DECORATIVE STONE

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Abstract

Stone, one of the oldest building materials, used throughout the construction industry. No classification can completely eliminate overlap between dimension stone, aggregate, and decorative stone. The basic types of decorative stone are rough stone, aggregate, cut or dressed stone, and synthetic stone.

Thousands of types and varieties of stone are used in the decorative stone industry. Consequently, only the dominant commercial rock types are Granite, Pegmatite, Basalt, Tuff, Marble Tavertine, Sandstone and Conglomerate, Slate／Schist／Gneiss, and Quartzite.

Many large quarries producing dimension or building stone also produce large quantities of waste rock. This waste material is normally crushed to aggregate, screened, and sold as decorative stone. The Production has two processes called: (Quarrying, and Processing). A number of finishes can be applied to a stone on an edge (E), a surface (S), or both (B). Decorative and dimension stone data are difficult to separate because geologists keep statistics only on dimension stone, sand and gravel, and crushed stone. Marble stones are most common dimension stone that used in industry. Specifications are less developed in the decorative stone industry, where color and texture are of principal importance, along with the surface treatment used.

Architects rated factors affecting their choice of stone from most important to least as follows: (1) appearance (overwhelmingly), (2) durability, (3) cost, and (4) availability. Cost, Transportation and Substitutes are the economic factor affecting on the use of Decorative Stone.

1) INTRODUCTION

Stone, one of the oldest building materials, today remains a well established material used throughout the construction industry. It is still widely considered to be the most aesthetically pleasing, prestigious, and durable building material. The use of natural stone is much less prevalent now than in the past, though demand is rising. New and reopened quarries are coming online to meet increased demand related to new building technology and increased residential use of stone. Natural stone is becoming a key design element in modern homes. Buyers prefer low-maintenance natural materials inside and outside the home.

2) CLASSIFICATION

No classification can completely eliminate overlap between dimension stone, aggregate, and decorative stone because most stone is multipurpose. Much stone used for decorative purposes is not produced specifically for that end use. About 50% of the rock quarried for dimension stone becomes waste, which can be sold as decorative stone coproducts (Figure 1) composed of the exact stone used in the dimension stone side of the business. Thus, dimension stone and decorative stone are intimately intertwined. Many uses require a compromise between decorative and structural qualities (O. Bowles, personal communication).

Shipley (1945) used the term *decorative stone* interchangeably with *ornamental stone*. Gary, McAfee, and Wolf (1972) defined decorative stone as that used for architectural decoration, such as mantels, columns, and store fronts, but added that it is sometimes set with silver or gold in jewelry as

curio stones. Bates and Jackson (1987) and Jackson (1997) also restricted decorative stone to that used for architectural decoration. Murhov and others (2002) proposed doing away with the term “decorative stone” in favor of *decorative rock materials*. Meanings of otherwise identical terms used in the stone industry differ between geologists, engineers, and quarries; they often carry a much broader meaning for quarriers and engineers compared to their very specific use by geologists (Makens, Dobrell, and Kennedy 1972).

Geologist define decorative stone, including ornamental stone, more broadly as any stone used primarily for its color, texture, and general appearance. It is not used primarily for its strength or durability, as is construction stone, or in specific sizes, as is dimension stone. The decorative stone industry uses a much wider range of stone types, such as naturally rounded pebbles, compared to the dimension stone industry. Decorative stone usually serves some structural purpose, but it is not load-bearing to any great extent. Weak or costly stones that are attractive serve in solely decorative applications.

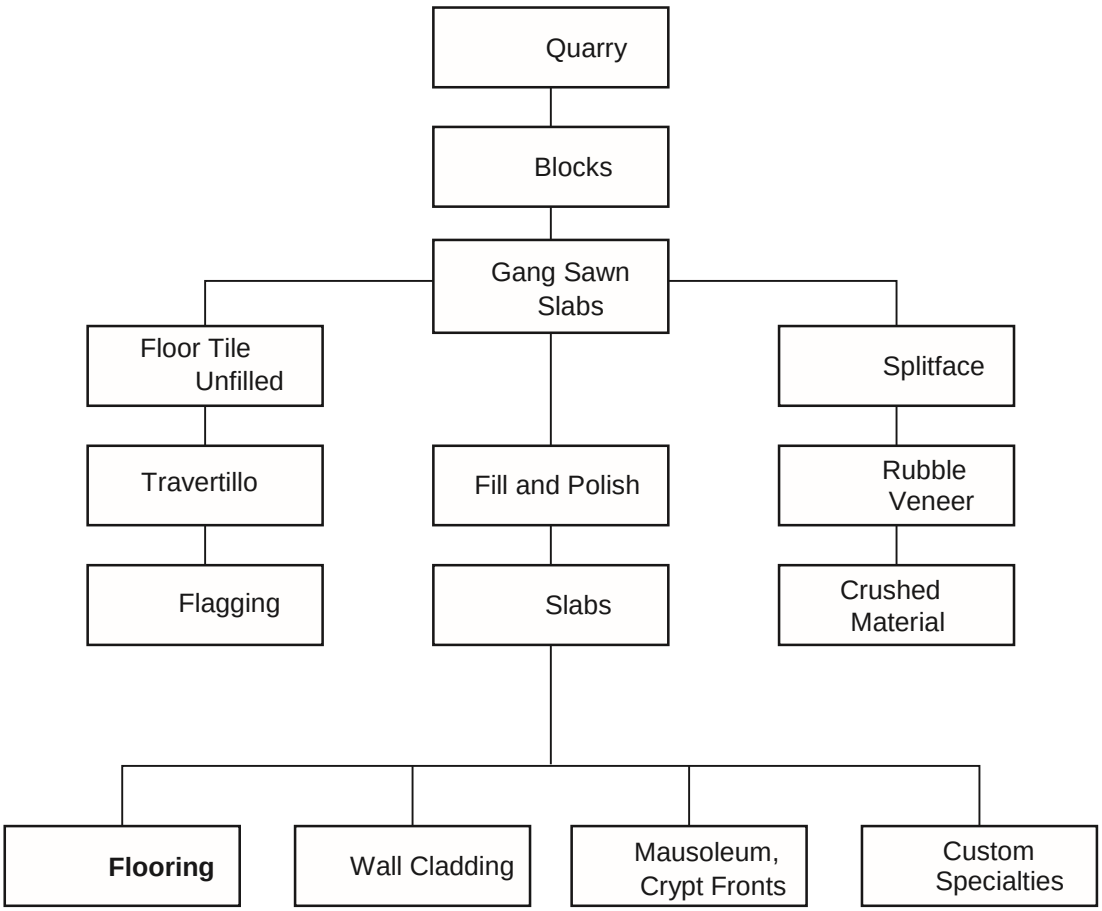

Figure 1.:Materials flow from quarry (top) to numerous products, produced by New Mexico Travertine west of Belen, New Mexico. Travertillo is travertine tile with rounded corners similar to ceramic saltillos produced in Mexico.

The basic types of decorative stone are rough stone, aggregate, cut or dressed stone, and synthetic stone:

- Rough stone (unprocessed or slightly processed)
  - Fieldstone (moss rock)
  - Flagstone
- Aggregate (lightly processed; screened or not)
  - Uncrushed stone:
    - River rock
    - Scoria and cinder
    - Fused argillaceous rock
  - Crushed stone:
    - Rubble
    - Exposed aggregate
    - Dash

- ❖ Terrazzo

- ❒ Cut or dressed stone (moderately to highly processed; no set size)
  - ➢ Statuary and objet d'art
  - ➢ Fireplace rocks and hearthstones
  - ➢ Ashlar
  - ➢ Monuments and memorials
  - ➢ Tile and paving blocks
  - ➢ Veneer and wall cladding
  - ➢ Miscellaneous
- ❒ Synthetic stone (made from various raw materials)

3) STATISTICS AND END USES

Decorative and dimension stone data are difficult to separate because the U.S. Geological Survey keeps statistics only on dimension stone, sand and gravel, and crushed stone. The value of domestic dimension-stone production in 2004, which includes some decorative stone, was about $257 million compared to imports of about $1.49 billion and exports of about $64 million. Production in 2004 was 1.30 Mt, of which about 35% was for decorative uses (Dolley 2005). The principal uses are rough blocks in building construction (41%) and monument stone applications (25%) . In 2004, dimension stones used or sold were granite (35%), limestone (28%), sandstone (13%), marble (5%), slate (1%), and miscellaneous stone (18%), by tonnage. Dressed stone was mainly sold for flagging (25%), ashlar or partly squared pieces (24%), and curbing (22%), with the rest miscellaneous or unspecified (29%), by tonnage (Dolley 2005).

Crushed stone was valued at $9.7 billion in the United States in 2004. Imports were 15 Mt and exports were 2 Mt. About 1.61 billion t of crushed stone was consumed. Of the 806 Mt identified by use, 82% was construction aggregate, 15% for

cement and lime and chemical or metallurgical manufacturing, 2% for agriculture, and 1% for miscellaneous uses. Crushed stone used for decorative purposes is scattered through several of these categories. Limestone and dolomite constitute about 86% and granite 8% of crushed stone in the United States. About 6% is sandstone and quartzite, miscellaneous, marble, calcareous marl, slate, volcanic cinder, scoria, and shell (Tepordei 2005).

3-1) Rough Stone

Rough stone is used as it is found in nature with very limited processing such as minor hand shaping, edge fitting, and size or quality sorting. This stone type is often marketed locally in relatively small tonnages and includes fieldstone and flagstone. The primary end uses of rough stone are landscaping, edging, paving, and large individual stone landscape or interior accents (Figure 2).

3-1-1) Fieldstone

Fieldstone is picked up or pried out of the ground (gleaned) without extensive quarrying and includes garden or large landscaping boulders (Hansen 1969; Austin, Barker, and Smith 1990). Boulders and cobbles can be split or roughly trimmed for use in rubble walls and veneers, both interior and exterior. Popular fieldstone rock types include sandstone, basalt, limestone, gneiss, schist, quartzite, and granite, but many others are suitable. Individuals or small companies collect much of the fieldstone because the industry is labor intensive and markets are small. Shipping costs often preclude selling fieldstone far from where it is collected. The stone can be sold in small quantities from the backs of vehicles (Austin, Barker, and Smith 1990). Fieldstone includes many rock types, sizes, and shapes, with the

only common denominator that it must be set by hand and be durable.

Figure 2. Medium-to-large stone, for use as accents, on display in a New Mexico stone yard

Figure 3. Slabby sandstone moss rock used in a retaining wall. The blocks are mottled by attached lichens.

Moss rock is fieldstone partially covered by algae, mosses, lichens, and fungi, which give the rock an aged and variegated patina (Austin, Barker, and Smith 1990). The plants are supported by moisture and nutrients in the stone. Moss rock is used for landscaping, walls, and fireplaces. Although almost any durable rock can be moss rock, most are slabby or rounded sandstone and limestone (Figure 3).

3-1-2) Flagstone

Flagstone or flagging consists of thin, irregular slabs used for paving, walkways, and wall veneers. Random-shaped flagging is produced widely in the United States. Suitable stone breaks very easily in one direction, producing flags. Any fissile stone can be used, but sandstone (bedding planes) and slate (cleavage surfaces) are best and dominate the market. Limestone and dolostone are quarried as flagstone in the Great Lakes area of the United States.

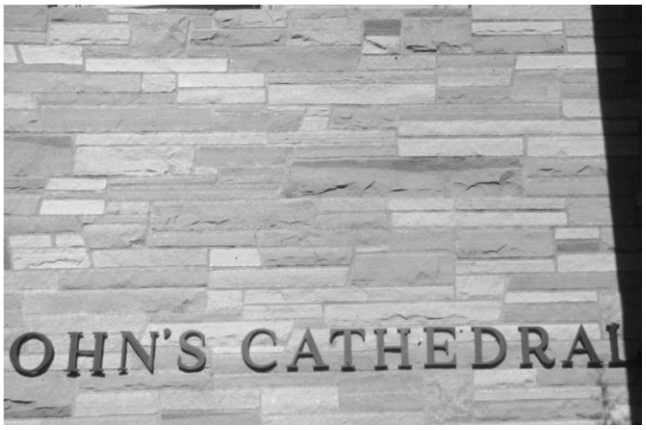

Figure 4. Ashlar blocks of Coconino Sandstone (Jurassic) used as a veneer for a wall of St. John's Cathedral, Albuquerque, New Mexico

Figure 5. Granite blocks used for curbing in a parking lot near Bar Harbor, Maine

Table 1.:Typical coverages by size for decorative stone aggregate

Aggregate Type	**Size, *in.***	**Size, *cm***	**Depth**	**Coverage, *ft²/st***	**Coverage, *ft²/t***
Rock	–1/4	0.64	2 in. (5.08 cm)	115 150	126

	1/2	1.27			165
River rock	3/4–1	1.91–2.54	1 rock	120	132
	1–3	2.54–7.62		90	100
	3–6	7.62–15.24		60	66
Riprap	1–3	2.54–7.62		90	100
	3–8	7.62–20.32	1 rock	60	66
	6–12	15.24–30.48		30	66
Pea gravel	3/8	0.95	2 in. (5.08 cm)	110	121

From Arizona Trucking and Materials brochure, Tucson.

Figure 6. Small river rock and volcanic cinder used for a xeriscape lawn

The Coconino sandstone is quarried extensively in Arizona and produces very high quality, red-to-pink-to-white flagstone (Townsend 1962). Sandstone flags up to 0.5 m^2 can be split to a thickness of 3 cm or less. Flagstone slabs 3 to 10 cm thick are used for walkways in hightraffic areas; they must be resistant to abrasion and have low relief on the wear surface to minimize tripping. If used in walkways, these thin slabs must be set on a very firm base. Thicker flags of sandstone or granite can be used in walls (Figure 4) or set on edge as curbing (Figure 5).

3-2) Aggregate

3-2-1) Uncrushed Stone

Natural aggregate is lightly processed, usually by washing or screening, yielding products suitable for decorative use.

Fragments can be either rounded or angular and must be resistant to weathering. Many types of decorative stone aggregate can be used for rock lawns or area covers in virtually unlimited colors. Typically, local materials are used, which limits choice but lowers cost. The aggregate is placed on UV-resistant black, impermeable or semipermeable polyethylene (most often 4 mils thick) covering a prepared surface treated with weed killer. A wide variety of sizes are used at an application rate of at least 50 kg/m^2. The rate varies depending on aggregate size and layer thickness (Table 1).

River Rock. River rock constitutes distinctive water-rounded pebbles, cobbles, and boulders commonly used as an area cover (Figure 6). White to gray is typically specified, but other colors are available. River rock most commonly is granite or gneiss, but any durable rock can be used. The rounding usually is done in a river or coastal marine environment. In Pennsylvania, white-to-buff vein quartz is a popular river rock for landscaping.

Figure 7. Rock lawn with accent pieces in Belen, New Mexico

Figure 8. Large exposed aggregate panel on a commercial building

A diverse market has arisen worldwide in rounded stones sold typically by weight ($0.07 to $1.65/kg) or bag. The stones are often polished, not always naturally, and may be fairly exotic rock types like jade, but more common stones are also widely sold.

Scoria and Cinder. Scoria or volcanic cinder is a lightweight, vesicular equivalent of basalt (Figure 6) or other basic volcanic rocks. It is used primarily for desert landscaping in the southwestern United States; it is less common elsewhere but is available in most parts of the country. Scoria is sold as either red-to-brown or black-to-gray varieties, but both are otherwise similar. Reddish hues are more popular and, hence, more valuable than other hues (Osburn 1980). The color differences of cinder are a result of the presence (red) or absence (black) of oxygen during volcanic eruption and emplacement.

Fused Argillaceous Rock. Natural fires in North Dakota lignite produce fused interbedded claystone and sandstone (E.C. Murphy, personal communication). In New Mexico, natural coal fires produce a similar material locally called “red dog” (Hoffman 1996). Red baked and fused shale related to coal fires is mined in the northern Powder River basin of Wyoming (Harris 1991; Heffern and Coates 1997). These materials are used as low-

quality aggregate in areas lacking better materials or in landscaping.

3-2-2)Crushed Stone

Crushed stone is the most common decorative aggregate and can be produced from virtually any pleasing stone. It is broken mechanically and usually screened before use; larger sizes are often called rubble. Harris (1991) uses the term *decorative aggregate* to describe crushed and sized stone used for landscaping such as area cover, rock lawns, walkways, and borders around plants or gardens (Figure 7). This chapter describes rubble, exposed aggregate, dash, and terrazzo here under crushed stone, although exposed aggregate, dash, and terrazzo are used with a binder such as cement.

Rubble. Rubble consists of large rough stone or blocks produced in quarrying, often as waste, and used for retaining walls, seawalls, bridgework, and landscaping. Only landscaping rubble is considered decorative stone because it is used primarily for its color, texture, or general appearance. In New Mexico, large boulders of pegmatite are used in landscaping as accent pieces (Austin, Barker, and Smith 1990).

Smaller rubble is popular as wall facing in homes and commercial buildings. The primary purpose is aesthetic-it replaces brick or other veneer-but ease of installation, weather resistance, light weight, and ability to bond well with mortar are also important. Rubble can be set in random patterns across 0.05 to 4 m^2 of exposed rock. Low-density rocks, such as pumice, have several advantages: shipping costs are lower, setting is easier for the stone mason, and few, if any, anchors are required to tie the stone veneer to the wall (Power 1994). In Minnesota, waste rock from processing granite dimension stone, called grout, is used as decorative stone, including sawn, split, and even polished slabs.

Exposed Aggregate. Exposed aggregate is one of the most common methods of using crushed stone (Figure 8). Stith (1970) found the most important properties to be color, hardness, soundness, absorption, shape, size distribution, and impurities.

Many colors and shapes are available, making exposed aggregate compatible with almost any architectural scheme. Color should be uniform and permanent because it is the architects' main criterion. Observation of weathered and fractured outcrops of the proposed aggregate can be useful in determining how the stone will react (Cutcliffe and Dunn 1967). Spalling and other forms of physical deterioration should be noted. The color should vary only slightly, if at all, between weathered and fresh outcrops. Variations in color from exposure to sunlight or weather should be noted to minimize color differences across the faces of a structure (Cutcliffe and Dunn 1967). Color segregation of stone by quarry procedures, blasting, stockpiling, blending, batching, and weathering should be avoided (Cutcliffe and Dunn 1967; Evans 1993).

The ability to cast exposed aggregate in complex shapes and with background coloring (dash) of cement gives the architect great freedom. Aggregate, mixed with white or gray cement in a 2:1 ratio, can be precast into panels or cast in place in walls and floors or walkways, with the aggregate dispersed or concentrated in the facing layer (Stith 1970). The aggregate is exposed by sand blasting, bush hammering, wire brushing, or acid washing the surface of the aggregate/cement mixture (Cutcliffe and Dunn 1967), and then it is sealed.

Dash. Dash, either coarse (for texture) or fine (for color), is added to exposed aggregate, stucco, or concrete. Sand dash is added to stucco and small-scale, exposed-aggregate surfaces for color. Very fine dash is added to concrete or cement as a

permanent pigment instead of more expensive mineral pigments that may react with the cement compounds. Wellmixed, nonreactive dash material avoids blotchiness or shade variation common with artificial or mineral pigments and can be used in conjunction with stucco dash or exposed aggregate.

Terrazzo. First produced by the Romans more than 1,500 years ago, terrazzo floors provide quality at low original and maintenance cost and have a very long life. Terrazzo, a mixture of sized, crushed stone, and cement, offers variety in color and design (Figure 9). This mixture is poured into a prepared floor area, hardened, ground smooth, sealed, and often polished (Reed 1978 ; American Geological Institute 1997).

Figure 9: Terrazzo flooring (polished) at the Dulles International Airport, Washington, D.C. Lighter area near lower center in front of pillar is a reflection off the highly polished surface. Exposed aggregate forms the surface of the pillar.

Figure 10: Renowned sculptor Allan Howser, of Taos, New Mexico, surrounded by statues and rock ready for his chisel

The stone aggregate has low porosity and low absorption. The portion of the terrazzo that needs protection is the portland cement matrix, which is porous and will absorb stains. The primary application of terrazzo is in high-traffic, public areas and buildings. Relatively soft stone—usually limestone, dolostone, or marble—is preferred for terrazzo, but granite is also used. Quality control is paramount during quarrying so that color can be matched across batches. Maintaining consistent color during processing ensures quality, color continuity, and freedom from impurities. The Terrazzo, Tile and Marble Association of Canada (www.ttmac.com) recommends a thin-gauge epoxy or polyacrylate for sealing.

3-3) Cut or Dressed Stone

Cut or dressed stone is finished on one or more sides by various methods and is used where uniform surfaces are needed. Typical uses are in walls, monuments, sculptures, waterfalls, or other relatively small, very detailed artistic renderings. Many stones are fashioned into structural or decorative adornments such as capitals, veneers, friezes, cornices, corbels, coping, and ribbing. Nonstructural statuary and art, along with stones too soft or brittle for structural use, are used in some parts of buildings, although in low volume.

3-3-1) Statuary and Objets d'Art

Artists use stone for carving, sculpting, or producing objets d'art (Figure 10). Carvable stone is commonly soft and uniform, such as marble, limestone, soapstone, and alabaster. Some sculptors carve commercial granite and jadeite, though those stones are hard. Color, texture, softness, and the ability to take a polish are important for statuary stone. Carvable stone commands the highest price but accounts for the smallest sales volume of any of the stone categories. Many small firms and artisans cut and polish semiprecious gems and ornamental stone

from hard stone such as jade, agate, quartz, jasper, chalcedony, chert, and petrified wood (Burchett and Eversoll 1991), or softer stone such as tuff, talc (Steatite), serpentine (Verde antique), marble, travertine, and gypsum (Alabaster).

3-3-2) Fireplace Rocks and Hearthstones

Many types of stone are used in fireplaces. Commercial use is restricted to relatively few types compared to the many used by individuals. Although rough stone and aggregate are often used in rustic fireplaces, dressed stone is more typical. Moss rock, flagstone, river rock, scoria, and ashlar are often used as a decorative facing on a fireplace. Argillite or millstock slate is cleaved or rough-finished and used as hearthstones and mantles (Carpenter 1983). Polished travertine is often strengthened with epoxy or cement and is very popular for hearthstones.

3-3-3) Ashlar

Ashlar consists of rectangular, nonuniform stones with at least two smooth parallel sides, set randomly or by design in a wall. The exposed surface of each piece is generally <0.4 m^2, laid exposing the sawn or naturally smooth face or the rough (broken) face (Figure 4). Ashlar blocks are prepared either from natural slabs that split and fracture into usable shapes or by sawing the required two parallel sides usually about 7 to 15 cm apart. The remaining sides have an attractive broken appearance that, when exposed, is called split-faced ashlar. Natural or sawed blocks are broken in a hydraulic guillotine to assorted sizes, palletized, shipped to the job site, and laid by hand in courses similar to brick.

3-3-4) Monuments and Memorials

Stone is cut and polished for tombstones, historical markers, and similar monuments and memorials. A typical stone used for monuments and memorials is pure white, statuary-grade marble. Monument stone must be hard, take a high polish, and be resistant to weathering. Tombstones are most often one of the varieties of granite.

3-3-5) Tiles and Paving Blocks

Tiles are cut or split stones with one very thin dimension that can be polished (Harris 1991). Typically they are 0.3 m^2 or 0.5 m^2 (12 in. × 12 in. or 18 in. × 18 in.) and 10 to 15 mm thick and can be used in many ways on all interior surfaces, including floors and walls (Figure 11). Tiles can be made from many types of stone, but most are slate, granite, marble, limestone, basalt, or tuff. Travertine is also cut into tiles.

Bluestone, slate, and argillite (Carpenter 1983; Power 1983), as decorative stone, are used primarily as flagging and floor tiles, but are also used for sills, stair treads, risers, shower and toilet stalls, and exterior spandrels and facings. They are available in various shades of green, gray, purple, red, black, or variegated. Slate finishes vary from the natural split surface to knife-shaved, sand rubbed, and honed or semipolished (Harben 1990).

Tiles and paving blocks made of tuff generally are called cantera stone but include adoquin, sillar, tufa, tuff, calduro, and others (Kuiper 1988). Most of these are imported to the United States from Mexico.

Figure 11. Various sizes of flagstone and floor tile composed of red Lyons Sandstone (darker color) of Permian age and other flagstone (lighter color) in stone yard near Lyons, Colorado

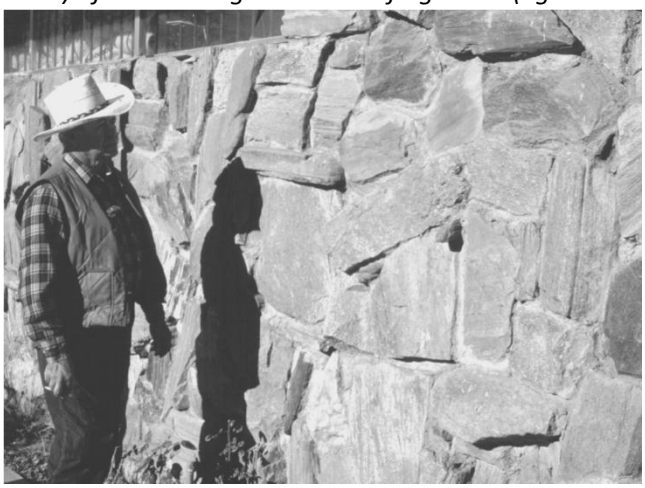

Figure 12. Precambrian Vadito schist used as veneer wainscoting in Santa Fe, New Mexico

3-3-6) Veneers and Wall Cladding

A veneer is any rock that can be laid up on a wall. Wall cladding is composed of larger sheets, often filled and polished, of travertine, serpentine (verde antique), marble, and others. Schist (Figure 12), which cleaves along preferred directions, yielding relatively flat stones, is also used.

3-3-7) Miscellaneous Uses

Nonforested areas of the United States use stone in the manner that other areas of the country use wood, such as limestone fenceposts in Kansas. An Internet search reveals many unusual uses for stone around the world, including lamps with

bases of rough stone. In some lamps from Bali, even the lamp shade is carved from stone. Intricately carved stone furniture with latticework backs is for sale on Web sites from India. Stone dishes and lidded boxes from ancient cultures can also be purchased, in addition to modern examples, particularly from Southeast Asia. A number of sites sell “healing” stones and are devoted to stone therapy, and soap-shaped deodorant stones are also available. These are but a few examples illustrating the widespread use of stone across the ages.

3-4) Synthetic Stone

Cast stone is defined as a refined architectural concrete building unit manufactured to simulate natural cut stone, used in unit masonry applications. The earliest known use of cast stone was in AD 1138 (Cast Stone Institute 2005). Cast stone is a masonry product used as an architectural feature, trim, ornament, or facing for buildings or other structures. Cast stone can be made from white or gray cement, manufactured or natural sands, carefully selected crushed stone, or well-graded natural gravels and mineral coloring pigments to achieve the desired color and appearance while maintaining durable physical properties that exceed most natural cut building stones. Cast stone is an excellent replacement for natural cut limestone, brownstone, sandstone, bluestone, granite, slate, keystone, travertine, and other natural building stones (Cast Stone Institute 2005). Some cast stone, however, can suffer deleterious effects from prolonged exposure to sunlight.

Stone or slag, usually crushed, is the main ingredient in the production of manufactured stone by melting and frothing. Basalt is melted and cast into various forms (Kuzvart, Woller, and Hora 1992). Irregularly shaped boulder- and cobble-sized masses

are used as artificial scoria or cinder. Manufactured stone can be used in floor and wall panels.

Crushed marble is combined with a binding polymer, and perhaps a coloring agent, to produce cultured-marble tiles. Ground limestone is mixed with organic resins to produce cultured marble molded into a variety of shapes. Quartz stone is a relatively new product made from pure quartz and polymer binders, creating a countertop or flooring material that has properties similar to those of natural granite.

4) GEOLOGY AND DISTRIBUTION OF MAJOR DECORATIVE STONES

Hundreds if not thousands of types and varieties of stone are used in the decorative stone industry. The terms used in the stone industry vary widely between countries, the professions involved in the stone industry, and segments of the industry. In Scandinavia, the stone industry differentiates hard stone from soft stone. The latter includes limestones and marble that, if siliceous, may be harder than some igneous rocks like tuff that are called hard (Shadmon 1988). Complete coverage of all local industry classifications is nearly impossible. Consequently, only the dominant commercial rock types are discussed here as an overview.

4-1) Granite

Commercial granite, which has a wider meaning than geological petrographic definitions, includes all feldspathic intrusive rock with visible grains and all metamorphic rocks with gneissic texture. It includes true granite plus other intrusive igneous rocks (Murhov et al. 2002) and their metamorphic equivalents-syenite, monzonite, gabbro, anorthosite, amphibolite, and gneiss. Commercially, dark fine-grained igneous

rocks, even of diabase or basalt composition, are often called black granite (Power 1983). Commercial granite, whether light or dark, has high strength and durability and is relatively impervious to water and weathering.

Commercial granite in the United States is quarried at more than 100 sites in 20 states. The dominant companies are Cold Spring Granite, Rock of Ages Corp., and Coggins Granite Industries. Major production centers (Harben 1990) include Georgia (Elberton), North and South Carolina, New York, Massachusetts, Vermont, New Hampshire, Minnesota (St. Cloud), South Dakota, Wisconsin, and Texas (Burnet and Llano counties). Near Elberton, Georgia, about 100 companies quarry and sell granite as rough blocks or finished products such as memorial markers.

Prominent European igneous decorative stones are Scandinavian red granite (rapakivi type in Finland), norite, diabase, and larvikite (anorthoclase syenite, labradorite). Rossa (red) Aswan granite and red porphyry (porfido rosso antico) is produced in Egypt. Green porphyry (porfido verde antico) is produced in the Peloponnesos region of Greece (Kuzvart 1984). Spain, India, the Republic of South Africa, Australia, and Brazil are also noted sources of granite in the world market.

4-2) Pegmatite

Most pegmatites have about the same chemical and mineralogical composition as granite, but pegmatites are typified by very large, interlocking crystals. Most pegmatites have a coarsely crystalline granite composition with abundant quartz and orthoclase feldspar. Other minerals, notably muscovite or white mica, may be abundant. Boulders are preferred to highlight this coarse texture. Many stone or landscaping companies stock large pegmatite boulders, which are moved to the building site

by flatbed truck. In Quebec, amazonite pegmatite from Saint-Ludger-de-Milot and Lac Saint-Jean is used for decorative stone aggregate and for small decorative objects. Michigan architects surveyed by Johnson (1983) highly favored coarse pegmatite.

Although not extensively quarried today, old mines operated when sheet muscovite was mined in the past are inviting to enterprising stone dealers.

4-3) Basalt and Traprock

In the western United States, Tertiary and Quaternary basaltic rocks are exposed over thousands of square kilometers. Basalt is finegrained, hard, tough, dense, and durable. It is composed of pyroxene and calcic plagioclase and is well suited for use as a decorative stone for landscaping.

Traprock is a common term for basaltic dikes or flows. Power (1994) states the correct petrologic term for traprock is diabase or dolerite. When sold as cut building stone, it is commonly called black granite.

4-4) Tuff

The main use of tuff is as cantera stone floor tiles and wall cladding (Figure 13). Some Mexican tuff is sculpted into statuary. The tuff varies in color, with pastels predominating. The stone is characterized by many inclusions of large pumice fragments (up to 30%) and phenocrysts, up to 50 mm in diameter, of quartz, biotite, feldspar, magnetite, and rock fragments such as granite or basalt (Kuiper 1988). The high porosity of tuff makes this rock suitable where low weight is a factor. In addition, the porosity gives the stone a texture that is visually appealing for rustic application (Figure 14).

Figure 13.: Volcanic tuff (cantera stone), cut with a chain saw, was used as the primary building stone at The Lodge (built circa 1930) at Los Alamos, New Mexico. Although containing voids and depressions, the cantera stone hardens somewhat with time to produce a more durable veneer.

Figure 14.: Cantera stone blocks used to form a wall at Bandelier National Monument, New Mexico

4-5) Marble and Travertine

Geologically, marble is a metamorphosed carbonate and travertine is a sedimentary carbonate deposited from flowing water, usually in a spring system. Commercial marble is any crystalline rock composed predominantly (>50%) of calcite ($CaCO_3$), dolomite ($CaMg(CO_3)_2$), or serpentine ($Mg_3Si_2O_5(OH)_4$). Serpentine with white calcite or dolomite stringers forms verde antique. Commercial marble must take a polish and may include

crystalline limestone, travertine, and serpentine in addition to metamorphic carbonate. Crystals range in size from fine (easily polished) to coarse. The ability to take a polish is important, but the color and crystalline character can be more important.

4-5-1) Limestone, Dolostone, and Marble

Carbonate rocks, usually marine in origin, are found in many parts of the United States and many other nations. The Bloomington– Bedford District of southern Indiana has produced a well-known dimension limestone (commonly called Indiana Limestone) for more than a century. Limestone and dolostone are usually gray, but can be white, buff, tan, or black. White marble is composed of nearly pure calcite. Dolostone is composed predominantly of dolomite. Mineral impurities that darken limestone and dolostone include iron carbonates, iron oxide, iron sulfide, chert, silica, clay, graphite, and carbonaceous matter (Power 1994). Crystallinity, bed thickness, ease of polishing (3 to 3.4 on the Mohs hardness scale), and the presence of fossils, stylolites, or other textures and structures make limestone and dolostone attractive decorative stones. Bedding can vary from thin to massive and is important in determining the end use of commercial marble and travertine. Limestone imported into the United States comes primarily from Spain and France.

The Georgia Marble Company in Georgia and the Vermont Marble Company in Vermont quarry the bulk of U.S. commercial marble production. Marble, particularly white marble, is commonly crushed and sized and sold in lots ranging from carloads to bags of <45 kg. White marble from Georgia (Power 1994) and varicolored travertine from New Mexico (Austin and Barker 1990) are premium decorative stones. The Yule quarry in

Gunnison County, Colorado, which supplied white marble for the Lincoln and Jefferson Memorials in Washington, D.C., has recently operated intermittently after being closed for many years. Marble imports come principally into the United States from Italy, Portugal, Spain, and Turkey.

4-5-2) Travertine

Commercial travertine is hard, dense to vuggy, finely crystalline, compact, massive to concretionary or fibrous limestone that takes a polish (Austin and Barker 1990). Impurities in travertine impart colors ranging from white to pink, red, tan, yellow, green, gold, brown, or black. Variations in impurities can cause multicolor banding of layered travertine. Travertine may be called tufa (within the industry; tuff is used to describe cantera or volcanic tuff, but never travertine), calcareous sinter, marble, Mexican onyx, or onyx marble. New Mexico Travertine produces most of the domestic travertine (Barker, Austin, and Sivils 1996).

4-6) Sandstone and Conglomerate

Sandstone suitable for cutting, flagging, and curbing has been produced worldwide for thousands of years. Commercial sandstone consists of both sandstone and siltstone. Color variations are due largely to iron oxide. Moss rock is a popular sandstone found in many areas as loose fieldstone on surface outcrops. Picture rock is sandstone that exhibits complex color (liesegang) banding from variations in weathering and which is sold as slabs cut to simulate landscape paintings.

4-7) Slate, Schist, and Gneiss

Slate is a fine-grained metamorphic rock with pronounced, relatively smooth, and flat cleavage surfaces that is used mainly for roofing. Stair treads, floor tile, flagging, wainscoting, trim, chalkboards, billiard and laboratory tables, plaques, and signs are also produced. Slate can be purple, gray or black (reduced), red or green (oxidized), or mottled. These colors can alter or bleach

on exposure (called semiweathering), but roofing slate should have permanent colors (called unfading) or at least alter evenly to a pleasing shade and be from the same lot. Most slate is initially split by hand from quarry blocks (Sweet 1990) with further punching by foot treadles and machine shaping.

Slate production in the United States is concentrated in New York, Vermont, Virginia, and Pennsylvania, where it is centered at Pen Argyl and Slatedale.

Slate production techniques have changed little with time. Quarrying must be done slowly with little blasting because it would split the slate. Wire and chain saws are also used. Cold weather limits the quarrying season in many places; the stone is ruined if it is freeze-thawed while in large blocks, so none can be quarried ahead without careful storage. Slate is still largely hand split and punched with foot-driven treadles. Because of the assistance of nature in prying weakened surfaces apart by alternating freezing and thawing, flagstone quarries tend to be small and close to the surface.

Sale of slate in the United States is particularly strong in the South, Southwest, and California (Harben 1990) because of its resistance to color change over years in direct sunlight. Slate is growing more important in world markets for its natural unpolished appearance, nonslippery and multicolored durable surfaces, and relatively low price (Vagt 2003).

4-8) Quartzite

Quartzite is metamorphosed quartz sandstone that breaks through the grains rather than around them. Commercial quartzite is a hard siliceous rock commonly white to light-gray to bluish-gray or pinkish. Gneiss is often marketed as quartzite. In Virginia, thin-bedded to massive quartzite of the Cambrian Weverton Formation has been quarried since 1893 (Sweet 1990).

Quartzite is marketed for flagstone, veneer facing stone, and other decorative uses. Fern stone is quartzite containing dendritic limonite along bedding planes. Idaho also produces quartzite used as both flagging and building stone.

5) PRODUCTION

Decorative stone operations range from very small to very large. Many large quarries producing dimension or building stone also produce large quantities of waste rock, although their preferred output is large, sound, rectangular blocks. This waste material is normally crushed to aggregate, screened, and sold as decorative stone. It may alternatively be processed into ashlar (Figure 15). Aggregate quarries produce rock that can be used as higher-value landscaping stone as easily as lower-value concrete aggregate. Demand, appearance, and cost of the stone are most commonly the deciding factors in the choice between these two alternatives.

Figure 15: Breaking and palletizing ashlar from dimension stone waste at New Mexico Travertine in Belen, New Mexico

Figure 16.:Limestone capstone being carefully hand-dressed at the finishing plant of New Mexico Travertine, Belen, New Mexico

A number of finishes can be applied to a stone on an edge (E), a surface (S), or both (B):

- **Natural cleft**—natural, nonuniform finish (S)
- **Sawn**—dull, smooth finish created by a diamond or wire saw (E/S/B)
- **Split**—split with the natural grain (E/S)
- **Honed**—smooth, formal look, no shine (E/S/B)
- **Polished**—smooth, mirror finish (E/S/B)
- **Flamed**—slightly pebbled, medium relief (E/S/B)
- **Sandblasted**—slightly textured finish, light relief (E/S/B)
- **Rocked**—hand-cut, chiseled finish, heavy relief (E)
- **Bush hammered**—small pyramidal indentations, medium relief (E)
- **Tumbled**—rotated in a drum; rocks semirounded (B)

Only two producers are active at this time. Georgia Marble produces only their white marbles, which under French ownership will expand over the next 5 years using imported stone. New Mexico Travertine produces several colors of travertine from its quarry but has expanded to use more than 12 limestones from other domestic quarries. Tennessee Marble Company produces tiles and slabs but primarily markets the stone for cut-to-size projects and has limited access to stones

other than Tennessee pink, which is difficult to produce and is limited in slab size (Matthews 2002).

5-1) Quarrying

Quarrying decorative stone uses the same general techniques used in the production of other types of stone, but details are adjusted depending on the desired finished product. For example, blasting is minimized using small charges of low-velocity explosives for slab blocks. Stone quarries use diamond wire saws, belt saws, chain saws, and air wedges that allow rapid, more accurate quarrying and produce thinner products than in the past. Great care and considerable hand dressing (Figure 16) are necessary for high-quality wall capstone, flagstone, or slate. Accent pieces used in landscaping, such as large pegmatite boulders, require preservation of the coarsely crystalline surface during transport to the final site. Cranes may be needed to lift pieces, and padding is used to prevent damage in transit. Contrast this to the production of crushed stone, which requires almost no protection.

Stratification in rock produces zones of weakness called rift by producers. These are important because they determine the direction in which the stone splits most easily. Spacing of the rift determines the thickness of the quarried layer. Bed seams, joints, cutters, reeds, and runs are additional terms used in the sandstone industry to describe other natural planes or directions in which the stone splits or can be cut (Bowles and Barton 1963).

5-2) Processing

By the early 1900s, the muscle power of earlier ages had given way to steam, electricity, and compressed air. In recent years, carbides and diamonds for cutting and higher grade steels for drills have allowed for more efficient cutting of stone, but the

basic equipment was similar to that of the past. Since the Browning torch was developed, it has been widely used in the granite industry and has revolutionized channel cutting (Meade 1986a). Channel cutting with diamond-studded belt saws is doing the same to limestone and marble production (Harben 1990). High-pressure water jets are also being used to quarry granite in North Carolina.

Automation that allows affordable production is being introduced rapidly, but much waste is still produced, leading to coproducts. Products include tiles and other decorative pieces such as kitchen counters, table or desk tops, bathroom counters and basins, and fireplace mantels. The trend is toward thinner slabs, specialty surfaces (polished or flame textured), and new applications such as coordinated lines of furniture in homes. Production of large volumes of crushed stone is ensured by modern drilling equipment, blasting techniques, and crushing and processing machinery.

6) SPECIFICATIONS

Formal specifications exist through the Marble Institute of America for most stones used in the dimension stone industry. Specifications are less developed in the decorative stone industry, where color and texture are of principal importance, along with the surface treatment used. The ability to be split into flat slabs is important in the production of flagstone, of less importance in fieldstone and moss rock, and of no importance for river rock.

Strength, porosity, adsorption, and durability are important in some decorative stone end uses and of little importance in others. Durability and strength are significant in crushed stone

used for some decorative purposes, such as terrazzo and exposed aggregate (Ault 1989). The Aggregates and Dimension Stone chapters in this book cover physical properties in detail.

6-1) Flagstone

Irregularities on a flagstone wear surface must be <1 cm in height (Harris 1991) to minimize tripping. A standard test for abrasion resistance of stone subjected to foot traffic is given in American Society for Testing and Materials (ASTM) Standard C241.

6-2) Tiles and Paving Blocks

Slate for floor tiles sold in the United States comes in four basic square or rectangular sizes from 15 × 15 to 46 × 46 cm (Figure 17). Size is limited only by the curvature of foliation, which can cause tripping in tiles more than 1 m across. Tile thickness varies from 6 mm for light-duty and housing use to 9 mm for heavy-duty use in public areas (Harben 1990). Flexure testing of slate is covered by ASTM C120. A minimum abrasion resistance (ASTM C241) of 10 is required for carbonate floor tile. Where two or more marbles are combined, there should be a maximum difference of 5 points of abrasion resistance. For stairways, floors, and platforms subject to heavy foot traffic, a minimum abrasion resistance of 12 is recommended.

Figure 17. Processing line for square floor tiles at New Mexico Travertine

6-3) Exposed Aggregate

In general, tests for exposed aggregate are variations of those used for cement and road building or construction-aggregate end uses. Standard evaluation techniques for such end uses may have severe shortcomings when applied to exposed aggregate. Highway service records, acceptance tests, and government ratings of stone do not correlate with its quality as exposed aggregate (Cutcliffe and Dunn 1967).

Hardness is determined by Los Angeles abrasion, ASTM, or Micro-Deval tests. The aggregate should be hard enough to minimize replacement of faulty exposed aggregate because repair costs are extremely high, if repair is possible at all (Cutcliffe and Dunn 1967; Stith 1970). Abrasion resistance is less significant in exposed aggregate, but softness or brittleness may cause excessive fines during batching (Cutcliffe and Dunn 1967).

Soundness is the main criterion that determines the durability of exposed aggregate during temperature and humidity cycles, weathering, and erosion. Several sides of an exposed aggregate particle often are not encased in cement, making poor-quality stone very susceptible to weathering. A variety of tests involving freeze– thaw cycling and exposure to solutions are applied to exposed aggregate as discussed by Stith (1970) and Cutcliffe and Dunn (1967).

Water absorption should be <1.5% because high absorption promotes weathering and staining (Shergold 1954; Stith 1970). Average pore space and percentage saturation also influence soundness. Completely saturated rocks, small pores, and capillaries are more deleterious than larger, better-drained pores (Verbeck and Landgren 1960; Yedlosky and Dean 1961; Stith 1970).

Particle shape and size distribution are less important factors for exposed aggregate. The two main criteria are few thin or platy particles and minimal dust or fines. Impurities to avoid are shale, clay, iron sulfides and pyrite, chert, gypsum, bituminous materials, dolomite, limestone, or any reactive material >1% by weight (Cutcliffe and Dunn 1967; Stith 1970).

6-4) Dash

Dash is fine-grained (up to 9 mm) exposed aggregate, and the basic principles and specifications previously described for exposed aggregate apply. Stone grains as small as 1.5 mm are used as concrete block facing (Ladoo and Myers 1951).

6-5) Terrazzo

Aggregates for terrazzo use are tested by methods applicable to aggregates for other uses. These include ASTM Standards C33, C88, C131; Los Angeles abrasion; and sodium sulfate tests. Terrazzo is essentially exposed aggregate with only one side exposed, so the criteria previously described for exposed aggregate generally apply. Specifications and data on terrazzo are available from the Terrazzo, Tile and Marble Association of Canada or the National Terrazzo and Mosaic Association.

6-6) Veneer and Cladding

Modern use of interior decorative stone as veneers and cladding does not require the high ASTM standards for compressive or flexural strength called for in structural stone. Exterior veneer and cladding stone is hung, using a variety of support and anchor systems, to the structural wall behind. Stone that meets the minimum ASTM criteria for flexural strength, modulus of rupture, and density is usually suitable for exterior veneer.

The standard specification for marble dimension stone (exterior) is ASTM Standard C503. Marble in this context includes calcite, dolostone, travertine, and serpentine. Marble for exterior use must be sound and free of spell cracks, open seams, pits, or

other defects that would affect its strength, durability, or appearance. Molded, cast, or artificially aggregated units are discussed under the section on Synthetic Stone

6-7) Cantera Stone

The criteria established by ASTM for cantera (consolidated volcanic tuff) stone are as follows: bulk specific gravity (C97), 1.336 to 1.88 ; absorption (C97), 9.9% to 22%; modulus of rupture (C99), 435 to 1,520 psi; compressive strength (C170), 1,800 to 9,960 psi; and an abrasive hardness (C501) of 3.3 (Kuiper 1988).

7) ECONOMIC FACTORS

The decorative stone industry tends to be vertically integrated in the United States, although a dealer/distributor network is also in place. Many producers market both through their own sales operation and through various representatives. This is due in part to the desire of clients to view the stone before purchase. Developers of large projects often visit the quarry, but it is often advantageous to have examples of the stone available regionally at distributors.

The decision to use a particular stone in a project is made by architects who, as a group, are the greatest single influence on demand in the decorative stone industry. The reputation and trade name of the stone are the principal factors rather than test results used by architects to determine durability. Architects rated factors affecting their choice of stone (Johnson 1983) from most important to least as follows: (1) appearance (overwhelmingly), (2) durability, (3) cost, and (4) availability. Appearance of stone depends on color, texture, and uniformity. Limestone was the most frequently selected stone with granite second, but exposed aggregate panels were preferred for small commercial buildings. Stone is specified often for government

buildings, sometimes for churches, and increasingly for commercial or residential structures.

7-1) Costs

Decorative stone ranges from a moderate cost, high-bulk commodity to a high cost, low-bulk one. Crushed stone for landscaping (ranging from $15 to $90/t) is an example of the former, whereas stone for sculpture (perhaps $6,000 for a large block of Carrara marble) represents the latter. Decorative stone often commands a higher price than identical stone used where aesthetics are not considered.

In 2005, costs for decorative stone in Tucson, Arizona, ranged from $22 to $42/t for sized, bulk, landscaping materials in various colors. Tumbled stone was $88/t and standard boulders were about $0.18/kg. Specialty boulders ranged up to $0.88/kg. Transport was $15 to $70 per load in the greater Tucson area with large orders trucked free to the jobsite .

7-2) Transportation

All major forms of transport are used for decorative stone. Truck transport of aggregate (86%) predominates over rail (6%) or inland/ coastal water transport (barge 2% and lake <1%), whereas sea transport (<1%) is least common (Anon. 1988). Any transport by water, barge, or ship is the lowest cost. Truck transport is very effective, though usually more costly per unit shipped, because of flexibility and orientation toward individual irregular shipments and low capital outlay (Hayes 1991). The stone is shipped in bulk or palletized (Figure 18) and is loaded onto the truck at the production site to be carried directly to the end-use site with no intermediate handling. Delivery by truck is prompt, and damage is minimal even for polished or slabbed stone. In contrast, rail transport may cost more because it is oriented to large predictable shipments, is capital intensive, and has high fixed costs. High railcar coupling speeds may damage

more stone than road vibration during truck haulage. Rail rates often are set according to the finish rather than simply by the type of stone. Timing is important because most consumers need rapid delivery once a decorative stone is ordered. Distribution yards closer to consumers than production facilities are often used for flexibility and rapid delivery (Hayes 1991).

In Michigan (Johnson 1983) in the early 1980s, transport costs ranged from 20% to 100% more for highly finished stone than for the same stone when unfinished, rough, split, or sawn. Crushed stone transport cost was only about 40% of that for unfinished stone. Shipping of decorative stone on the Great Lakes was not readily available then, although its cost would have been about 10% of rail rates. Lake transport was reserved for large volumes from established producers with regular shipments, such as coal or iron ore (Johnson 1983).

Figure 18.:Various rock types sorted by size, shape, and surface coating (such as moss rock); palletized, and ready for shipment by truck in New Mexico Travertine's yard

Most factors applicable to construction aggregate transport apply to decorative aggregate. Decorative stone aggregate carries significantly more value than construction aggregate,

even if they are the same rock, so higher transport costs are justified. Decorative stone includes a wide variety of products requiring transportation. Although much stone is used locally, certain segments of this market will support higher cost transport offshore and worldwide. Decorative stone is often sold in relatively small lots, so bulk transport cost advantages cannot often be realized, although they are substantial if the shipment is large.

End uses of decorative aggregate such as landscaping rock are the most sensitive to transport cost and thus travel the least distance, although this distance can be significant. Aggregate has been imported into the United States (Timmons and Harben 1987) to areas accessible to ships such as the eastern, Gulf, and southeastern coasts of the United States, and large portions of the Midwest by barge. This is particularly true for low-volume retail sales where small lots may be shipped long distances because the per-ton retail value is high. Polished or slabbed decorative stone, a high-value commodity, can be shipped any distance if well protected. In contrast, decorative aggregate is resistant to exposure and shock and needs minimal protection during transport.

7-3) Substitutes

All decorative stones have competition from substitute materials, and more are appearing. Examples include concrete, enameled porcelain, stainless steel, aluminum, brick, plastic, synthetic stone, crushed glass and slag, and recycled materials. The aesthetic appeal, prestige, and durability of stone are exceeded by few substitutes. For this reason, substitutes simulate stone, often at lower cost. Stone substitutes are often designed as prefabricated modules or precast panels, as

recommended for much of the potential decorative stone in Michigan (Bourque and Associates 1999). Some decorative stone such as terrazzo or exposed aggregate is also used in panels.

*8)*TARIFFS AND DEPLETION ALLOWANCES

Complex tariffs on imported dimension stone also apply to dimension stone used as decorative stone. In the United States, the tariffs in 2003 varied from free to 6.5% for Normal Trade Relations (NTR) status according to type, size, value, and degree of preparation (Dolley 2005). Tariffs on crushed or rough stone, including that used for decorative purposes, are 3.0% ad valorem (Dolley 2005).

In the United States, the depletion allowance for domestic or foreign decorative stone depends on the form of the stone and its end use. For dimension stone, it is 14%. For slate used or sold as sintered or burned lightweight aggregate, it is 7.5%. For stone used for rubble and other nonstructural purposes, the depletion allowance is 5%.

9*)* MARKETS AND TRENDS

The use of steel, glass, aluminum, plastic, and reinforced concrete made stone nonessential in construction and caused a long-term decline in use of large structural blocks (Johnson 1983). Sales of stone for exterior paving and curbing have decreased because of increased use of asphalt and concrete. In the last few decades, the beauty, heat and sound insulation, and permanence of stone have led to its use for exterior cladding (sheets or panels) of many commercial buildings (Hora 1994).

Stone acceptance and usage in the United States have grown in recent years. In Europe, use of decorative and roughly dressed stone dropped from 50% to 0.25% relative to crushed stone during the 20th century (Kuzvart 1984). Recently the aesthetic appeal of stone and the development of thinner stone in lightweight panels and frames have offset this to a degree (Johnson 1983) and have increased the use of stone veneers and cladding. Thin-stone slab applications are favored by architects because of lower cost relative to glass and steel (Sweet 1990). Dimension stone is being used more commonly in the residential markets. Improved quarrying, finishing, and handling technology, as well as greater variety of stone and the rising cost of alternative construction materials, are among the factors that suggest a continuing increase in demand for dimension stone during the next 5 to 10 years (Dolley 2005). Domestic crushed stone production appears to be stable or increasing slightly. While crushed stone free on board (f.o.b.) prices are not expected to increase significantly, the delivered prices are expected to increase, especially in and near metropolitan areas, mainly because more aggregates are being transported longer distances (Tepordei 2005).

Veneer style has shifted to smaller pieces of stone assembled in panels for unit construction, giving a cubic look, particularly for granite buildings. Extensive engineering and testing led to precasting of stone and concrete panels, epoxy bonding of finished stone panels before installation on site, and most recently, bonding of ultra-thin stone veneer to expanded aluminum backing (Meade 1986b). Use of stone increased for decorative interiors with various shades and colors of marble in lobbies and foyers. Residential use of thin stone tiles and countertops, particularly granite, has increased. Decorative stone panels and tiles made from agglomerated stone such as

Chilean lapis are bonded into tiles for high-contrast colored trim (L.P. Meade, personal communication). Over time, taste in stone architecture changes and some stones fall out of favor, such as the brownstone fronts once popular on urban residences (Ladoo and Myers 1951).

The trend in North America is for specialized use of stone for architectural purposes. The trend in stone use is away from blocks and toward veneer and cladding in larger thin panels that, depending on stone type, may need to be backed by glass fiber/epoxy or other strengtheners. Wider spans may need to be thicker or use special anchors depending on wind load or other factors. A trend in architecture is toward smaller, thinner preassembled stone panels set in larger panels for rapid installation onto steel frameworks or exterior walls to yield a look as if built with large stone blocks.

The broader residential market that uses a wider variety of stone is growing, particularly in the Southwest, but demand is not great enough to create demand for all quarry waste. This contrasts with Italy, where virtually all stone quarried is used, so U.S. costs remain higher for stone and also for fabrication. The European participation in the Marble Institute of America shows that the U.S. market is viable for importers. Multinational participation in the U.S. stone industry is helping establish acceptable standards for suspension systems and artificial supports. The U.S. stone industry carries much higher product liability, and environmental, safety, and health costs, compared to foreign producers (Meade 1986a).

The stone industry remains labor intensive, which limits markets for relatively costly U.S. stone. Technology improvements, particularly widespread diamond (Harben 1990) or flame cutting, partly offset this. Improvements in mechanical

fasteners and cements have fostered the decorative stone panel market, which is also being standardized to improve competitiveness. Increased panel sales means increased sales of exposed aggregate, often turning quarry waste into a product. Chemical treatment to increase durability of stone is making a wider variety of stone types available (Johnson 1983).

Zoning and alternative land use are constant concerns of the stone industry. Federal agencies and sometimes state or local agencies regulate stone quarries and sand and gravel operations. The decorative stone industry in the United States is subject to the same safety, health, and environmental pressures and regulations as the aggregate and dimension stone industries. Much decorative stone is produced as a coproduct of urban stone quarries that are under extreme pressure to relocate farther from growing population centers and to impact less on wetlands. Many inoperative quarries are being converted into scenic and high-value commercial and residential developments. Shortages of aggregate in most urban areas are likely because of local zoning restrictions and land development alternatives. The stone industry will continue to be concerned with environmental restrictions and safety factors.

Matthews (2002) characterized and summarized trends in the North American dimension stone and the largely derivative decorative stone markets as follows:

- Domestic stone production is unable to meet increasing demand; >97% is imported.
- Besides Italy, Turkey and Mexico are supplying stone.
- Per capita use of stone is less than half that of Europe, so market growth is likely.

- Increased stone use during the 1990s was in residential fireplaces (stone), bathrooms and entryways (tile), and kitchen countertops (granite).
- Colors in demand are beige, yellow, and white; green and black are still high in demand.
- Limestone is the stone of choice, and buyers want honed, sandblasted, water jet, flamed, or antique finishes. Granite and marble are declining in market share against limestone. Slate, quartzite, and sandstone demand is increasing. Cross-cut travertine will lead demand. Indiana limestone, available only in buff-beige or gray, will decline.
- The latest finish for granite is water-blast, which is evenly textured while maintaining color, and will partly replace flamed granite. Textured finishes that do not alter the characteristics or color of the stone are preferred.
- The demand for tile, including natural stone tile and tile decorative accessories is displacing ceramics and hard floorcoverings, the dominant domestic market. The carpet industry is competing by consolidating carpet sales with ceramic and stone. This will lead to increased demand for natural stone tiles.
- Stone marketing is often domestic and local in scope. Most producers are regional and neither promote nor sell nationally. They do not use outside distribution channels.
- The lack of vertical integration in stone production and marketing is eroding. Many fabricators are becoming installers and importers, making stone use more affordable. Many contractors or developers directly import stone.
- Producers typically operate a quarry serving a small fabrication plant capable of producing only cubical work sold to contractors for commercial or residential cladding. Very few producers are capable of producing tiles, slab, or shapes.
- Countertops are the largest use of granite, which now competes with synthetic and laminate tops. As the price of

synthetics increases and that of granite decreases, granite use in kitchens will dramatically increase

- The do-it-yourself market is significant.
- Local craftsmanship will rise as stone demand grows. The shortage of qualified stone professionals, a sore spot with consumers, is temporarily being filled mainly by workers from Mexico. Fabricators and installers must continually train workers to ensure quality installations that foster market growth.
- New domestic trade shows for hard surfaces are promoting flooring and countertops that include stone.
- Buyers want delivered-to-their-door prices from local companies rather than ex-factory imports with their price and timing uncertainties.
- Buyers will pay a premium for quicker service and delivery of stone, preferably in a designed package.

CONCLUSIONS

- Stone, one of the oldest building materials, used throughout the construction industry.
- No classification can completely eliminate overlap between dimension stone, aggregate, and decorative stone. The basic types of decorative stone are rough stone, aggregate, cut or dressed stone, and synthetic stone.
- Decorative and dimension stone data are difficult to separate because geologists keep statistics only on dimension stone, sand and gravel, and crushed stone. The value of domestic dimension-stone production in 2004, which includes some decorative stone, was ~ $257 million compared to imports of ~$1.49 billion and exports of ~$64 million. Production in 2004 was 1.30 Mt, of which about 35% was for decorative uses.
- Thousands of types and varieties of stone are used in the decorative stone industry . Consequently, only the dominant commercial rock types are: Granite, Pegmatite, Basalt, Tuff, Marble and Tavertine, Sandstone and Conglomerate, Slate⁄Schist⁄Gneiss, Quartzite.
- Many large quarries producing dimension or building stone also produce large quantities of waste rock. This waste material is normally crushed to aggregate, screened, and sold as decorative stone. The Production has two processes called: (Quarrying , Processing), A number of finishes can be applied to a stone on an edge (E), a surface (S), or both (B)
- Marble stones are most common dimension stone that used in industry. Specifications are less developed in the decorative stone industry, where color and texture are of principal importance, along with the surface treatment used.
- The decision to use a particular stone in a project is made by architects who, as a group, are the greatest single influence on demand in the decorative stone industry. Architects rated factors affecting their choice of stone from most important to least as follows: (1) appearance (overwhelmingly), (2) durability, (3) cost, and (4) availability. Cost, Transportation and Substitutes are the economic factor affecting on the use of Decorative Stone.
- Sales of stone for exterior paving and curbing have decreased because of increased use of asphalt and concrete. The use of steel, glass, aluminum, plastic, and reinforced concrete made stone nonessential in construction and caused a long-term decline in use of large structural blocks.

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موجز باللغة العربية

تعتبر الصخور من أقدم مواد البناء التي تدخل في عالم صناعه الإنشاءات، كما ان تقليل التداخل والمزج بين انواع الصخور الثلاثة: احجار الزينة، الفتات الصخري، والكتل الصخرية وليس هناك تقسيمه محدده بل تقسم صخور الزينة الي أربع انواع: الصخور الخشنة Rough Stones، الفتات الصخري Stone Aggregate، صخور القطع Cut Stones، الصخور الصناعية Synthetic Stones. ويوجد الاف الانواع من الصخور التي تستخدم في الصناعات القائمة على صخور الزينة ولكن تعتبر صخور الجرانيت، البيجماتيت، البازلت، الفتات البركاني (Tuff)، والرخام، الكنجوريميت، النيس، الشيست، السيليت والكوارتزيت من اهم الصخور التجارية الأساسية المستخدمة في اعمال الديكور .وقد لاحظ ان صخر الرخام والماربل Marble هي اكثر الصخور انتشارا واستخداماً كصخور كتلية Dimension Stones وذلك لتعدد اشكال انسيجتها والوانها مما يجعلها اكثر جاذبية لاسطوحها بعد عمليات المعالجة والصقل.

وكثير من المحاجر الكبيرة التي تنتج صخور البناء Dimension or Building Stones تقوم ايضا بإنتاج كميات كبيره من Waste Rock التي يتم طحنها واستخدامها كصخور زينه (Decorative Stone أو كفتات صخري Aggregate Stones كما ان عمليه الانتاج تحدث عن طريق المحاجر وعمليات التحجير، ويوجد بعض العمليات النهائية على الصخر اما علي الحواف او علي سطح الصخر او علي الاثنين.

أحجار الزينه

بحث مقدم من

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كلية العلوم

جامعة طنطا

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