How Concrete got started

Luke M. Snell, P.E., FACI, Honorary Member - ACI
Emeritus Professor of Construction - SIUE
Concrete Consultant
Xenia, OH

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Definitions

- Cement - a substance to make objects adhere to each other
- Concrete - a mass of separate objects held together with cement to form one unit

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To understand concrete

We need to know about cement

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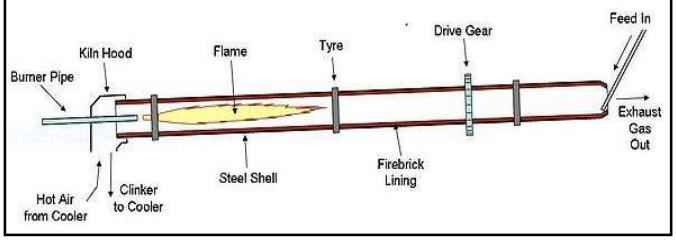
Portland Cement is basically made from Limestone and Clay

Must be heated in excess of 2640 F (1450 C)



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Some of the biggest/hottest equipment

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Heat breaks the molecules apart, then they recombine

Clinker

portland cement

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So how did it all start?

Where did the idea of heating rocks to make a cement come from?

How did we start on the journey of making portland cement?

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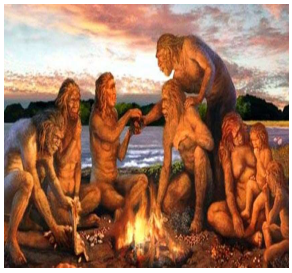
Some ideas from Archaeologist



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Man learned to make and control fire

Early Man - 0.2 to 1.7 Million years ago

Ability to make and control fire - 128,000 years ago

No agreement by archaeologist on these dates

The above dates are conservative estimate

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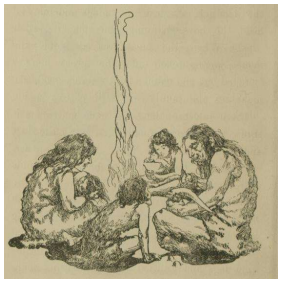
Camp or cooking fires



Typical fires burns up to 1100 F (600 C)

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To have a safe fire

- **Used a fire ring**
- **Seen devastation caused by forest fires and uncontrolled fires**
- **Fire ring provided a safe fire**

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Stones for fire rings – likely Gypsum

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Gypsum

Soft Rock (Mohs Hardness of 1.5 – 2)

Plentiful in many areas

Calcium Sulfate Dihydrate $CaSO_4 \cdot 2H_2O$

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At 300 F (150 C)

Water is driven from the gypsum leaving a powder

Chemical process is:

$CaSO_4 \cdot 2H_2O \rightarrow CaSO_4 \cdot 1.5\ H_2O + 0.5\ H_2O$ (released as steam)

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Temperatures easily obtained in the fire ring

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When exposed to water

Water from rain or used to put the fire out

Reverts back to gypsum ($CaSO_4 \cdot 2H_2O$) however:

- Powder become a "putty" when wet
- Sets up quickly - within minutes
- Bonds well to surface it is applied to (Plaster)
- Provide a weak bond that holds things together

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Likely this was our first "man-made" cement

Discovery was likely accidental

Could be easily reproduced

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This new cement would have limited use

Breaks and falls apart when wet

Limited to interior use or in extremely dry places

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First recorded use of Gypsum was in the pyramids

2600 BCE

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Blocks to build the Pyramids

Average weight about 2.5 tons

Only had simple machines

Blocks were pushed into place by brute force

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Gypsum was used to "butter" the joints

Research project at Southern Illinois University Edwardsville

Measured the force required to move two concrete blocks over each other

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When gypsum was placed between the blocks, it reduced the friction by well over 50%

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Gypsum plentiful in Egypt

Easy to process - required only low temperatures to make
They would not need (or had) a lot of fuel

Only needed the gypsum mortar for the few minutes to push the blocks into place. Quick setting would not be a problem

Gypsum would not be needed to bond blocks together - the weight of the blocks were sufficient to hold the pyramid together

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Gypsum was also used as a plaster

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Provides a smooth surface to paint or decorate

Continues to be widely used for home construction (dry wall)

Craft projects - Plaster of Paris, a pure form of Gypsum

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Most early gypsum projects would not survive in a wet environment

We have not found any gypsum projects older than the pyramids

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Gypsum use would be limited

Competed with mud and clay construction

Mud was free, available and required less processing

It was the ideal material to use in dry areas

Clay became the cutting-edge technology

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Clay construction would provide a comfortable, cheap and cool living space

Widely used in Africa and the Middle East

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Making and building with sun dried bricks

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Mud and Clay Structures

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Saudi Arabia

Casa Grande - USA

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These structures meet the definition of a concrete building

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Making clay a more useful material

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First known use of heating of rocks/soils to make something

Clay figurine fired at low temperatures ≈ 1000 F (540 C)

Time period ≈ 28,000 BCE

Found in the Czech Republic

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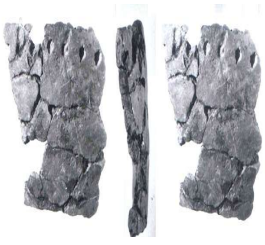
Using fired clay to make pottery provides a useful waterproof vessels



China ≈ 18,000 BCE

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Making Pottery spread to other areas:

Japan and Russia ≈ 14,000 BCE

Middle East ≈ 9,000 BCE

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The early figurine and pottery were:

Made at temperatures that could be achieved by a campfire

Proved to be more durable and useful than unfired clay objects

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Expanded Techniques for heating clay to improve bricks

Fired Bricks were first used in Jericho ≈7000 BCE

Fired at temperatures that could be achieved by campfires

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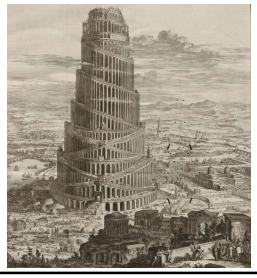
Fired Brick – Biblical story "Tower of Babel"



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Tower of Babel

Fired bricks with asphalt as a "cement"

Estimates from Biblical Scholars that this story was written 4000 - 7000 years ago

We can assume that fired brick technology was well developed and understood by this time

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Fuels used for fires

Wood

Dung

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Early man learned that Dung Fires

Ideal for making pottery

Fuel was easy to find

Less breakage in production

Provided stronger pottery

Provided better pottery than a wood fire

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Dung Fires

Used in Western USA
(Buffalo Chips)

Still common in impoverish areas

Serious health problems
from the smoke

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People gathering Dung

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Modern research on using dung to make pottery

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Sheep dung provides the hottest fire

Sheep dung was plentiful - thought to be the first domesticated animal

Although early man could not measure the temperatures of a sheep dung fire, they:

1. could feel that the fire was hotter
2. had less breakage when making pottery
3. knew they had better and more durable pottery

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Someone realized that even hotter fires would made better pottery

Searched for methods to trap the fire's heat that was lost from an open fire

Created an oven or kiln that captures the heat

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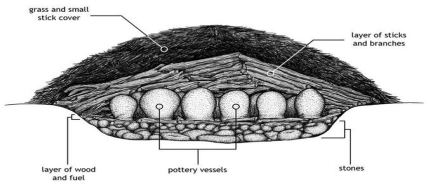
Early Kiln Construction - Used by early Native Americans



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Note the small rocks in the bottom of kiln

If they used limestone - a very common rock

The trapped heat was sufficient to change or break up the limestone rocks

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Limestone rocks starts to break up

at temperatures above 1650 F (900 C)

The attempts to make better pottery was probably the first time they achieved this high a temperature that could break up limestone

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The heat converted the limestone into quick lime:

$CaCO_3 \rightarrow CaO + CO_2$ (this is released as a gas)

$CaCO_3$ Limestone
CaO Quicklime
CO_2 Carbon Dioxide

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When quicklime becomes wet

$CaO + H_2O \rightarrow Ca(OH)_2$ + heat

Process is called slaking

Very caustic (pH ≈12.5) and can burns a person

(Both chemical and heat burns)

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Quicklime is difficult and dangerous to handle

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A technique used in the USA 1800s

- **Dig a hole and place quicklime in the ground**
- **Moisture from soil will slowly and safely react with the quicklime**

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This material is now a cement

Can be mixed with aggregates to make concrete or a mortar between bricks/stones

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Completing the Limestone cycle

Reacts with CO_2 from the air and hardens

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3$$

Bonds bricks/stones or aggregates together and thus they would have created a superior "concrete"

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Likely this was the next step in making concrete

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Steps needed to make Lime

1. Needed to achieve the high temperatures
2. Determine how long they needed to heat the limestone
3. Learn how to safely handle the quicklime
4. Know when the slaking process was completed

A complex process with many steps that needed to be figured out – likely centuries

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To get lime into mass production

Needed to create a better and larger kiln

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Needed small limestone rocks and lots of fuel

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First kilns were before steel hammers, saws and axes

Very labor intensive and quite dangerous

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To make a "batch of lime" in the kiln

Weeks to gather and break up limestone into small rocks (about 1"(25 mm) diameter and smaller)

Weeks to gather the fuel

3 - 7 days in kiln - constant supervision

7 - 30 days slaking

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Archaeologist have found:

Lime was used as a cement to make concrete floors for buildings in modern day Turkey and Israel about 7000 BCE

Obviously, they knew how to make lime by this time

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The Göbekli Tepe Temple – Turkey 7000 BCE

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Lime continues to be used today

Construction
Masonry – make mortar "fatty"
Soil stabilization
Asphalt paving

Agriculture
Improves the soil

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Lime continues to be used

Manufacturing
Steel – biggest user of lime

Environmental
Clean the gases from smokestacks
Treat acidic wastewater

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Tinkering with Lime

Romans – added Volcanic Ash 27 BCE - 476 CE

Build roads, harbors, buildings that at still exist

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Tinkering with Lime

Roman Concrete

Vitruvius documented in his book "De architectura" the details of making lime with volcanic ash and the techniques for successful concrete construction

Note: these construction projects were not reinforced, thus corrosion of reinforcement would not be an issue

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Examples of Roman Concrete

Colosseum -72 CE

Pantheon - 125 CE

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Rediscovering Roman Concrete

Technique was "lost" in the middle ages until a Monk found and translated "De architectura" in the 1400

The Abbey Cathedral of Saint Gall (Switzerland) where Vitruvius' manuscripts were rediscovered

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Development of Natural Cement

1500s

Found that limestone rocks with a small % of clay made better lime – called the new material "Natural Cement"

Looked for limestone with the clay containments that when processed (as lime) would harden in water

If so, they had the rocks to make the natural cement

Pure lime needs CO_2 and thus would not set in water

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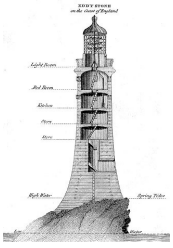
Notable Structures made with Natural Cements

John Smeaton 1750s - Eddystone Lighthouse (UK)



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Notable Structures made with Natural Cements

Canvas White 1820s – Erie Canal (USA)

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First Patent for an "Improved Cement"

Joseph Aspdin – 1824

Figured out the right amounts of clay to add to the limestone in the kiln

Recognized the need of higher temperatures in the kiln than was being used to make lime or natural cement

The new cement was called portland cement because when it set, it looked like limestone rocks from the Isle of Portland

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Highlights in the Timeline for Concrete

1. **Early man - 1.7 to 0.2 million BCE**
2. **Control and use of fire - 126,000 BCE**
3. **1st clay figurine - 28,000 BCE**
4. **1st pottery - 18,000 BCE**

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Highlights in a Timeline for Concrete

5. **Making gypsum - unknown - 30,000 to 10,000 BCE??**
6. **Making lime - unknown - 10,000 to 7,000 BCE??**
7. **Oldest surviving artifact where lime was used (Israel and Turkey) - 7,000 BCE**
8. **Oldest surviving artifacts where gypsum was used (Pyramids in Egypt) - 2,600 BCE**

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Highlights in a Timeline for Concrete

9. **Romans adding volcanic ash to concrete and possibility air (produced a very durable concrete) - 26 BCE to 476 CE**
10. **Use of natural cements - 1500 to 1900**
11. **Patent for "portland cement" - 1824**

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Continued improvements to cement to make a better concrete

Concrete is 2nd most used material in the world (Water is 1st)

Tallest buildings are now made with concrete

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Challenges in Concrete's Future

- **Dealing with carbon dioxide when making cement**
- **Developing non – limestone-based cements**
- **Location of cement and concrete plants**
- **Obtaining and acceptance of supplemental materials**
- **Acceptance of non-steel reinforcement**

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Questions

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