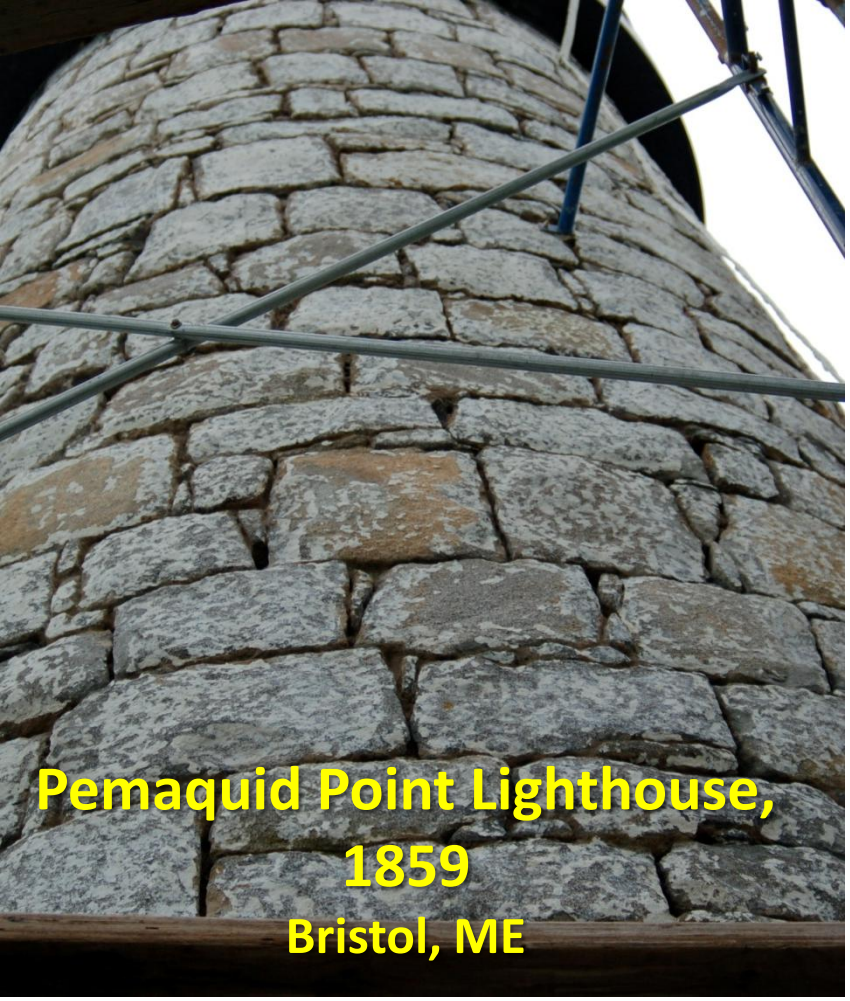
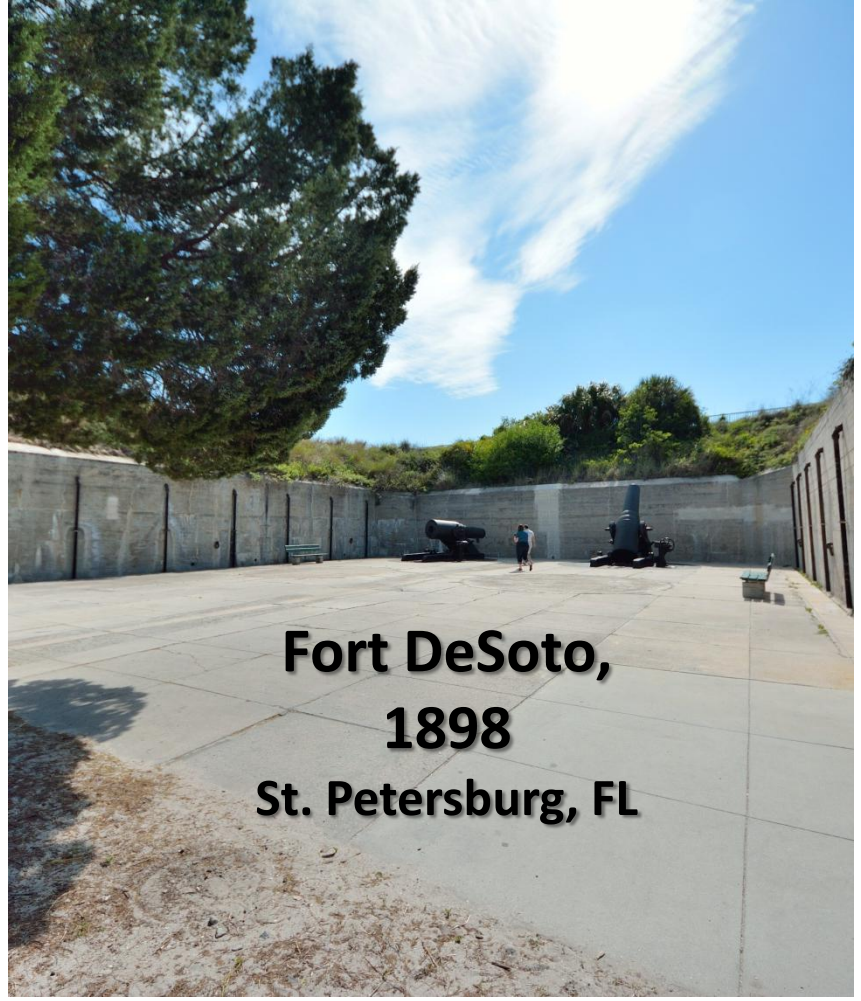




REPLICATE?

REVISE?

REPLACE?

HISTORIC CEMENTS 101

POZZOLANS

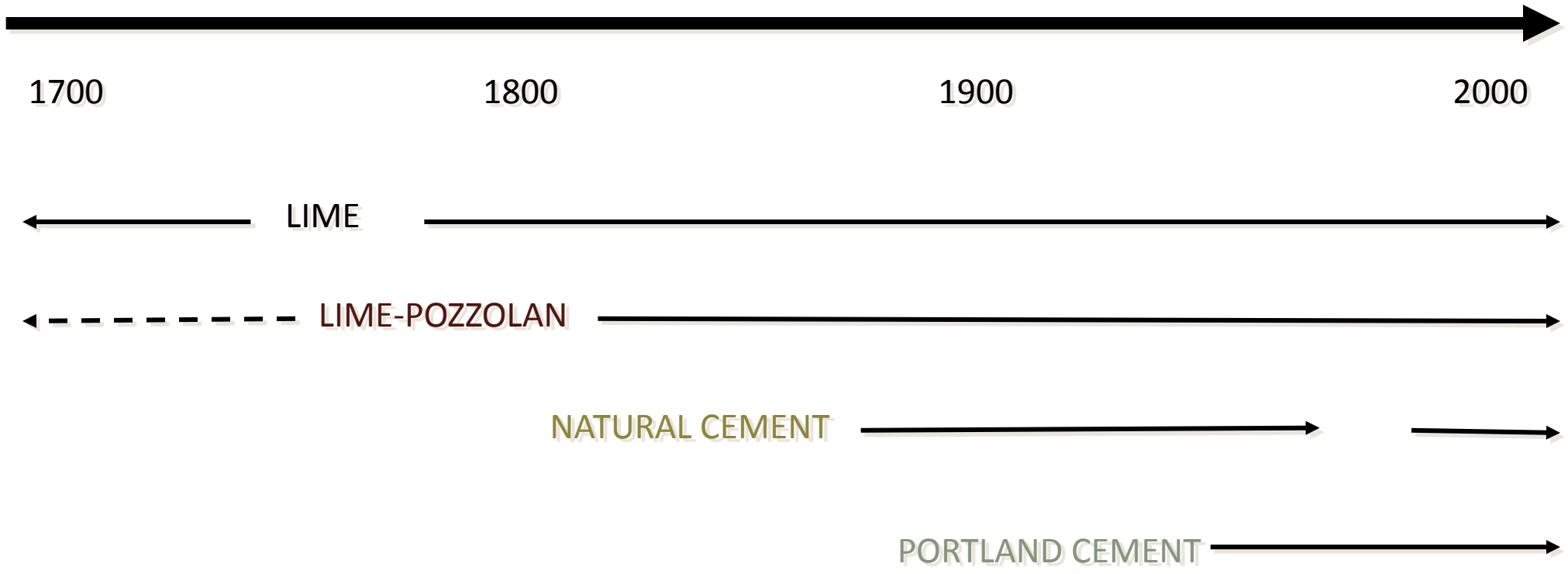
- LIME – POZZOLANS
  - Volcanic Ash – Lime
  - Calcined Clay – Lime
  - Slag – Lime
  - Iron Scale - Lime
- NATURAL HYDRAULIC LIMES
  - From Unintentionally Hydraulic to Eminent
- NATURAL (& ROMAN) CEMENTS
- EARLY PORTLANDS
- OTHERS…

NHL 3.5

NATURAL CEMENT

HISTORIC CEMENTS WERE NUMEROUS…

NORTH AMERICAN BINDER HISTORY

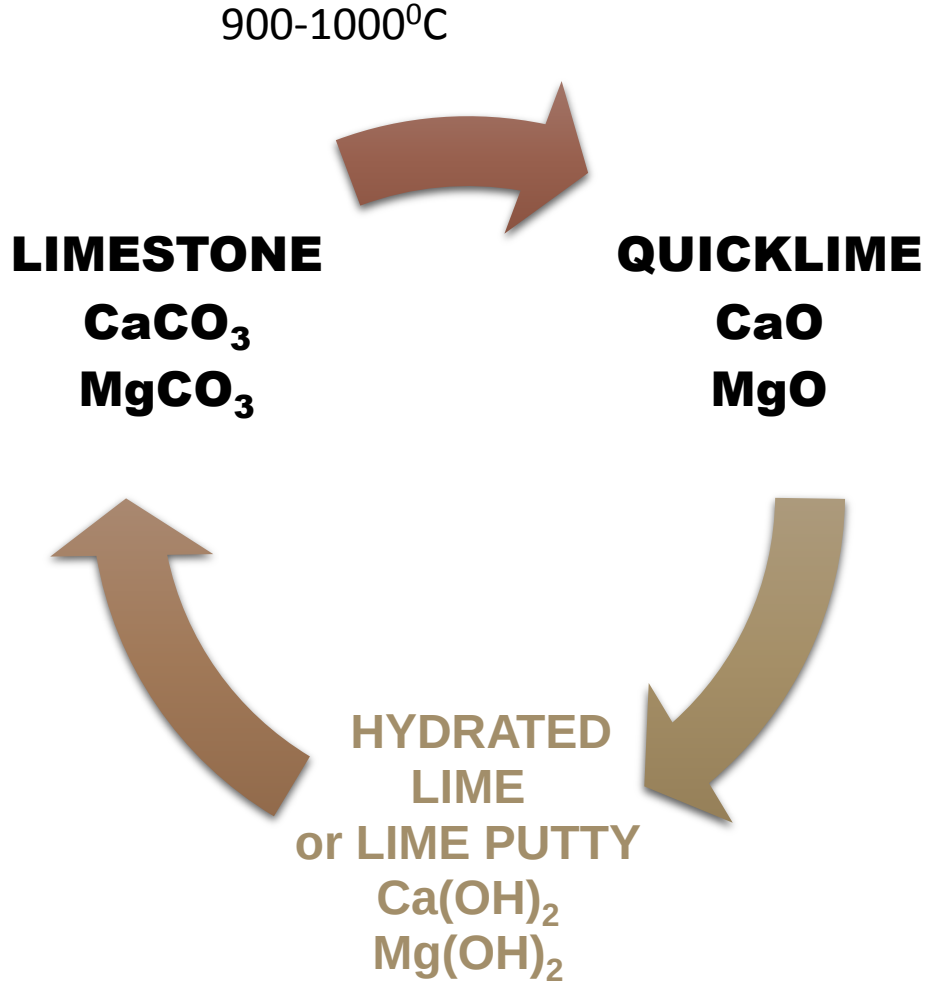


LIME

- Quicklime ASTM C5
  Hydrated Lime ASTM C207
  Lime Putty ASTM C1489
- “Air Lime”
- Non-Hydraulic Lime

New York Botanic Gardens Stone Mill
Built 1840, Lime-Sand Mortar
Repointed 2008, Lime-Sand Mortar

THE LIME CYCLE



Step 1: Calcination

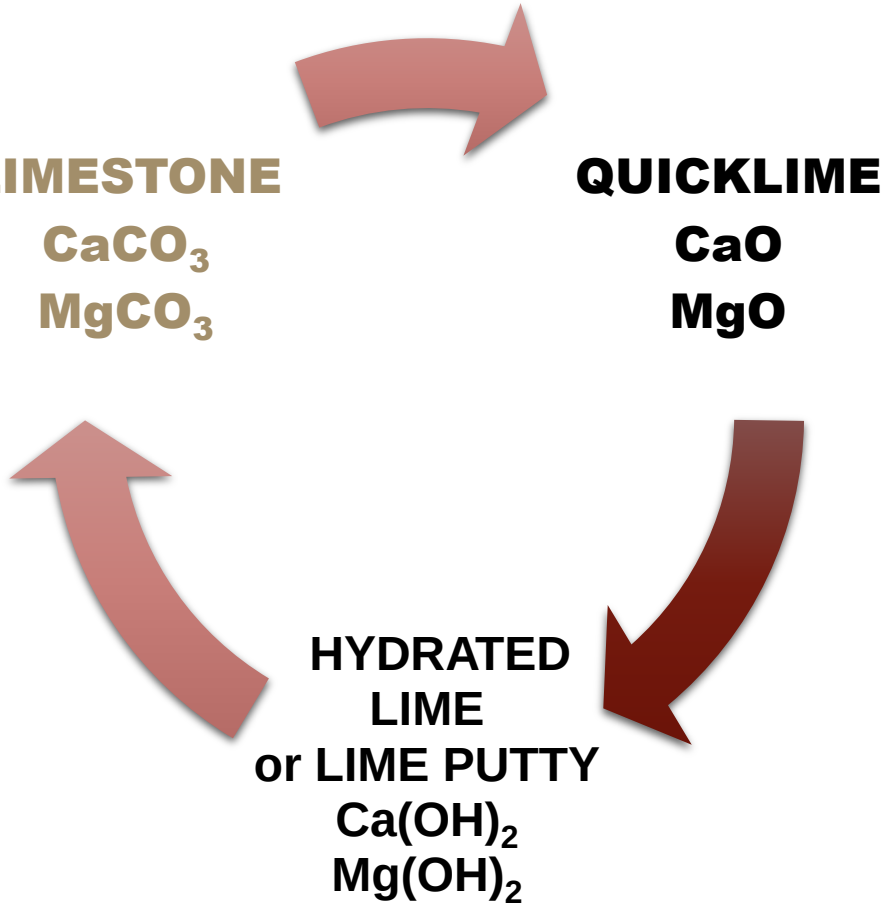
LIMESTONE
$CaCO_3$
$MgCO_3$

+HEAT

$-CO_2$

QUICKLIME
CaO
MgO

THE LIME CYCLE



Step 2: Hydration

QUICKLIME
CaO
MgO

-HEAT
$+H_2O$

HYDRATED LIME
or LIME PUTTY
$Ca(OH)_2$
$Mg(OH)_2$

PUTTY VS. HYDRATE
HI-CAL VS. DOLOMITIC

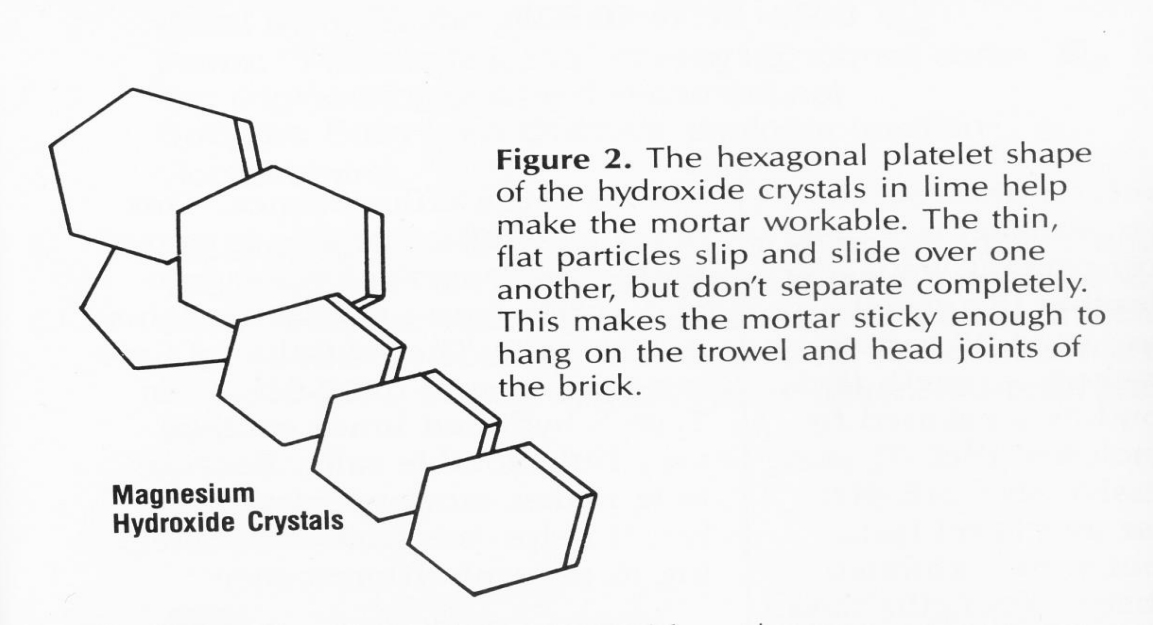
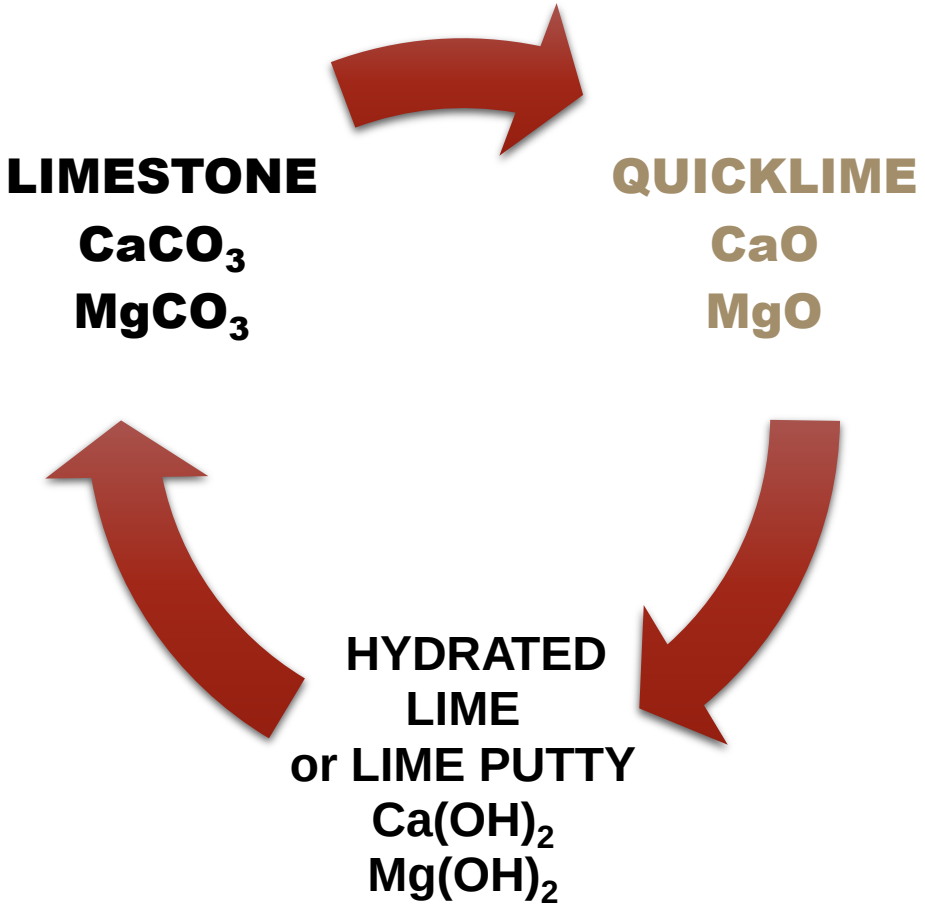


Figure 2. The hexagonal platelet shape of the hydroxide crystals in lime help make the mortar workable. The thin, flat particles slip and slide over one another, but don't separate completely. This makes the mortar sticky enough to hang on the trowel and head joints of the brick.

- Getty Institute Study:
  - Hi-Calcium Lime Develops Hexagonal Platelet Microstructure in 4 Months
- National Lime Association:
  - Magnesium Hydroxide Has Hexagonal Microstructure
- Workability:
  - Water Retention
  - Plasticity
  - "Feel"

THE LIME CYCLE



Step 3: Carbonation

HYDRATED LIME
or LIME PUTTY
$Ca(OH)_2$
$Mg(OH)_2$

$+CO_2$

LIMESTONE
$CaCO_3$
$MgCO_3$

HYDRAULIC CEMENT

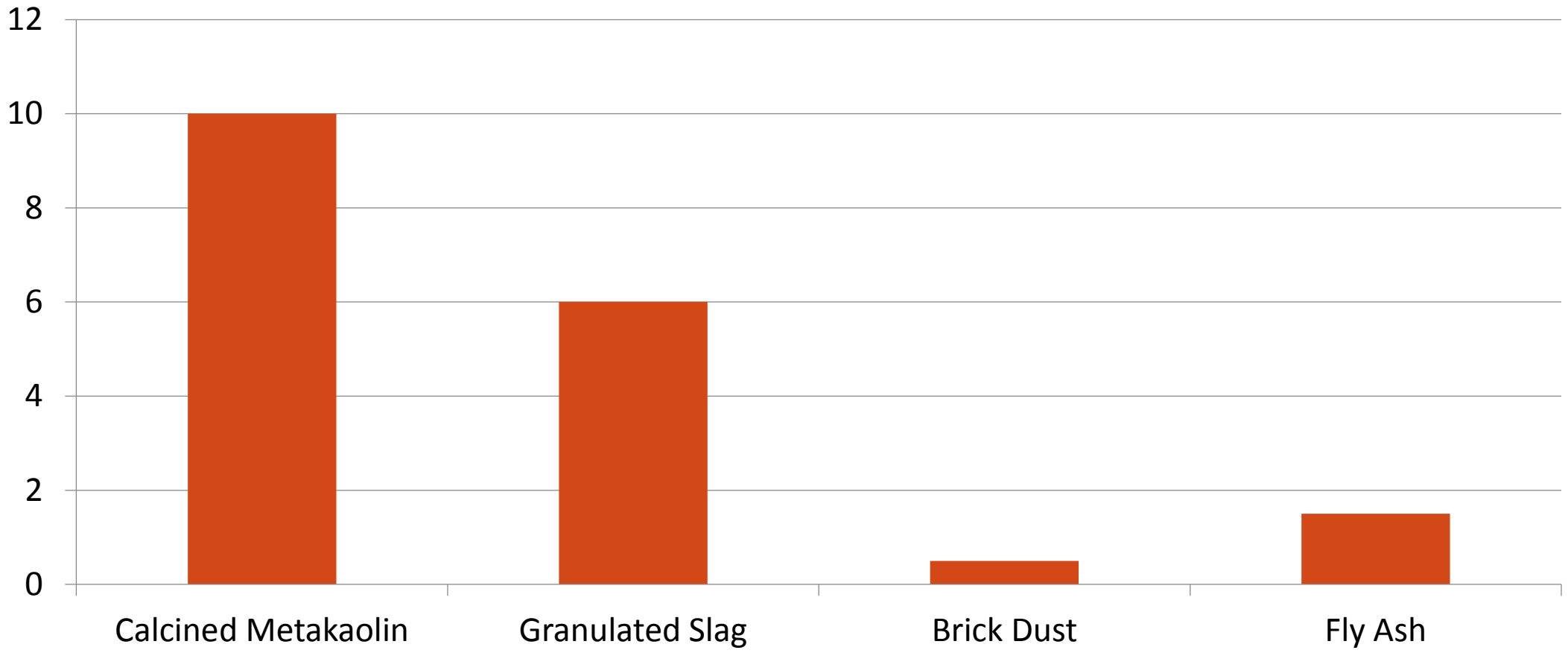
A CEMENT THAT HARDENS BY REACTION WITH WATER (HYDRATION) AND CURES UNDERWATER

POZZOLANS

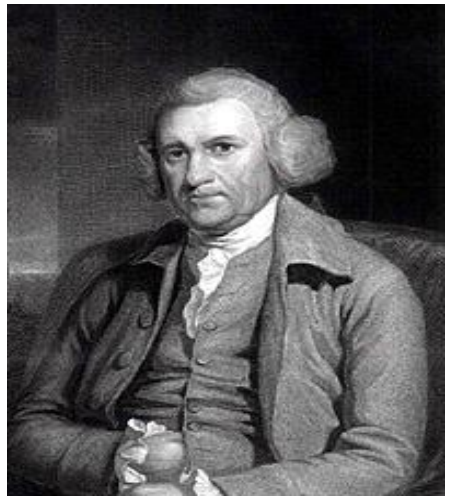
Siliceous or aluminous material, which in itself possesses little or no cementitious value but will, in finely divided form and in **the presence of moisture**, chemically react with calcium hydroxide $Ca(OH)_2$ to form compounds possessing hydraulic cementitious properties

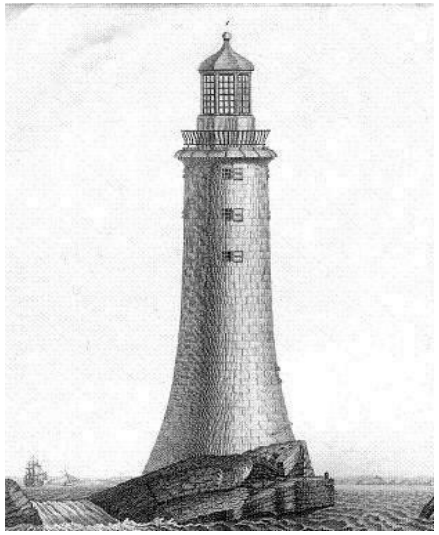
- Natural (Volcanic ash, volcanic tuff, pumicite)
- Artificial (fly ash, silica-fume, granulated blast furnace slag)

POZZOLANIC REACTIVITY



HYDRAULIC MORTARS





- John Smeaton
  - 1750's: Researched Lime from Various Sources
  - Discovered that Clay Impurities Made Lime Hydraulic
  - 1759: Eddystone Rock Lighthouse Built with Hydraulic Lime / Pozzolan Blend
  - Research Published After His Death in 1791

“ROMAN CEMENT”

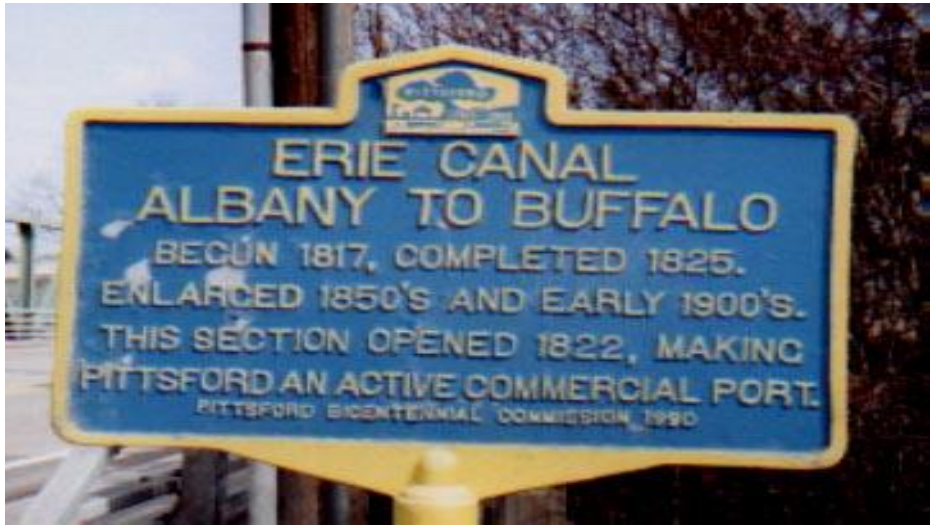
Pontcysylte Aqueduct, Wales, Completed 1805

- 1796:
  Parker’s Roman Cement Patented in England
- Unrelated to Cement Used by the Romans
- Hydraulic Cement from Argillaceous Limestone Septaria
- Used in British Canals, Some Imported to USA
- Low Magnesium Natural Cement
  - “Younger” Geology of Europe vs. North America

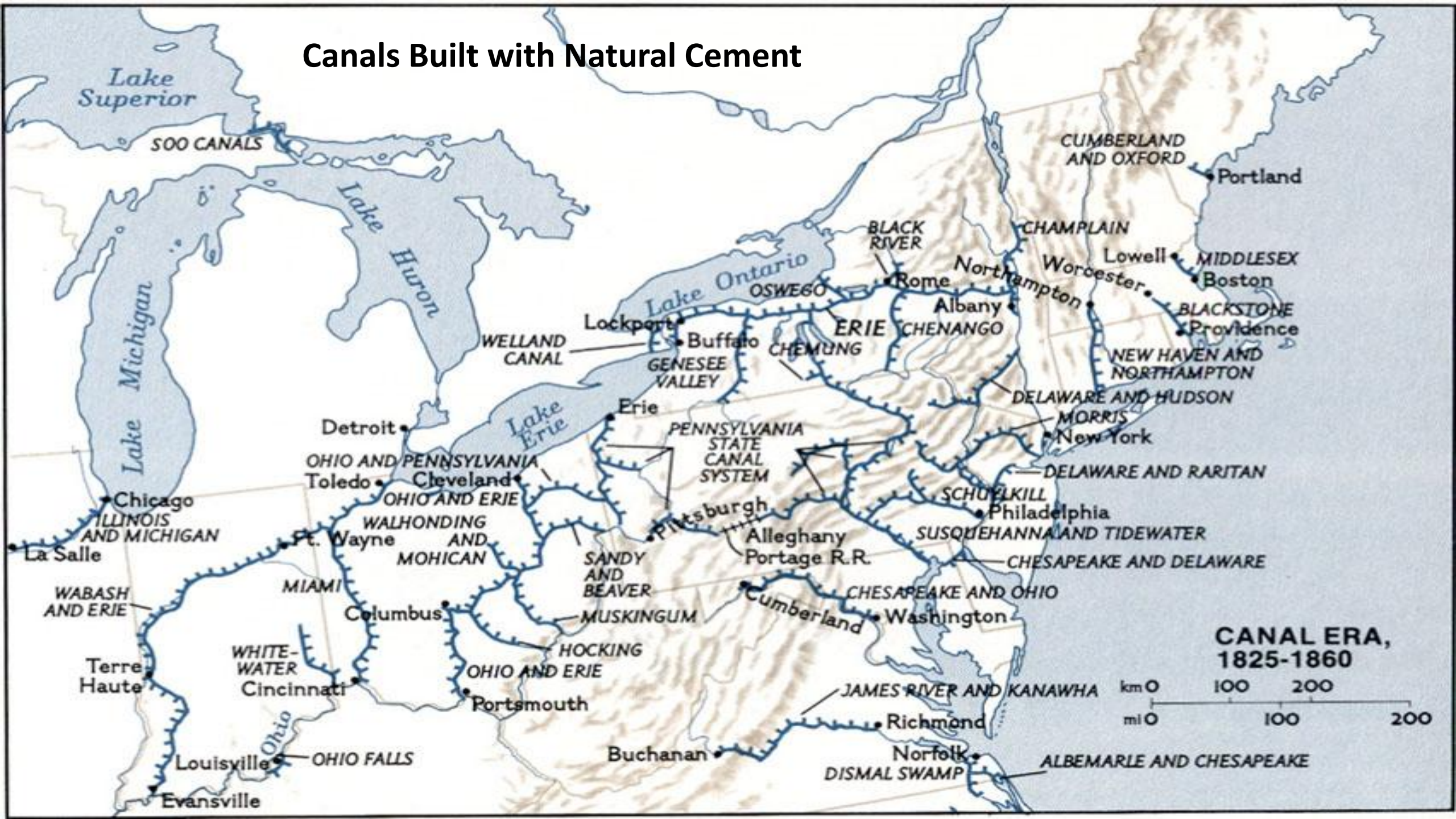
AMERICAN NATURAL ROCK CEMENT

Canvass White

- Sent to England by the Builders of the Erie Canal to Learn Their Secrets
- Learned of Use of Roman (Natural) Cement by the British
- Recommended Use of Roman Cement for the Erie Canal
- Transatlantic Shipment of British Cement Deemed Impractical
- Found Rock to Produce Natural Cement in New York State
- Set Up His Brother in the Cement Business

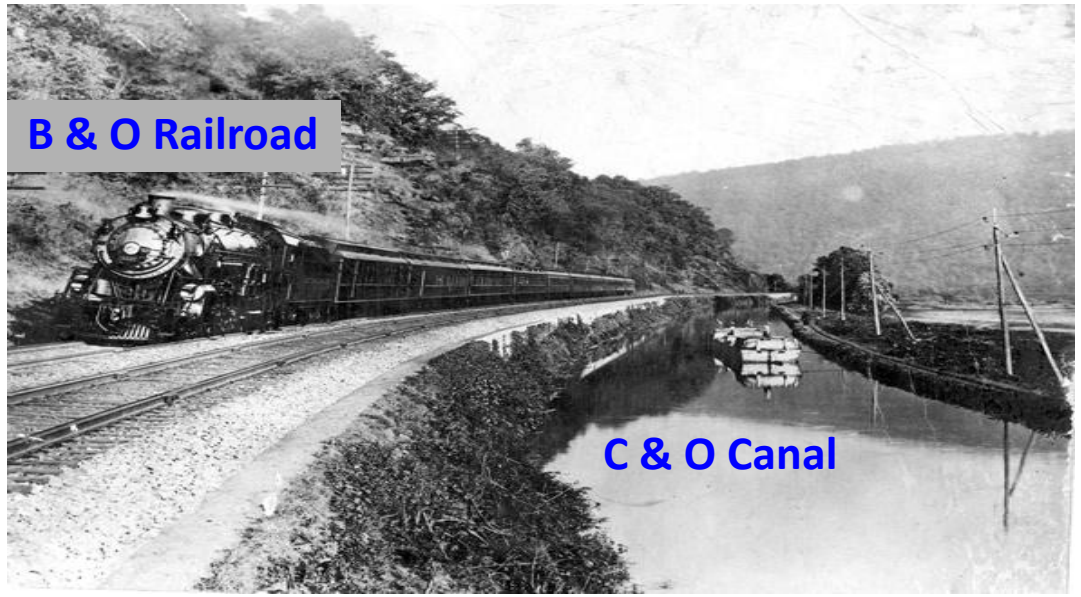


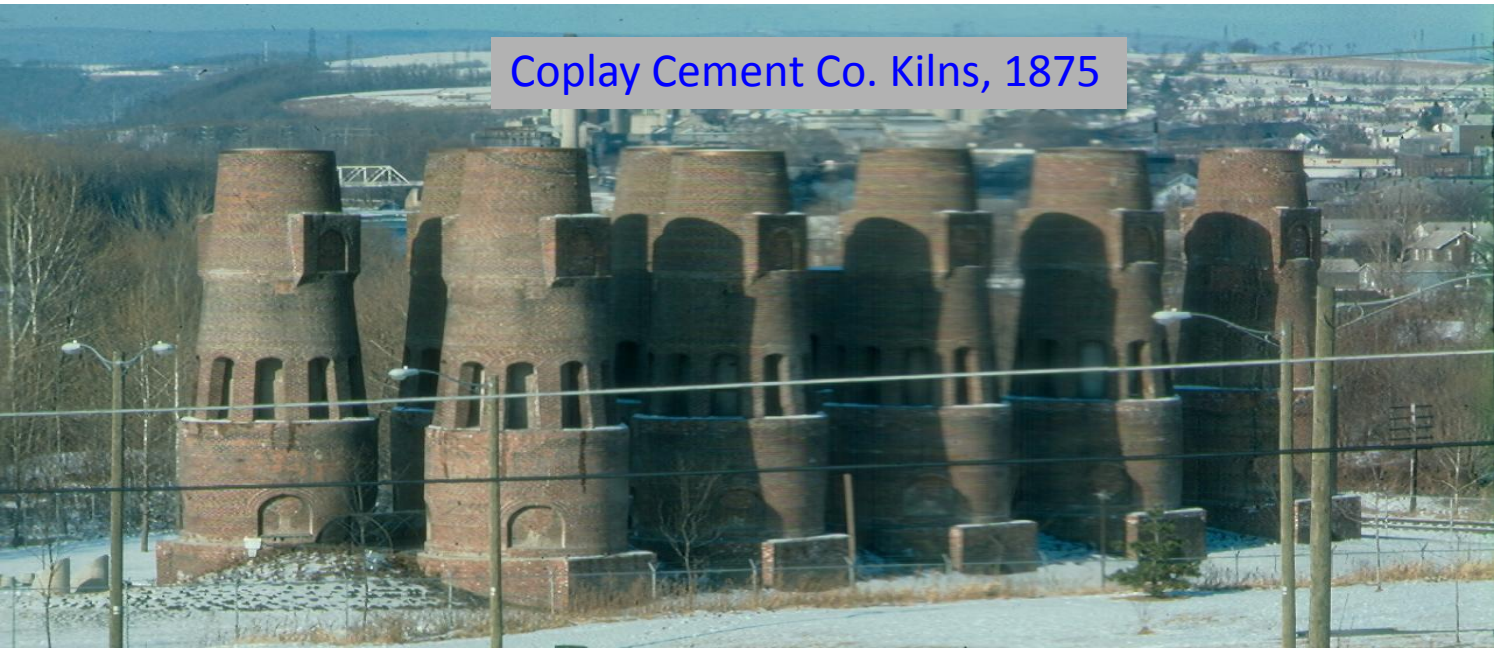
Canals Built with Natural Cement



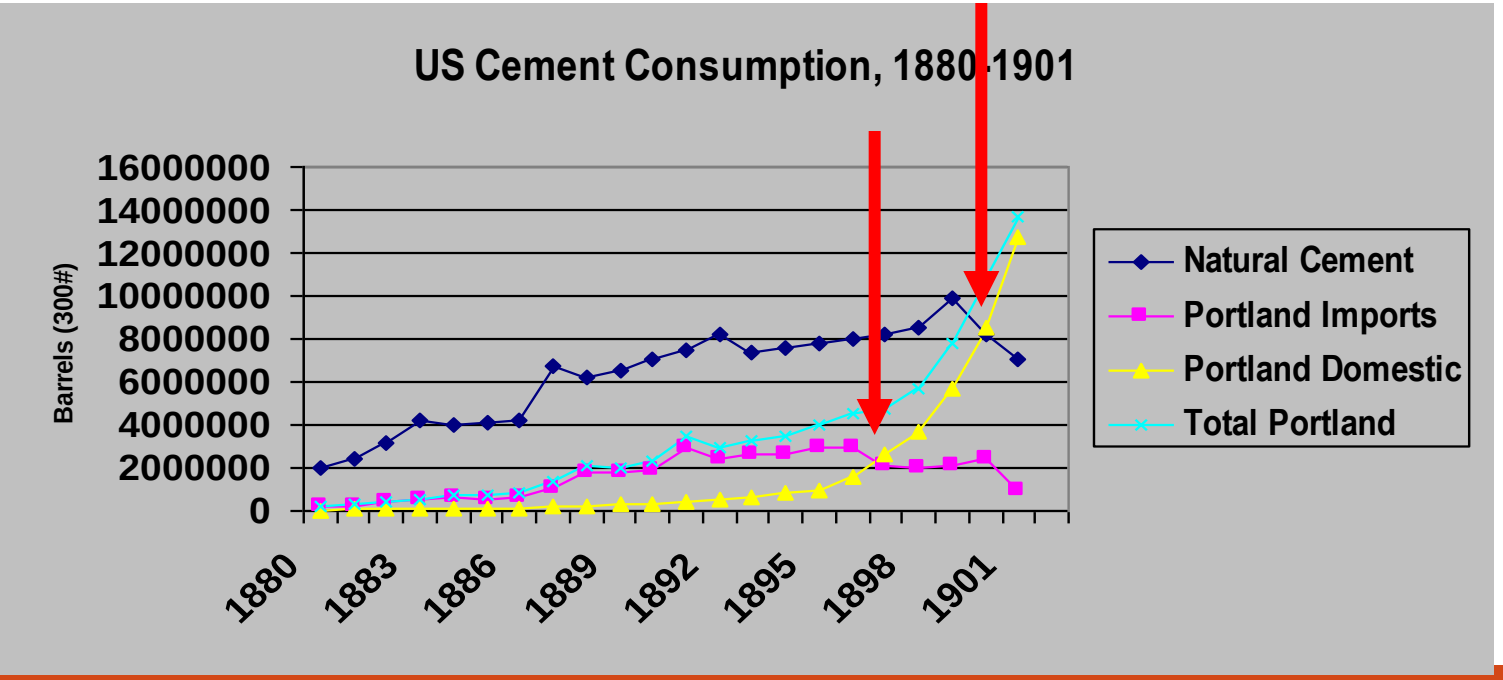
AMERICAN NATURAL CEMENT

- Military Construction of 51 “Third System” Seacoast Forts
- Canal & Railroad-Building
- Industrial Revolution





Coplay Cement Co. Kilns, 1875



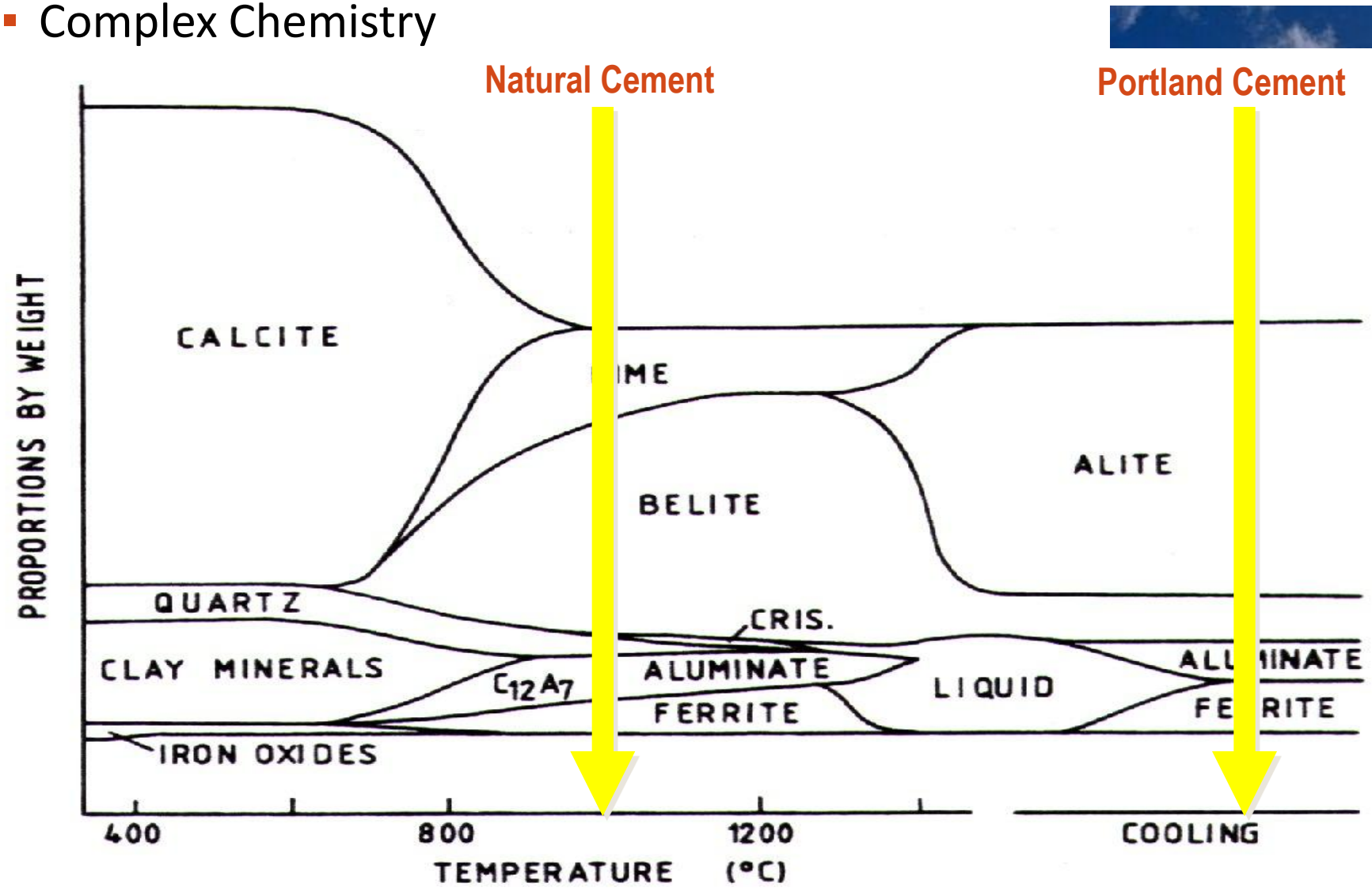
PORTLAND CEMENT

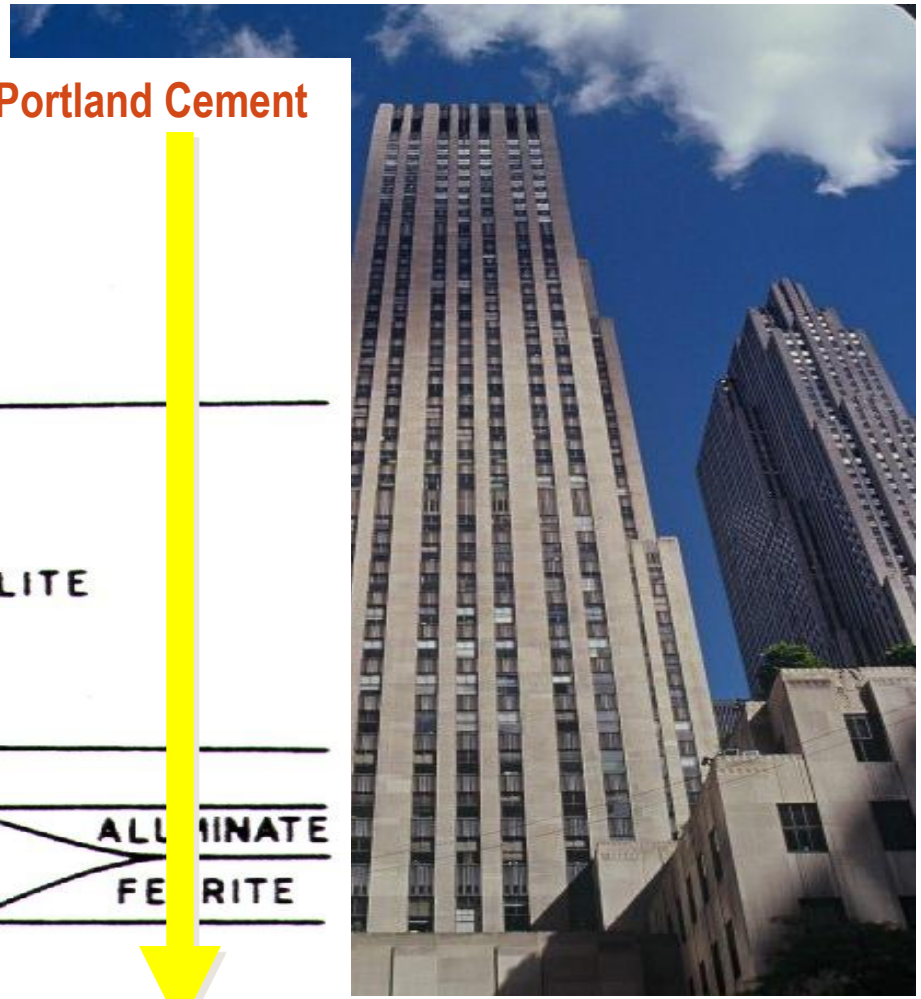
- US Domestic Production Begins 1872-1875
  - Coplay Cement Co., Lehigh Valley, PA
  - Production Rates are Low Until 1897
  - Imports Exceed Domestic Production Until 1897
  - Portland Overtakes Natural Cement 1900
- Significant Process Changes Over Time

PORTLAND CEMENT

ASTM C150

- Complex Chemistry





NATURAL HYDRAULIC LIME (NHL)

- Made from Impure Limestone Without Modifications or Additions
- 3 Strengths:
  - 2.0 Mpa
  - 3.5 Mpa
  - 5.0 Mpa
- Never Intentionally Manufactured in the United States
- Imported for Limestone & Marble Non-Staining White Mortars

100 Centre Street, NYC
Built & Repointed with Natural Hydraulic Lime

AMERICA'S HISTORIC VIEW OF NATURAL HYDRAULIC LIME

"The hydraulic limes are usually, compared to portland or good natural cements, only feebly hydraulic. This fact, taken in connection with the abundance of materials suitable for the manufacture of natural cements, has prevented the introduction of hydraulic lime manufacture into the United States, though in Europe the industry is of considerable importance. No hydraulic lime is at present made in this country."

-Edwin C. Eckel,
"Cements, Limes & Plasters", 9th Edition, 1928

HOW DO WE DECIDE WHAT TO DO?

REPLICATE, REVISE OR REPLACE?

SPHC is a venue for education and advocacy concerning the wide range of distinct cementitious materials used historically in the United States and around the world. These cements are not only an important record of the technology and materials available at a particular time and place, but are components of a building system whose performance and appearance are character-defining features of the structures in which they are located.

HISTORIC CEMENTS: SHOULD WE USE ORIGINAL MATERIALS?

- AUTHENTICITY:
  Historically Correct,
  Repair/Replacement “In-Kind”
- PRESERVATION: Technologies and Methods Unique to a Particular Period
- PRACTICAL:
  Durability, Compatibility, Sustainability

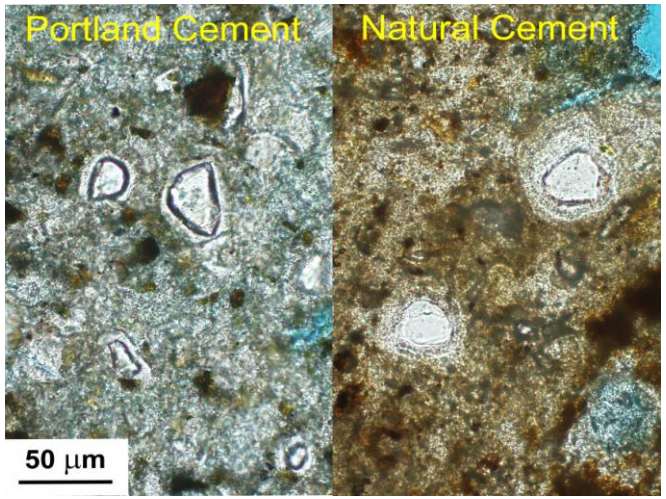
A PROPOSED DECISION TREE

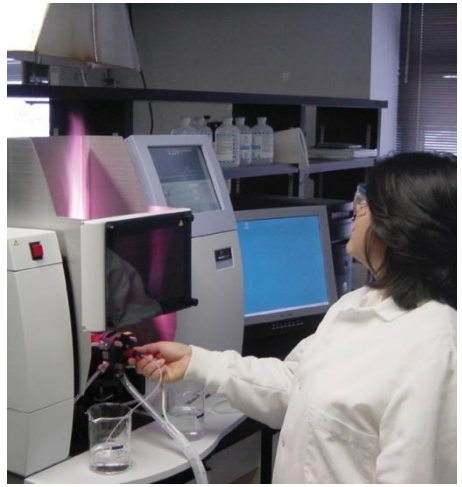
REPLICATE, REVISE OR REPLACE?

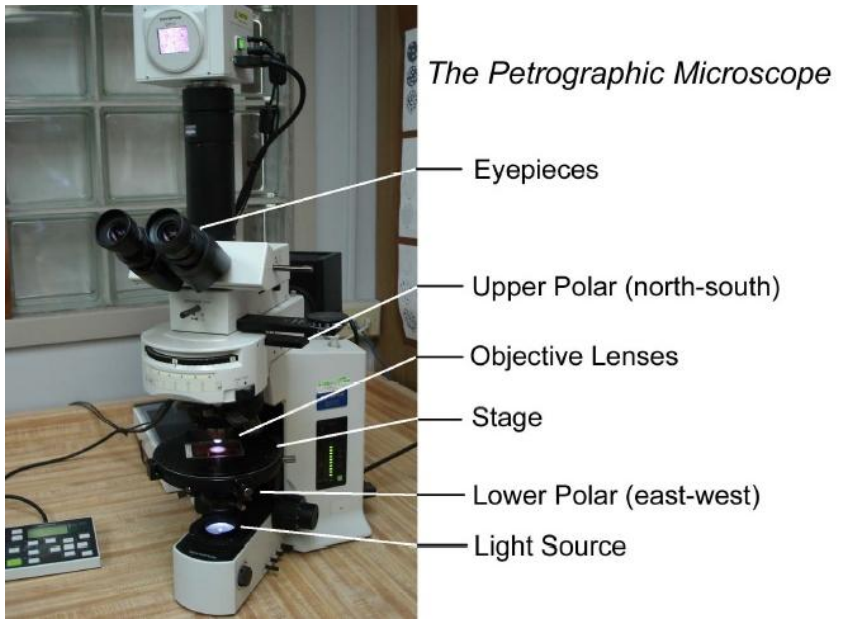
STEP1: ANALYZE ORIGINAL

- **INDEPENDENT LABORATORY**
- **ASTM C1324**
- **PETROGRAPHER TRAINED IN HISTORIC MATERIALS**
- **SUFFICIENT DETAIL TO PERMIT PEER REVIEW**

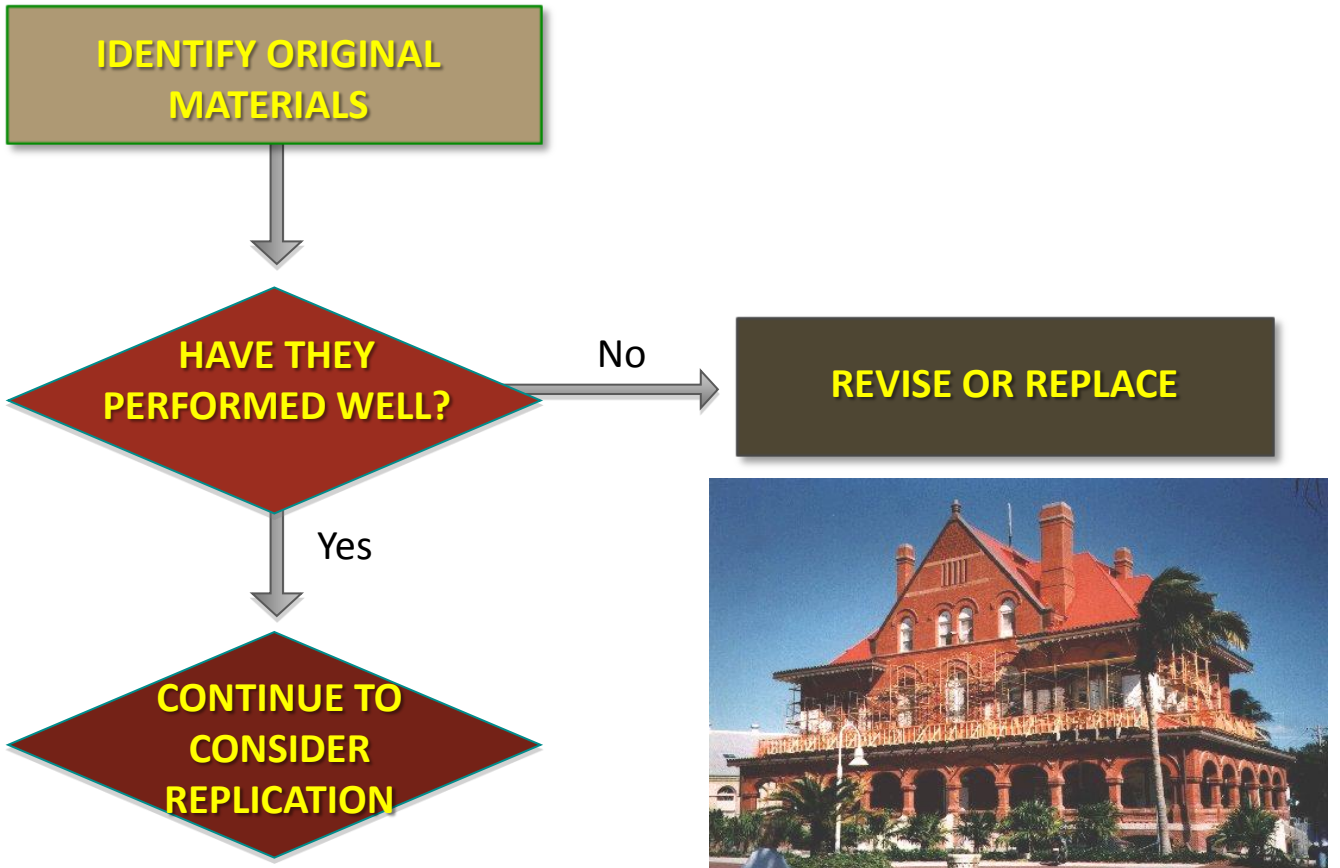
- Chemical Analysis
- Microscopy
- XRD
- SEM







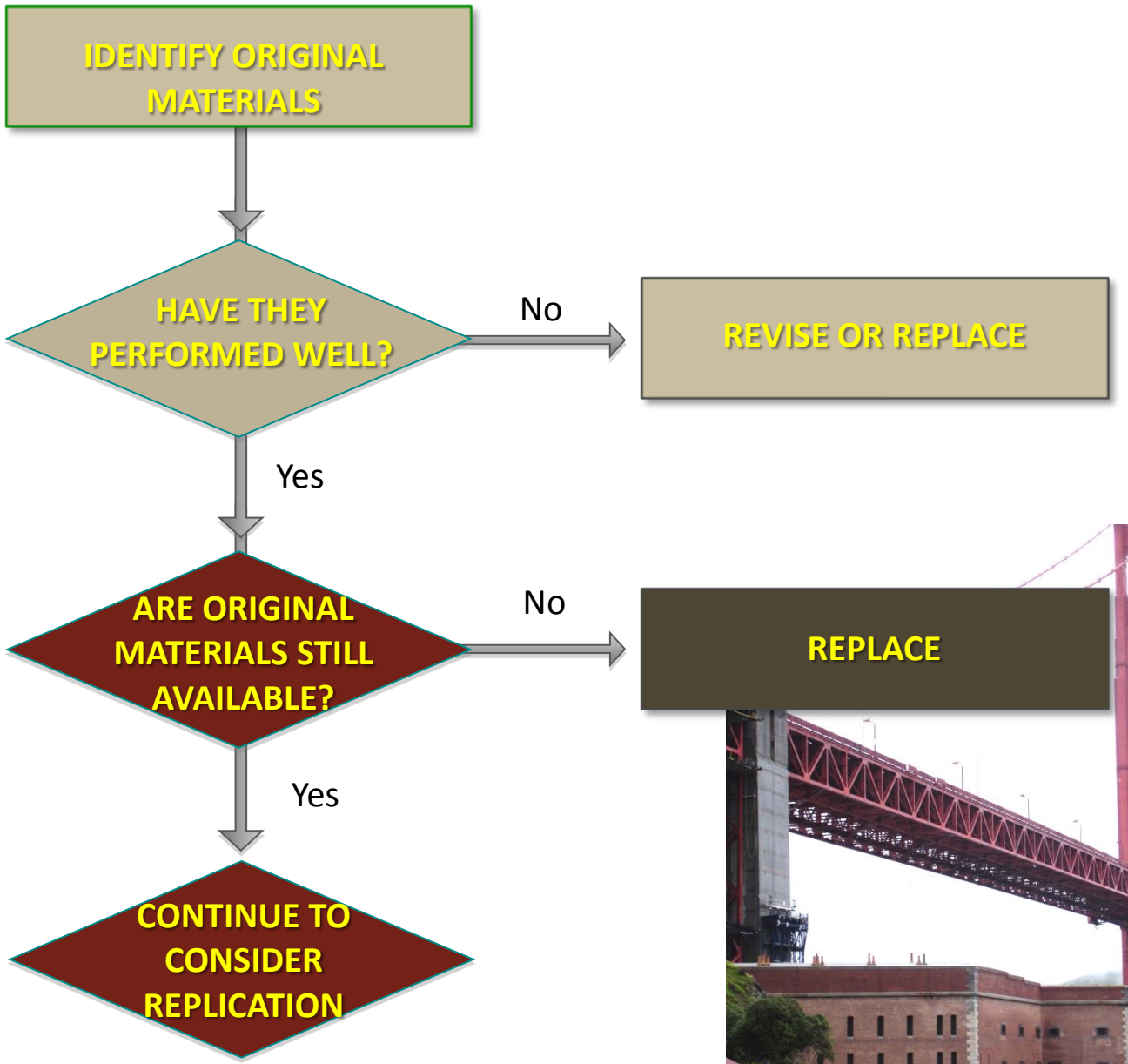
STEP 2: EVALUATE PERFORMANCE



KEY WEST CUSTOMS HOUSE, 1910

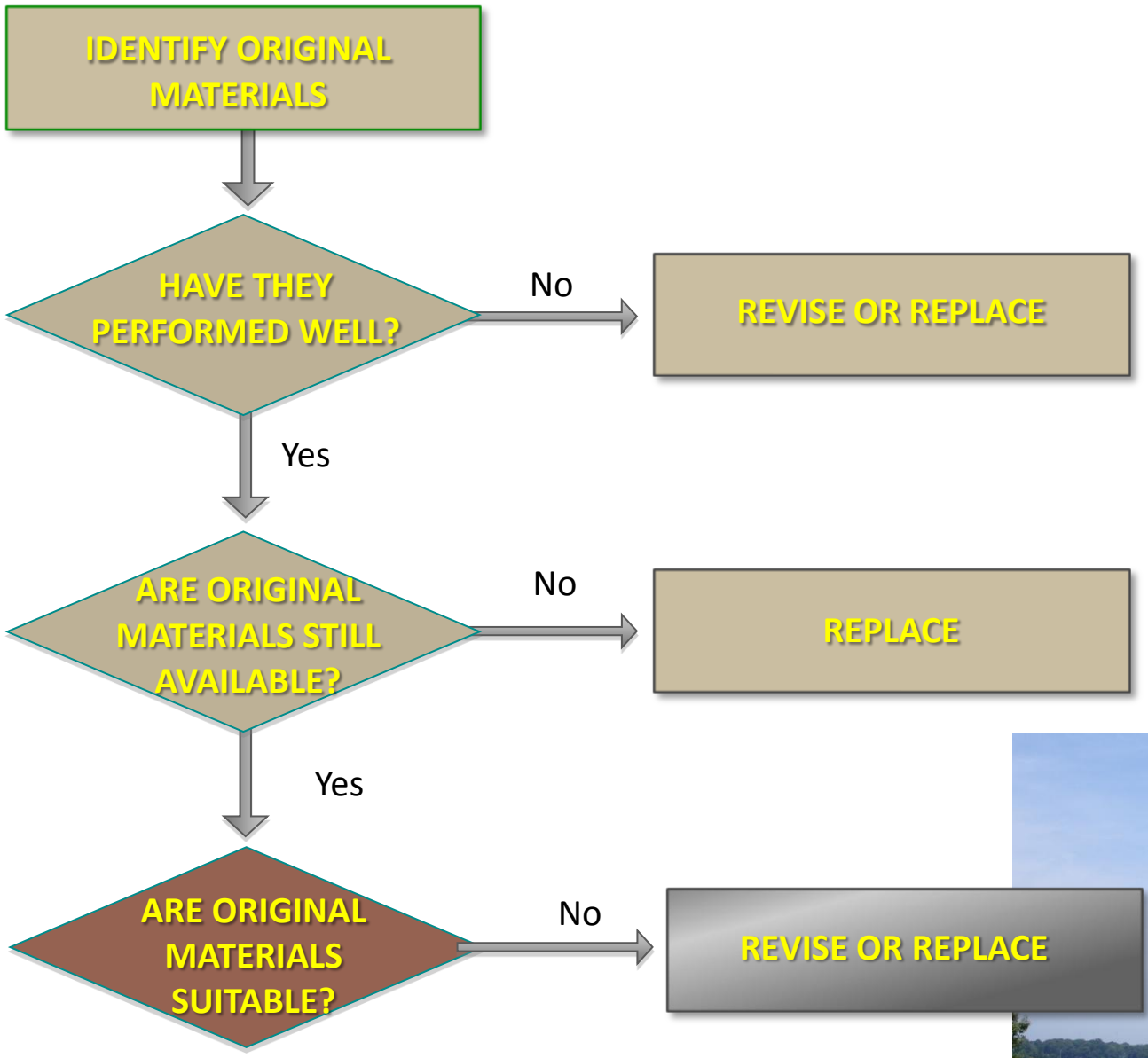
- 22% RED PIGMENT
- SAND TOO FINE
- MORTAR TURNED TO DUST
- "DON'T REPLICATE A MISTAKE"

STEP 3: ARE ORIGINAL MATERIALS STILL AVAILABLE?



FORT POINT, SAN FRANCISCO
Prior to 2004 Original Natural Cement Was Unavailable

STEP 4:
ARE ORIGINAL MATERIALS SUITABLE FOR RESTORATION?



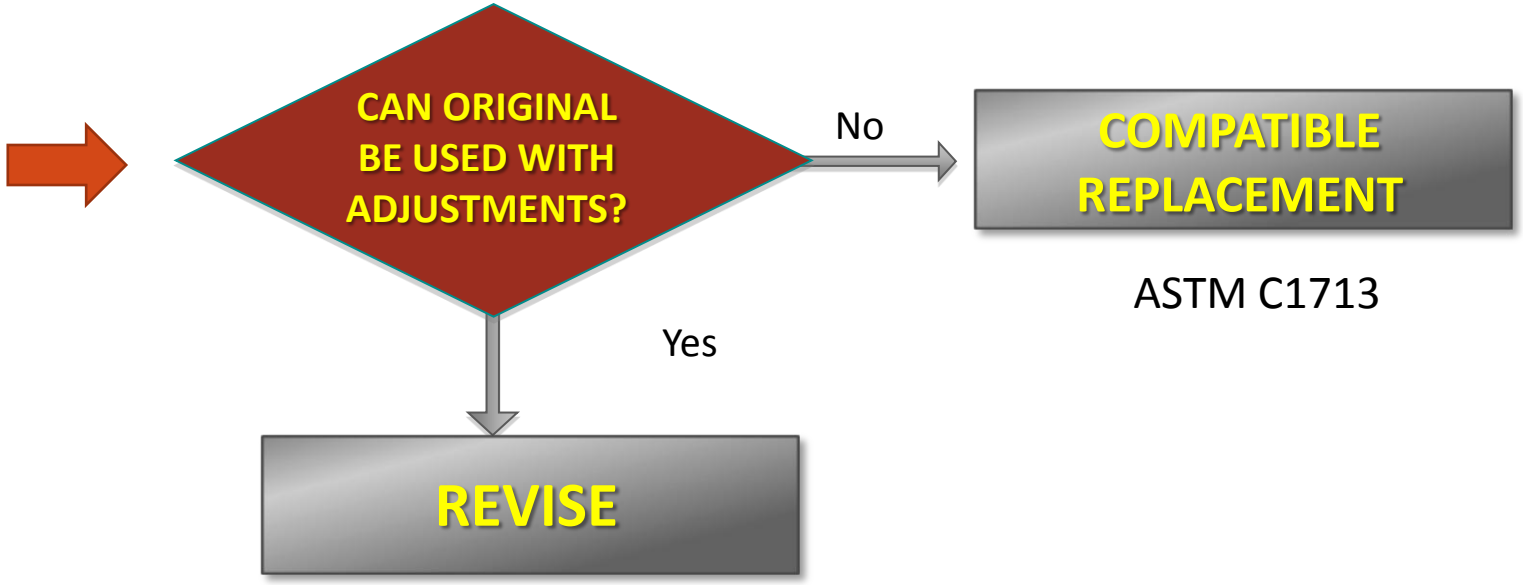
2006

LONDONTOWNE PUBLIK HOUSE
BUILT 1758-1764

- Originally Constructed with Lime Mortar
- After 250 Years' Groundwater Exposure: Salt-Contaminated
- Lime Unsuitable for Salt-Contaminated Masonry
- Replaced with Natural Cement

REVISE OR REPLACE?

STEP 5: REVISE VS. REPLACE



KEY WEST CUSTOMS HOUSE, 1910

- **RED PIGMENT LIMITED TO 10% OF BINDER WEIGHT**
- **SAND REPLACED WITH ASTM C144 SAND**
- **CORRECTED TO TYPE O BY PROPORTIONS, ASTM C270**
- **"DIDN'T REPLICATE A MISTAKE"**

REPOINTED 2014
NHL 3.5 MORTAR

BROOKLYN NAVY YARD BUILDING 20

BUILT EARLY 1900’s, PORTLAND CEMENT MORTAR

BROOKLYN NAVY YARD BUILDING 128

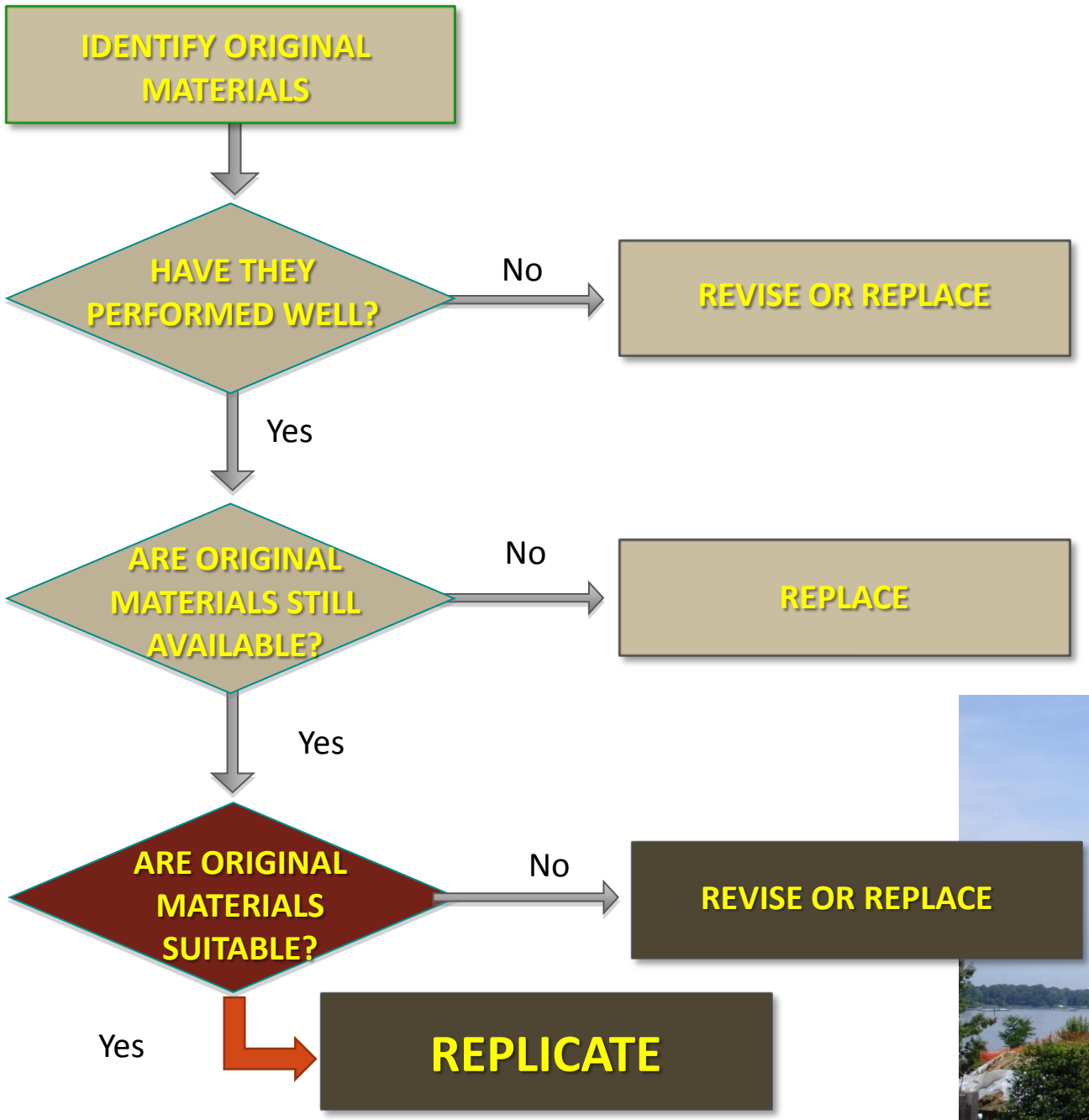
BUILT IN MULTIPLE PHASES

PORTLAND CEMENT MORTAR

REPOINTED 2012

3 DISTINCT DIFFERENT CUSTOM MORTARS

STEP 4:
ARE ORIGINAL MATERIALS SUITABLE FOR RESTORATION?



Courtesy National Park Service

FORT JEFFERSON
Dry Tortugas, Florida

Repaired with
Natural Cement
Replication Mix

AMERICAN MUSEUM OF NATURAL HISTORY

BUILT:1890’S WITH NATURAL CEMENT

REPOINTED 2007-8 WITH NATURAL CEMENT

NY BOTANIC GARDENS STONE MILL
BUILT 1840, LIME-SAND MORTAR

RESTORED 2008, LIME-SAND MORTAR
CHIMNEYS REBUILT W/TYPE K MORTAR

AUTHENTICITY MATTERS!

WE NEED TO APPLY GUIDING PRINCIPLES WISELY