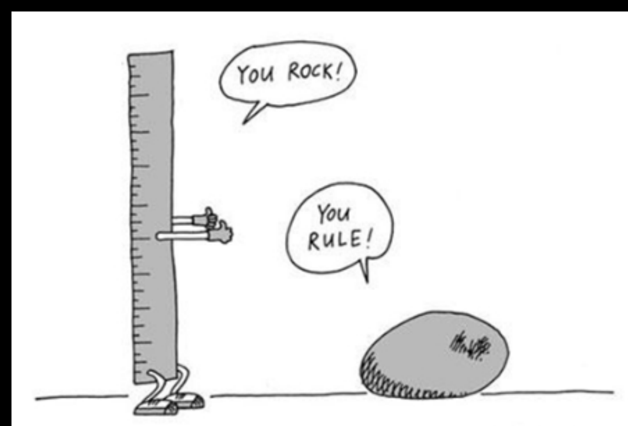
APTI Atlanta 2006

ASSOCIATION FOR PRESERVATION TECHNOLOGY INT'L
STONE RESTORATION WORKSHOP
ATLANTA 2006

BASSETTI
ARCHITECTS

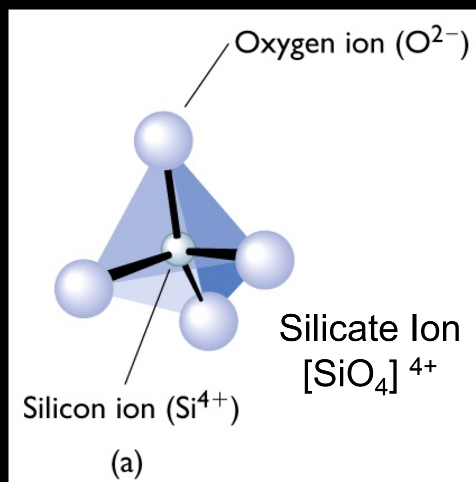
Stone Restoration Workshop

- *In-classroom seminar by:*
  - George Wheeler, PhD, Columbia University Historic Preservation Program
- *In-the-field Demonstrations and Hands-On Practice by:*
  - Frank Genello, American College of Building Arts
  - Simeon Warren, American College of Building Arts

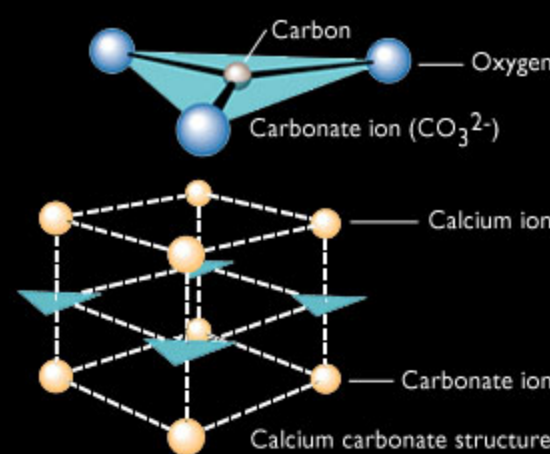


Mineralogy

- *Silicate vs. Carbonate Minerals*
  - *Two basic chemical compositions of all stone*
  - *Understanding the mineralogy of the stone is critical to*
    - *Understanding soiling problems*
    - *Proper cleaning of the material*



VS



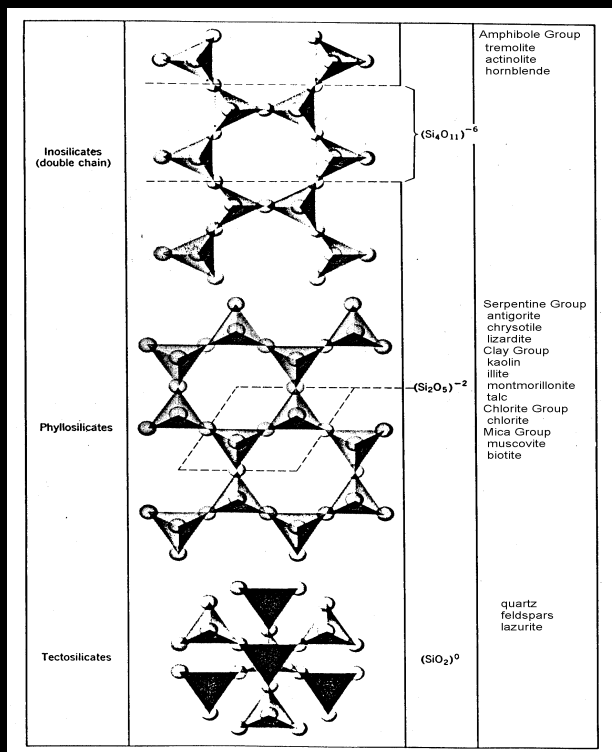
ASSOCIATION FOR PRESERVATION TECHNOLOGY INT'L

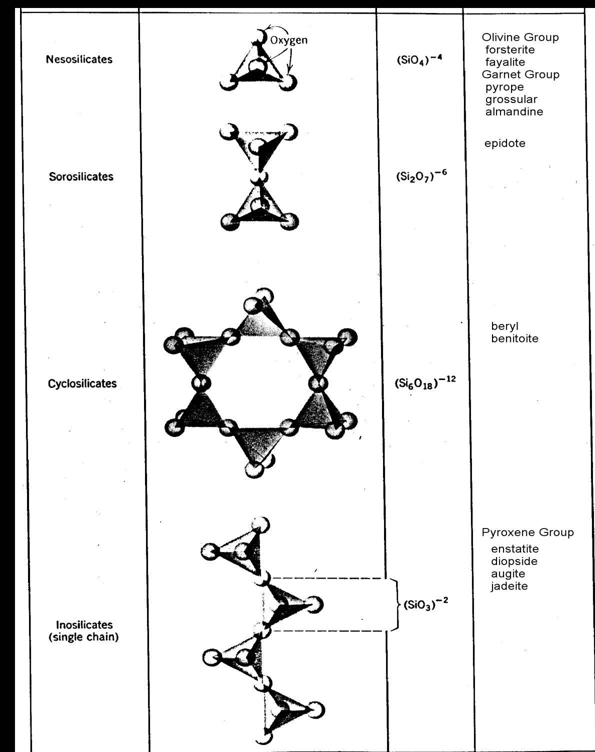
STONE RESTORATION WORKSHOP

ATLANTA 2006

Mineralogy

- *Molecular Structure of Silicate Minerals*





BASSETTI
ARCHITECTS

Mineralogy

- *Silicate rocks include:*
  - Quartz
  - Agates
  - Feldspars
  - Chlorite
  - Amphibole
  - Pyroxene
  - Olivine

Mineralogy

- *Silicate Stone With Increased Iron & Magnesium*
  - Chemically weaker stone
  - Mechanically weaker stone
  - Darker colors

ASSOCIATION FOR PRESERVATION TECHNOLOGY INT'L
STONE RESTORATION WORKSHOP
ATLANTA 2006

Mineralogy

SILICATES

Mineral (or Group)	Chemical Formulation	Weathering Product(s): Mineral product	Weathering Product(s): Dissolved Product	Hardness
Quartz	SiO_2	quartz	silicic acid	7
Feldspars				
Alkali Feldspars				
Microcline	$KAlSi_3O_8$	clay	silicic acid, potassium bicarbonate	6
Orthoclase	$KAlSi_3O_8$	clay	silicic acid, potassium bicarbonate	6
Plagioclase Feldspars				
Albite	$NaAlSi_3O_8$	clay	silicic acid, sodium bicarbonate	6
Anorthite	$CaAl_2Si_2O_8$	clay	calcium bicarbonate	6
Amphiboles	$(Mg,Fe)_7Si_8O_{22}(OH)_2$	goethite	silicic acid, magnesium bicarbonate	5-6
Pyroxenes	$(Mg,Fe)SiO_3$	goethite	silicic acid, magnesium bicarbonate	5-6 (7)
Olivines	$(Mg,Fe)_2SiO_4$	goethite	silicic acid, magnesium bicarbonate	5-6
Serpentines	$Mg_3(Si_2O_5)(OH)_4$			3-5
Clays	broad range of K, Na, Ca, Fe, Mg aluminosilicates			~2
Micas	broad range of aluminosilicates	clay, iron oxides		2-2.5
Talc	$Mg_6Si_8O_{20}(OH)_4$			1
Chlorites	broad range of Fe, Mg, Mn aluminosilicates	iron oxides		2-3

BASSETTI
ARCHITECTS

ASSOCIATION FOR PRESERVATION TECHNOLOGY INT'L
STONE RESTORATION WORKSHOP
ATLANTA 2006

Mineralogy

- *Non-Silicate (Carbonate) Rocks Include:*
  - Gypsum
  - Aragonite
  - Dolomites
  - Calcites
  - Pyrites
  - Hematites

BASSETTI
ARCHITECTS

ASSOCIATION FOR PRESERVATION TECHNOLOGY INT'L
STONE RESTORATION WORKSHOP
ATLANTA 2006

Mineralogy

- *Carbonate Minerals*
  - Can be detected by dropping acid on it and seeing if it reacts
  - CaCO3 + HCl -> CA 2+ & CO2

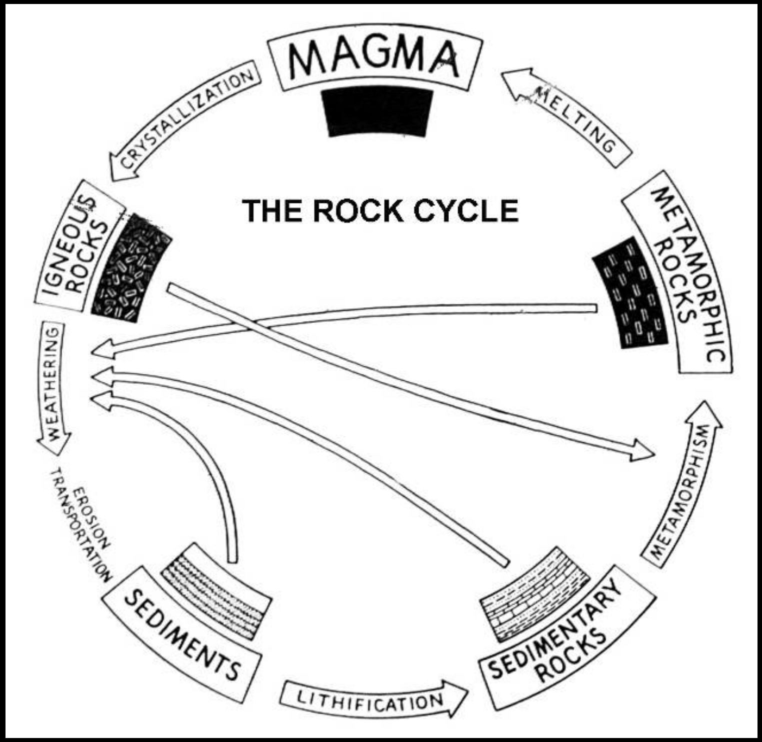
NON-SILICATES

Mineral	Chemical Formulation	Solubility	Hardness
Calcite	$CaCO_3$	acid	3
Aragonite	$CaCO_3$	acid	3.5-4
Dolomite	$(Ca_{0.5},Mg_{0.2})CO_3$	acid	3.4-4
Gypsum	$CaSO_4 \cdot 2H_2O$	acid and water	2
Pyrite	Fe_2S	acid	6-6.5
Hematite	Fe_2O_3		5-6.5
Goethite	$FeO \cdot OH$		5-5.5
Limonite	$FeO \cdot OH \cdot nH_2O$		5-5.5
Magnetite	Fe_3O_4		6
Pyrolusite	MnO_2		1-2

BASSETTI
ARCHITECTS

Rock Identification

- *Rock creation process – Circle of Life*



Rock Identification

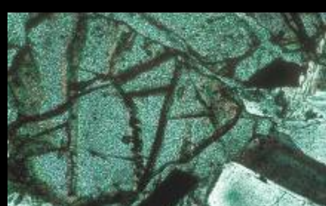
- *Volcanic Rocks vs. Plutonic Rocks*
  - Volcanic = porphyritic textures – fine ground mass with large individual grains – cooled quickly
  - Plutonic = All large grains – cooled very slowly

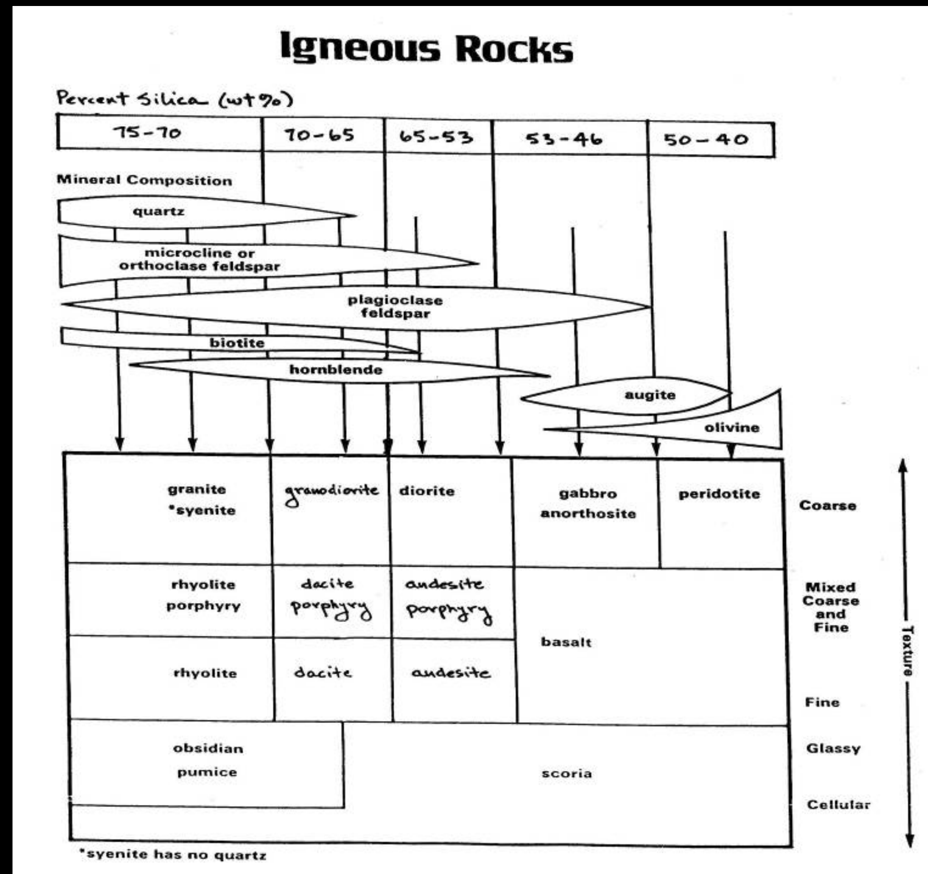



POP QUIZ!

Rock Identification

Igneous
Rock
Table

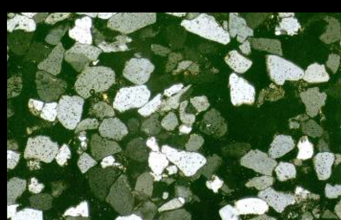




Rock Identification

Sedimentary Rock Table

sandstone
(quartz arenite)



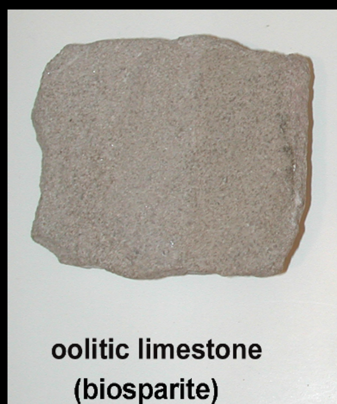
CLASSIFICATION OF SEDIMENTARY ROCKS

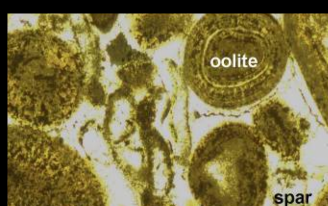
Classified by Composition	*Rock*	*Classified by Origin*	*Rock*
I. Clastic Sediments			
A. Coarse or mixed particles			
1. Rounded	Conglomerate		
2. Angular	Breccia	Glacial deposition	Tillite
		Hillslope weathering	Talus breccia
B. Medium to small particles			
1. Chiefly quartz	Sandstone		
2. Much feldspar as well as quartz	Arkose		
C. Indistinguishable particles			
1. Fine quartz sand	Siltstone	Wind deposition	Loess
2. Mud (very fine quartz, and clay)	Mudstone & Shale		
3. Clay	Mudstone & Shale		
II. Nonclastic Sediments			
Calcium carbonate	Marl, Chalk, & Limestone	Hot-spring deposition	
		Calcium carbonate	Travertine
Calcium magnesium carbonate	Dolomite	Silica	Geyserite
Silica	Diatomaceous earth		
Vegetable carbon	Coal		
Salt	Rock salt		
Calcium sulfate	Anhydrite		
Hydrous calcium sulfate	Gypsum		
Phosphate	Phosphate rock		

ASSOCIATION FOR PRESERVATION TECHNOLOGY INT'L
STONE RESTORATION WORKSHOP
ATLANTA 2006

Rock Identification

Metamorphic
Rock
Table





CLASSIFICATION OF SEDIMENTARY ROCKS

Classified by Composition	*Rock*	*Classified by Origin*	*Rock*
I. Clastic Sediments			
A. Coarse or mixed particles			
1. Rounded	Conglomerate		
2. Angular	Breccia	Glacial deposition	Tillite
		Hillslope weathering	Talus breccia
B. Medium to small particles			
1. Chiefly quartz	Sandstone		
2. Much feldspar as well as quartz	Arkose		
C. Indistinguishable particles			
1. Fine quartz sand	Siltstone	Wind deposition	Loess
2. Mud (very fine quartz, and clay)	Mudstone & Shale		
3. Clay	Mudstone & Shale		
II. Nonclastic Sediments		Hot-spring deposition	
Calcium carbonate	Marl, Chalk, & Limestone	Calcium carbonate	Travertine
Calcium magnesium carbonate	Dolomite	Silica	Geyserite
Silica	Diatomaceous earth		
Vegetable carbon	Coal		
Salt	Rock salt		
Calcium sulfate	Anhydrite		
Hydrous calcium sulfate	Gypsum		
Phosphate	Phosphate rock		

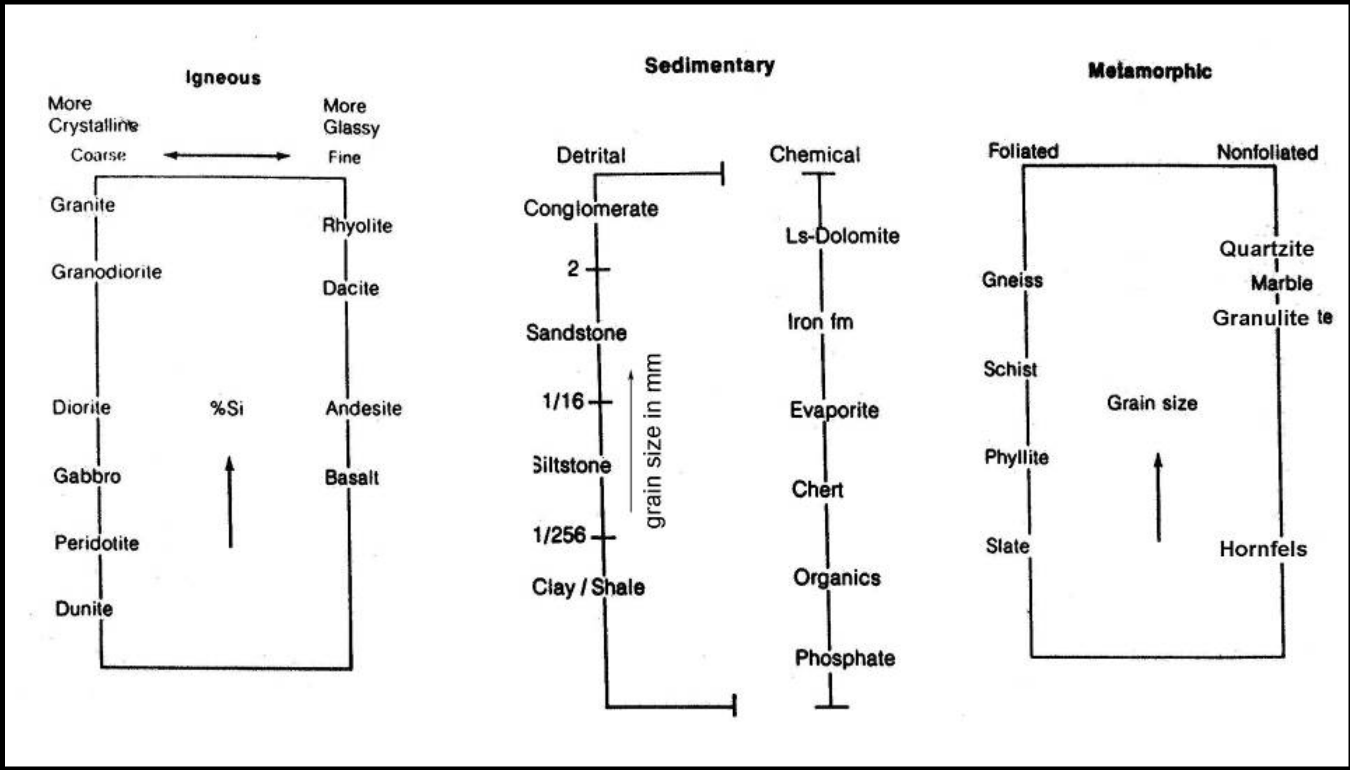
BASSETTI
ARCHITECTS

Rock Identification

- *Overall Scheme for Rock Identification*

Lighter

Darker

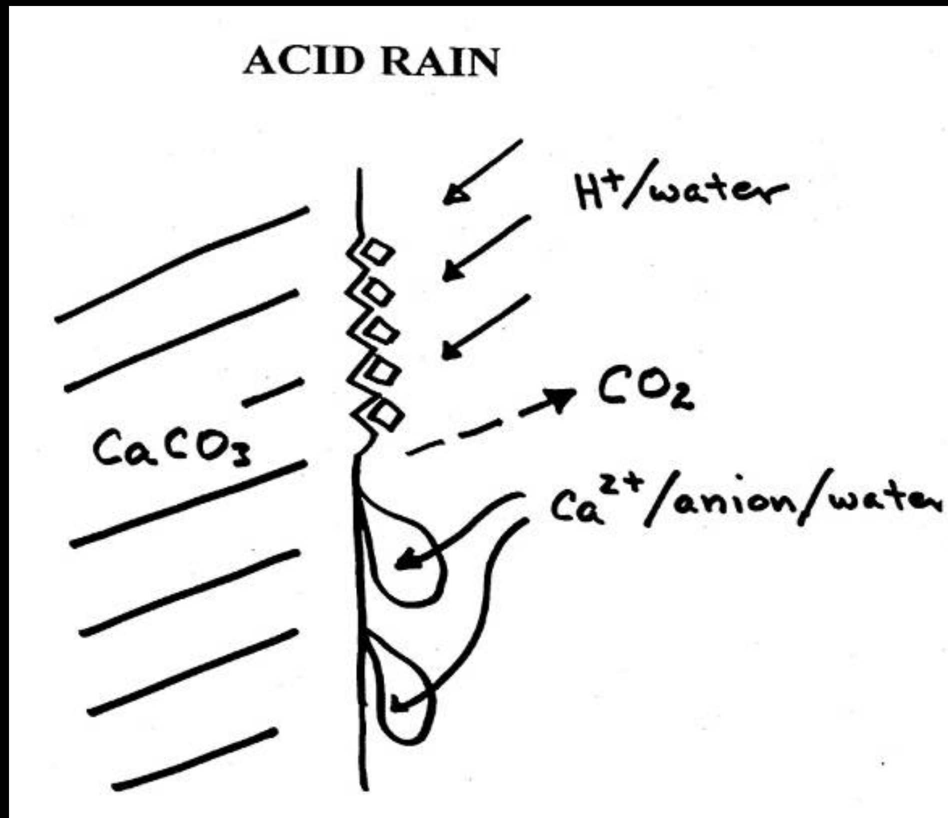


Types of Stone Deterioration

- *Acid rain*
- *Dry deposition*
- *Salt crystallization*
- *Freezing water*
- *Hygric swelling*
- *Biological effects (Biodeterioration)*
- *Thermal effects*

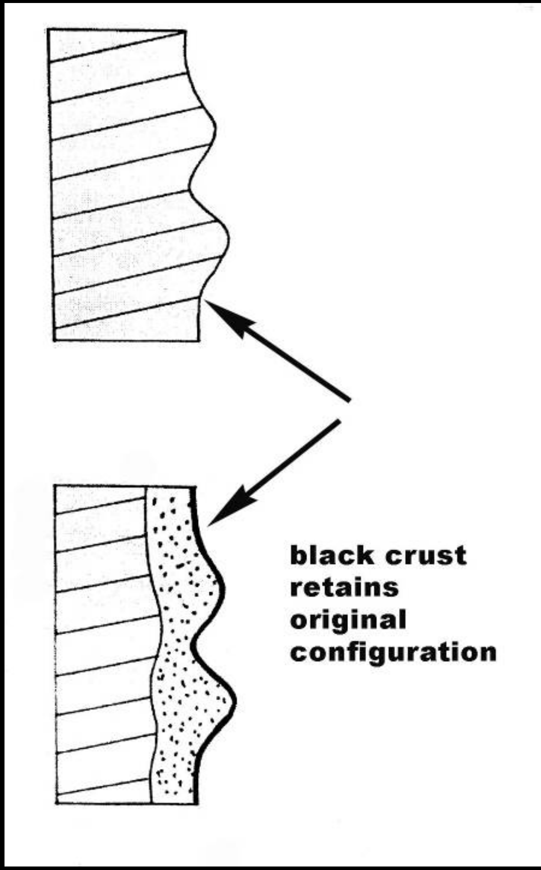
Types of Stone Deterioration

- *Acid Rain*
  - Acid dissolves carbonate rock



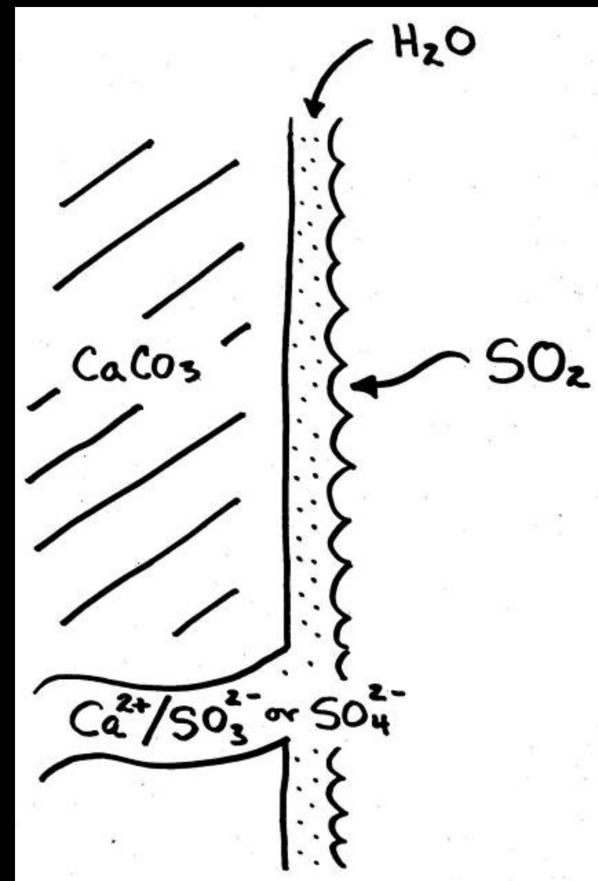
Types of Stone Deterioration

- *Gypsum Crusting*
  - Black from fly ash (not calcium)
  - May be on top of original surface or in place of original surface
  - Can merge with surface and then break off
  - Be careful to select the correct acid wash



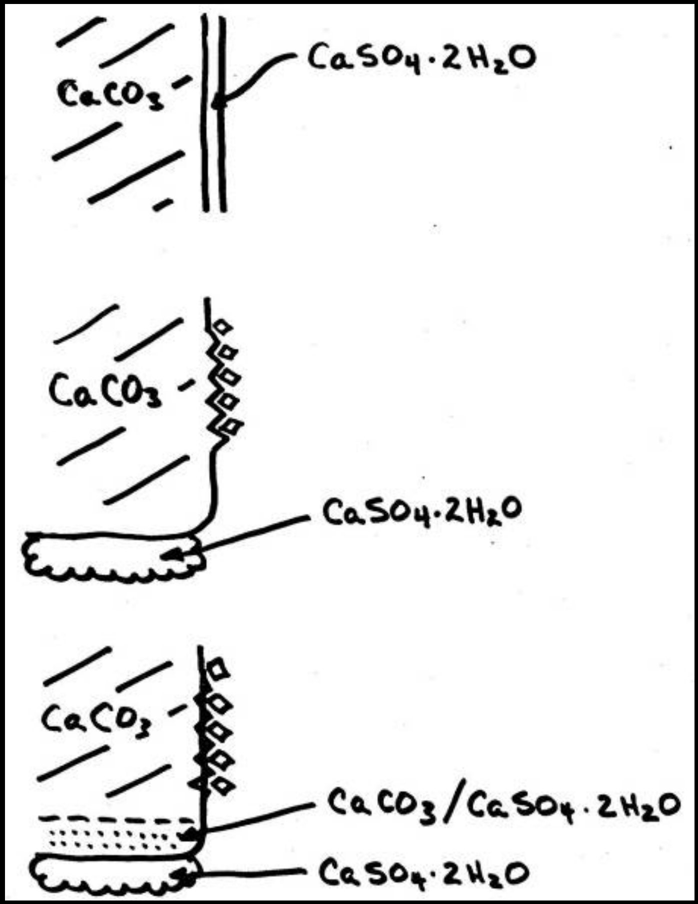
Types of Stone Deterioration

- *Dry deposition*
  - Dissolved material from acid rain is re-deposited as gypsum crusts elsewhere on the rock on top of original surface
  - Usually found in protected parts of the rock where rain will not wash away the gypsum
  - Gypsum can be re-absorbed back into surface of rock and will not come out



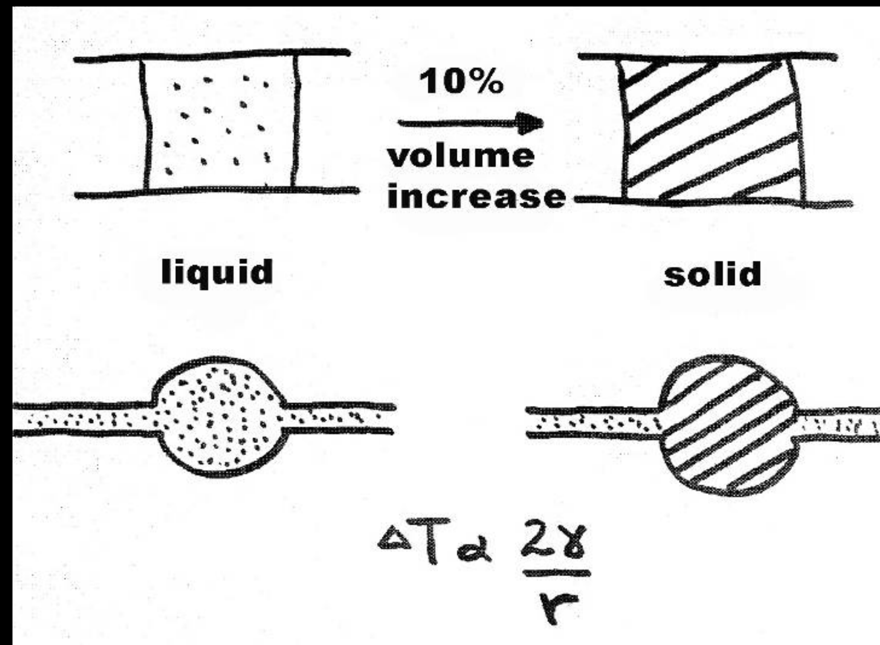
Types of Stone Deterioration

- *Salt Crystallization*
  - Salts are dissolved from within the rock, transit to the surface and then deposited when water evaporates
  - Efflorescence



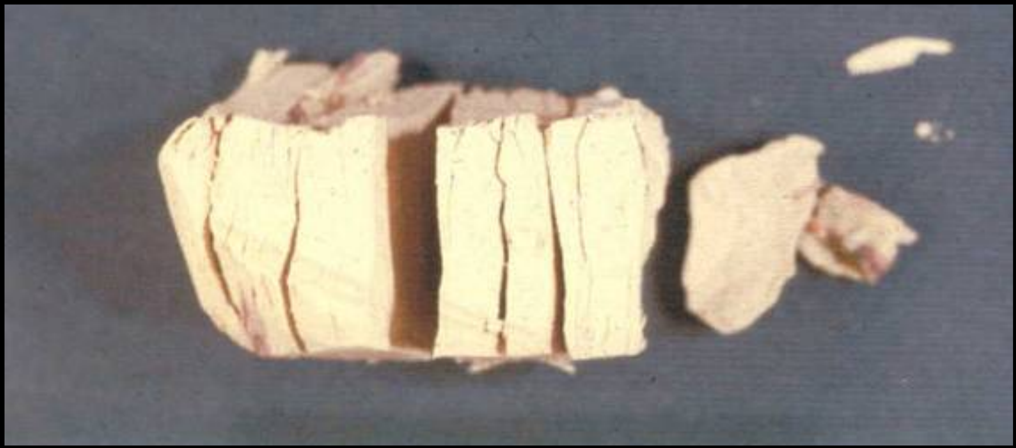
Types of Stone Deterioration

- *Freezing water*
  - Freeze thaw cycling
  - Spalling



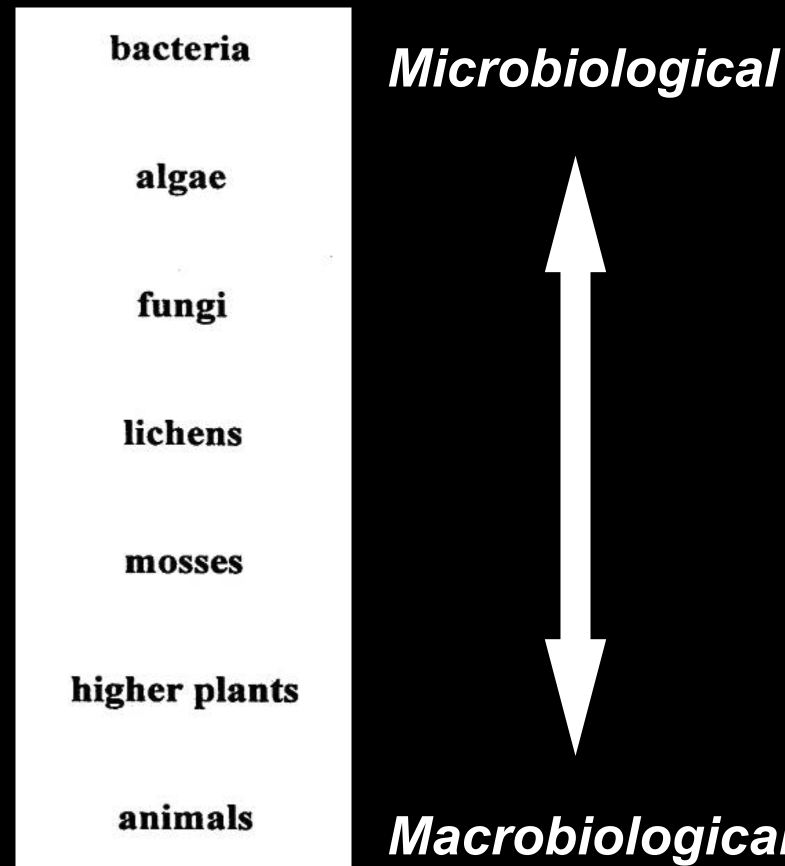
Types of Stone Deterioration

- *Hygric swelling*
  - Rock absorbs water and can then be subject to freeze/thaw cycles, salt crystallization, or other thermal effects
  - Clay in stone helps swelling
  - Egyptian Limestone (below, after 3 cycles)



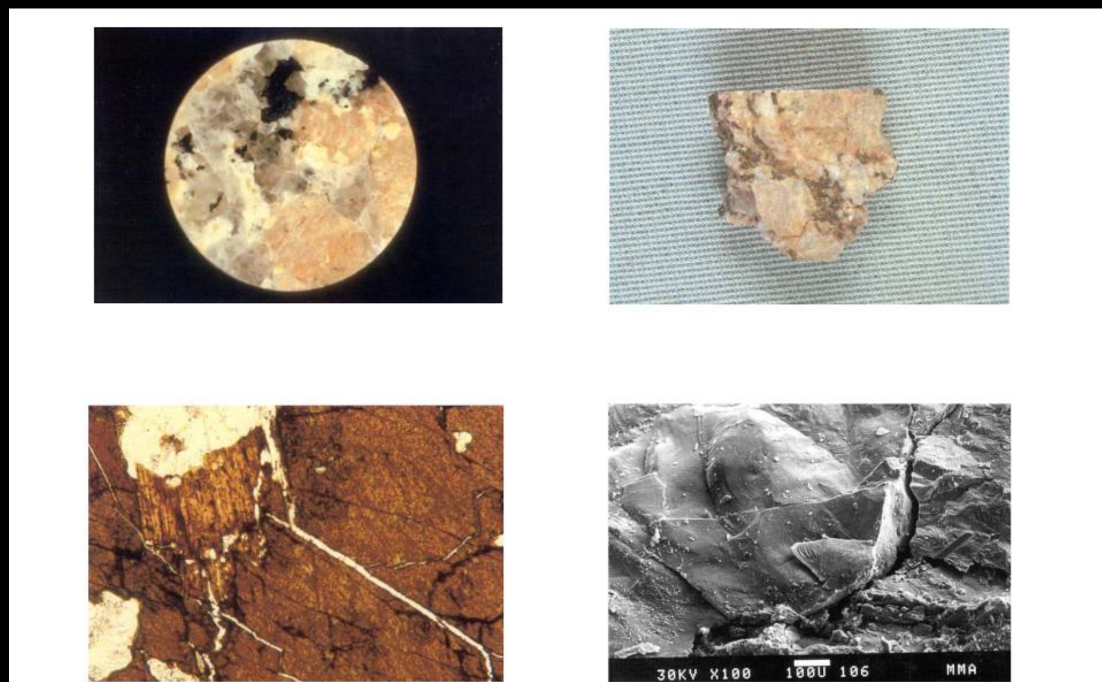
Types of Stone Deterioration

- *Biological Effects (Bio-deterioration)*
  - Plant life creates complex acids to dissolve and suck minerals out of rock
  - Plant life grows into crevices
  - Light, Nutritive input, temperature, and water affect bio-deterioration



Types of Stone Deterioration

- *Thermal Effects*
  - Expansion and contraction creates weak planes in rock

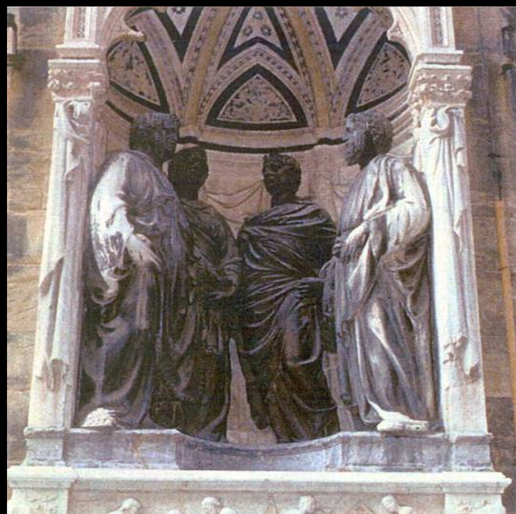


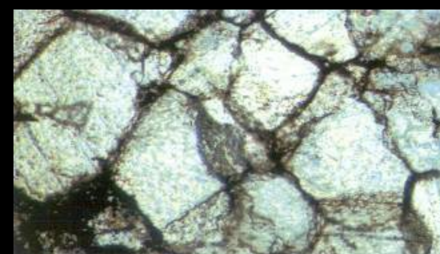
Types of Stone Deterioration

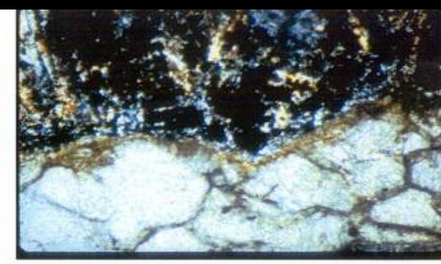
- *Water is an AID to soiling in Silicate rocks*
- *Water PREVENTS soiling in Carbonate rocks*

ASSOCIATION FOR PRESERVATION TECHNOLOGY INT'L
STONE RESTORATION WORKSHOP
ATLANTA 2006

Types of Stone Deterioration







POP QUIZ!

BASSETTI
ARCHITECTS

Cleaning Methods

CLEANING METHODS

Chemical	*Physical*
water	water
detergent	steam
base-acid	particulate
	laser

Cleaning Methods

MARBLE, LIMESTONE, TRAVERTINE

⇒ **Calcium Carbonate (Calcite)**

SLIGHTLY ***soluble in water***

READILY ***soluble acids***

NOT soluble in bases like NaOH

Cleaning Methods

SANDSTONE, GRANITE, SCHIST

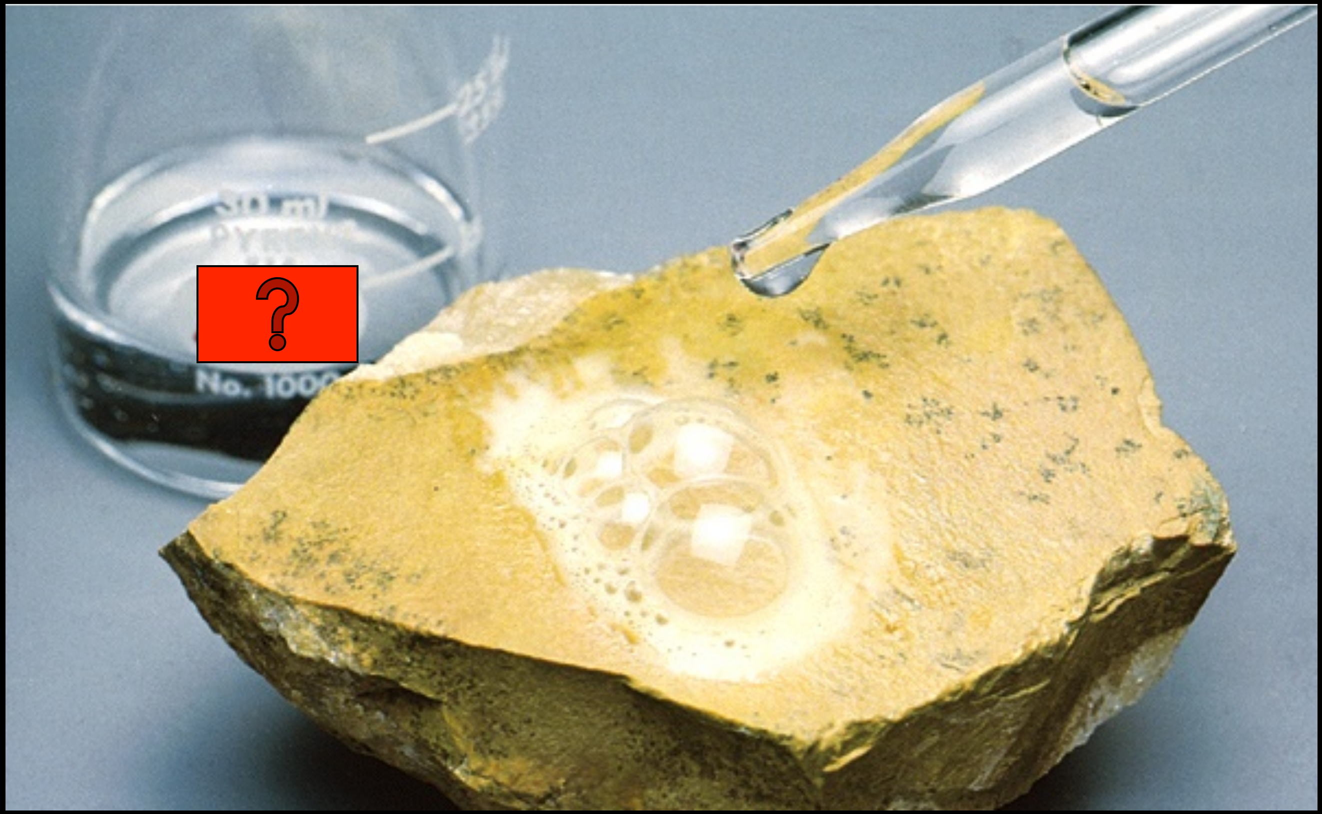
⇒ **Silicon Dioxide (Quartz)**

NOT ***soluble in <u>water</u>***

ONLY ***soluble in <u>hydrofluoric acid</u>***

READILY ***in strong <u>bases</u> such as NaOH***

Cleaning Methods



POP QUIZ!

Water washing

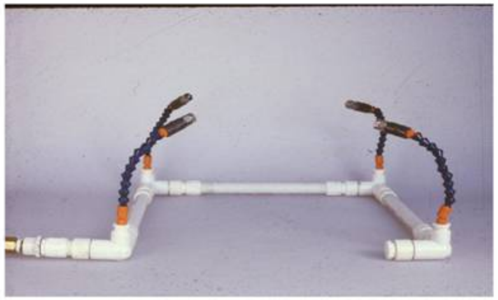
- *Intermittent water spraying does least damage to delicate stone*
- *Intervelometers – photo equipment timer can turn water on or off for a few seconds throughout the day*
- *Irrigation sprinkler timers – not as sensitive*
- *Controlling the length of cleaning timing is critical*
- *Test water for contaminants and acidity*
- *5 micron filters required to remove iron in water*

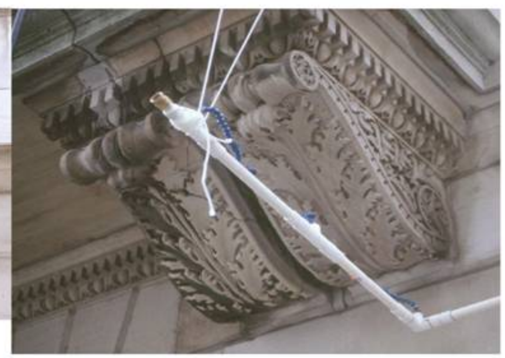
Water washing

- *If stone is delicate, you may not want to try and wash out gypsum crusting that has been reabsorbed*
- *Partial Cleaning*
  - Not really possible with water except for reabsorbed gypsum

- ***Cold** water is better for **removing gypsum***
- ***Warm** water is better for **emulsifying hydrocarbons***

Water washing





Chemical Cleaning

- *Aesthetic concerns – can alter color of stone*
- *Material Science concerns – can remove excessive amounts of the stone or add materials that lead to later deterioration*
- *Very fast cleaning method – dwell time is critical and must be carefully controlled*
- *Difficult to isolate areas to be cleaned*

Chemical Cleaning

- *Alkaline Cleaners*

Alkaline cleaning agents

Agents based on: Sodium hydroxide ($NaOH$) Potassium hydroxide (KOH) Ammonium hydroxide (NH_4OH) Sodium carbonate ($NaCO_3$) Sodium bicarbonate ($Na(CO_3)_2$)	For cleaning limestones Must be followed by neutralization with acetic acid-based compound On sandstones, unglazed terracotta and faience, brick, unpolished granite for the degreasing and removal of heavy soiling. Followed by use of hydrofluoric acid-based compound	All have the potential for depositing soluble salts within masonry. This can largely be overcome if the products containing them are used correctly and on appropriate surfaces Must never be used without neutralization

Chemical Cleaning

- *Acidic Cleaners 1*

Acidic cleaning agents

Agents based on: Hydrofluoric acid (HF) Ammonium bifluoride (NH_4HF_2), also known as ammonium hydrogen fluoride	For cleaning sandstones, unpolished granite, brickwork and unglazed terracotta and faience	NH_4HF_2 releases HF in contact with water. Must not be used on glazed surfaces. Must not be used on limestone, marble and lime-based mortars or renders. Use on calcareous and argillaceous sandstones must be controlled carefully
Agents based on: Acetic acid (CH_3COOH)	For neutralizing limestone and marble surfaces after use of alkaline cleaning. Used with other acids in efflorescence treatments	

Chemical Cleaning

- *Acidic Cleaners 2*

Agents based on:	
Hydrochloric acid (HCl) (muriatic acid)	For removing cement splashes and calcium carbonate (lime) deposits Included with glycolic acid in efflorescence treatments and limestone neutralizers
Other ingredients include:	
Phosphoric acid (H_3PO_4) (orthophosphoric acid)	Included with HF formulations to counteract attack on iron constituents in masonry, usually sandstones
Sulphuric acid (H_2SO_4)	Included in some formulations as a minor ingredient

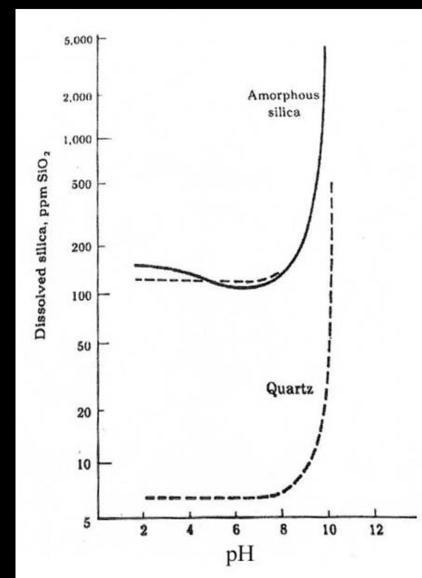
ASSOCIATION FOR PRESERVATION TECHNOLOGY INT'L
STONE RESTORATION WORKSHOP
ATLANTA 2006

Chemical Cleaning

- In all cases, salts must be cleaned out after neutralizing wash

RINSE, RINSE, RINSE!

- Don't use alkaline cleaners on quartz containing stone due to high solubility of quartz in alkali solutions.
- USE ACIDIC solutions on quartz!



BASSETTI
ARCHITECTS

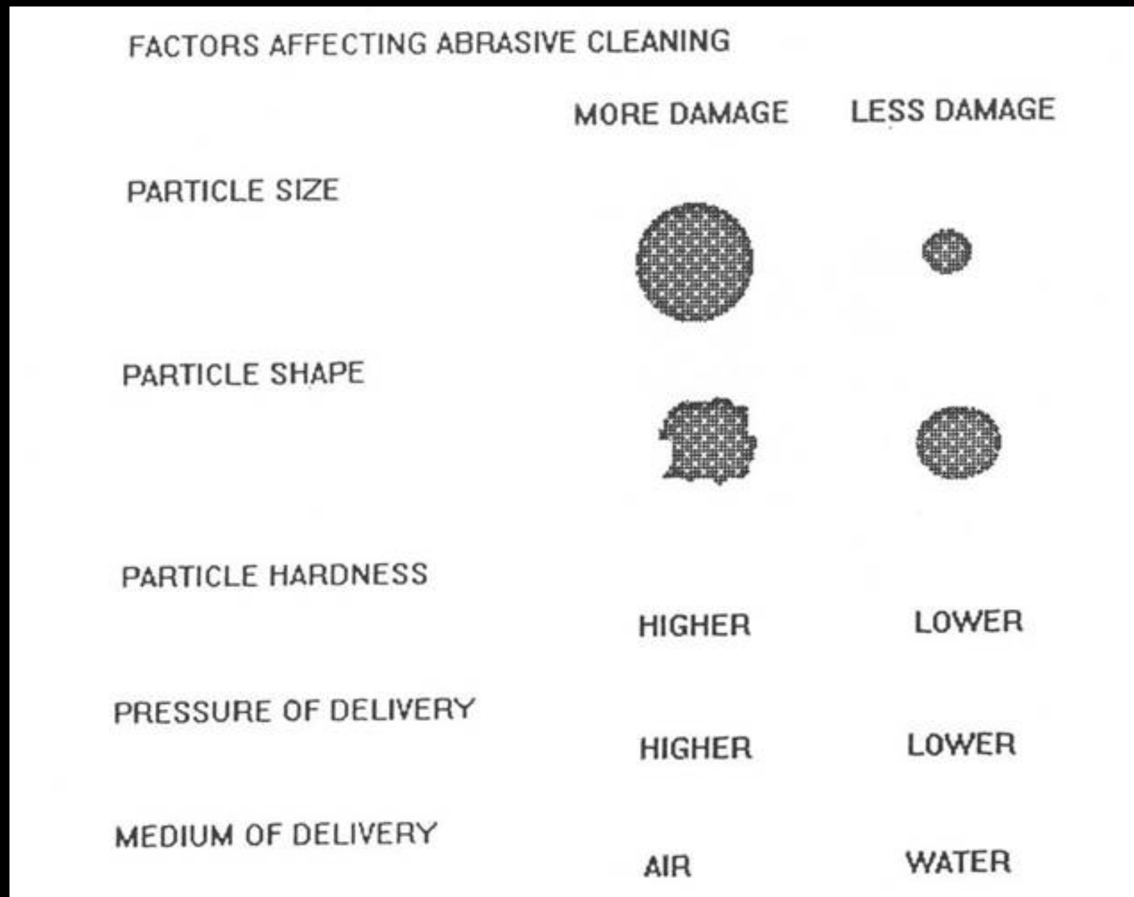
Chemical Cleaning

- *Advantages of Chemical Cleaning*
  - Speed of execution

Chemical Cleaning

- *Disadvantages of Chemical Cleaning*
  - Usually requires pressure washing for adequate removal of chemical residues
  - Usually requires acids either as a cleaning agent or neutralizing agent that can attack the substrate
  - With speed of execution comes limited control
  - Can leave residues that lead to efflorescence and possibly salt damage
  - Can alter color of stones by changing oxidation state of iron oxide compounds
  - Can deposit fine white particles on surface

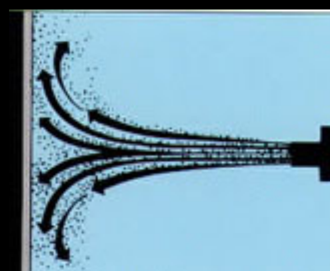
Abrasive Cleaning



Abrasive Cleaning

- *Façade Gommage or Thomann Hanry*

• Medium	glass beads or aluminum oxide
• Size	15-90 microns
• Shape	round-to-angular
• Pressure	35-50 psi
• Delivery	air
• Working Distance	approximately 10 inches perpendicular to surface

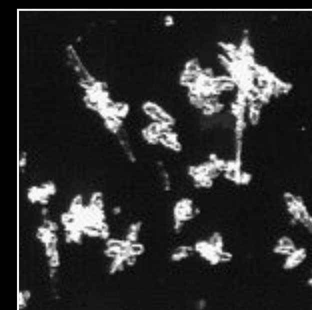


- Containment can be difficult on non-flat surfaces (vacuum)
- No competitive bidding – only one contractor can provide services

Abrasive Cleaning

- *Armex*

• Medium	sodium bicarbonate
• Size	60-600 microns
• Shape	angular
• Pressure	40-50 psi
• Delivery	air and water
• Working Distance	approximately 12 inches
	60 degrees to surface



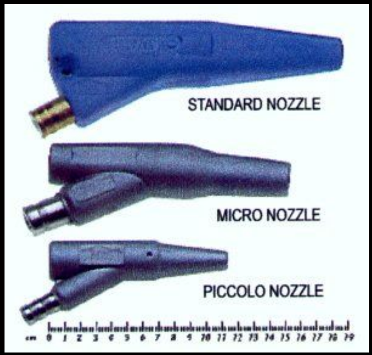
- Not as effective as other abrasive techniques
- May leave sodium bicarbonate residue (results in sodium sulfate salts)

ASSOCIATION FOR PRESERVATION TECHNOLOGY INT'L
STONE RESTORATION WORKSHOP
ATLANTA 2006

Abrasive Cleaning

- *Jos Quintec*

• Medium	dolomite
• Size	60-600 microns with 75% between 70 & 270 microns
• Shape	round-to-angular
• Pressure	30 psi
• Delivery	air and water
• Working Distance	approximately 12 inches, vortex yields 45 degree angle to surface



- Containment is a major problem
- Can be used by any trained contractor – competitive bidding easy
- Multiple nozzle sizes and shapes

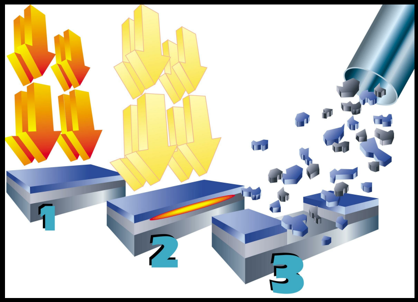
BASSETTI
ARCHITECTS

Abrasive Cleaning - Summary

- Can be used on different stone (and other masonry) types in juxtaposition
- Cannot not be easily used on fragile stone surfaces
- Containment is often a problem
- Can be difficult to achieve uniform cleaning at times
- Does not remove subsurface materials
- Can easily be used in conjunction with other techniques
- Requires trained operators
- Dry techniques eliminate risk of staining
- Wet techniques can mobilize salts
- Soft pointing may be damaged during cleaning
- Resoiling rates may be higher than for other techniques
- Localized cleaning can easily be carried out
- Cleaning is non seasonal
- Cannot remove sub-surface soiling (migration of gypsum into stone)

Laser Cleaning

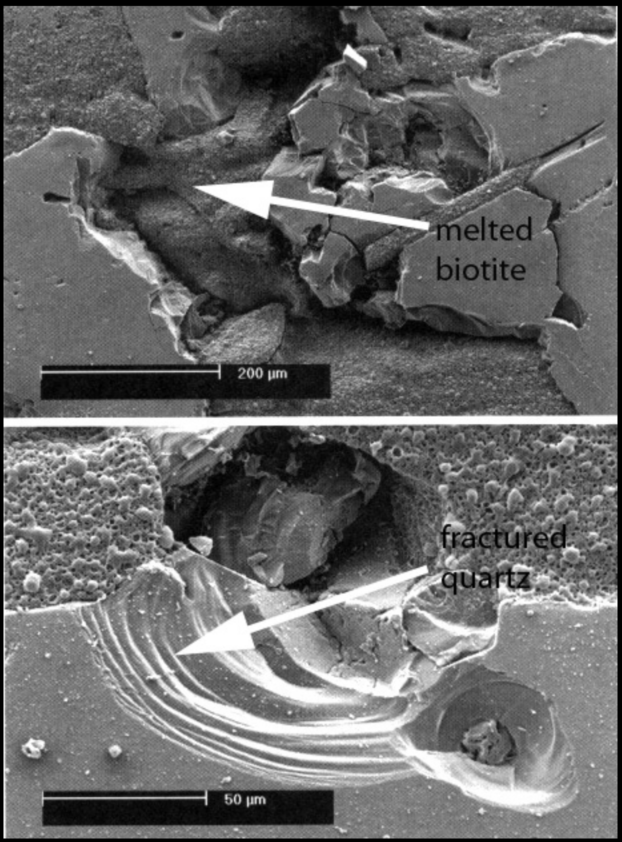
- *Advantages*
  - Not a particle so it can be used on very delicate stone
  - Only works on dark soiling on light colored stone
    - dark absorbs laser energy
    - if used on dark stone, it will damage the stone
  - Physically the most gentle of all cleaning methods
  - Partial cleaning possible – control over small areas
  - Laser cleaning leaves "patina" of gypsum or oxalates



ASSOCIATION FOR PRESERVATION TECHNOLOGY INT'L
STONE RESTORATION WORKSHOP
ATLANTA 2006

Laser Cleaning

- *Disadvantages*
  - Primary risk is yellowing of the stone
    - Sources include patina inherent to object, alteration of structure of the marble, transformation of iron minerals or organics in soiling.
  - Slow – lasers do not cover a large area
  - Can only be used on a narrow range of stone types
  - Expensive
  - Does not remove subsurface gypsum
  - Requires a skilled Operator



BASSETTI
ARCHITECTS

Stone Consolidation

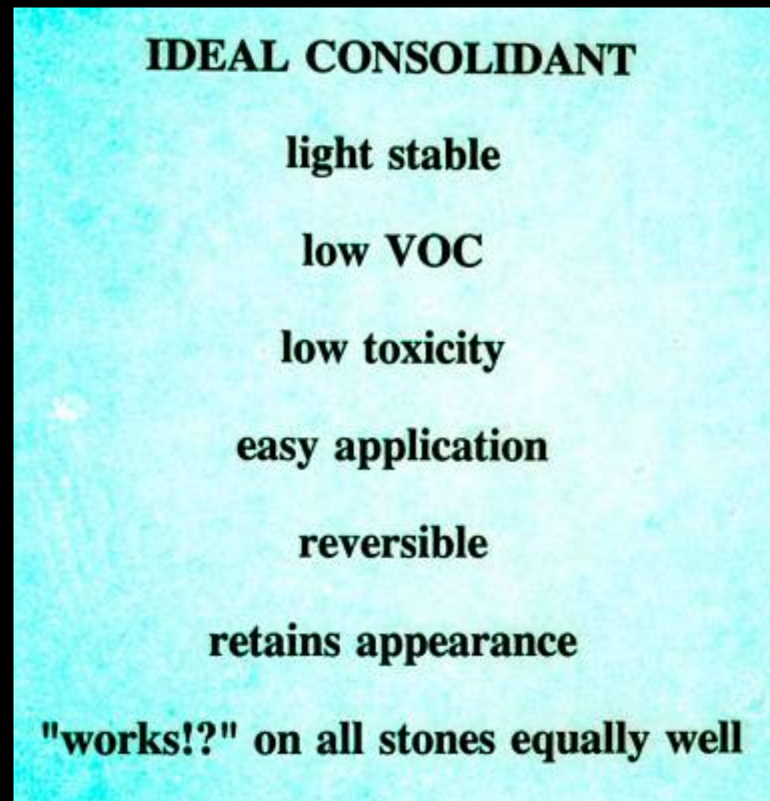
- *What Types of Stone Benefit from Consolidation?*
  - *Limestone*
  - *Marble*
  - *Sandstone*

COMMON ROCKS IN SCULPTURE & MONUMENTS

LIMESTONE	SEDIMENTARY
MARBLE	METAMORPHIC OF LIMESTONE
SANDSTONE	SEDIMENTARY
ALABASTER	SEDIMENTARY
GRANITE	IGNEOUS, PLUTONIC
DIORITE	IGNEOUS, PLUTONIC
GABBRO	IGNEOUS, PLUTONIC
RHYOLITE	IGNEOUS, VOLCANIC
BASALT	IGNEOUS, VOLCANIC
GNEISS	METAMORPHIC OF GRANITE

Stone Consolidation

- *Characteristics of the ideal Consolidant*
  - *Low VOC is not common*
  - *There is no such thing as "reversible" – removal damages stone*
  - *Consolidant can be applied to all substrates, but may not work equally well*



ASSOCIATION FOR PRESERVATION TECHNOLOGY INT'L
STONE RESTORATION WORKSHOP
ATLANTA 2006

Stone Consolidation

- *Types of Consolidants*
  - *Epoxies are not used much anymore*
  - *Toxicity of barium is a problem in environment*
  - *Calcium hydroxide = lime method*

Organic Monomers or Resins

epoxies
acrylics

Biomineralization

calcium carbonate

Inorganic Salts

barium hydroxide

calcium hydroxide

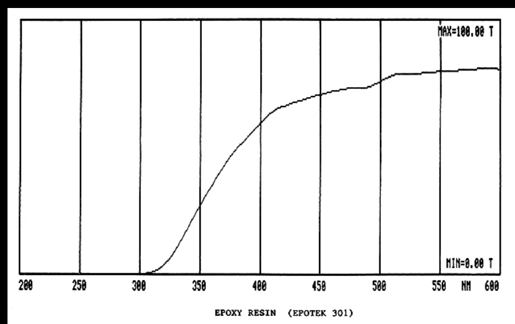
Alkoxysilane Monomers, Oligomers, or Resins

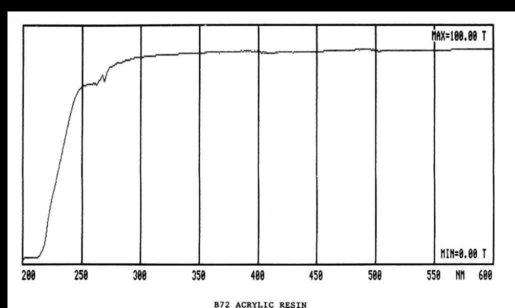
MTMOS
MTEOS
TEOS
Silicone Resin

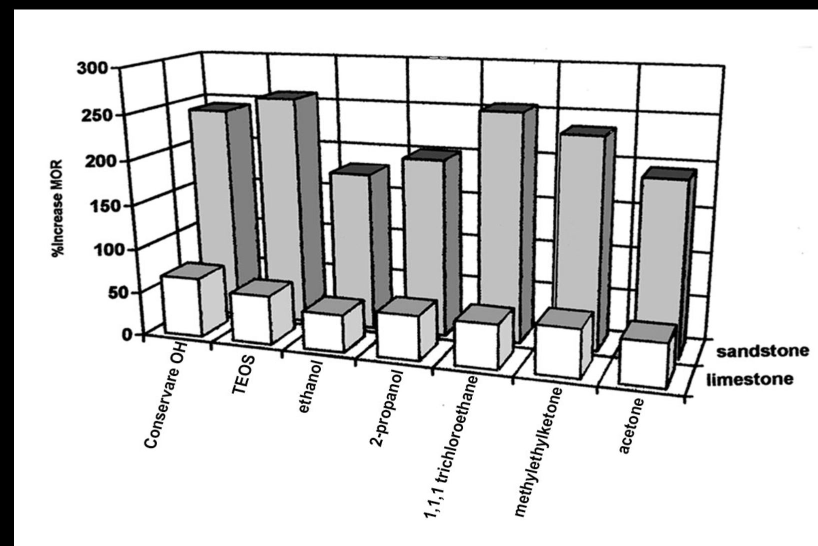
BASSETTI
ARCHITECTS

Stone Consolidation

- Consolidants can strengthen the face of stone, but are subject to UV light degredation







Adhesives and Pinning

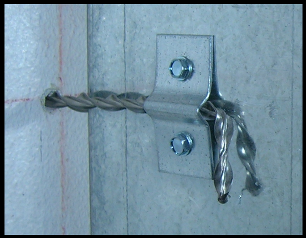
- *Stone Adhesives include:*
  - *Acrylics*
    - *Methyl methacrylate (MMA)*
    - *Acryloid B-72 (ethyl methacrylate and methyl acrylate co-polymer*
    - *Acryloid B-48N (methyl methacrylate co-polymer)*
    - *Addition of Poly Vinyl Acetates (PVAC)*
  - *Epoxies*
    - *Manufacturers include Akemi and Sikadur*
  - *Polyesters*
    - *Manufacturers include Akemi and Sebralit*

ASSOCIATION FOR PRESERVATION TECHNOLOGY INT'L
STONE RESTORATION WORKSHOP
ATLANTA 2006

Adhesives and Pinning

Mechanical aids to reconstructing stone include:

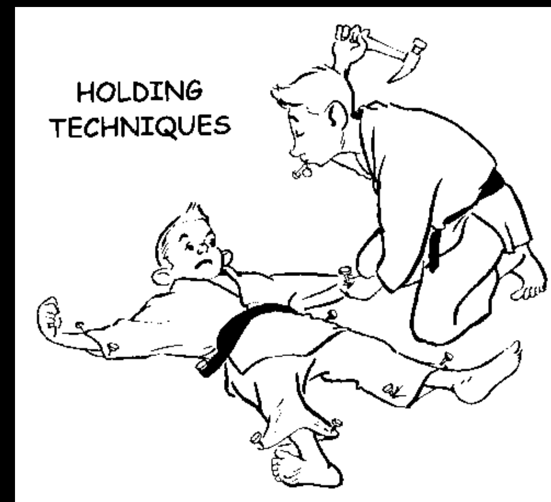
- *Staples*
- *Dowels*
- *Drilled in anchors*
- *Carbon Fiber Reinforcement*
- *Strong-back support of masonry*
- *Teflon*
- *Nylon*
- *Brass*
- *Aluminum*


BASSETTI ARCHITECTS

Adhesives and Pinning

- *Considerations in Pinning Materials*
  - *Material Properties (strengths and weaknesses)*
  - *Installation techniques*
  - *Aesthetic effects*
  - *Coefficients of Expansion (stone versus pins)*
    - *Titanium = Limestone & Marble*
    - *Steel = Concrete and cement mortars*
    - *Aluminum and organic resins are higher than stone, typically*
  - *pH ranges affect steel corrosion*
    - *Low pH = more acidic = more corrosion*



Compensating for Loss of Material

Usually employed when:

- There is a structural necessity
- To alleviate further damage
- Provide visual integration

Compensating for Loss of Material

Two basic methods:

- Replacement
  - In-kind
  - Near in-kind
  - In pre-cast imitation
- Repair
  - Surface
  - Composite (plastic)

Compensating for Loss of Material

Technical Considerations In Choosing A Compensation Method:

- Is it reversible?
- Does it damage the original?
- Does it require removal of the original materials?
- Equal to or less than the strength of the original materials?
- Is it easy to work?
- Is it stable?
- Is it transferable to all cases?
- Is it cost effective?
- Does it satisfy aesthetic requirements?

Compensating for Loss of Material

Additional Considerations

- What is the scale of the loss?
- What is the environment of the loss?
- What are the available resources (materials, craftsman, etc)?

- Additional outdoor considerations include:
  – Durability of the method
  – Good weathering properties
  – No salt content
  – Same properties as stone (thermal expansion, water absorption, exchange, strength, etc.)

Compensating for Loss of Material

Disadvantages of Replacement Option:

- May not be a fulfilling aesthetic
- Usually requires removal of the original materials
- Not a simple process
- Can be expensive

Compensating for Loss of Material

In-Kind Replacement with Dutchmen

dutchmen

Compensating for Loss of Material

Two approaches to Composite Stone Fill (Patching):

- Integral Solution
  - Color, texture, and volume all in one material
- Multi-layer solution
  - Bulk material to create volume plus a refined surface

Compensating for Loss of Material

Advantages of Stone Patching:

- Quick
- Inexpensive
- Relatively easy to match shape and color of original material

Disadvantages of Stone Patching:

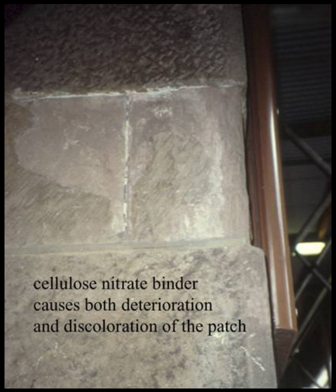
- Inorganic based products – may introduce salts, weak adhesion, variable opacity, may require retouching
- Solvent based products – toxicity, working properties, shrinkage, stability
- Thermoplastic resin based – strength, working properties

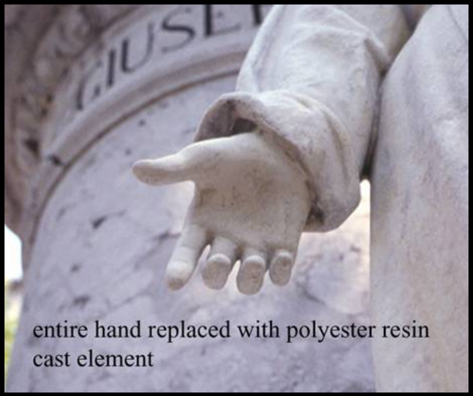
Compensating for Loss of Material

Components of a Stone Patching Material:

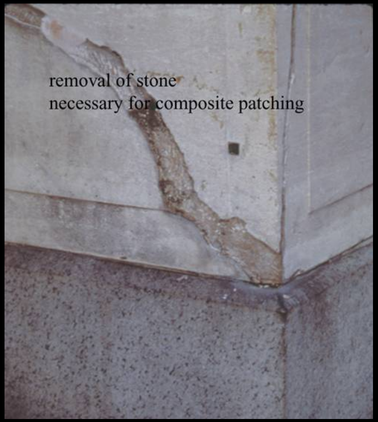
- Binder
  - Cement, Lime, Pozzolans, Plaster, wax, resins
- Filler
  - Stone Dust, Microballoons, Fumed Silica, Frit, Wax, Minerals, Crushed Stone
- Color
  - Dry Pigment, Glass, Stone Dust

Compensating for Loss of Material


cellulose nitrate binder causes both deterioration and discoloration of the patch



entire hand replaced with polyester resin cast element


removal of stone necessary for composite patching


replacement with cast polyester resin


replacement with Pliacre and paint


organic components in fills can discolor

In The Field Hands On Experience

- *Carving stone*
- *Cutting out a Dutchman*
- *Installing marble wall cap*

- *Some photos…*

THANK YOU!

QUESTIONS?