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Dimension Stone: A Guide to Prospecting and Developing

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Dimension Stone: A Guide to Prospecting and Developing

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Table of Contents

DIMENSION STONE: A GUIDE TO PROSPECTING AND DEVELOPING

By Chris Papertzian

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February 27, 1995

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Introduction

This document is intended for the explorationist who may not be familiar with methods used when exploring for and evaluating building stone prospects. Such knowledge is necessary to plan and execute an effective stone exploration program, and is useful to prospectors and field workers in general. A variety of rock types are used in building stone construction, therefore, anyone working in terrain with good outcrop exposure may benefit from learning to recognize a potential dimension stone quarry site. Stone types most frequently quarried for building stone are reviewed in Appendix I.

Site development with respect to quarrying techniques is presented to provide an understanding of procedures rather than to influence prospectors to become quarriers. Quarrying is a specialized aspect of the industry which calls for judgement gained through experience in order to properly exploit a given deposit. The initial stages of development, however, may be considered an important part of deposit evaluation, and are given due attention. Quarrying techniques, machinery and stone cutting procedures are illustrated in Appendix II.

The American Society for the Testing of Materials (ASTM) has designated several tests for building stone. These are reviewed in Appendix IV.

GEOLOGICAL DEVELOPMENT STEPS

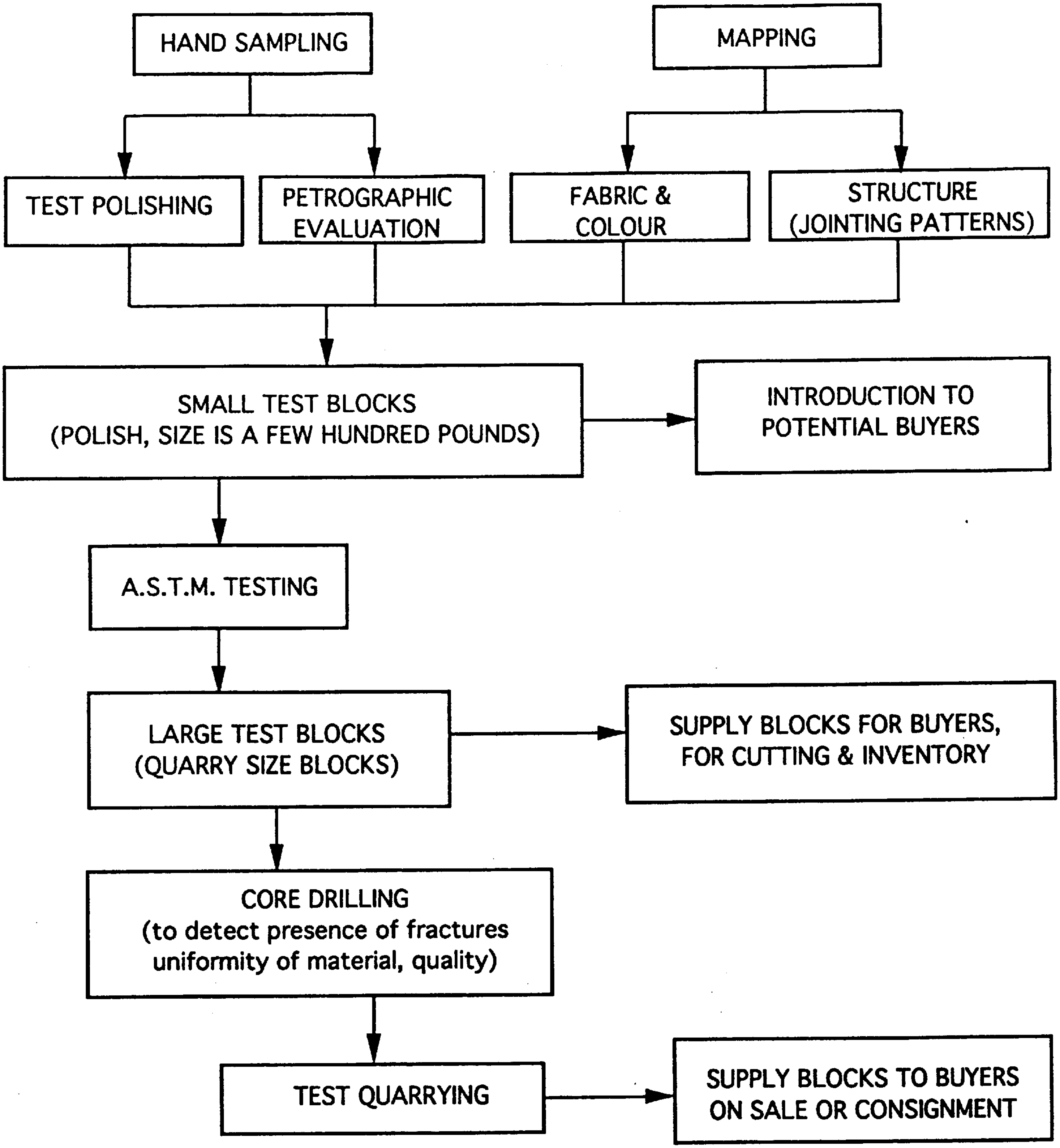

Figure 1 (modified, after Richter, 1985)

Processing, including methods, equipment and end products, is included for reference and interest in Appendix III. Although of secondary importance to explorationists, this topic helps provide an understanding of the importance of aesthetics and fashion to the dimension stone industry. Stone products and their definitions are listed in Appendix V.

Currier (1960), summarizes a more scientific variation on the prospecting and evaluating sequence for building stone occurrences which has been reproduced in Appendix VI, and other useful prospecting criteria for Ontario are listed in Appendix VII.

Figure 1. presents the order in which geological development should occur according to Richter (1985).

A Brief History of Stone Use

Primitive man used stone for tools and weapons. Later, stone was used for a variety of other purposes, from grinding grain to paving thoroughfares. The most enduring use, however, has been in building construction. Stone houses built by early cliff dwellers survive in Mesa Verde National Park, Colorado, and remnants of large stone cities and temples have been found in the jungles of Mexico, Central America and South America. Although methods of construction have changed greatly since the Stone Age, natural rock is still a very important building medium.

In North America, stone was the preferred structural building material for public buildings up to the beginning of this century. Provincial and state buildings, county courthouses and university buildings were generally built of stone that was quarried locally. Buildings were constructed utilizing a massive foundation of stone blocks, upon which rested thick stone walls. Wooden beams were used to hold up the floors and the roof. These buildings, though solid and built to last, could not be supported above four stories.

In the 1890's a new technique for the construction of buildings was developed: a massive, steel framework of beams was bolted together to give the structure strength and rigidity, a style of building which could be extended to great heights. High-rise buildings of today are constructed in this way, with thin curtain walls fastened to the steel framework. These walls may be made from brick, metal, plate glass or thin, rectangular dimension stone slabs from 2.5cm to 5cm thick and fabricated from limestone, marble or granite.

Dimension Stone

A stone which meets certain standards of durability and aesthetic appeal, is available in sufficient quantity and can be extracted, sized and dressed to meet commercial requirements may be quarried as dimension stone.

Dimension stone is defined as "A natural rock material that has been selected, trimmed, or cut to specified or indicated shapes or sizes with or without one or more mechanically dressed surfaces" (Taylor 1992).

Dimension stone is used primarily in the building and construction industries. Almost any bank or office building exhibits stone that is cut, shaped or polished for walls, floors, counters, columns and steps. The building and construction industries account for approximately 80 percent of finished stone products, while the remainder is used for landscaping, commemorative or funerary purposes and ornamental objects. In Figure 2., Richter (1985) describes the distinctive differences in characteristics between building and monument stone.

Granite as Dimension Stone

Although limestone, marble, sandstone and slate are also quarried for the stone market, granite is presently the focus of most dimension stone exploration in Ontario. A resurgence in the popularity of granite as a building material among architects and other materials specifiers is due, in part, to lower production costs

DISTINCTIVE CHARACTERISTICS OF MONUMENT AND BUILDING STONE

CHARACTERISTICS	BUILDING STONE	MONUMENT STONE
COLOUR	uniform	very uniform
COMPOSITION	uniform	very uniform
TEXTURE	variations permitted veins, flow, phenocrysts	fine-grained only very uniform
STRUCTURE (JOINTING)	minimum 2 meters spacing, sheeting helps, regularity important	minimum 1-1.5 m spacing
ACCESS	very important	
MINIMUM AVERAGE BLOCK SIZE	2 x 1 x 1.3 m	1.5 x 1 x 1.3 m
OPTIMUM BLOCK SIZE	3 x 1.3 x 1.5 m	
QUARRY RECOVERY RATE	>50%	>20%

Figure 2 (after Richter, 1985)

from improved methods of quarrying and processing. Contributing to the interest in this stone is the existence of a wealth of relatively unexplored granite bodies (i.e. not evaluated for the building stone market). The methods and procedures outlined in this paper are therefore biased toward granite exploration, but may, in most instances, be applied to other dimension stone types.

Granite is defined in various ways. Scientific workers use more criteria in classifying rocks than do members of the building stone industry. The former base their definitions of "true" granite on quartz content and feldspar ratios. The building stone industry definition of granite is more general, and includes most crystalline igneous or metamorphic silicate rocks with a high feldspar content. The mineral grains are generally visible to the naked eye, and often have an interlocking texture similar to jigsaw puzzle pieces.

In addition to the true granites, various other rock types may be placed in this category, including tonalite, monzonite, syenite, gneiss, anorthosite, diorite and diabase, and others. Even some very non-granitic, basic rocks such as basalt and gabbro may be identified as granites if they meet production criteria and other established standards of physical strength and durability. (see Appendix IV: ASTM tests).

Products and Markets

Formerly, stone quarries were small operations opened to supply local needs such as blocks for home construction, foundations, walls and pavement. Today, stone serves a global market and operations are larger. The expanding and changing global market has established a need for more types of granite and new deposits of conventional premium granites. With the benefit of global marketing, stone quarries may be opened in areas where local demand would not support them. Another factor affecting quarry viability is the international demand for rare or unusual colours and textures. The more unique a stone is, the better chance it has to succeed commercially. It is also important for a stone processor/supplier to have a wide variety of stone types, colours and textures available for the global market. The more strongly coloured varieties will probably not be used on large commercial buildings, but can be used to best effect in smaller areas (Marmont 1993). It is common to import rough stone from Italy, Spain or India for a specific use. Stone that is available in large quantities and is consistent in quality is used for facings on large commercial buildings.

Near the last turn of the century, stone became progressively more expensive for building in relation to manufactured materials. Steel, concrete, ceramics, plastics and other modern substances proved superior for specialized construction. In the last 20 years, however, the building stone business has undergone many changes. Advances in quarrying, processing and installation have combined with a renewal of stone's visual appeal to promote favourable comparison with other materials, particularly in the area of decorative cladding. Contemporary building design is seldom dependent upon stone as a structural element, but stone panels are often used as durable, low-maintenance, decorative veneering. Tiles and panels, cut accurately to thicknesses ranging from 1cm to 5cm, are a highly saleable product, and now yield higher production from raw quarried blocks than was formerly possible. In addition, a greater range of colours and textures is now available, as the need for uniformity of grain size, colour, and texture declines in importance. Indeed, some of the newer granites finding approval on the market display the swirled patterns and irregular colouring of gneisses and migmatites, or coarse-grained porphyritic textures. The popularity and high market share of premium, uniform granite,however, continues,s sustained by demand from large commercial applications and monument production.

Potential Value

An outcrop roughly one hectare in area is required to sustain a dimensional stone quarry. If the deposit can be mined to a depth of 20 meters, the site would yield approximately 12,500 twenty-tonne blocks, allowing for a 50 percent wastage. This would be enough to sustain a quarry for several years at a reasonable production rate.

Assuming an average price of $450.00 per cubic meter, FOB the quarry, the potential gross value of the stone would exceed $40 million. Fully processed, the stone would be priced at about $400 million.

These hypothetical figures are given to illustrate that stone can be undervalued as a prospecting target. It must be remembered that there are significant costs involved in quarrying, shipping and processing, and that other factors, such as increased wastage or changes in consumer demand, could act to increase the risk. The task of identifying a commercially exploitable building stone quarry is difficult. One only has to consider how rare such operations are to appreciate the risks.

Many granite quarries produce far more than 50 percent waste, remaining economically viable because of the colour, rarity, or premium quality of the product quarried. Such quarries may enjoy only a 20 percent recovery rate, but the stone commands a very high price, thereby creating a profitable operation. The ability to market off-grade or undersized stone blocks and waste material can also enhance the value of a deposit. In Europe, by-products such as rubble stone, quarry dust and cuttings are sold as road stone, soil additives and concrete aggregate. In North America a waste to production ratio of 1:1 or more is considered acceptable, and the waste material is a cost rather than a revenue.

Mineral Exploration

Exploration for any mineral commodity usually follows a series of planned initial steps based on limiting factors. For example, available financing, time limitations, and value of the commodity are major considerations. Initially, a regional investigation is completed to establish which area(s) will be looked at in more detail. The size of the preliminary region depends on the amount of time and money the explorationist is able to commit to the undertaking. A weekend prospector, for instance, will most likely work within driving distance of home. At the other end of the scale, a company specializing in exploration may have several full-time

workers assigned to a project, with a correspondingly large preliminary region to investigate. As the research progresses, sections of the region are ruled out, based on the absence of favourable conditions. Gradually an "area of interest" is defined, from which targets are selected for field surveys.
In the case of dimension stone, the researcher will be looking for indications of large, lightly-fractured stock- or pluton-sized deposits of intrusive rocks. Some methods of making these determinations are discussed below.

Ideally, the prospector will have ample time during the winter months to research and plan an exploration program for the following field season. Regardless of when the project begins, the first phase of exploration takes place indoors. The office of the nearest Resident Geologist is the best place to begin studying the region selected for exploration. A review of the literature available may include several government publications. Geological reports and maps, open file reports and bulletins, geological survey field work summaries, aerial photographs, mineral deposit inventories, topographic maps, assessment files and Resident Geologist's annual reports are all potentially helpful. The search can be made simpler by talking with the Resident or a Staff geologist, who will provide information about previous exploration, recommend likely areas to prospect and advise the researcher where and how to locate available information. Many rock types found in the jurisdiction of the Resident Geologist will be on display, and may be useful when correlated with geological maps.

In the early stages of research, when a promising area for exploration has been identified, the prospector should verify that the ground is available for staking before spending more time on the area. This information is found on claim maps, which may be viewed or purchased from the office of the Mining Recorder, often located in the same building as the Resident Geologist. Claim maps show areas open for staking, presently staked, and the boundaries of lands temporarily or permanently withdrawn from exploration. Other helpful claim map information includes the location of mining leases, minesites, pits and quarries. Recently, this information has been made available for viewing, at no cost, on a computer database in some Mining Recorders' offices. Past producing quarries should be examined in the context of modern markets, updated technology, changes in architectural fashion and previously unrecognized potential. Information may be readily available on these sites. Many old quarries have produced crushed rock and may not have been evaluated for dimensional stone.

Dimension Stone Exploration

Preliminary Research

When the location and boundaries of the primary region have been determined, and the researcher has learned how to gain access to data in the Resident Geologist's office, the selection of exploration targets can begin.

Reports and Maps

Bedrock maps are available for most of the province in a variety of scales and formats. Most of these accompany reports, bulletins and summaries. Descriptions of local bedrock formations in these publications include outlines of outcrop, lithology, mineralogy, structural features, colour and textures. Some reports will provide more recent coverage than others, and will reflect the accuracy possible with modern mapping techniques, notably in the area of geophysically inferred geology. Older material should not be ignored, however, as the quality of work is usually very good, and all avenues should be investigated. In the case of granites, references to colourful, homogeneous and unfractured rocks should be noted for future follow up.

Topographic Maps

Topographic maps add the important third dimension of relief to a standard map, showing hills, valleys, escarpments and other landforms, in relation to wetlands, rivers and lakes. They also show cultural features such as power lines, railways, roads, towns, villages and even individual rural buildings are also shown in good detail at the production scale of 1:50,000, which is a practical size for later use in the field.

Aerial Photographs

Aerial photographs are one of the most useful tools available to the building stone explorationist. Areas of exposed outcrop which cannot be seen from the road due to vegetation or other topographic obstructions are more readily observed from above. Air photograph surveys are flown at a number of different scales: 1 inch = 1/4 mile; 1 inch = 1 mile, 1:20,000 and 1:30 000. Air photos can be viewed stereoscopically, which permits a better assessment of topographic relief. The object of this operation is to identify significant outcrop areas within easy access of existing roads. A distance of about two kilometers from an existing road is commonly considered the maximum distance over which a quarry access road could be economically built, depending on factors specific to the site, such as topography, availability of fill, and alternate land use (Marmont, 1993). Consideration must be given to the ease with which the target area can be reached, not only with respect to quarrying, but also regarding the removal of samples. Significant outcrop is defined here as an exposure having an area approximating one hectare (100 m x 100 m), preferably in the form of one massive body, but possibly as a cluster of smaller outcrop areas. Selected outcrop may be rated by aerial exposure, then depicted on topographic maps to assist in prioritising follow up field visits.

When assessing outcrop via air photos, note that outcrops with few vertical joints exhibit white or pale grey tones on air photos, indicating sparse vegetation cover. These areas represent good exploration targets. Outcrops containing more closely spaced, vertical joints display a darker grey tone, caused by vegetation growing in the joints, and become an area of lesser interest for building stone exploration.

Smaller outcrops are difficult to identify on air photos because they can be obscured by trees. Sometimes these smaller outcrops have cliff faces which can be very important in evaluating the quarrying potential of a rock unit.

Although initially costly, an actual flight in a small, fixed-wing aircraft over the area is a very useful approach, and may save money in the long run. The pilot should be instructed to follow roadways at an altitude sufficient to survey the terrain within 2 km of the road. Interesting outcrop should be circled and observed from different directions, allowing the prospector to determine the best ground approach. If the plane is equipped with a GPS (geographical positioning system), locations may be recorded and later plotted directly onto topographic maps.

Small, hand-held GPS units are becoming very popular for many field applications, and are particularly functional in prospecting for dimension stone: Using satellite-based triangulation, the position of the operator, including elevation, can be determined anywhere on the planet with an error of only a few metres. Used in conjunction with topographic maps, the system provides highly accurate locational data. Several co-ordinate systems, including military grid, latitude/longitude and universal transverse mercator (UTM) zones are programmed into the unit, allowing accurate plotting of sample sites, points of interest and even outcrop boundaries. When following new bush roads which are not yet shown on any map, the routes can be plotted directly onto topographic reference maps.

Assessment files

When a claim is staked, the claim holder holds the mineral rights on that claim for two years. On the second anniversary of staking, the mineral rights will expire unless work valued at no less than $400 has been performed during the preceding two years. The same yearly assessment rate applies for as long as the claim holder wishes to retain the mineral rights. This is known as, "keeping the claim in good standing". The assessment work must be registered with the Mining Recorder for credit, and the details of the work filed with the Resident Geologist's office for access and examination by the public. For a given piece of ground, there may have been several claim holders over the years who have reported a great deal of work. Some assessment files date back to the early part of this century, while others were filed yesterday. Most assessment work is done in the search for base or precious metals, and occurs in rock types generally unsuitable for dimension stone exploration. However, some exploration work may be located in contact zones of plutonic rock bodies. Geological mapping is often performed for assessment credit, in which case copies of the map and the accompanying report will be in the assessment files. Diamond core drilling has been done on many properties. Drill logs from these projects, describing the subsurface rocks, are also kept in the assessment files. If the descriptions warrant further inspection, there is a possibility that the core is stored at a drill core library, and may be viewed by appointment through the office of the Resident Geologist.

Infrastructure and Access

Explorationists may wish to confine their search to certain geographical areas in consideration of proximity to overall infrastructure: existing markets, transportation and processing plants. Transportation can account for 70 percent of the price of a quarried block delivered to the processor, making the location of the quarry one of the most important cost factors. For this reason, remote sites have little possibility of profitable access to larger markets. This is especially true for lower value stones, such as ashlar and flagstone.

Access to the site is important from the beginning. Even preliminary sampling requires the removal of specimens which are heavier than those in most reconnaissance surveys. Should the initial samples prove promising, access becomes even more critical. The cost of moving heavy equipment to the site for test quarrying can be very high, if the location is too far from the road or geographically difficult to reach. Examination of topographic, geologic and road maps will help the prospector determine which sites are most feasible for investigation.

Assigning Priorities

During the preliminary assessment, a number of targets may be identified. An order of site priority should be established, starting with the largest, most accessible exposure and working down through the list. Logistic planning of the field work to follow will correlate this list with other factors to produce the most effective exploration program. A decision matrix is useful here. A series of key criteria are selected and each is given a scoring scale. Each site is then evaluated on the key criteria and a score given. The score for each site is totalled and an order of priority is established. This method makes it possible to weigh each criterium according to the circumstances of each region.

Field Reconnaissance

When the field work portion of the exploration program has been planned, a preliminary look at the rocks is in order. At this time, the prospector will normally take to the field in a sturdy exploration vehicle of some sort - usually a truck equipped with four-wheel drive. Unlike most mineral commodities, however, deposits of massive granitic rocks can often be seen distinctly from above. This, then, is the point at which an aerial survey is most helpful. If a fixed-wing aircraft is used, significant outcrop exposure can be spotted, examined from all sides and its location transferred to topographic maps for follow-up ground visits. A helicopter is roughly three to four times as expensive as fixed-wing, but has the advantage of being able to land on the larger exposures. Unless the outcrop can be assessed quickly, the cost will be too high for sustained exploration purposes.

The remaining and most likely reconnaissance procedure is to walk the outcrop and examine the rocks. Armed with geologic and topographic maps which cover the area(s) selected for the day's work, the prospector sets out to locate the outcrop exposures identified during the preliminary research, or spotted from the air. Standard prospecting equipment, including rock hammer, safety glasses, notebook, compass and hand lens, is required. There are, however, additional items necessary for stone exploration: a large (3 kg) sledge hammer, smaller sledge hammer (about 1 kg), pry bars, steel wedges, heavy work gloves and steel-toed boots. This is by no means a complete list of all the gear and provisioning needed to prospect safely; it is assumed that the explorationist has had previous experience and know-how in this area, or will research the subject thoroughly before beginning.

While searching for predetermined targets, it is inevitable that the prospector will come across roads that are not shown on any maps, or conversely, tracks which used to be better-travelled, and are shown as roads. In either case, the topography and geology maps should be consulted, and the road investigated if it looks as though there may be outcrop exposure in that direction. Newer, unmapped roads are more frequently found in areas where lumber companies are working. These roads may also expose outcrop which has never been evaluated or mapped geologically. As many roads as possible should be travelled, checking outcrop and making notes for future reference. If prospecting in an area where the maps indicate outcrop within a couple of kilometers of the road, bush traverses may be productive, keeping in mind that extremes in topographic relief and other natural obstructions can restrict road construction significantly.

Site Evaluation

Before an outcrop may be considered a prospect, it must meet restrictive criteria: substantial exposure, moderate positive relief, lithological uniformity, suitable joint density and orientation, strength and durability, no observed deleterious minerals, proximity to infrastructure, aesthetic appeal and demand. Most of these properties can be determined at the outcrop, provided enough of the formation is accessible. After several outcrops have been visited, details may become difficult to remember, so it is important for the prospector to keep a record of the suitability of the outcrop in each of the above categories as well as others, such as colour and grain size, for future reference. Each outcrop visited will yield information, some of which may seem of little value until it is combined with other data, eventually providing knowledge about the area in general. A good set of field notes is essential in the event that the prospector or another interested party wishes to revisit a site which may warrant further evaluation.

Exposure

The easiest outcrops to evaluate are well-exposed, bare of overburden and plant growth. In the best case, the site has been polished by glacial action, producing a smooth surface which has weathered for only a few thousand years. Fresh, representative color and texture may be very close to the surface of the rock.
An outcrop which is obscured by rooted vegetation is more difficult from the points of view that it will be difficult to survey, and that vertical jointing and/or overburden thickness may be excessive. At the reconnaissance stage it is not practical to remove this type of vegetation. Moss and lichen present another problem: their often extensive coverage may hide good, massive deposits. It is difficult to tell if good-looking outcrop will continue under moss or lichen,

and a minor amount of clearing with a mattock may be warranted. The depth of overburden and/or overlying waste rock is very important to the development of a quarry. If they are too thick, the deposit cannot be worked profitably without a high front-end cost. Where overburden obscures outcrop with good potential, the reconnaissance explorer can only note the thickness and extent of cover in relation to visible outcrop.
To fully evaluate a site, vegetation and overburden must be removed completely.

Relief

Positive relief in the form of a hill or scarp provides a far easier geographic feature to quarry than a flat-lying outcrop or depression. Drainage problems are reduced, and a "drive-up" quarry face represents lower costs for removal of overburden, waste rock and quarry blocks. Waste rock which can be removed efficiently and cheaply from the quarry face may become a profitable sideline, if crushed and sold as aggregate. Advantages of positive relief for the prospector include easier, more accurate estimation of the volume of the deposit, better assessment of lithological uniformity and often a good view of horizontal fracturing, also known as sheeting. Vertical fracture patterns and sheeting may be well-exposed on the flanks of hills, but should be interpreted with caution, as they can be more concentrated here due to frost action, weathering and pressure release. The degree of fracturing may thus appear greater than what will be encountered in the mass as a whole. The fracture pattern will ultimately determine the size of the blocks that can be extracted, and the amount of waste.

It should be noted that moderate positive relief is the ideal situation. Very high sheer cliff faces are harder to quarry, and even a steeply inclined outcrop slope can present problems.

Jointing Density

Joints are fractures without displacement which may form in any type of rock. In granitic bodies, they developed, at depth, as molten granite cooled after intrusion, and are aligned roughly parallel and perpendicular to the margins of the granite body. Joint surfaces are planar or curvi-planar, and often occur with parallel joints to form part of a joint set (Bates and Jackson, 1987), having a systematic orientation defined by strike and dip. Subsequent structural and metamorphic events, such as folding or faulting, may superimpose additional joint sets with orientations geometrically related to fold axes and fault directions (Marmont 1993). In sedimentary rocks, joints may form during compaction and lithification.

Jointing may be the most important consideration in outcrop evaluation. Without the ability to produce blocks of a size best suited to production needs, the economic feasibility of a quarry becomes less likely. Specialty stone is occasionally quarried in smaller blocks, but stone for large-scale applications is cut using modern gang saws which typically accept blocks up to $12m^3$, and weighing about 30 tonnes, with dimensions of approximately 2.5m X 2.5m X 1.8m. This circumstance has resulted in an optimum outcrop joint spacing. While the best case is not often achievable, minimum standards have been set. Outcrop joint density should be spaced and oriented such that blocks measuring at least 2m X 2m X 1.5m are obtainable. The significance of these restrictions in the field is that vertical joints may be as little as 2 meters apart if they are very close to true vertical, and sheeting may be as little as 1.5 meters if truly horizontal. Waste will increase with the presence of closer joint spacing, irregular jointing, inclined joints, two or more joint sets or when the angle between the joints deviates appreciably from 90 degrees (Marmont, 1983).

If the initial investigation leads to a more detailed examination of the outcrop, the prospector can establish an orthogonal (90 degree) grid. Using this method, highly accurate mapping can be completed to evaluate joints, faults, layering and other geological features that may affect the block size or quarrying procedure. Distances between joint sets can be measured with a tape, while directions can be determined with a compass. Lithological mapping and sampling may also be tied to the grid, giving a true representation of the fracture pattern, lithology, and sample locations. From this information, a reasonably precise estimation of the potential block size can be determined.

Lithological Uniformity

The uniformity of the stone is of great importance to quarriers, particularly suppliers to the monument industry. For example, monument stone is generally fine-grained and equigranular. Colour and grain size should show little variation for most applications. Degrees of imperfection are tolerated in building stone products, but are usually accompanied by a proportional decrease in the value of the stone. The presence of other intrusive rocks as dikes or sills is detrimental to efficient quarry operations in ways similar to fracturing, with the added problem that alteration along contacts between the two rock types may have changed the character of the surrounding granite enough to spoil it for use as building stone. Veining, mafic knots, concentrations of one type of mineral, inclusions and other irregularities should be absent or rare. Shear zones are also undesirable because they, too, represent zones of alteration, both chemical and physical. The geology of a site should, therefore, be as simple as possible, consisting ideally of one uniform rock type, in large volume.

Bedding

In quarrying terms, bedding is a structural feature found in granites, other crystalline rocks and sedimentary rocks, which causes a tendency for the rock to split in well-defined planes roughly parallel to the ground surface. This condition is desirable in quarrying as it aids in block removal considerably. As previously mentioned, granite sheeting, or bedding, should be at least 1.5 meters thick. Limestone and sandstone commonly occur in layers that can be readily quarried, shaped and trimmed into ashlar blocks. In limestone and sandstone quarries, thick, massive bedding is necessary for the extraction of large blocks. In ashlar or flagstone applications, bedding should be medium and thin, respectively.

Durability

The durability of a stone is defined as, "the power to resist the action of weather and other such influences as may tend to promote decomposition or disintegration in the stone" (Parks, 1912). Some stones clearly weather more rapidly than others. Accurate determination of durability is accomplished in the lab, using procedures described in appendix IV. In the field, an estimation may be made using a hand lens to examine the rock for mineralogy, texture, alteration and, for sediments, type of cementation.

Mineralogy and Texture

An examination is made to determine the mineralogical composition of the stone, which will provide information on likely weathering characteristics and the ability to take a polish, and to determine the presence of deleterious minerals such as sulphides, mica, olivine, hypersthene and garnet. A free quartz content in excess of 30 percent is also a concern. (Stones containing more than 30 percent quartz are generally avoided by producers since they have a very high hardness, and are expensive to process). Texture refers to grain size, shape, arrangement, distribution, foliation, layering, and gneissosity. Texture should be uniform in a deposit for both micro and macro scale considerations. In granites there is a microscopic fabric that allows the rock to break in one direction more easily than in another. This easy direction is known to quarriers as the "rift", and is usually caused by the weak alignment of elongate mineral grains. The next easiest direction of split is called the "run", followed by the head grain, or "hard way", which is the hardest direction of split. The rift, run, and head are commonly found in granite and marble deposits and may be present in limestone and sandstone deposits. Generally, fine to medium-grained stone is more valuable than coarser-grained stone, but finer-grained deposits tend to be more fractured, making it more difficult to produce. This important feature of the finer-grained stones may be related to brittleness acquired while cooling more rapidly at shallower depths than coarse-grained rocks. Granite studies describing the effects of grain size, shape and arrangement upon strength are currently under way at the AECL's Underground Research Laboratory in Whiteshell, Manitoba (personal observation). There may be evidence to suggest that finer-grained stones with interlocking grain boundaries may be superior to the coarser-grained samples with rounded grains in some applications.

Absence of Deleterious Minerals

Exterior cladding must be free of deleterious minerals, which are subject to chemical and/or physical weathering. Sulphides tend to oxidize, leaving streaks and stains on the surface. Soft minerals such as olivine and pyroxene, formed at great depth and temperature, are unstable under conditions found on the earth's surface. They erode, and leave a pitted surface. Other minerals, such as epidote, were created during alteration or metamorphism, and occur as softer inclusions in the rock. These minerals are also subject to weathering and pitting. Some minerals are damaged or dislodged during processing: garnets and other hard mineral grains may pluck from the surface during polishing; mica crystals may fray at the edges, allowing water to penetrate behind them, leaving the stone susceptible to severe frost damage in northern climates.

Aesthetic Appeal

If all other factors are positive, the stone style must be pleasing to the eye. If it is not an attractive stone, demand will not warrant production. Colour and pattern (macroscopic texture) are the two main criteria which determine to a large extent the appeal of a dimension stone. While some stones retain their appeal through time, others have periods of demand and then the market moves on to another stone. Familiarity with market standards helps in judging if the stone is a stable or periodic demand product.

Colour and colour uniformity are very important in a dimension stone. When cladding a building with stone, it is imperative that the colour be uniform throughout. This is not to say a desirable rock cannot have colour variation, but such variation must be predictable. It is also important that the colour remain stable. Some building stones fade in colour with extended exposure to light. For example, some light blue marbles fade to white when used in exterior applications.

The colour of a deposit often changes with depth from the effects of weathering. This is particularly true within 30 centimeters of the surface, and can extend as deep as 10 meters. Near the surface, discolouration tends to be the greatest along foliation planes or gneissosity.

Darker, iridescent, or unusually coloured stone commands premium prices. Black, blue, and deep red are especially popular at the present time, with patterned stones recently gaining a share of the market. Quarries where these stones are obtained often contain closer-spaced joint patterns than is usually acceptable, resulting in higher production costs and waste to production ratios as high as 9:1. Volume demand tends to be lower and prices higher for this specialized stone.

The most financially successful quarries produce low to average value stone, such as greys, pinks, whites and browns of various grain sizes and textures. These stones are generally in greater and constant demand because they are used on larger projects, and are produced from quarries where uniform blocks can be obtained on a regular basis.

Texture which is visible to the naked eye is also an important consideration in evaluating the appeal of a stone. Monument producers generally require fine-grained stone, because lettering engraved in coarse-grained stone is less legible. Porphyritic, gneissic and other prominently visible textures are often used in smaller quantities to create decorative patterns in foyers or rooms which are not inhabited for extended lengths of time. Bold patterns and bright colours can be overwhelming in a living room. There is a technique for cutting patterned stone known as "butterflying", which matches adjacent stone tiles as mirror images, often with striking effect. Gneisses with muted colouring and extensive, flowing patterns have been successfully used in large applications, as external cladding and interior panelling.

Site Location

In addition to infrastructure and access, alternate land use must be considered. If the site is located in the vicinity of residences, cottages or other private property, there may be public opposition to quarry development. The required permitting may be difficult, if not impossible, to achieve. Noise and dust guidelines developed by the Ministry of Environment and Energy may limit the use of explosives and other equipment to the extent that quarrying is not feasible.

Land Tenure

Land tenure in Ontario involves mineral and surface rights. The Crown, or provincial government may own both rights, or an individual may own them privately. It may also be that the Crown holds one of these rights, while the other is held privately. The Ministry of Natural Resources publishes Provincial Series maps scaled at 1: 100,000 showing the distribution of private lands, and the Ministry of Northern Development and Mines publishes claim maps that also denote the status of land on a township basis. Production of building stone from a surface quarry is regulated by the Aggregate Resources Act, administered by the Ministry of Natural Resources, except for private lands in areas which are undesignated by this Act. Undesignated private lands may be under municipal authority, and may require public consultation and by-law amendment prior to development. Consultation with the Resident

Geologist, Mining Recorder or Mineral Development officer is recommended if there is any question of land status or administrative authority.

Although the prospector has the right to access lands open for staking and prospecting, it is a good idea to obtain permission from land owners before performing exploration surveys of any type on private land. Many owners are agreeable to prospecting on their property, provided it is done responsibly, with minimal disturbance to their lives and possessions. If a quarry is successful, normally a small royalty per tonne is paid to the land owner.

The following is a list of the logistical steps used in acquiring and developing a property:

1) Determination of site ownership
2) Aggregate Resources Act
3) Municipal Zoning
4) Acquisition of Quarrying rights
    a) Option to Lease
    b) Option to Purchase
    c) Mining Claims/quarry permits

Test Block Removal

When an outcrop area has been selected for testing, the next step is to remove a small sample of approximately 0.1 m^3 (about 1.5 ft^3). This should be a fresh sample, containing no weathered stone. A block of this size will weigh approximately 250 kg (550 lb), requiring a crew to remove it from the site for testing. The importance of access is evident here, as a truck equipped with a crane is very useful in this situation if it can be driven to the site. Otherwise, the sample must be skidded out with a stone boat in summer, or a sled in winter. The extracted block can be cut on a slab saw both parallel and perpendicular to the grain to reveal the stone's best appearance. If an attractive result is achieved, some preliminary ASTM tests can be completed on the stone (Appendix IV).

Samples may also be obtained from frost-wedged blocks or boulders that are on site. These are less desirable, however, because they may be weathered to considerable extent, and the colours may not be true. In addition, there is the possibility in some cases that the sample has been transported from elsewhere by glacial movement.

Assuming the sample is to be broken free from the outcrop, it can be obtained by using a portable gas- or air-powered rotary percussion drill, along with plugs and feathers, pry bars and sledge hammers. When holes about 45 cm deep have been drilled approximately 15 cm apart along the sample boundary, plugs and feathers of matching length are installed in the holes. The plugs are tightened in sequence, using a small 1 kg hammer, causing the rock to split along the line of drilled holes. For this method to work, at least two faces of the block must be free initially. In other words, the samplers must be working at the top of a vertical face. When the block has broken free from the outcrop the plugs and feathers can be retrieved, and the sample moved using pry bars.

The sample block can be transported by truck to a processing plant for cutting. Monument producers or custom shops tend to be more interested in this type of work due to the size of the block. Larger processors are generally not inclined to deal with sample blocks because they are set up to handle larger materials and would realize no profit from the smaller job. The sample is cut into a number of 3cm X 31cm X 31cm slabs and polished. At this time a number of ASTM tests should be performed on the sample if it shows promise.

Should the prospector wish to test an outcrop at depth for fracturing, consistency of colour, or variations in texture, diamond drilling may be performed. Vertical holes of the largest diameter possible should be drilled at strategic locations on the outcrop, from 20m to 30m deep. Recovered core may be stored on site, or partially removed, to be used for promotion of the deposit to potential quarriers or investors. Diamond drilling is expensive, however, and may not be cost-effective for the prospector.

It is hoped that the above information will increase interest in building stone exploration among Ontario prospectors, while providing an overview of the industry in general. The methods described are those most commonly in use today, but others will certainly evolve, along with the building stone industry.

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APPENDIX

I

APPENDIX I

Limestone

Limestone is a sedimentary rock that has been used in more structures than any other rock type, due to plentiful deposits throughout the world, often in layers which can readily be cut and carved into ashlar blocks. The most common varieties are pink, yellow and grey to buff colours. Limestones weather well except in smoggy industrial areas, where acid rain causes the rock to deteriorate.

One famous limestone structure is the great pyramid of Giza, built of limestone blocks quarried along the Nile river approximately 4600 years ago. The Romans constructed arches utilizing tightly fitting limestone blocks that also appeared in stadiums, public buildings, city gateways, bridges, aqueducts and related structures about 2000 years ago. The large cathedrals of England and France were constructed of limestone during the period 1100 AD to 1400 AD.

Marble

Marble is a metamorphic rock, formed when very pure limestone is exposed to high temperature and pressure. The bulk chemical composition remains the same, but the calcite is recrystallized, forming larger crystals which accept polishing very well. In the building stone industry, any limestone, dolomite, or serpentinized dolomite which will take a polish may be classified as marble (Hewitt, 1964).

The Greek Parthenon, constructed approximately 2400 years ago, is built with marble blocks. The marble for this structure originated from nearby quarries which are in operation today.

The Carrara district of northern Italy is very famous for marble building and statuary stone, with quarries that have been worked for centuries. The stone for Michelangelo's "David" came from this region. In North America, the Danby Marble quarry in Vermont is noted for marble of very high quality.

Marbles are coloured by the presence of trace amounts of different chemicals. Iron oxide, for example, produces shades of tan or pink, while grey tints or black streaks result from traces of carbon.

Granite

Granite is an igneous rock formed when felsic magma cools slowly and crystallizes deep in the earth's crust, most commonly in diapiric plutons or stocks which have an inverted teardrop shape. These bodies are exposed where overlying material has been eroded away. Granite typically consists of interlocking grains of quartz and feldspar, along with various amounts of dark minerals rich in iron and magnesium. Some dark granular igneous rocks, although not properly granite, are included in the commercial definition of a granite. These "black granites" may include basalt, diabase, gabbro, diorite and anorthosite.

Granite occurs in a wide range of colours from white to dark grey to black, and from pink to deep red. The crystalline texture of granite allows it to take on a deep polish. It is highly resistant to the elements and is one of the most weatherproof stones. The amount of quartz in a granite determines how difficult the stone will be to cut. The greater the quartz content, the more expensive the stone will be to cut and shape. This hardness and resistance to wear accounts for the use of granite in columns, steps, balustrades, counter tops and thin panels 1.5cm to 13cm thick on the outside of modern high-rise buildings.

Some of the more famous granites with good reputations in the dimension stone business are pink and red granites quarried in Minnesota, dark and light grey granites from Vermont and light grey granite from North Carolina.

Generally, successful granite quarries are those that have been able to produce a consistent product, relatively uniform and homogeneous in colour and texture. If matching replacement stones are needed for repairs, they can be easily obtained.

The 1993 stone directory, assembled by the Department of Natural Resources, Canada, lists 66 granite quarries in the province of Quebec, 10 in Ontario, and 28 others throughout the rest of the country. There were 23 stone companies operating quarries in Quebec, 7 companies in Ontario, and 17 others for the rest of the country. This group manufactures a wide variety of products, such as architectural granite slabs, panels, tiles, monuments, furniture, kitchen counters, mantle pieces and ornamental commodities.

Sandstone

Sandstone is a sedimentary rock, consisting of quartz grains cemented together by calcite, iron oxide, silica, or clay. The most common colours are buff, grey, brown, and red. Sandstone does not take a polish and therefore is used mostly in exterior applications. It is used less frequently now than formerly, having been replaced by brick and other varieties of dimension stone. Sandstone is also known as freestone and was the first stone to be quarried in Ontario because of the ease with which it could be extracted, cut and trimmed into ashlar blocks.

Slate

Slate is a metamorphic rock originating from the sedimentary rock shale. When shale is subjected to high temperature and pressure, the small mica-like minerals rotate into a parallel position with their flat surfaces aligned in a plane perpendicular to the direction of pressure. Consequently, slate splits easily into thin sheets along these parallel planes. Slate is very resistant to weathering, and for centuries has been used as a roofing material. It was also the material of which blackboards were made. Today slate is used in the form of rectangular tiles for flooring in lobbies, entrance halls and similar, high-traffic areas. It is also used in the construction of billiard tables.

APPENDIX

II

APPENDIX II

QUARRYING TECHNIQUES

Two stone quarrying techniques are employed today. The Scandinavian, or "Drive-In" method is highly mechanized and based on drilling; the Mediterranean, or "Derrick" method, is labour intensive and less highly mechanized, due to the terrain in which the quarries are located.

SCANDINAVIAN (DRIVE-IN) METHOD

The Scandinavian method is highly mechanized, employing the latest technology. Light hydraulic drills capable of drilling holes as small as 23mm in diameter are used.

The advantages of hydraulic drilling are:

a) less drilling time
b) less noise
c) less vibration
d) cleaner environment for the operator, due to dust collection
e) the hole is free of oil and water.

A primary block which can be up to 4000 m^3 (8m X 6m X 80m) is removed, and a slot is cut on either end with a slot drill. Drill holes are normally 64mm in diameter with114mm spacing. After the initial line of holes is drilled, a guide is attached to the drill and stationed in the original holes, while the web (residual rock between two holes) is drilled out. This creates an open slot which has broken the block free on either end. In practice, the slot depth is approximately 6 meters or less. This slot can be created by using a flame cut, which costs about 40 percent more.

After a set of end slots has been cut, holes are drilled along the back of the block and underneath the block to free it. The holes are spaced approximately 20cm apart and are loaded with smooth blasting cartridges that contain detonating fuses. Both sets of holes are shot simultaneously, freeing the primary block.

The block is further divided into $10m^3$ to $15m^3$ blocks using the drill guide method. These secondary blocks are dropped onto a bed of sand or old tires and removed with a 40-tonne capacity front end loader or a fork lift. To a squaring house, where drills are used to square the block.

The waste is removed from the block using plugs and feathers or backhoe-mounted hydraulic splitters. The splitters can easily be positioned over pre-drilled holes in the block, charged, and the waste split off.

MEDITERRANEAN (DERRICK) METHOD

The Mediterranean, Derrick, or Italian method is a different system altogether compared to the Scandinavian method. The Italian quarries have been in operation for over 2000 years, while the Scandinavian quarries are a recent development. Italian deposits tend to be irregular and in mountainous terrain, usually too steep to accommodate modern equipment. Marble deposits are also more variable and many parts of the deposits are waste. Manual labour is used to good effect under these conditions.

Using this method, blocks broken from the quarry face tend to be relatively small. Fixed derricks are used to move the stone around the quarry and a number of faces are worked simultaneously. Instead of drilling out large, primary blocks, one or two pilot holes are drilled into the block, and it is cut free with wire saws.

After the primary blocks are broken free from the face of the quarry they are further divided, using drills on a quarry bar, and trimmed with wire saw trimmers. Trackless equipment is kept to a minimum, or absent altogether.

1) Flame channelling
2) Drilling and blasting
3) Diamond wire saw
4) Water jet

1) Flame Channelling

Flame channelling equipment mixes diesel fuel with compressed air to create a concentrated flame. Under pressure, the mixture reaches temperatures high enough to exfoliate the rock, leaving a channel in its wake. This method is generally used to separate a large, primary block which is then cut up by conventional means; drilling, plug and feather splitting and wire sawing.

In cutting, the burner is moved across the rock, causing it to spall and form a channel. Granites with a high quartz content are favoured, because it is the rapidly-expanding quartz which causes spalling. Weathered zones, fractures and areas lacking quartz will slow the process considerably.

Cutting rates vary from $1m^2$ to $1.5m^2$ per hour, with costs averaging $12.50 per square meter. Burner tips can be leased for about $1600 per year. An automated version of the jet burner exists, which can move vertically and horizontally, independent of the operator. The 1989 cost of this unit was approximately $19,000.

The major drawback of flame channelling is noise, which is sufficient to damage the hearing of the operator. If there are residences nearby, the public may object to the noise. Ministry of Environment and Energy noise guidelines may not be met. Another disadvantage is that thermal damage can affect up to 30cm of stone on either side of the channel. The method is also very dusty and the rock has to be quartz-bearing for the technique to work. Fractures can dramatically reduce the cutting rate by diffusing the heat of the burner.

2) Drilling and Blasting

A quarry bar is used to support pneumatic drills, ensuring that the drill holes are in line and drilled to the same depth. In primary blocks, drill holes may be 15cm to 20cm apart or more, depending on the type of stone. Marbles, for example, may break easier than granites, requiring less closely-spaced holes. Prima-cord, K-pipe, black powder and other low velocity explosives are used for blasting the primary block loose from the outcrop. Dynamite or fuel oil mixed with ammonium nitrate (ANFO) are not used, as these high-velocity explosives cause extensive fracturing, and may render the entire site useless for the extraction of building stone. In some cases only every second or third hole is partially loaded with black powder. After the primary block is separated from the quarry face, it is reduced to smaller blocks for processing.

3) Diamond Wire Saws

This newer technology is beginning to find use in North American quarries. A diamond wire saw can cut a granite block 30m X 10m X 5m from the surrounding material in about 11 hours using a wire speed of 22 to 25 meters per second. These saws are equipped with an automatic shutdown feature in case the wire breaks.

An advantage of this method is a dramatic decrease in the amount of waste produced in comparison to drilling and blasting. In a number of case histories, waste rock has averaged 75 percent with the drilling and blasting method, while the use of diamond wire saws reduces waste to about 25 percent. Additional savings have been realized in lower manpower requirements; while the diamond wire saw is running, the operator is free to perform other duties, periodically checking the saw. Other benefits to this method include value added to blocks by virtue of their having two or more squared faces. Processors will pay a premium for these blocks, and the sizing of blocks with squared faces is a more efficient process. This technology also provides a cleaner work area and lower noise levels, and is relatively compact when compared with silicon carbide, due to the absence of pulleys and long cables. Finally, sawing causes less vibration than percussion drilling, and is less likely to cause unwanted breakage of the stone.

There are two different types of wire saws used to extract large quarry blocks: one is a wire with an abrasive slurry added to it, while the other is an impregnated diamond wire using water for cooling and flushing. The latter method is generally used for cutting large blocks.
A comparison between the two methods of wire sawing, beads versus slurry, reveals that the diamond bead technology represents a 50 percent increase in the cutting rate, doubling the production. The difference in total costs between the two methods is negligible.

Diamond wires contain electroplated or impregnated diamond beads, which are fed through a series of pre-drilled holes in the quarry face. A motor drive, which may be electric or diesel, keeps the wire moving. Electric machines range between 40 and 50 horsepower, while diesel machines are in the range of 50 to 100 horsepower. The speed of the wire can be regulated between 10 meters and 50 meters per second. A speed of 40 to 50 meters per second is found to be optimum for soft rock, while a speed of 30 meters per second is found to extend the bead life in harder rock. The tension applied to the wire is regulated by the power consumption of the drive pulley motor, reducing the possibility of breaking the wire due to excessive tensile forces in the cable. The cutting rate varies with the hardness of the rock; the harder the rock, the slower the cutting rate and the shorter the wire life. Water is usually applied with the spin direction of the wire at a rate of 25 litres to 40 litres per minute. Water acts as a coolant and a cleaning agent, removing rock particles from the saw cut. There are four diamond wire cutting techniques, described below:

Methods 1 and 2 are used to extract blocks from a quarry face.

1) Loop: A horizontal and vertical pilot hole are drilled and the diamond wire is fed through these holes to form a loop. In order to feed the wire through the pilot holes a thin string is first blown through with compressed air. A thicker rope is drawn through with the string and finally the diamond wire is pulled through using the rope. The block is then cut from the top downward (Figure 3a).

2) Traditional: One vertical pilot hole is drilled and the wire is stretched over the top of the block in a loop. The diamond wire is forced down the pilot hole by use of a rod that has a pulley attached to either end of it to facilitate the movement of the wire. The rod is secured in place by a positioner that is anchored into the rock and allows the rod to be moved vertically down the hole (Figure 3b).

Methods 3 and 4 are used to extract blocks below ground level.

3) Traditional: This method is identical to that described above, except that two vertical pilot holes are utilized,along with two positioners and rods with pulleys. The block is then cut from the surface downwards (Figure 3c).

4) Mixed Technique: Two vertical holes and one horizontal pilot hole are drilled and the diamond wire is fed through these holes as well as across the top of the block to form a loop. The block is cut from the bottom to the top (Figure 3d).

Wire saws employ abrasives in the form of beads that are either impregnated or electroplated with diamonds. The diamond beads are separated by spacers, and come in a number of different configurations: they can be crimped, heavy "nail"-type, or spring-type, and the spacers may be made of rubber or plastic. The beads and springs are alternated and a metal sleeve is crimped to the wire, typically every 4 or 5 beads. This prevents the beads from sliding on the wire due to compression and expansion, and also from being lost if the wire breaks. The number of beads used for marble quarrying ranges between 27 and 32 beads per meter. This configuration has been used very successfully in cutting marbles.

Rubber spacers do not perform well when used in cutting granite. The rock is much harder and the granite chip slurry tends to clog up the spring spacers between the diamond beads. This causes the wire to wear prematurely and also causes excessive wear on the internal diameter of the diamond beads. Plastic is therefore used for spacers in wire which is used to cut granite. The diamond wire is placed in a mold and plastic is injected to fill the intervals between the beads and the wire. The plastic has a smaller diameter than the beads and will not interfere with the cutting. The plastic also protects the wire from the abrasive slurry produced from the granite. The number of beads per meter on cable used for quarrying granite is between 33 and 40 (figure 4).

The best wire performance is achieved when beads that are separated by springs are allowed to rotate freely causing the beads to wear evenly over the life of the wire. Bead rotation is not possible in wires that are impregnated with plastic. To achieve even bead wear, the wire is twisted around its centre axis once for every meter of wire length. This, along with altering the distance between the drive wheel and the guide pulleys, causes varying rotation of the wire around its axis, producing even wear.

A typical diamond cutting wire for granite would have beads or cutting elements with a diameter of 11mm, containing synthetic diamond abrasives, 40 to 50 U.S. mesh size, imbedded in a sintered metal matrix around an impregnated annular steel tube, mounted on a cable 5mm in diameter. The beads are separated by plastic to protect the cable from wear. Alternately, the electroplated bead consists of a steel tube on which the diamond abrasive is bonded through electrolytic deposition of nickel. The diamond size is typically 30/40 to 40/50 U.S. mesh.

Generally, electroplated beads are used in marble quarrying while impregnated beads are used in granite quarrying. Wire life using impregnated beads tends to be twice the life of electroplated beads. Wire sawing of granite is not used as commonly as it is for marble, as costs tend to be higher for granite than they are with marble. It is, however, a faster method for extracting granite than flame burning or percussion drilling. Up to 70 percent of wire saw cuts made in a quarry are vertical.

With the older wire saws, a silicon carbide abrasive is added to water to form a slurry which is applied to the spin direction of the wire. The combination of abrasive and pressure on the wire cuts the rock. A sump collects the abrasive slurry, which is recirculated back to the wire, a method used widely in the monument industry. Wire saws are available which can make up to 5 cuts at a time on a single block.

DIAMOND WIRE CUTTING TECHNIQUES

Cuts into a rock face
- a) loop
- b) traditional

Cuts below ground level (squaring)
- c) traditional
- d) mixed technique

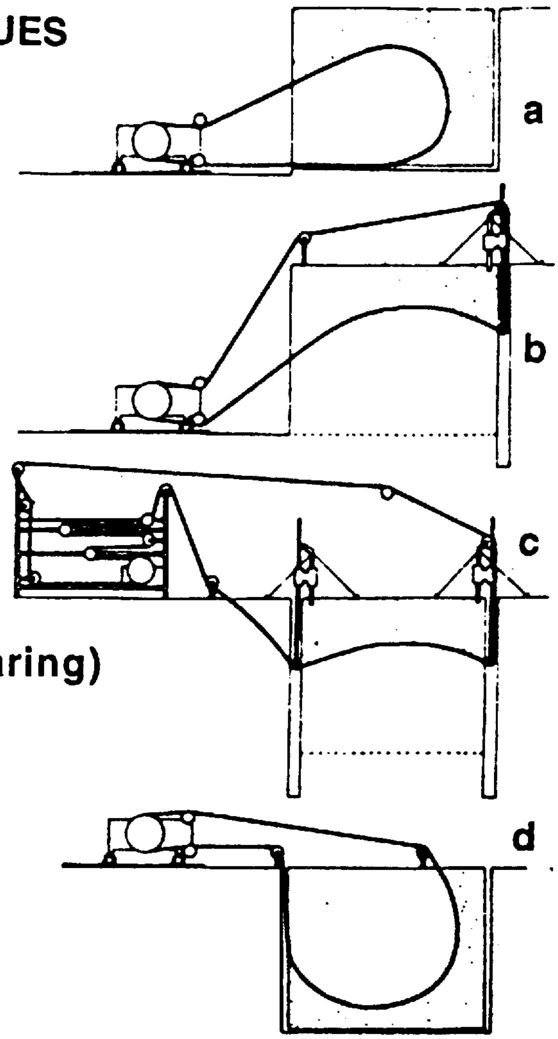


Figure 3 (from U.N. Institute of Training and Research, 1988)

DIAMOND WIRE DESIGNS (a, b, c, d) & SOME JOINTS (e & f)

1) diamond beads
2) rubber spacers
3) steel cable
4) diamond layer
5) support
6) heavy "nail"-type spacers
7) spring-type spacers
8) crimped spacers
9) welded joint
10) screw-type joint
11) diamond wire ends
12) simple pressure joint

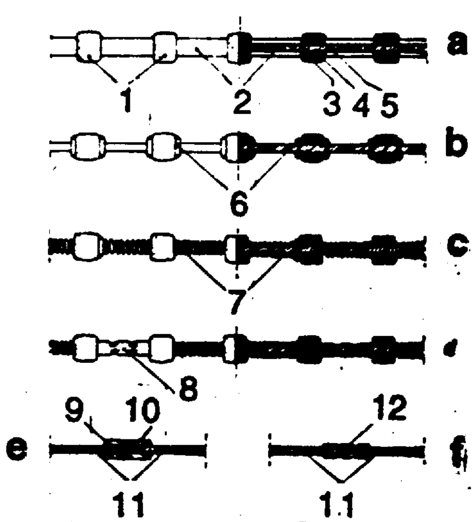


Figure 4 (from U.N. Institute of Training and Research, 1988)

4) WATERJET TECHNOLOGY

This is relatively new technology that is not widely in use on a production scale. The method combines the use of water or a mix of water and abrasives under high pressure. Water is forced through a pinhead-sized opening in a sapphire or diamond nozzle at a pressure of 36,000 P.S.I. and a velocity equal to twice the speed of sound (figure 5). Abrasive can be mixed with water at the nozzle or it can be in the form of a pre-mixed slurry.

Slots can be cut to a depth greater than 6m at nearly 1m^2 per minute. Hose pressure and abrasion damage to nozzles appear to be the limiting factors at this time. Some research has been done with ceramic nozzles and pressures up to 70,000 P.S.I.

Advantages in using this type of cutting system are:

a) Cutting is omni-directional allowing three-dimensional cutting.

b) Channel width (kerf) is very narrow, eliminating waste.

c) High quality cut edges reduce finishing and grinding operations.

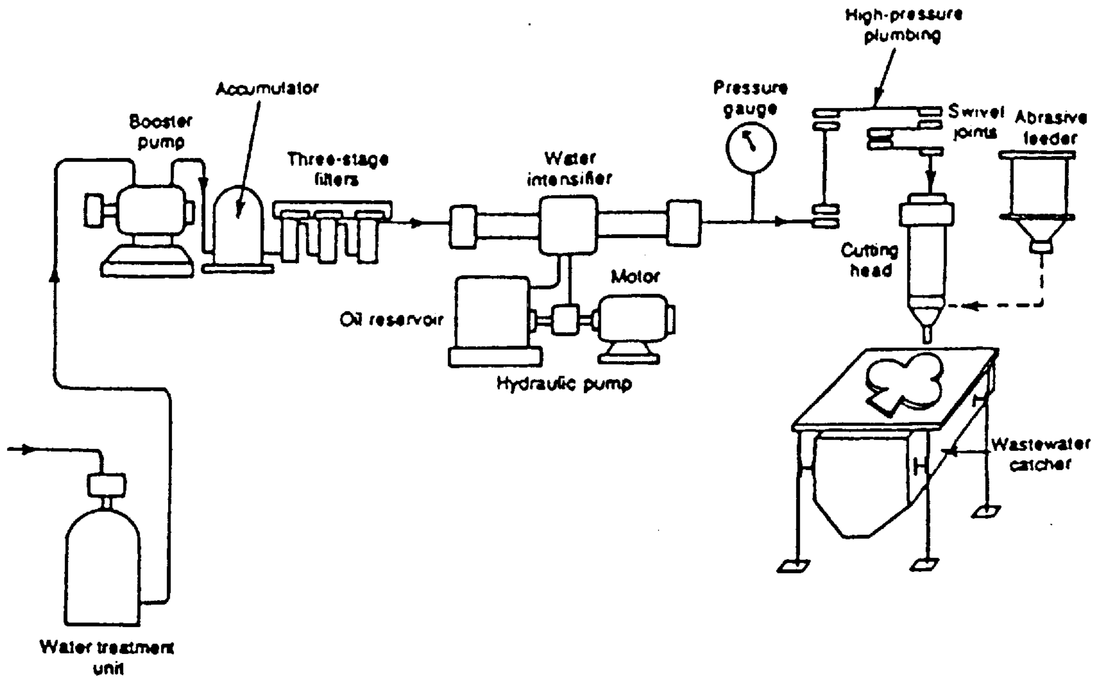
d) Energy and cutting are more efficient than conventional methods.

To date, the only stones on which this technique does not work are some sandstones and black granites. The granular structure of these rocks is not compatible with the use of high-pressure water.

Other Quarrying Techniques

Beltsaws and Chainsaws

Saws resembling very large wood-cutting chainsaws may be used for quarrying softer stone. Diamonds, tungsten carbide or other cutting media fastened to belts or chain teeth provide cutting action through continuous rotation around an arm, or bar. The saw is pivot-mounted on



Layout of a Typical Waterjet-Cutting System.

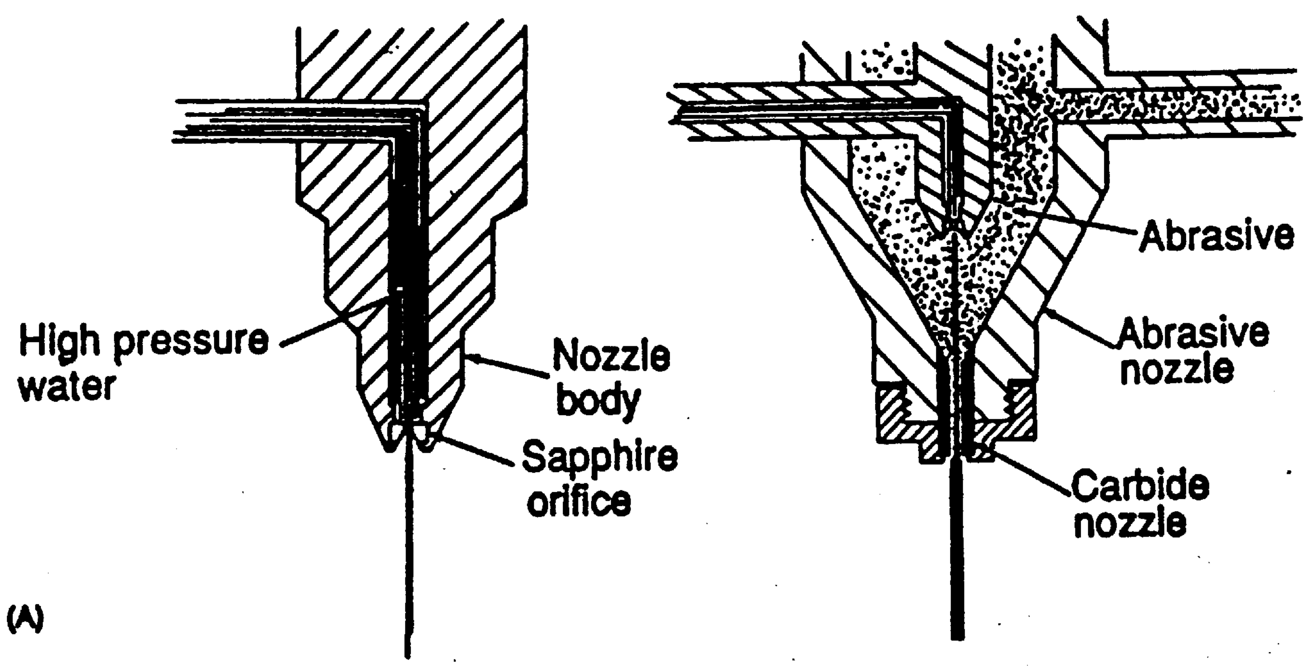


Figure 5 Schematics of Cutting Nozzles; (A) Plain Waterjet and (B) Abrasive Jet.

(from Solomah, 1991)

a track which is secured to the rock. To begin a cut, the arm of the saw is pivoted into the rock at a low angle and slow revolution speed. The saw body remains stationary while the arm is gradually rotated until it is vertical or horizontal in the rock. After the initial cut is made, the saw body and blade move along the track to continue the cut.

The maximum depth of cut is 3.3 meters, penetrating the rock at a rate of 8.25cm per minute (in limestone, using tungsten carbide teeth).

Polycrystalline diamonds have now been bonded to tungsten carbide matrices. One tooth can cost as much as $100.00 and there may be as many as 144 teeth per belt. When cutting through rock, the diamond layer is conserved as the tungsten carbide segment wears away, leaving the diamond component relatively intact. Diamond impregnated belts are designed to be run at lower speeds than tungsten carbide cutters.

Splitting Blocks

A number of different methods for splitting smaller blocks from larger blocks are listed below:

a) **Plugs and Feathers**; (wedges and shims)

A line of holes is drilled in the rock along the desired split, and each is furnished with a plug, or wedge, and two greased feathers, or shims, one on either side of the plug. The holes can be of varying depths to accommodate different lengths of plugs and feathers. The plugs are tightened sequentially with a hammer, inducing a break in the rock along the line of drilled holes.

b) **Hydraulic, Compressed Air Splitters and Rams**;

These methods work almost identically to the plug and feather method described above. A line of holes is drilled deep enough to accommodate the splitters, which are inserted in the drill holes and pressurized with hydraulic oil or compressed air to split the rock.

A ram is a device used for moving large blocks a short distance away from the quarry face after they have been dislodged. It is similar to a bottle jack that uses hydraulic oil to activate a cylinder, or ram, to lift objects or move them apart.

c) Air Bags;

The use of air bags to wedge blocks is relatively new. The deflated bag is inserted between the block and the quarry face, then inflated with air from a compressor. The bags collapse to 2.22cm when fully deflated, and may be inserted back to back to accomplish twice the movement.

A vertical cut made with a 0.64cm wire saw or a 0.95cm diamond wire saw does not allow enough room for an air bag in the kerf. A pocket is drilled out to allow the placement of a 100-tonne hydraulic ram to move the block enough to allow insertion of an air bag.

d) Black powder and Prima-cord;

As with the other methods, holes are drilled in a line on a block that is to be split. The holes are usually fairly closely-spaced (2.5cm to 5cm apart), and are drilled all or most of the way through the block. Some of the drill holes are partially filled with black powder and carefully tamped. Upon detonation, the explosion breaks the block along the desired line.

Prima-cord is also used to break blocks. This explosive is in the form of a cord and is applied in the same manner as black powder.

APPENDIX

III

APPENDIX III

STONE PROCESSING

Three types of saws are utilized in processing cut blocks:

1) Gang Saws
2) Circular Diamond Saws
3) Stationary Wire Saws

Gang Saws

Square blocks of 20 to 25 tonnes are cut at processing plants, using gang saws, or frame saws, similar in appearance to giant bread slicers. The similarity ends there, however, as these saws are designed to slice substantially harder substances. Steel blades are continuously bathed in a water-abrasive slurry or clear water throughout the cutting cycle and are drawn back and forth under pressure to cut the stone block. A 40 to 60 blade gang saw of $6m^2$ to $7m^2$ surficial cutting capacity requires 9,000 litres of slurry per hour, along with 125 kg of fresh sand and 1000 to 1200 litres of fresh water added each hour to the slurry in circulation. Modern gang saws employ diamond blades for better performance, but are too expensive for some applications.

On traditional steel-bladed frame saws, marble is cut at a rate of approximately 20 cm per hour, granite at half this rate or less. These saws use abrasives mixed with water, and may use a rocking frame or, if cutting marble, a rectilinear-trajectory frame, employed when cutting granite.

Three types of shot are used for abrasives, depending on the type of stone: cast iron or steel grit for cutting granite, silicon carbide grit for hard or veined marble, quartzose sand for ordinary marble. Lower-strength quartzose sand is also used to trim cracked blocks, a process using low blade-to-block pressures. When the mixture of water and abrasive remains constant, the surfaces of cut slabs are usually smoother, free from grooving caused by overly large grains of shot.

Rectilinear-trajectory frame saws are used exclusively for cutting granites because these blocks can seriously impair the life of a diamond blade. High pressure is applied uniformly along the length of the blade. The blades are usually tall, with circular holes or vertical slots to allow the shot to move into areas of contact between the blade sides and the block. The blades are also thicker, cutting more rock between the slabs, thereby making them more expensive to operate.

Reciprocating frame saws with diamond-coated blades mounted on blade frames which move along a vertical or sub-vertical plane are used to cut modular stone, or agglomerated blocks. They usually have 25 to 30 dogbone-shaped blades, but as many as 70 blades may be used.

Reciprocating frame saws with diamond impregnated blades mounted on rectilinear-trajectory frames have become popular with marble producers. Marble saws using silicon-carbide grit and quartzose sand have been replaced by diamond-coated blades in most modern processing operations. These saws contain 80 or more blades and can run at 130 strokes per minute at high pressure. The diamond coatings on the blades improve cutting to a rate of 35cm/hr for medium to hard marbles, and provide a production life of 800 to 850 square meters. Newer saws have fixed blade frames with sawing action achieved through lifting the trolley holding the block up to the blades.

Circular diamond saws

Bridge saws with one diamond-coated disc blade are used primarily for block trimming. The blade may measure up to 3.5m in diameter and can cut to a maximum depth of 1.4 meters. The trolley holding the block is raised into the cutting disc, and a number of passes are required to cut the desired depth. The bridge slides along two parallel vertical guides and a hydraulically controlled mobile disc drive shaft. The back and forth movement and the slow trolley ascent during the cutting process is automatically controlled.

Bridge saws with multiple diamond disc blades may have anywhere from 2 to 20 blades and cut to a depth of 45cm. These saws were originally designed to cut smaller blocks of granite that would not fit on a reciprocating frame saw. The precision and smoothness of the cut is an advantage, but the limited depth of cut is a major disadvantage. Bridge saws have remained basically the same for the last 20 years, but have been upgraded in the area of control instrumentation:

a) Systems have been added for slowing the speed of the saw as it starts and finishes a cut, reducing the chance of chipping the edge of the rock slab.
b) The direction of the cutting disc can change automatically.
c) The depth of cut can be changed for each pass of the disc.
d) Bridge movement is programmed electronically.

The stability and vibration characteristics of this equipment have undergone a considerable amount of research and development. High-frequency vibrations may produce noise which is damaging to health, and mechanical vibrations can reduce the life span of the cutting disc as well as the moving components of the saw.

Stationary Wire Saws

The two uses for the wire saw in processing are slabbing and block squaring: The slabbing operation produces thick slabs, usually for the monument industry, and the block squaring operation prepares blocks for further fabrication with multi-disc or frame saws.

Polishing Lines

Slabs which are to receive a polished surface are taken from the slabbing process to the polishing line. Polishing lines with mobile bridges and fixed work beds which have been used extensively in the past to polish individual small to medium-sized slabs, are characterized by a fixed cement work bed which can be quite long. Before the slabs are polished they are washed down with a high pressure hose to remove rock and abrasive grit left over from the primary cutting process. The slabs are placed on the work bed and the polishing operation is carried out by moving the bridge back and forth over the slab. The bridge incorporates rotating heads that are fitted with appropriate abrasive and polishing elements.

The polishers can be of rotary head or rocking head type, depending on the rock being polished. Rotating heads use pie-shaped polishing bricks which wear flat during the polishing process, and are used on soft stones such as limestone or marble. Rocking head, wobbly head or tangential rocking head polishers are employed exclusively in the polishing of granites. Through the use of reduction gears, 12 to 15 rotations are required to move the polishing shoe back and forth over the stone once. The polishing bricks develop a rounded shape and are therefore only in tangential contact with the stone. This facilitates the higher polishing pressures required to polish granite. Lines dedicated to polishing granite use higher peripheral speeds and polishing-element pressures, with heads moving in a circular trajectory along planes oriented nearly, but not exactly, parallel to the surface of the slab. Recent trends have been to use heads with oscillating abrasive elements, increasing productivity and the life of the abrasive.

The most commonly used polishing agents are oxalic oxide, tin oxide, and aluminum oxide. Oxalic oxide produces a high finish with little labour, but is not very durable. Tin oxide, while more costly, imparts a high durable gloss to the stone. In general, hard polishing agents are recommended for softer rock and soft polishing agents are used on hard rock. The direction of polishing, as well as correct pressure is very important. In veined marbles, for example, too-high pressure will "open" the softer veins and polishing results will be poor. The speed of the buff, as well as the degree of moisture and the quantity of abrasive powder are all very important to the final finish.

The ability to polish a granite slab depends on the freshness of its silicate minerals; altered minerals tend to be softer, and polish poorly. This is especially true if the rock contains kaolinized or sericitized feldspars and/or chlorite-altered pyroxenes. Granites containing coarse-grained biotite seldom polish well either, due to biotite flaking, creating pits in the rock surface. Rocks composed of minerals with a large contrast in hardness are also very difficult to polish in most cases.

Polishing lines with mobile multiple bridges and fixed work bed fitted with a system for programmed movement of the rock slabs are identical to the systems described above, but more automated. The line is programmed to move the slabs between the various polishers after each polishing operation has been completed. This method is used when large or thick slabs are being polished, such as rock slabs for the monument industry. The slabs, fed into the polisher on a conveyer belt or roller line, are levelled using a coarse abrasive, silicon carbide imbedded in a magnesite block or diamond grit. A polisher may have a dozen heads, with the first one or two heads devoted to levelling the rock slab. The next three or four heads employ a finer abrasive, followed by three or four heads of still finer abrasive. Finally one or two heads will consist of a very fine abrasive, and the last head is devoted to washing the slab. This process is fully automated and the entire slab is polished with one pass through the line. When polishing has been completed, the slabs are trimmed for a particular application. Usually the slabs are placed on a table where a bridge saw is programmed to cut them to a specific size.

A problem that occurs with some coloured marbles which does not lend itself to automation is the "filling" or "stopping" required to fill natural cavities in the rock. This is usually accomplished with white cement or polyesters mixed with appropriate colours of marble dust and applied by hand before final buffing.

Automated bevelling and edge polishing machines are finding use in the industry, replacing manually operated equipment. Used in both small- and large-scale production, these specialized machines are usually employed in the monument industry.

Granite Finishes

Slabs and tiles may be finished many ways, depending on end use:

Bush Hammering: a type of finish where the surface of the stone is hammered with a chisel. This was formerly done by hand, but is now performed by machine in large-scale operations.

Flame-Finishing: rock slabs on a rolling bed are passed under a 3000° C flame, which is angled 45° to the surface. At this temperature, fusion and vitrification take place in the surface silicates of igneous rock, creating a glassy finish. This process is limited to granite and other igneous rocks.

Sandblasting: produces a matte-textured surface with no gloss, using accelerated sand particles as abrasives, wearing rock surfaces to a depth of 5 mm. Modern equipment allows recycling of sand, reducing operation costs. Sandblasting is also employed for lettering and design work in the monument industry.

Ground Polished: the facing of the stone is finely ground to eliminate all irregularities, showing only very fine streaks, barely visible to the naked eye.

Bossaged: the surface is roughly split so the central part of the block is slightly elevated from the edges.

Tooled: the surface is composed of fine ,parallel streaks 1mm-2mm deep between which the ridge has a rough split texture.

Crenulated: a flat, rough, sawn facing in which there are regular grooves 1mm-1.5mm deep spaced about 5mm apart with the bottom of the grooves rough-sawn like the facing.

Denteled: the surface is made up of grooves 1mm-4mm deep between which the rough split texture remains.

Scabbed Texture: a flat facing made up of parallel streaks 3mm-7mm deep, 5mm-20mm apart, generally straight, separated by small fractures where rock has split off.

Marble Finishes (acceptable to the Marble Institute of America)

Natural Finish: a finish produced by sawing.
Sand Finish: a finish produced by sand rubbing.
Sand Blown Finish: a finish produced by sand blasting.
Honed Finish: a velvety smooth finish with no shine.
Grit Finish: refers to a smooth finish.
Polish: a mirror-like glossy finish that brings out the full colour and character of the marble.

Tiles

Tiles are made on a tile line, from rough blocks which need not be as large as those used for other applications. Tiles are usually cut with a multi-blade diamond circular saw, producing a number of tiles at once. The rough-cut tiles are polished on a scaled-down polishing line. After polishing, the tiles are cut to size, chamfered on the back, bevelled and packaged for shipment. Standard tile sizes are 12in. X 12in. or 12in. X 24 inches.

Monuments

Monument processors cut blocks into thick slabs with bridge or wire saws. Polished blanks are finished using sand blasting and other techniques, and polishing may be automated or hand-crafted. Monument bases are finished separately and may or may not be of the same rock type and finish.

APPENDIX

IV

APPENDIX IV

The American Society for the Testing of Materials (ASTM)

The American Society for the Testing of Materials (ASTM) sets standards that construction building stones must meet and regulates the various tests to establish these standards. Whether the stone is to be used as an exterior cladding or for an interior application such as floors or low level interior walls, it should meet the ASTM standards. No architect or designer will specify a stone for a project without the completion of these tests. A number of these tests which apply to building stone are described in some detail below:

Standard Definition of Terms (ASTM C 119-83c)

The terms used in definitions and nomenclature shall be interpreted in accord with commonly accepted scientific and technical terms of the geological sciences except as otherwise specifically noted. Examples of exceptions are the broader commercial definitions of granite and marble, which have become well established in the stone industry and trade. Definitions and terms included with these definitions have been formulated to accord with common industrial usage where this is not in conflict with current scientific usage.

Specific Gravity and Absorption (ASTM TEST C 97-83)

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.

The water absorption 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.

Water absorption = B-A/A x 100, where;
A = the dry weight of the sample in air in grams, and
B = weight of the saturated sample, surface dried, in grams.

The apparent porosity of a stone = B-A/V x 100, where;
A = dry weight of sample in air in grams, and
B = weight of saturated sample, surface dried, in grams, and
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 using the following formula:

P = 100/t (t-a), where;
P = porosity, and
t = true specific gravity, and
a = the bulk specific gravity.

Water can penetrate the pores of a rock, and by alternate freezing and thawing, may cause the rock to rupture. Also, water carrying dissolved gasses or salts can penetrate the pores of a stone and dissolve the stone along grain boundaries. The porosity of a stone can affect its durability, which depends to a degree upon permeability. Thus pore size and permeability are as important as percent porosity. Permeability is determined by the coefficient of saturation, which is the ratio between the amount of water absorbed by a one inch cube of rock in a stated time of immersion, (usually one or two hours), and the total amount of water the stone is capable of absorbing. A low coefficient of saturation should indicate high frost resistance for the stone. At least three 5cm cubed samples are required for the test. The surface finish may be of any type.

Abrasive Hardness of Stone (ASTM TEST C 241-51)

The hardness of a stone is a measure of its resistance to abrasion and depends on the mineralogy, texture, friability, character of cementation and metamorphic grade of the stone. Hardness affects the workability of a building stone and is a major factor in the cost of stone fabrication. Normally this is not taken into account unless the material is going to be used in traffic zones such as floors or stairs.

Three samples, measuring 5cm X 5cm X 2.5cm, are required to perform the test.
One 5cm X 5cm face should have the finish to be exposed to traffic for testing.

Compressive Strength (ASTM TEST C 170-50)

The compressive strength or crushing strength of a stone is determined by crushing three cubes of the rock. It is important to determine the crushing strength of a bedded or banded sample both parallel and perpendicular to the bedding.

Five samples, each measuring 5cm X 5cm X 5cm, are needed for the test. All faces must be flat, honed or polished, and opposite faces must be parallel.

Modulus of Rupture of Stone (ASTM TEST C 99-52)

Modulus of rupture is the measure of the stone's ability to withstand bending strain. A 20cm X 10cm X 6cm sample is placed on knife edge supports 17.8cm apart. A load is then placed on a steel edge bearing across the centre of the sample. The modulus of rupture or transverse strength is calculated in millipascals required to break the sample. A minimum of three samples are required where all faces must be smooth and opposite faces parallel. Samples may be tested wet or dry.

Granite Building Stone (ASTM STANDARD C 615-80)

This specification covers the material characteristics, physical requirements, and sampling appropriate to the selection of granite for general building and structural purposes.

Building granite shall include stone that is sawed, cut, split or otherwise finished or shaped, and shall specifically exclude molded, cast, or otherwise artificially aggregated units composed of fragments and crushed and broken stone.

The physical requirements for granite are as follows:

Physical Property	Test Requirements	ASTM Test Method
Absorption by weight, max, percent	0.40	C-97
Density, Min, Kg/m^3 (lb/ft^3)	2560 (160)	C-97
Compressive Strength, min, MPa (psi)	131 (19000)	C-170
Modulus of Rupture, min, MPa (psi)	10.34 (1500)	C-99
Abrasion Resistance,(A) min Ha (*)		C-241

(A) The minimum Ha (abrasive hardness) value has not been established at this time and is presently a topic of study by the committee C-18.

(*) $Ha = 10G(2000 + Ws)/2000Wa$, where;
G = Bulk specific gravity of the sample, and
Ws = average weight of the specimen (original weight plus final weight divided by 2), and
Wa = loss of weight during the grinding operation.

The abrasive value, Ha, is the reciprocal of the volume of material abraded multiplied by ten.

The weight superimposed on the specimen is 2kg, and is augmented by the weight of the specimen. The correction for the weight of the specimen, included in the formula, is based on the fact that the rate of abrasion is directly proportional to the weight. By basing the abrasive resistance values on the volumes rather than the weights abraded, a better comparison is obtained for materials that vary considerably in bulk density.

Marble Building Stone (exterior)
(ASTM STANDARD C 503-79)

This specification covers material characteristics, physical requirements, and sampling appropriate to the selection of marble for general exterior building and structural purposes.

Building marble includes stone that is sawed, cut, split or otherwise finished or shaped. It excludes molded, cast or otherwise artifically aggregated units composed of fragments and also crushed and broken stone.

Building marble (exterior) is classified as follows:

I - Calcite; II - Dolomite; III - Serpentine; IV - Travertine.

The physical requirements for exterior marble building stone are as follows:

Physical Property	Test Requirements	Classification	ASTM Test Meth.
Absorption by weight, maximum, %	0.75	I,II,III,IV	C 97

Density, min, kg/m^3 (lb/ft^3)	2595 (162)	I	C 97
	2800 (175)	II	
	2690 (168)	III	
	2305 (144)	IV	
Compressive Strength, min, M Pa (psi)	52 (7 500)	I,II,III,IV	C 170
Modulus of Rupture, min, M Pa (psi)	7 (1 000)	I,II,III,IV	C 99
Abrasion Resistance, min, hardness, Ha	10	I,II,III,IV	C 241

Limestone Building Stone (ASTM STANDARD C 568-79)

This specification covers material characteristics, physical requirements and sampling appropriate to the selection of limestone for general building and structural purposes.

Building Limestone shall include stone that is sawed, cut, split, or otherwise finished or shaped. It does not include molded, cast, or otherwise artificially aggregated units of composed fragments or crushed and broken stone.

Building limestone is classified as follows:

I - Low-Density: 1760 - 2160 kg/m^3 (110 - 135 lb/ft^3).

II - Medium-Density: 2160 - 2560 kg/m^3 (135 - 160 lb/ft^3).

III- High Density: greater than 2560 kg/m^3 (160 lb/ft^3).

The physical requirements for building limestone are as follows:

Physical Property	Test Requirements	Classification	ASTM Test Method
Absorption by Weight, Maximum, per cent	12.0	I low density	C-97
	7.5	II med density	
	3.0	III high density	
Density, Min, kg/m^3 (lb/ft^3)	1760 (110)	I low density	C-97
	2160 (135)	II med density	
	2560 (160)	III high density	
Compressive Strength min, MPa (psi)	12 (1800)	I low density	C-170
	28 (4000)	II med density	
	55 (8000)	III high density	
Modulus of Rupture min, MPa (psi)	2.9 (400)	I low density	C-99
	3.4 (500)	II med density	
	6.9 (1000)	III high density	
Abrasion Resistance min, hardness, (A) Ha	10	I low density	C-241
	10	II med density	
	10	III high density	

(A) Pertains only to stone subject to foot traffic. In stairways, floors, and platforms subject to heavy foot traffic, a minimum abrasion hardness of 10 is recommended.

Sandstone Building Stone (ASTM STANDARD C 616-80)

This specification covers the material characteristics, physical requirements, and sampling appropriate to the selection of sandstone for general building and structural purposes.
Building sandstone shall include stone that is sawed, cut, split, or otherwise finished or shaped, and shall specifically exclude molded, cast, or otherwise artificially aggregated units composed of fragments and crushed and broken stone.

Building sandstone shall be classified according to the free silica content as follows:

I-Sandstone, with 60% minimum free silica content.

II-Quartzitic Sandstone, with 90% minimum free silica content.

III-Quartzite, with 95% minimum free silica content.

The physical requirements for sandstone are as follows:

Property	Test Requirements	Classifications	ASTM Test Methods
Absorption by weight, max, %	20	I Sandstone	C-97
	3	II Quartzitic Sandstone	
	1	III Quartzite	
Density, min, kg/m^3 (lb/ft^3)	2240 (140)	I Sandstone	C-97
	2400 (150)	II Quartzitic Sandstone	
	2560 (160)	III Quartzite	
Compressive Strength min, MPa (psi)	13.8 (2000)	I Sandstone	C-170
	68.9 (10000)	II Quartzitic Sandstone	
	137.9 (20000)	III Quartzite	
Modulus of Rupture, min, MPa (psi)	2.1 (300)	I Sandstone	C-99
	6.9 (1000)	II Quartzitic Sandstone	
	13.9 (2000)	III Quartzite	
Abrasion Resistance, Ha	8	I Sandstone	C-241
	8	II Quartzitic Sandstone	
	8	III Quartzite	

Slate Building Stone (ASTM STANDARD C 629-80)

This specification covers the material characteristics, physical requirements, and sampling appropriate to the selection of slate for general building and structural purposes.

Building slate shall include stone that is sawed, cut, split, or otherwise finished or shaped, and shall specifically exclude molded, cast, or otherwise artificially aggregated units composed of fragments and crushed and broken stone. It specifically excludes roofing slate, blackboard slate and slate for industrial uses.

Building slate shall be classified into two uses:
I - Exterior; II - Interior

The physical requirements for building slate are as follows:

Property	Test Requirements	Classification	ASTM Test Methods
Absorption, max, %	0.25	I Exterior	C-121
	0.45	II Interior	
Modulus of Rupture, min, MPa (psi)			
Across grain	62.1 (9000)	I Exterior	C-120
	62.1 (9000)	II Interior	
Along grain	49.6 (7200)	I Exterior	
	49.6 (7200)	II Interior	
Abrasion Resistance Ha	8.0	I Exterior	C-241
	8.0	II Interior	
Acid Resistance, max, mm (in.)	0.38 (0.015)	I Exterior	C-217
	0.64 (0.025)	II Interior	

Flexure Testing of Slate (ASTM TEST C 120-52)

This test is used to determine strength and elasticity rather than compression or tension. Samples are placed flat on knife edges and a load is applied at the centre of the span until the sample fails. Six samples measuring 30.5cm X 3.8cm X 2.5cm are required for structural or electrical slate. To test for roofing slate, six samples measuring 10.2cm X 10.2cm with a thickness equal to that of the slate shingles are required.

The minimum specifications for the modulus of rupture across the grain for all three grades of slate are 62 MPa (9000 psi).

Water Absorption of Slate (ASTM TEST C 121-48)

This test is used to determine the pore space of slate, and requires more care and precision than with other materials, due to the dense nature of slate. A minimum of six samples are required for the test. They shall be square or rectangular slabs measuring 0.48cm to 0.79cm in thickness and not less than 10.16cm on any side.

The standard specifications for water absorption are as follows:

Designation	Absorption,(Max.), %
Grade S-1	0.25
Grade S-2	0.36
Grade S-3	0.45

Weather Resistance of Natural Slate (ASTM TEST C 217-58)

This test measures the weather resistance of natural slate in all outdoor installations by determining the depth of softening by an abraser or by hand scraping. The test is based on the fact that slates contain other minerals such as pyrite, calcite and carbon, which undergo chemical weathering, resulting in the conversion of calcite particles to gypsum. The swelling action that results causes the slate to disintegrate. The test requires at least three samples measuring 50.8cm X 101.6cm measured along the cleavage faces. The faces shall be ground smooth and finished with a No. 80 abrasive.

The specifications for the maximum depth of softening are as follows:

Designation	Depth of Softening, max., mm (in.)
Grade S-1	0.05 (0.002)
Grade S-2	0.20 (0.008)
Grade S-3	0.36 (0.014)

Standard Specification for Roofing Slate (ASTM TEST C 406-58)

This specification is for natural slate shingles commonly used on sloping roofs as well as rectangular tiles used for flat roof coverings. There are three grades of tiles based on the length of service that may be expected: Grade S-1 is expected to last 75 to 100 years; Grade S-2, 40 to 75 years; and Grade S-3, 20 to 40 years. The physical requirements for these grades are listed below:

Designation	Modulus of Rupture Across the Grain, min, Mpa (psi)	Absorption, max, percent	Depth of Softening max, mm (in.)
Grade S-1	62 (9000)	0.25	0.05 (0.002)
Grade S-2	62 (9000)	0.36	0.20 (0.008)
Grade S-3	62 (9000)	0.45	0.36 (0.014)

Standard Specifications for Slate Blackboards (ASTM STANDARD C-543-81)

This standard covers acceptance of slate in its natural state for blackboard use. It does not cover chalkboards made from pulverized slate particles.

The physical requirements for slate used in this application are as follows:

Physical Property	Test Requirement	ASTM Test Method
Abrasion Hardness, Min,	8.0	C 241
Absorption, max, percent	0.40	C 121
Acid Resistance, max,mm (in.)	0.38 (0.015)	C 217
Flexural Strength, min, MPa (psi)	62 (9000)	C 120

APPENDIX

V

APPENDIX V

STONE PRODUCTS & DEFINITIONS

Agglomerated Stone

The manufacturing of this product entails crushing marble or limestone into small fragments and cementing them back together in blocks. They can be cut and polished like any normal building stone, and resemble brecciated marble. The advantages to this product are:

a) Each slab is uniform in size
b) The particle size can be controlled
c) The colour can be controlled.

Portland white or grey cement or resins are used as binders in this process, and are usually colour co-ordinated with the rock fragments.

The production phase is broken into four different units.

a) Crushing of calcareous material.
b) Mixing and agglomeration of cement marble blocks. The mixture is vibrated and compressed to eliminate air bubbles. The block is cooked for 24 hours in its mold and then removed. The block is seasoned for 22 to 25 days before sawing.
c) Sawing of blocks into slabs.
d) Finishing of slabs into the desired products.

Ashlar

Roughly rectangular stone portions of nonuniform size, 5cm to10cm thick.

Architechtural Stone

Non-loadbearing, cut panels (1.5cm-13cm thick) used as curtain walls or veneer in building construction. Commonly referred to as dimension stone or cladding, including interior and exterior flooring. Nearly all stone can be used for this purpose, but granite is most often chosen for outdoor applications because of its chemical and physical stability.

Black Granite
Any crystalline igneous rock that is dark grey, green, brown, blue or black in colour. They are usually mafic intrusive rocks; gabbro, anorthosite, basalt, and others are included in this industry definition.

Commercial Granite
Includes all feldspathic rocks of granular or gneissic texture, and therefore, all plutonic rocks regardless of composition. May also include volcanic rocks, siliceous sediments, and metamorphic rocks. They are usually light in colour and typically include granite, syenite, quartz monzonite, granodiorite and several other rock types.

Commercial Marble
Denotes all carbonate rocks, including true metamorphic marble and limestone, which can be polished. The commercial distinction between marble and limestone is that marble includes any carbonate rock that can be polished while limestone is any carbonate rock that cannot be polished well, or is not required to be polished. The term marble also includes rocks composed essentially of serpentine, travertine, and onyx marble.

Curbing Stone
Curb stones are usually manufactured from granite and are approximately 0.15m X 0.45m X 2m in size. They are normally set next to the edge of the travelled portion of a roadway. Curb stones can also be manufactured from sandstone or limestone, but granite is preferred for its durability.

Decorative Aggregate
This material includes a wide variety of rock types used in fabricating the face mix for precast concrete panels. Various crushed crystalline igneous rocks are used, but other materials, such as white quartz, may also be employed. The main requirement for this type of application is that the aggregate must be resistant to weathering and discolouration.

Flagstone
Flagstone is stone which can be split into thin slabs, (1.5cm to10cm) for sidewalks, patios, etc. Rocks used for this application are either fine-grained metavolcanics or metasediments that have been sheared or tightly folded. These are usually schist, sandstone or siltstone, although slate, limestone and granite may be used for this purpose.

Landscape Stone
This is defined as any decorative rock used primarily as part of a landscape design and includes crushed, coloured stone, boulders and irregular blocks, for landscaping applications in driveways, sidewalks, rock gardens, borders, etc. The most common products are marble or white quartz chips, granite chips and boulders.

Monument Stone
All natural stone used for the manufacture of statues, tombstones, mausoleums, cenotaphs and monuments.Fine-grained stone of uniform texture and colour is required.

Ornamental Stone
Any rock with an attractive colour or texture suitable for the manufacturing of small articles such as ash trays, pen holders, bookends, etc. All types of intrusive rocks, marbles, vein deposits and some metasediments and metavolcanics are used for this purpose.

Paving Stone
Rectangular, brick sized blocks of roughly equal dimensions for sidewalks, driveways and road construction.

Quarry Block
Rectangular blocks of unfinished stone weighing 15 to 25 tonnes each. A 20-tonne block of granite would have dimensions of approximately 1.3m X 1.6m X 2.6m.

Rip Rap
Cobble-sized, or smaller, quarry stone used in gambion baskets along shorelines or in areas susceptible to water erosion. Large, angular blocks of quarry stone ranging from about 100kg up to 10 or 12 tonnes in size called armour stone are fitted on the faces of revetment walls, dikes, breakwaters or piers.

Roofing Slate
True slate is a fine-grained metamorphosed mudstone or shale which has a well developed slaty cleavage due to deformation. The cleavage allows the rock to be split into thin identical sheets with a smooth surface. Slate and some quartzites are used in this application. Natural stone provides a permanent roof covering and may be used on buildings of historic interest.

Rubble
Randomly sized and shaped stone for wall facing, fences, fireplaces, etc., also called fieldstone.

Tiles
Marbles and granites are used for tiles which are normally 7mm to 12mm thick, and compare to high-quality carpet in price. Other stones which split naturally and may be used for this application include quartzite, slate and some limestones.

Terrazzo Chips
This material is produced from crushed stone, usually coloured marbles or limestone, and is used in the elaborate construction of terrazzo floors. This differs from agglomerated stone in that the floors are usually poured in place and ground down to a flat smooth surface after curing. The stone chips and binding cement are usually different colours.

Trap Rock
This material consists of dark-coloured igneous rocks, such as diabase, basalt, gabbro and diorite which are crushed for aggregate. The term is usually reserved for fine-grained intrusive and extrusive rocks. Trap rock is used for high quality asphalt, road beds, ballast, rock wool and rip rap.

GRANITE PRODUCTS

1) Exterior facing stone
    a) smooth cut
    b) natural or rough cut (ashlar)

2) Interior facing stone
    a) polished
    b) natural or rough cut (ashlar)

3) Interior flooring stone

4) Exterior walkway stone

5) Monumental stone
    a) benches, artwork, walls
    b) tombstones, mausoleums, monuments.

6) Curbing and paving blocks

7) Landscaping and gardening stone

8) Crushed decorative stone

9) Tube mills for grinding ore. These can be erected vertically or horizontally, and employ granite as a grinding medium, in rounded or angular form. These mills are low cost, very energy-efficient, and grind ore extremely well.

10) Smooth granite cylinders 6m-9m long and 1.5m in diameter are used in the pulp and paper industry. Wet paper pulp is fed through a set of two rotating granite cylinders, squeezing the liquid from the pulp. The resulting material is a uniform thickness of paper which does not adhere to the granite rollers.

11) Rubble and rough blocks.

12) Broken or crushed stone
   a) armour stone
   b) gabion/rip-rap (wire stone-filled baskets used in retaining walls)
   c) crushed stone for artificial stone
   d) stucco dash
   e) aggregate for panels (exposed or precast, i.e. Granex Binder)
   f) road metal
   g) asphalt aggregate
   h) concrete aggregate
   i) winter sand
   j) rock wool
   k) roofing granules

13) Masonry products
   a) terrazzo tiles
   b) artificial blocks

14) Surface plate or bases for electronic, scientific and medical instruments.

15) Soapstone blocks
   a) fireplaces, stoves and kitchen warmers
   b) carvings
   c) storage units for solar heat

16) Commercial and Domestic uses
   a) kitchen counter tops, bar taps, sinks
   b) cutting boards, fireplace mantels, lamps, memorial urns
   c) window dressings and door surrounds.
   d) terraces
   e) domestic buildings

18) Pulverized stone
    a) non-toxic rose dust
    b) soil additive

LIMESTONE OR MARBLE PRODUCTS

1) Exterior facing stone
    a) smooth cut
    b) natural or rough cut (ashlar)

2) Interior facing stone
    a) polished
    b) natural or rough cut (ashlar)

3) Interior flooring stone

4) Tiles
    a) counter tops and fronts, baseboards, trim and ceilings.

5) Monumental stone
    a) mausoleums and monuments.

6) Ornamental
    a) counter and table tops, alters, lamps, ashtrays, bookends and gift shop novelties
    b) kitchen and bathroom use (tubs, counter tops, shower stalls)

7) Decorative Stone

8) Crushed stone
    a) stucco dash, cultured marble, tile grout
    b) concrete and bituminous aggregate
    c) terrazzo
    d) gabion filler stone
    e) poultry grit
    f) runway sand
    g) pulp and paper industry
    h) cement industry
    i) construction industry

j) metallurgical industry
k) concentrator processing
l) environmental uses
m) roofing granules
n) water treatment
o) acid neutralization
p) chemical stone for alkali works
q) flux stone
r) refractory stone
s) rip rap and jetty stone
t) dense-graded road base stone
u) macadam aggregate

9) Pulverized stone
   a) agricultural fertilizer plants
   b) agricultural marl and other soil conditioners
   c) calcite products, glass manufacture
   d) abrasives
   e) whiting or whiting substitute
   f) fillers and extenders
   g) animal and food supplement
   h) tile grout

10) Cornices and trim.

11) Landscaping and gardening

12) Masonry products
   a) terrazzo tiles
   b) brick
   c) artificial blocks

APPENDIX

VI

APPENDIX VI

Prospecting and Evaluating a Building Stone Occurrence

From: Currier, L.W., Geological Appraisal of Dimension Stone Deposits, U.S. Geol. Survey Bulletin 1109, 1960, 78 pp.

General Features:

1) Location of deposit or quarry, name of owner, district.
2) Size of quarry (if any)
3) Formation name, stone trade name (if any)
4) History of past operations.

Geologic Features:

1) Distribution of formation
2) Stratigraphic position
3) Thickness of formation and workable portion
4) Lithological classification, description, notable variations.
5) Petrographic description and classification.
6) Mode of origin and occurrence, form.
7) Major structural elements and attitude, folds, etc.
8) Contact relations to other formations.
9) Texture and fabric: variations, relation to other features.
10) Fractures and fracture systems:
    a) Joints: attitude, distribution and spacing
    b) Faults: attitude, displacement, width of shattered or gouge zones.
11) Rock cleavage; natural planes of parting, relation to other features.
12) Inclusions and segregations: distribution, nature.
13) Overburden: nature, thickness, variability, unevenness
14) Weathering: depth, nature, relation to other features.
15) Surface water: amount, direction of drainage.

Industrial Features:

1) Classification: points of similarity or difference with other commercial stones of its class.
2) Use of the stone: specific structures as examples.
3) Topography
4) Accessibility
5) Working facility, structural elements.
6) Workability of the stone, production and milling into finished blocks or other architectural and monumental units.
7) Colour, texture, and finishes.
8) Reserves, proven and inferred, areas available for development by potential competitors.

APPENDIX

VII

APPENDIX VII

ONTARIO PROSPECTING CRITERIA

(after Verschuren et al, 1989.)

1) Fine-to-medium grained stones are generally more valuable than coarse-grained stones.

2) Deep red granites (a premium colour) are typically developed within regional fault zones and are, therefore, inherently fractured.

3) Buff coloured dolostone in Southwestern Ontario is amenable to large quarry block extraction, which ultimately dictates its economic viability.

4) Stones containing in excess of 30% quartz have a very high hardness and are consequently avoided by producers.

5) Producers are reluctant to develop quarry sites greater than 2 km from existing roads, because transportation costs can account for up to 70% of the price of rough quarry block delivered to the processors. Remote quarries have less access to larger markets.

6) A quarry should be located as near to a processing centre as possible.

7) The best exploration targets are the youngest. Post-tectonic plutons are less fractured.

8) In high-grade metamorphic terrains, pre-tectonic or syntectonic rocks which were partially or totally recrystallized (orthogenesis, anatexis) and were deformed at temperatures and pressures allowing ductile deformation (upper amphibolite to granulite facies metamorphism) also represent good exploration targets.

9) Coarse-grained plutonic rocks, characteristic of deep-seated intrusions or the cores of plutonic bodies, are good exploration targets.

10) Regularly sheeted granites should be regarded as high potential exploration targets because:

(a) sheeting spacing often decreases with depth;
(b) sheeting is indicative of limited primary jointing;
(c) sheeting is also a product of weathering, and such jointing may therefore be only a surface phenomenon.

11) Marbles which have been physically and/or chemically altered by faulting or contact metamorphism may be a source of large fine-grained marble blocks.

12) Some building stone deposits change colour with depth.

CONVERSION FACTORS FOR MEASUREMENTS IN ONTARIO GEOLOGICAL SURVEY PUBLICATIONS

Conversion from SI to Imperial			Conversion from Imperial to SI		
SI Unit	*Multiplied by*	*Gives*	*Imperial Unit*	*Multiplied by*	*Gives*
			LENGTH		
1 mm	0.039 37	inches	1 inch	**25.4**	mm
1 cm	0.393 70	inches	1 inch	**2.54**	cm
1 m	3.280 84	feet	1 foot	**0.304 8**	m
1 m	0.049 709 7	chains	1 chain	20.116 8	m
1 km	0.621 371	miles (statute)	1 mile (statute)	**1.609 344**	km
			AREA		
1 cm@	0.155 0	square inches	1 square inch	**6.451 6**	cm@
1 m@	10.763 9	square feet	1 square foot	**0.092 903 04**	m@
1 km@	0.386 10	square miles	1 square mile	2.589 988	km@
1 ha	2.471 054	acres	1 acre	0.404 685 6	ha
			VOLUME		
1 cm#	0.061 02	cubic inches	1 cubic inch	**16.387 064**	cm#
1 m#	35.314 7	cubic feet	1 cubic foot	0.028 316 85	m#
1 m#	1.308 0	cubic yards	1 cubic yard	0.764 555	m#
			CAPACITY		
1 L	1.759 755	pints	1 pint	0.568 261	L
1 L	0.879 877	quarts	1 quart	1.136 522	L
1 L	0.219 969	gallons	1 gallon	**4.546 090**	L
			MASS		
1 g	0.035 273 96	ounces (avdp)	1 ounce (avdp)	28.349 523	g
1 g	0.032 150 75	ounces (troy)	1 ounce (troy)	**31.103 476 8**	g
1 kg	2.204 62	pounds (avdp)	1 pound (avdp)	**0.453 592 37**	kg
1 kg	0.001 102 3	tons (short)	1 ton (short)	**907.184 74**	kg
1 t	1.102 311	tons (short)	1 ton (short)	**0.907 184 74**	t
1 kg	0.000 984 21	tons (long)	1 ton (long)	**1016.046 908 8**	kg
1 t	0.984 206 5	tons (long)	1 ton (long)	**1.016 046 908 8**	t
			CONCENTRATION		
1 g/t	0.029 166 6	ounce (troy)/ ton (short)	1 ounce (troy)/ ton (short)	34.285 714 2	g/t
1 g/t	0.583 333 33	pennyweights/ ton (short)	1 pennyweight/ ton (short)	1.714 285 7	g/t

OTHER USEFUL CONVERSION FACTORS

	Multiplied by	
1 ounce (troy) per ton (short)	20.0	pennyweights per ton (short)
1 pennyweight per ton (short)	0.05	ounces (troy) per ton (short)

Note: Conversion factors which are in bold type are exact. The conversion factors have been taken from or have been derived from factors given in the Metric Practice Guide for the Canadian Mining and Metallurgical Industries, published by the Mining Association of Canada in co-operation with the Coal Association of Canada.

3268
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