The true specific gravity = $\frac{W}{Z}$.

The determination of true specific gravity may also be done by means of the "Le Chatelier flask", which is larger than a Pycnometer bottle, and requires 50 grams of sample. This method is described in U.S. National Bureau of Standards Technical Paper No. 349, 1927.

Apparent specific gravity is the weight of a stone compared to the weight of a volume of water equal to the volume of the stone exclusive of the pore space into which water can normally penetrate.

A method of determing the apparent specific gravity is to take a one inch cube and completely fill the pore space with water. This is done by soaking the cube in boiling water for 2 hours followed by 48 hours in water under pressure. The saturated cube is weighed in water, weight = C. The cube is dried in a dessicator at 110°C for 24 hours and weighed, weight = A.

Then apparent specific gravity = $\frac{A}{A-C}$

The apparent specific gravity equals the true specific gravity if all the pore space was filled with water when weight C was taken.

The bulk specific gravity of a stone is the specific gravity of the whole mass, pore spaces included, and will be less than the true specific gravity by an amount dependent on the porosity.

It is determined by ASTM method C97-47. A sawn cube of stone between 2 and 3 inches square is used. The sample is dried to constant weight for 24 hours in a dessicator at 110°C. Cool and weigh. The dry weight in air in grams = A. Immerse the stone in water for 48 hours. The sample is then surface dried with a damp cloth and weighed to give the weight in grams of the saturated sample, surface dried, in air, = B. The cube is then immersed in water and weighed while in the water, to give weight in grams, = C.

Then the bulk specific gravity = $\frac{A}{B-C}$

= $\frac{\text{dry weight of sample in air in grams}}{\text{weight of saturated sample, surface dried, in grams}}$

minus weight of immersed sample in water, in grams.

The <u>weight per cubic foot</u> of a stone is determined by multiplying the bulk specific gravity by 62.43 pounds (the weight of a cubic foot of water).

The <u>water absorption</u> of a stone is the amount of water absorbed by dry stone expressed as a percentage of the dry weight of the stone. The water absorption capacity of a stone is closely related to porosity.

$$\text{Water absorption} = \frac{B-A}{A} \times 100$$

Where A = dry weight of the sample in air in grams,

and B = weight of saturated sample, surface dried, in grams.

The <u>apparent porosity</u> of a stone = $\frac{B-A}{V} \times 100$

Where A = dry weight of sample in air in grams,

B = weight of saturated sample, surface dried, in grams.

V = volume of the sample = B-C, where C is the weight of the saturated sample in water.

The porosity of a stone can be calculated if the true and apparent specific gravities are known. The porosity is calculated by the formula

$$P = \frac{100}{t}(t-a)$$

Where P is porosity, t is true specific gravity and a is bulk specific gravity.

Water acts in a detrimental way on stone in two ways: first, water penetrating the pores of the stone may alternately freeze and thaw causing rupture by frost action; second, water carrying dissolved gases or salts in solution may penetrate the pores of the stone and cause solution of the stone along grain boundaries. The porosity of a stone may therefore affect its durability. However the durability more closely depends upon the permeability of stone, so that pore size and permeability are as important as percent porosity. A measure of the permeability of the rock can be ascertained by its coefficient of saturation.

Standard absorption for a building stone is determined by following ASTM test C97-47. The period of immersion of the 2-inch cube for this test is 48 hours.

Coefficient of Saturation:

The coefficient of saturation is the ratio between the amount of water absorbed by a one inch cube in a stated time of immersion, usually one or two hours, and the total amount of water the stone is capable of absorbing. The coefficient of saturation for two hours is a standard one used by Parks(1912, pp.62-68). A low coefficient of saturation should indicate high frost resistance for the stone. See also Goudge (1933, p.18).

Durability and Soundness:

An indication of durability is given by ASTM test 218-48, "Combined Effect of Temperature Cycles and Weak Salt Solution on Natural Building Stone". In this test three $2\frac{1}{2}$-inch cubes are used. The dry weight, saturated (surface dry) weight and weight in water are obtained as in other tests. The cubes are placed in dishes three inches in diameter and $\frac{3}{4}$ of an inch deep to which are added 2 grams of powdered gypsum and 25 millilitres of water. The specimens are placed in an oven and dried for 5 hours at 105°C. Remove and cool. Repeat cycle 30 times adding 25 ml. water each time. At the end of 30 cycles the cubes are cleaned by brushing with a stiff fibre brush. Immerse the cubes for 24 hours in water, surface dry and weigh. Weigh in water. The increase in absorption and increase in volume of each test specimen are determined. For details of the test the ASTM specifications should be consulted.

The standard magnesium sulphate soundness test used on coarse limestone aggregate can be used on limestone and marble building stone. See ASTM method C88-56T, "Soundness of Aggregates by use of Magnesium Sulphate".

Freeze-Thaw Tests:

There are no ASTM standard freeze-thaw tests for natural building stone. Freeze-thaw tests are occasionally made on 2-inch cubes following the ASTM test 291-61T for concrete specimens. Cubes are tested for decrease in compressive strength at stated numbers of cycles. This is a good comparative test where a standard building stone is available for comparison.

Abrasive Hardness of Stone:

The hardness of a stone is a measure of its resistance to abrasion and depends on the mineralogy, texture, friability, character of cementation and grade of metamorphism of the stone. Hardness affects the workability of the stone and is a major factor in cost of fabrication of cut stone. For exterior and interior uses the hardness of a stone is frequently not a critical property, but for stairs or floors where the stone is subject to wear the hardness or resistance to abrasion is important.

ASTM method C241-51, "Abrasion Resistance of Stone Subjected to Foot Traffic" gives a test for abrasive hardness of stone. Three samples 2 inches square and one inch thick are dried and weighed. They are clamped in an abrasion machine and abraded for 225 revolutions of a grinding lap using No. 60 alundum. The abrasive hardness is calculated as a measure of the loss in weight, (see ASTM C241-51). The abrasive hardness (H_a) is calculated by the following formula:

$$H_a = 10G \frac{(2000 + W_s)}{2000\, W_a}$$

where G is the bulk specific gravity of the specimen; W_s is the average weight of the specimen (original plus abraded weight divided by 2) and W_a is the loss of weight during abrasion. The higher the value of H_a the more abrasion resistant the stone is.

There is a wide variation in abrasive hardness of building stones. Abrasive hardness of marbles tested in our 1963 program ranged from 9.0 to 125.0. Most marbles averaged 18 to 25 in hardness. Limestones vary from a soft 4.6 for oolitic limestone to over 50 for hard microcrystalline limestone. The hardness of sandstones depend largely on their friability and bonding and range from 6.0 to 65 or more. The hardness of granites range from 50 to 90 on the average.

Results of a program of testing abrasive hardness of building stones used in natural stone flooring are reported by Kessler (1933, pp.646-648). He points out that "the wear resistance values obtained by this test procedure and the commonly accepted Moh's scale values for some materials are apparently not in accord. This may be due to the different forms in which minerals occur. The mineralogist usually deals with individual crystals of the substance while rocks are mainly aggregates of small crystals. Loosely bonded aggregations of hard minerals in this test invariably show low resistance to wear. This is illustrated by the tests on some of the sandstones which were almost entirely quartz but gave lower H_a values than most of the limestones. The abrasive resistance of sandstone seems to depend mainly on its cohesive strength."

In assessing the conclusions of his study Kessler (1933, p.648) states that "surfacing materials showing H_a values of 30 or higher are very resistant to wear and should prove reasonably satisfactory under severe traffic conditions. For railroad stations, hotel lobbies, department stores, etc., the surfacing materials should test as high as 15 or, in some cases, 20. For a large percentage of floor areas where the traffic conditions are not especially severe good service may be obtained from surfacing materials testing as low as 6."

A measure of the hardness and workability of the stone can be obtained by observing the rate of sawing of the stone under fabrication.

Compressive Strength:

The compressive strength or crushing strength of a stone is determined by crushing at least three two-inch sawn cubes of the stone. It is desirable when the stone is noticeably bedded or banded to determine crushing strength parallel and normal to the bedding.

Transverse Strength:

The transverse strength of a stone is a measure of its ability to withstand bending strain. Samples measuring approximately 8 inches by 4 inches by $2\frac{1}{2}$ inches are tested by placing the specimen on knife edge supports 7 inches apart and applying a load to a steel edge bearing across the centre of the specimen. The modulus of rupture is calculated by the following formula:

$$R = \frac{3k}{2bd^2} W$$

Where R = modulus of rupture in pounds per square inch,

k = length of span in inches,

b = breadth in inches,

d = thickness in inches,

W = load at centre in pounds.

QUARRYING METHODS

Geological features such as bedding, foliation, jointing, rift and grain are very important features to consider in planning a quarry operation. The thickness of beds largely determines the thickness of mill blocks which may be removed in sedimentary formations. Foliation is frequently present to some degree in granite and marble, and invariably present in gneisses. The direction of foliation is commonly coincident with the direction of rift or easy splitting in granites and gneisses. The direction, dip and frequency of joints is of primary importance in quarry development of all stones, and is particularly significant in granites. Spacing of vertical joints may govern the size of mill blocks which can be removed and if vertical joints are spaced too closely they may render the stone commercially useless for building stone. Sheeting planes or horizontal joints are frequently of great assistance in quarrying granite. If bottom joints of this type are not present the blocks must be broken off the floor by drilling and wedging. The directions of easy breaking, rift and grain, should be used in laying out the quarry plan and quarrying should follow these directions.

There are four main quarrying methods used in Ontario building stone quarries:

(1) Hand quarrying,

(2) Knox method,

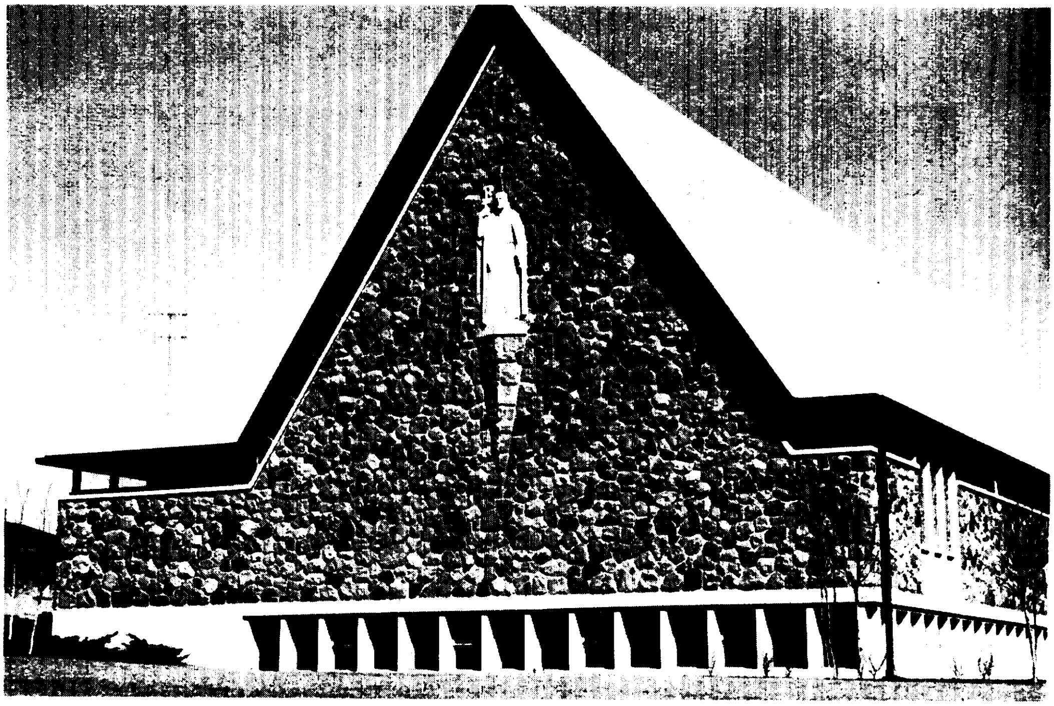
(3) Channeling by drilling and broaching,

(4) Wire saw method.

(1) Hand Quarrying:

Nearly all the small building stone quarries in Ontario, which produce mainly ashlar, flagstone, sills, coping, steps, etc., are operated by hand quarrying methods. Hand quarrying is employed in granite gneiss, paragneiss, limestone and sandstone quarries where the bedding or foliation planes are relatively closely spaced, usually from 2 to 10 inches apart. Equipment consists of air compressor, drills, crowbars, wedges, chisels, plugs and feathers and in some instances portable stone saws using diamond blades.

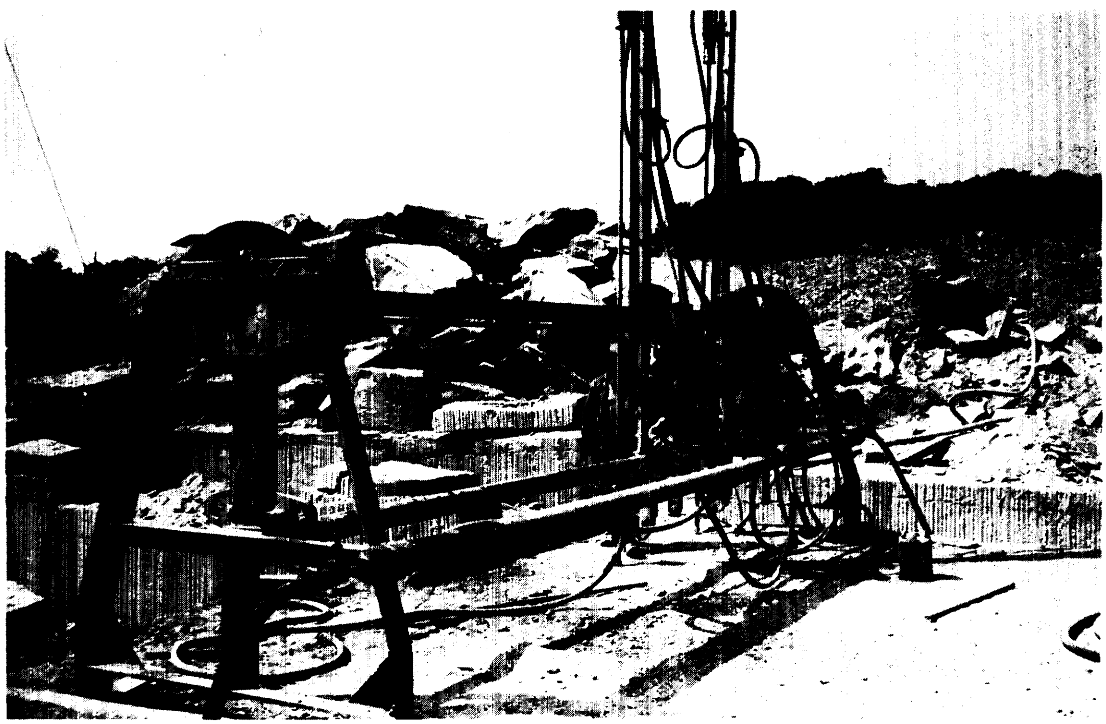
In the sandstone quarries the stone beds are usually broken along a given line by drilling a series of short holes 6 to 12 inches apart and employing plug and feather in the series of holes. The plugs or wedges are driven in sequence by a heavy sledge hammer. In the Inglewood area where the main sandstone beds may be up to 5 or 6 feet in thickness the break parallel to the quarry face may be achieved by drilling a series of vertical holes through the bed along the desired line 4 to 5 feet from the quarry face and blasting lightly with black powder. Thin sandstone beds may be broken along a desired line after having been quarried by scoring the line with a tracer chisel with a



Split faced granite field stone used in the Church of the Good Shepherd, Bayview Avenue, Toronto.

Splitting Medina sandstone along a bedding plane by use of plug and feather. Structural Sandstone Quarries, Glen Williams.

Portable electric diamond saw used to cut Eramosa dolomite beds at Ebel Quarries, Wiarton.



Quarry bar with two drills set up at Peninsula Limestone quarry, Thorold.

thin blade 3 to 4 inches long on both sides of the bed. The stone is then tapped sharply along the line of break.

The quarries in the Wiarton area quarrying the thin Eramosa dolomite beds of the Amabel formation employ portable diamond saws to cut the stone in place in the quarry. The diamond saws have blades of 12 to 18 inches in diameter. Cuts are made as desired, in one case observed, saw cuts 4 inches deep and 24 inches apart were made across a quarrying width of 15 to 18 feet. The stone is lifted by bars and fork lift trucks. Fork lift trucks are extensively used in transporting stone in the quarries.

(2) Knox Method:

The Knox method of quarrying is employed at Queenston Quarries. The building stone occurs in a ledge 10 to 16 feet thick, with beds 2 to 7 feet thick. When a sufficient area has been stripped of the overlying rock, the beds are examined for vertical joints, which may occur 10 to 50 feet apart. The Knox method which employs drilling and blasting, requires three free faces and a bedding plane on the bottom. The free quarry face is established at right angles to the jointing by removal of a key block from one joint to the other. The block to be quarried is then bounded by the free quarry face on one side and by the two joints at either end, or by one joint and an open end where the adjacent block has been removed.

Quarry blocks are split off parallel to the free face by making a back-wall cut parallel to the free face at a distance of 10 to 12 feet from the face. A series of $1\frac{1}{2}$-inch holes are drilled, 12 to 14 feet deep, on 2-foot centres in a line parallel to the quarry face at the required distance from the face. Jackhammers or Joy wagon drills are used for drilling. The line of holes may be from 10 to 50 feet long depending on the joint spacing.

In the Knox method the drillholes are reamed by a Knox bit, which grooves the hole on each side in the direction along which the break is to be made. The holes are loaded lightly with black powder and fired with instantaneous caps. An air space is left in each hole between the charge and the tamping. This air space is essential to the Knox method and results in the force of the explosion being exerted on a relatively wide surface. Where there are horizontal bedding planes in the block to be quarried, a charge is placed for each bed.

The quarry block is separated from the solid ledge by the blast and is then drilled and split by plug and feather into random mill blocks of 4 to 20 tons in size. Horizontal holes may be drilled to lift the beds where necessary. Blocks are handled by derricks.

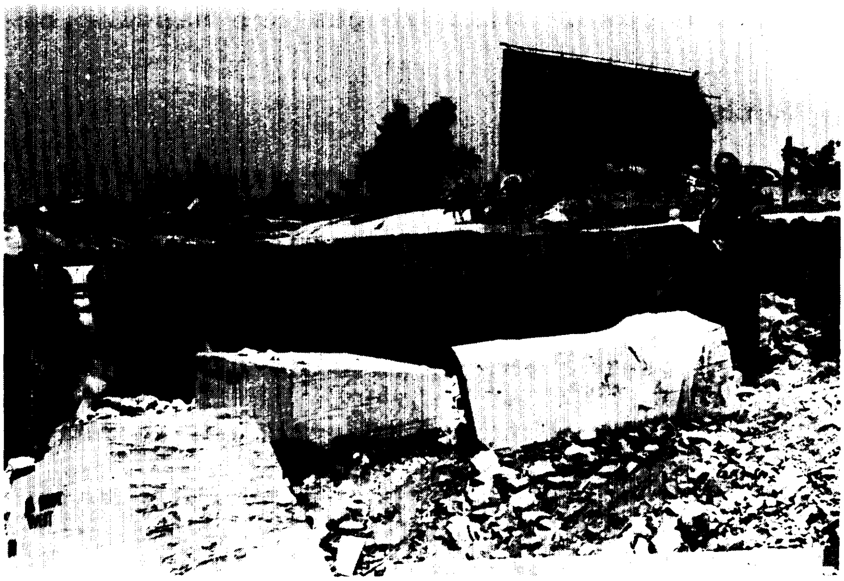
(3) Channeling by Drilling and Broaching:

The method of channeling by drilling and broaching using quarry bars is employed by limestone and granite quarries in Ontario. The method involves cutting out the block by closely spaced drilled holes, and breaking out the web of rock between the holes by a broaching tool. Two to four drills are mounted on each quarry bar, and clamped to drill at the required angle. The drills can then be moved along the bar to drill a series of parallel holes. The channeling is usually carried out on the four vertical sides of the block. If necessary horizontal holes can be drilled to break out the block at the base. Mill blocks are handled by derrick.

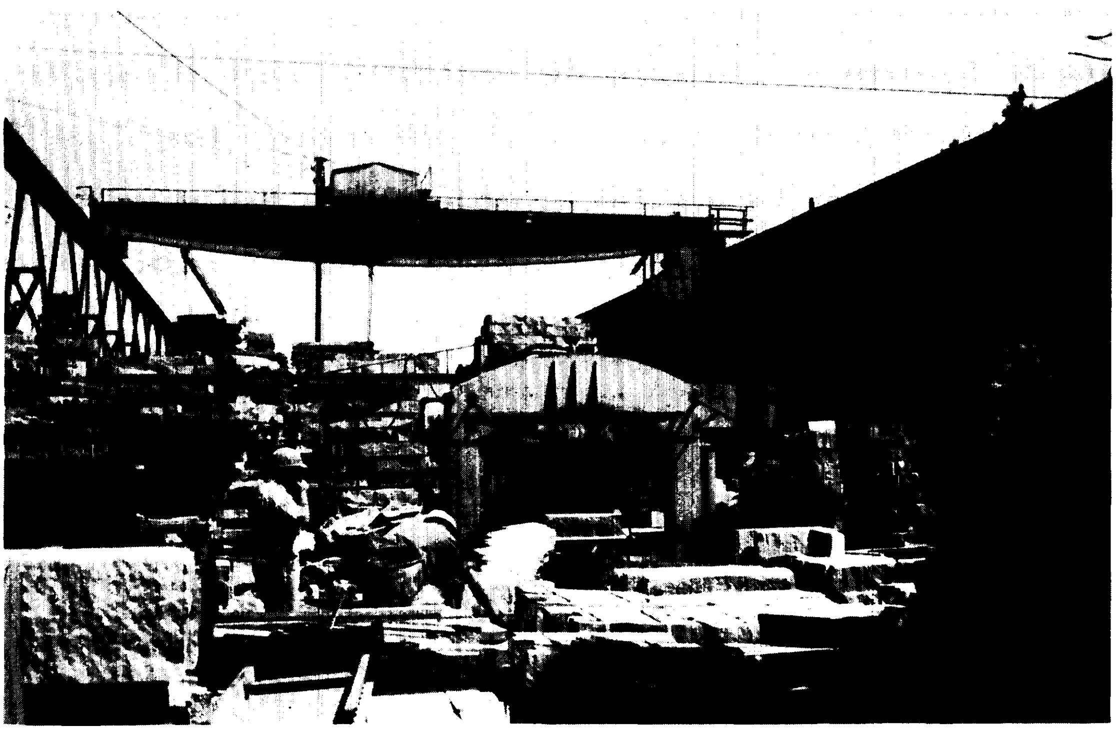
(4) Wire Saw Method:

The wire saw is employed to quarry marble at the Tatlock quarry of Omega Marble Tile and Terrazzo Limited. Sawing is done by a three strand steel wire, 3/16- to $\frac{1}{4}$-inch in diameter, using sand or carborundum as the abrasive. The continuous wire has a length of 1,000 to 2,000 feet in order that wear can be minimized and the wire need not be changed too often. A tension carriage near the driving pulley keeps tension on the wire. The wire travels over guide pulleys on standards to the cutting face where there are two guide standards mounted at either end of the cut. These guide standards are usually 30 to 100 feet apart, and have an upper guide pulley and a lower guide pulley. The cutting section is between the lower guide pulleys. Where the guide pulley standards cannot be set up at open ends of the block to be quarried, holes must be drilled to accommodate the standards. After the wire saw has cut out a lengthy block of marble, the wire may be used to cut the block up.

Wire saws are also used in stone dressing plants for cutting stone.



Mill blocks of marble are cut by wire saw at the Tatlock quarry of Omega Marble Tile and Terrazzo Limited. Guide pulleys may be seen in this photograph.



Stone dressing yard at Queenston Quarries showing guillotine and overhead crane.

DRESSING STONE

In many of the small sandstone and limestone quarries the stone is dressed by hand cutting, using hammers and chisels for cutting and shaping the stone. In several quarries split faced ashlar is made by splitting the stone by guillotine, a hydraulic cutting machine whose cutting edge consists of a series of one-inch teeth which will accommodate themselves to irregularities in the stone. Portable quarry diamond saws are used in some of the limestone quarries for cutting stone to desired sizes.

In cut stone plants where mill blocks are handled, overhead electric cranes up to 30 tons in capacity are used for moving blocks. Mill blocks are cut by gang saws which employ 5-inch steel blades with silica sand as the abrasive. A recent innovation is the use of diamond-set gang saw blades which greatly increase the rapidity of sawing. Sawing rates in limestone are from $1\frac{1}{4}$ to $1\frac{1}{2}$ inches per hour with silica sand abrasive and from 12 to 14 inches per hour with diamond-set blades.

Stone cutting is also carried out by circular diamond saws up to 72 inches in diameter and by wire saws using sand or carborundum as abrasives. Planing machines are employed for giving the stone a smooth finish, making special shapes and mouldings. Polishing of marble and granite is done on rubbing and polishing beds.

PROSPECTING AND DEVELOPMENT OF STONE DEPOSITS

In prospecting for sandstone, limestone, marble and granite deposits, a geological map is important to indicate the areal extent of the potentially favourable deposits. Commercial deposits of limestone and sandstone are likely to be confined to relatively thin stratigraphic horizons which can be followed across country along strike. Essential features to be noted by the prospector in limestone and sandstone deposits will include nature and thickness of bedding, number of quarriable beds, jointing, crossbedding if present, colour, texture, uniformity, weathering characteristics and soundness. In the Medina sandstone of the Georgetown - Inglewood area uniform even bedding is desirable and crossbedding ruins the commercial stone. In the Potsdam sandstone formation some of the best stone comes from crossbedded sections where the crossbeds are on a large scale.

An important feature in flat-lying strata is thickness of overburden. In certain sections at Inglewood the thickness of overburden has become excessive for open pit quarrying. Where beds cannot be examined in outcrop, core drilling is helpful in determining the extent and character of the stone deposit.

In examining granite and marble deposits the size, shape, attitude and structural features are important. Jointing, intrusion, alteration and inclusions may affect commercial exploitation of the stone. Side hill quarry sites are preferable to pit quarries due to ease of drainage.

BUILDING STONE PRODUCTION IN ONTARIO

Figures for Ontario building stone production of limestone, sandstone, granite and marble for the past twenty-five years are given in the accompanying table. Building stone production has increased markedly since World War II, and now exceeds a million dollars per year.

The main production of limestone comes from Queenston Quarries near Queenston, Peninsula Limestone quarry at Thorold, and from a group of small quarries producing mainly ashlar, flagstone, etc. from the Wiarton area of the Bruce peninsula. A steady production of sandstone has come from the group of quarries in the Medina sandstone between Limehouse and Inglewood. Some sandstone production comes from the Kingston, Perth and Ottawa areas. Granite production has been irregular and usually of minor extent. Recent production has come from River Valley and Vermilion Bay. The increased granite production from 1947 to 1951 was due to the construction of the Port Arthur breakwater, and was largely quarried at Silver Harbour by Canadian Dredge and Dock Company. Marble production is largely terrazzo chips from the Madoc area.

BUILDING STONE PRODUCTION IN ONTARIO

Year	Limestone		Sandstone		Granite		Marble		Total	
	tons	$	tons	$	tons	$	tons	$	tons	$
1962	30,583	432,658	34,009	544,981	3,507	44,118	34,926	288,480	103,025	1,310,237
1961	39,900	527,880	25,381	425,796	3,563	60,632	27,348	246,915	96,192	1,261,223
1960	38,914	492,640	84,143	450,553	4,080	122,373	40,423	356,762	167,560	1,422,328
1959	60,028	751,490	33,049	550,994	2,070	58,522	51,440	327,644	146,587	1,688,650
1958	59,512	818,578	27,848	560,427	2,724	73,644	33,989	301,135	124,073	1,753,784
1957	59,549	864,920	38,680	543,764	3,247	79,051	40,328	298,496	141,804	1,786,231
1956	44,487	595,644	47,880	479,062	4,838	159,213	34,178	267,486	131,383	1,501,405
1955	37,152	498,561	27,570	269,868	2,978	100,935	33,699	258,813	101,399	1,128,177
1954	57,079	630,395	16,718	187,114	3,340	57,375	32,189	316,247	109,326	1,191,131
1953	86,855	619,634	15,557	151,382	2,959	33,343	31,336	262,145	136,707	1,066,504
1952	117,868	485,183	17,091	140,081	1,987	30,405	30,638	211,105	167,584	866,774
1951	36,889	425,574	22,942	200,389	238,956	740,866	38,113	196,986	336,900	1,563,815
1950	40,876	455,788	21,977	177,052	224,375	691,688	34,227	174,738	321,455	1,499,266
1949	22,986	282,080	13,503	134,108	286,162	871,568	33,131	174,083	355,782	1,461,839
1948	29,261	285,318	12,815	99,276	304,003	577,888	49,847	260,809	395,926	1,223,291
1947	23,639	207,238	15,513	84,447	36,114	243,117	29,659	129,726	104,925	664,528
1946	18,730	143,569	11,365	43,975	717	6,397	8,402	58,333	39,214	252,274
1945	99,777	131,579	3,680	19,845	717	6,829	5,818	45,081	109,992	203,334
1944	51,452	56,861	5,223	20,431	-	-	1,933	13,472	58,608	90,764
1943	2,583	28,523	7,813	17,190	270	3,038	4,167	24,852	14,833	73,603
1942	4,882	86,026	18,835	33,004	165	2,380	4,295	27,675	28,177	149,085
1941	19,358	85,787	14,062	27,190	513	3,326	5,993	26,456	39,926	142,759
1940	11,906	62,511	3,446	11,008	9,353	30,269	4,792	22,157	29,497	125,945
1939	12,717	96,084	4,124	16,322	454	1,650	6,519	30,642	23,861	145,347
1938	3,961	19,747	4,662	16,220	319	1,779	10,537	40,694	19,663	80,716
1937	12,204	128,273	8,680	22,934	1,519	5,768	6,685	27,247	29,088	184,222

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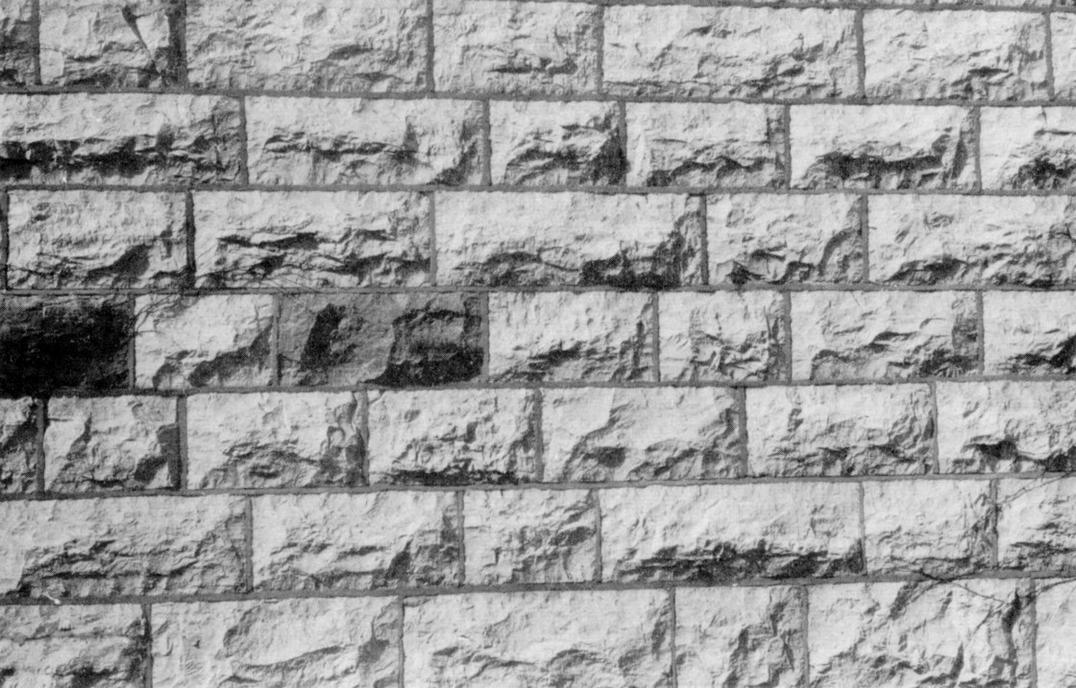

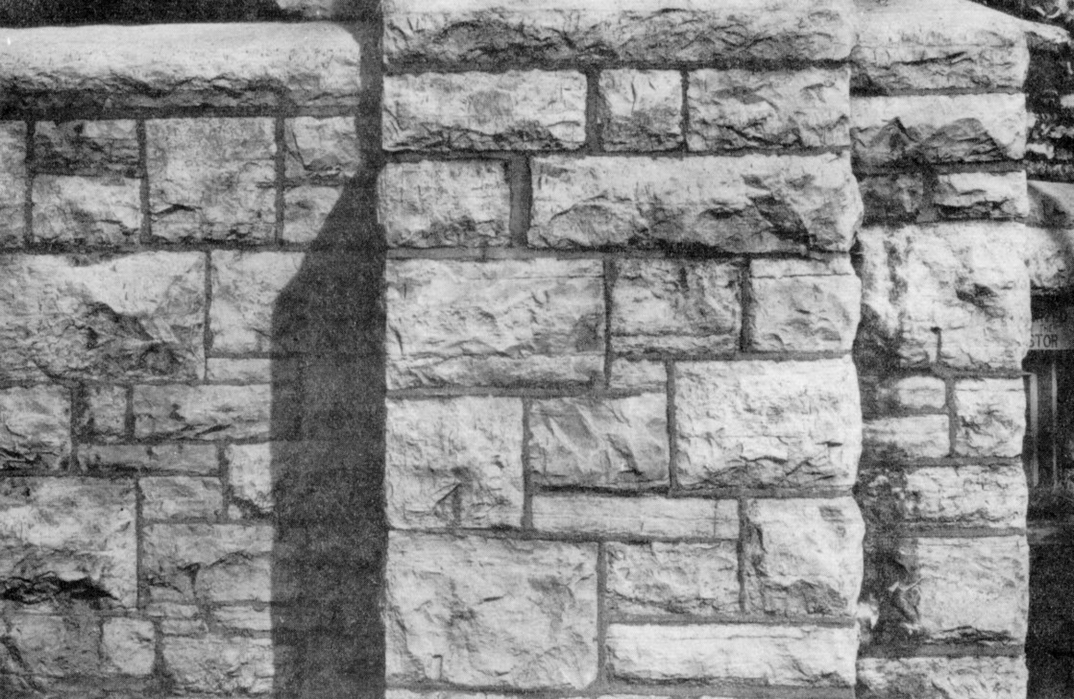

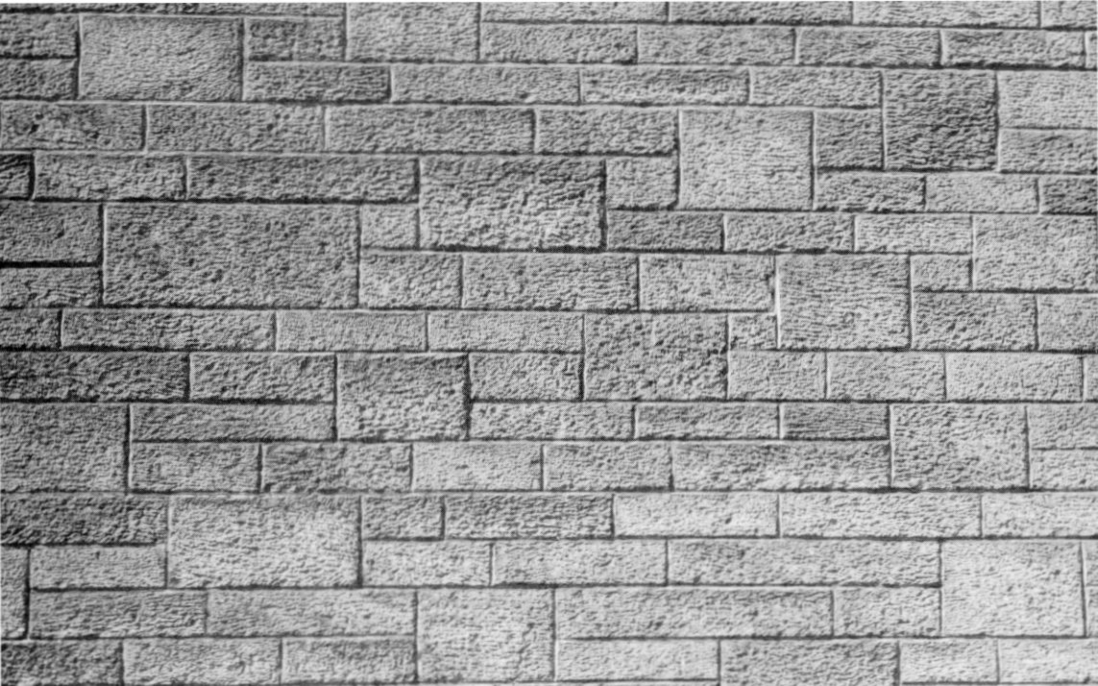

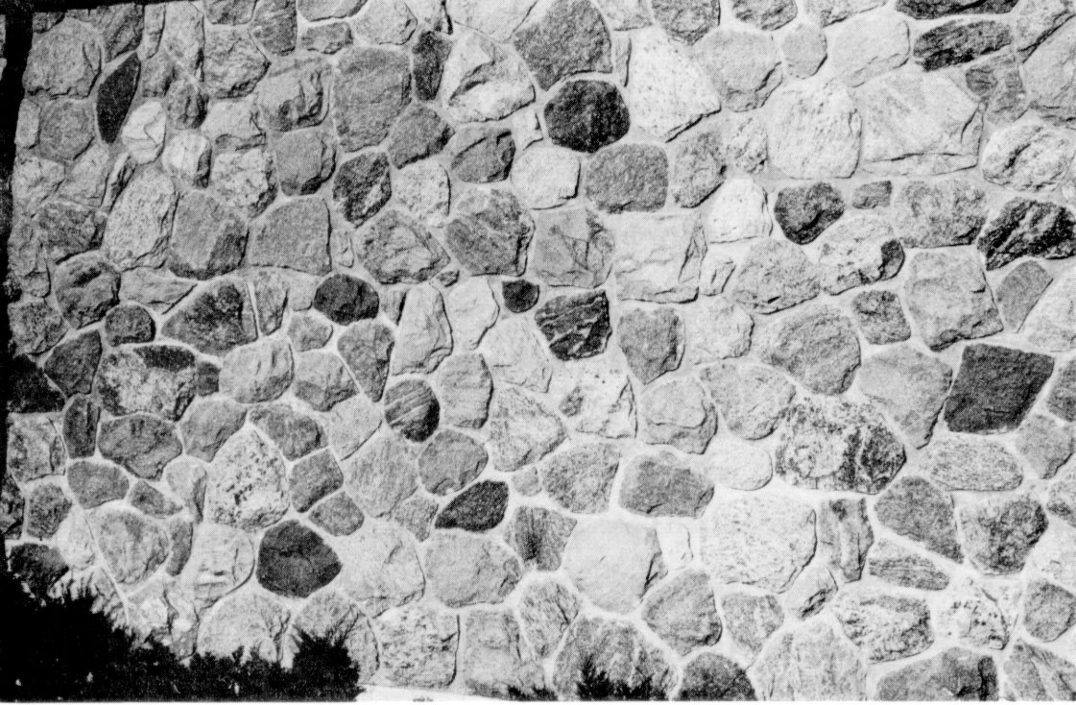

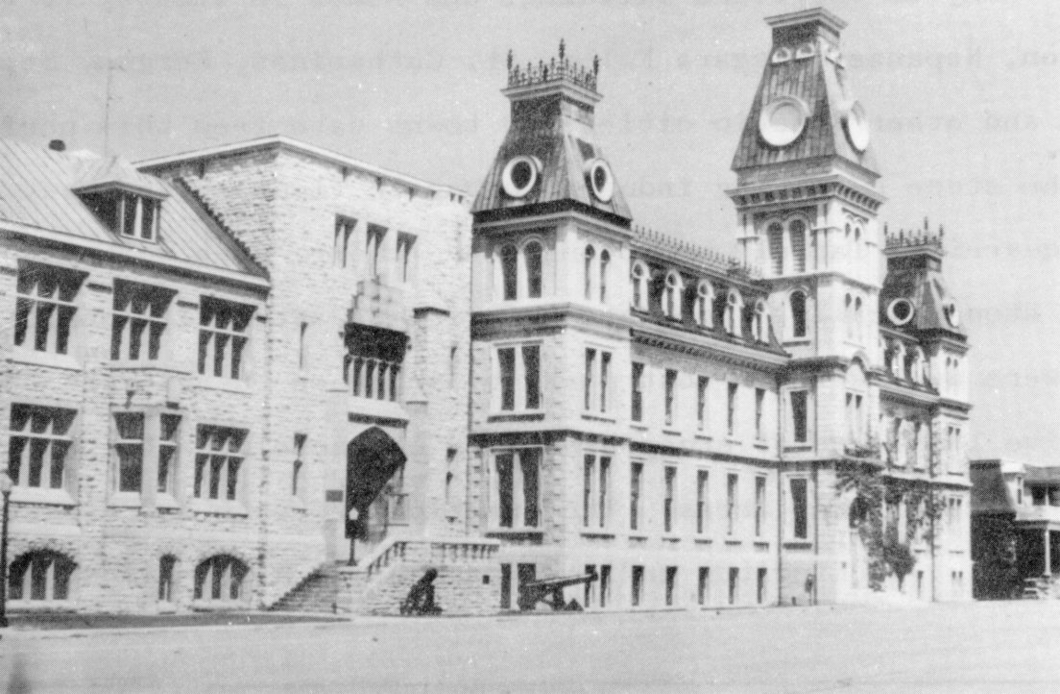

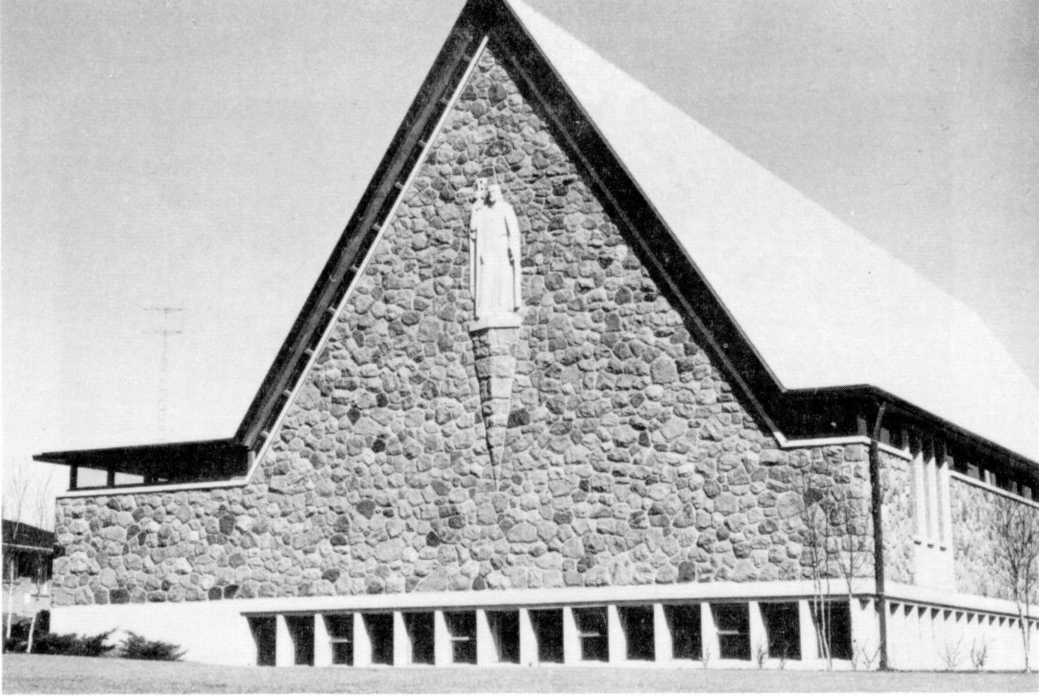

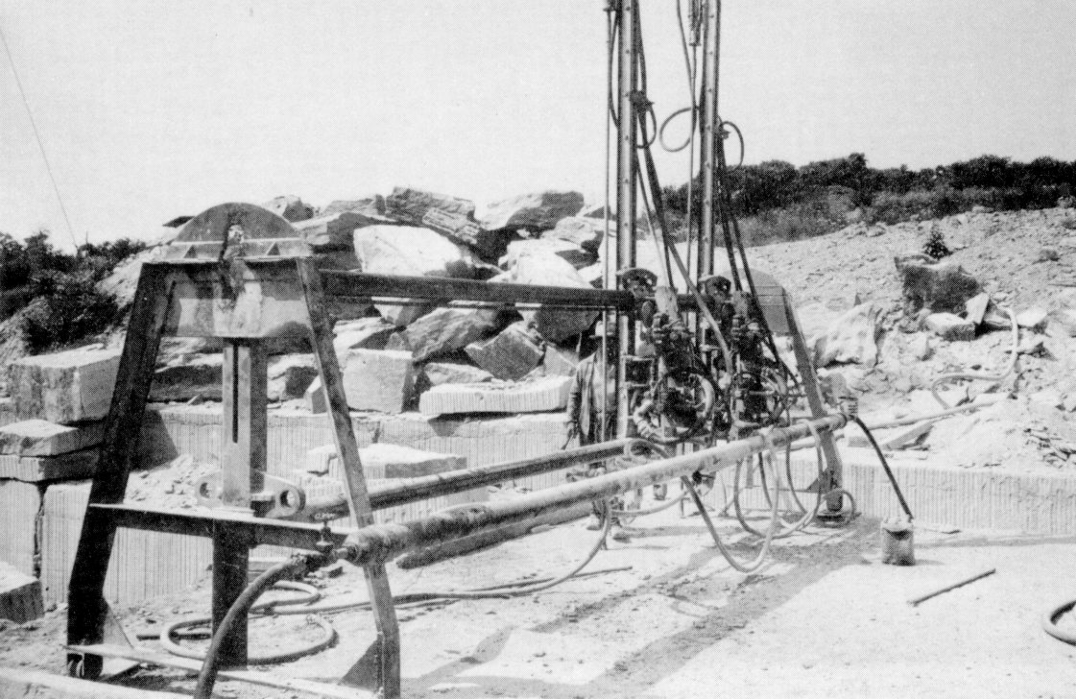


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