Dois mil anos de tecnologia do concreto e os grandes desafios para o novo milênio

Paulo J.M. Monteiro

Department of Civil and Environmental Engineering

Demanda mundial/ano

- Concreto: ~~11 bilhões t~~
- Água: 1~~,0 bilhões t~~
- Agregado: ~~9 bilhões t~~
- Cimento: ~~1,5 bilhões t~~

~~Demanda de concreto para 2050: 16 bilhões t~~

Mehta & Monteiro, third edition, 2006

Demanda mundial/ano

Concreto: 33 bilhões t

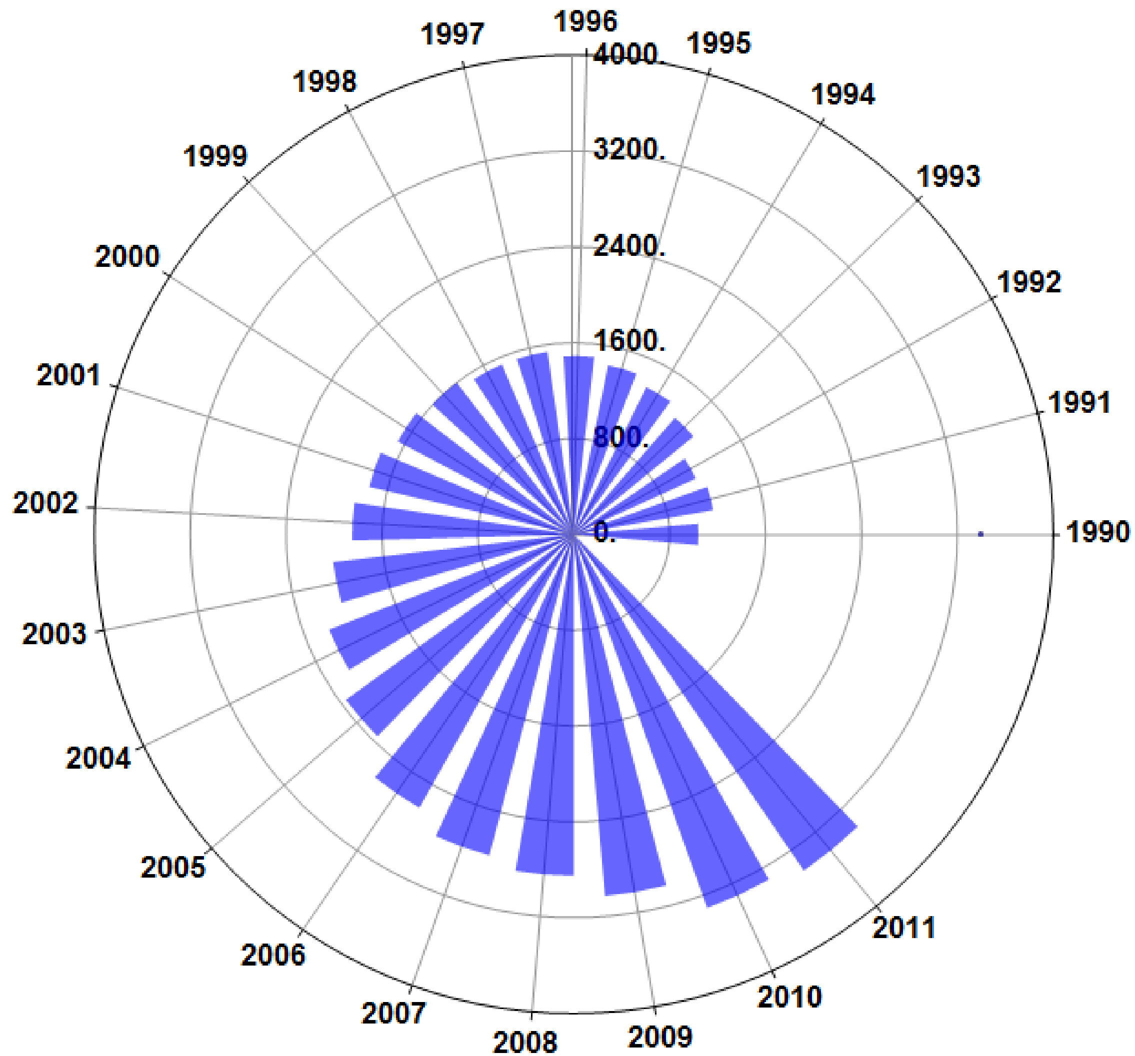
Água: 2,7 bilhões t

Agregado: 27 bilhões t

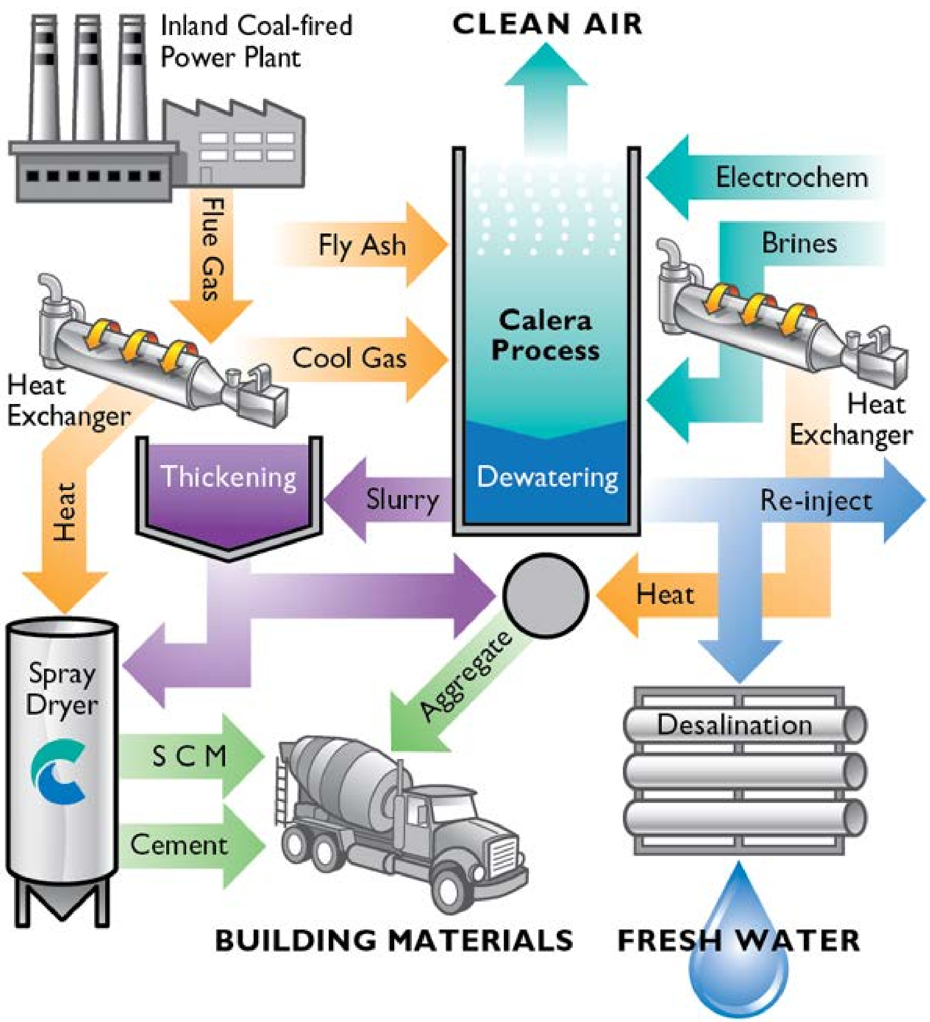
Cimento: 3,7 bilhões t

Mehta & Monteiro, fourth edition, 2014

Produção recente de cimento



Novas oportunidades

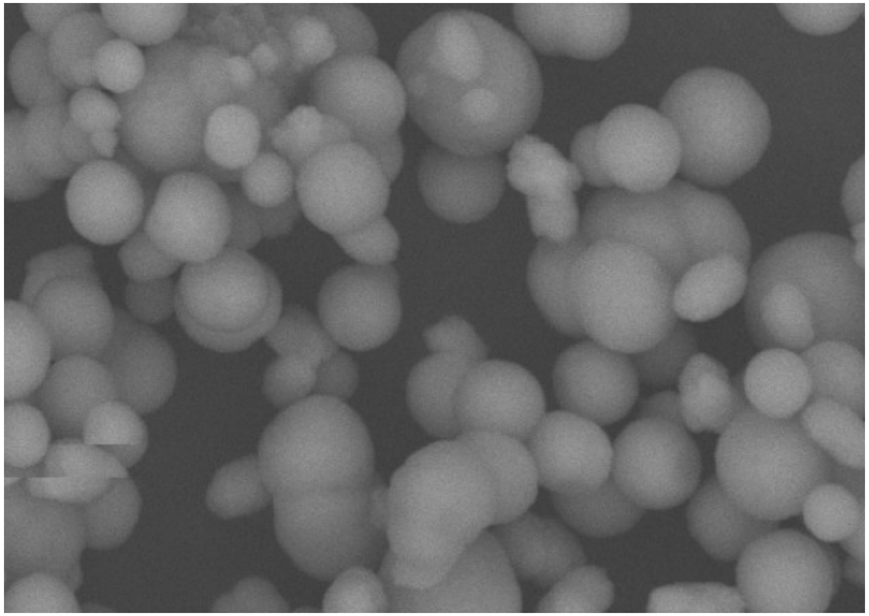


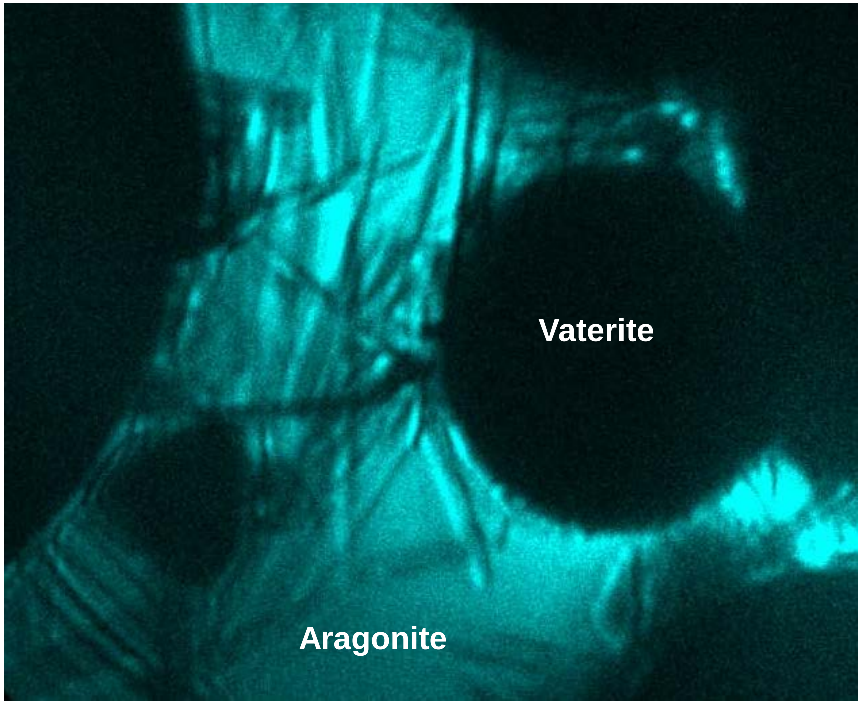
Moss Landing, Ca

<u>Produtos:</u>

Carbonato de Cálcio Amorfo
Vaterita
Aragonita
Calcita

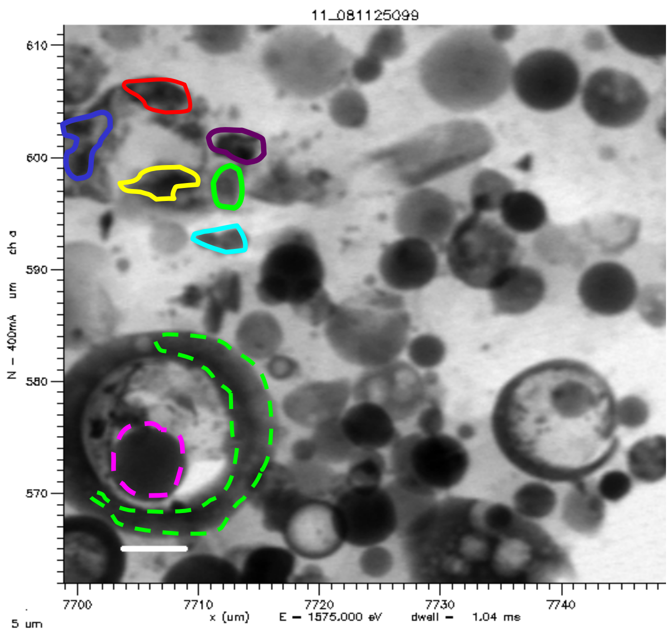
Self-cement



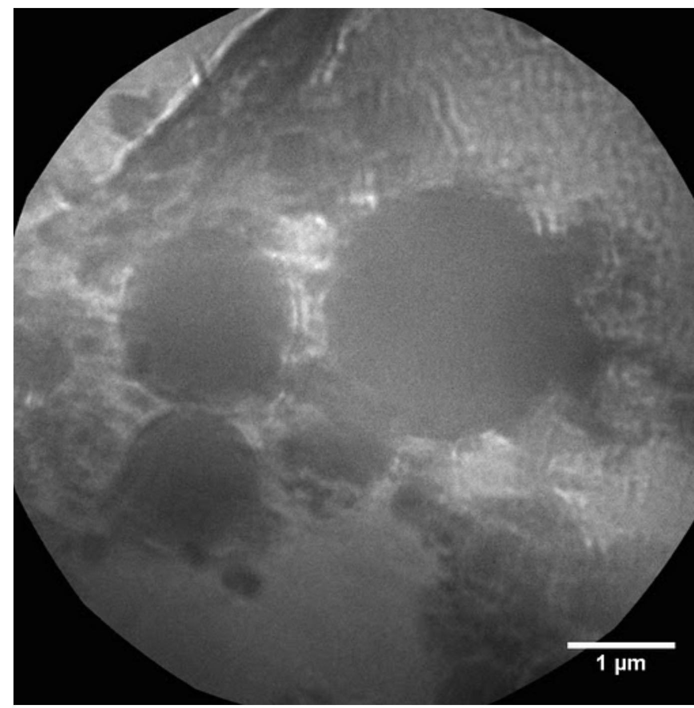


28 MPa em 28 dias!

Geopolímeros



Solução 10 M NaOH



Indústria conservadora

Corrosão (from MATCO's)

Nossa própria experiência...

Topo do mundo em 2009...

Winners of 22nd annual National Concrete Canoe Competition

Com cimento Portland

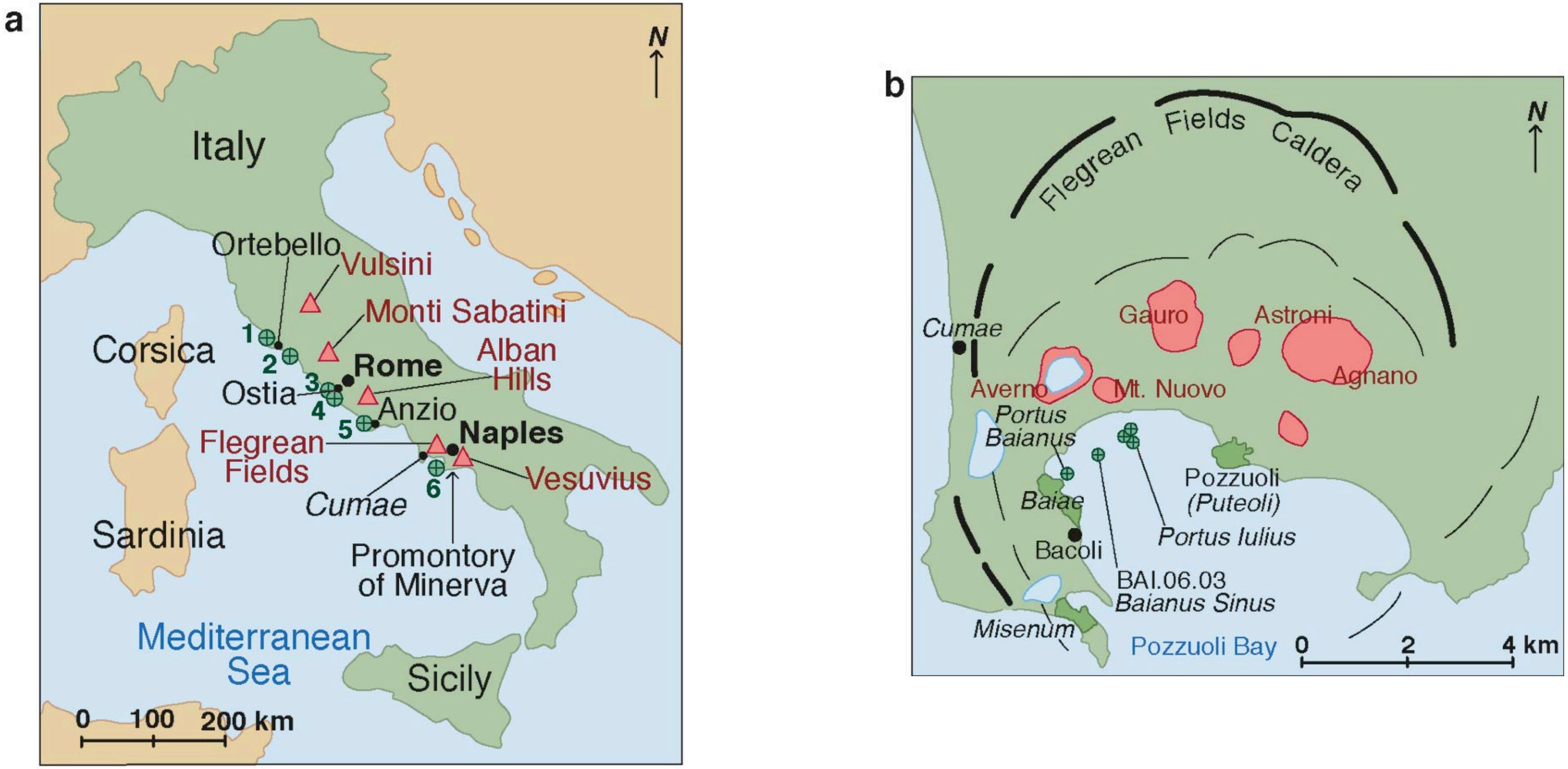
Fundo do lago em 2010

Com geopolímeros

Objetivos da moderna tecnologia de concreto

- Materiais e construção sustentável
- Durabilidade (por longos períodos)

Pozolana:
O ingrediente romano



Notas históricas:

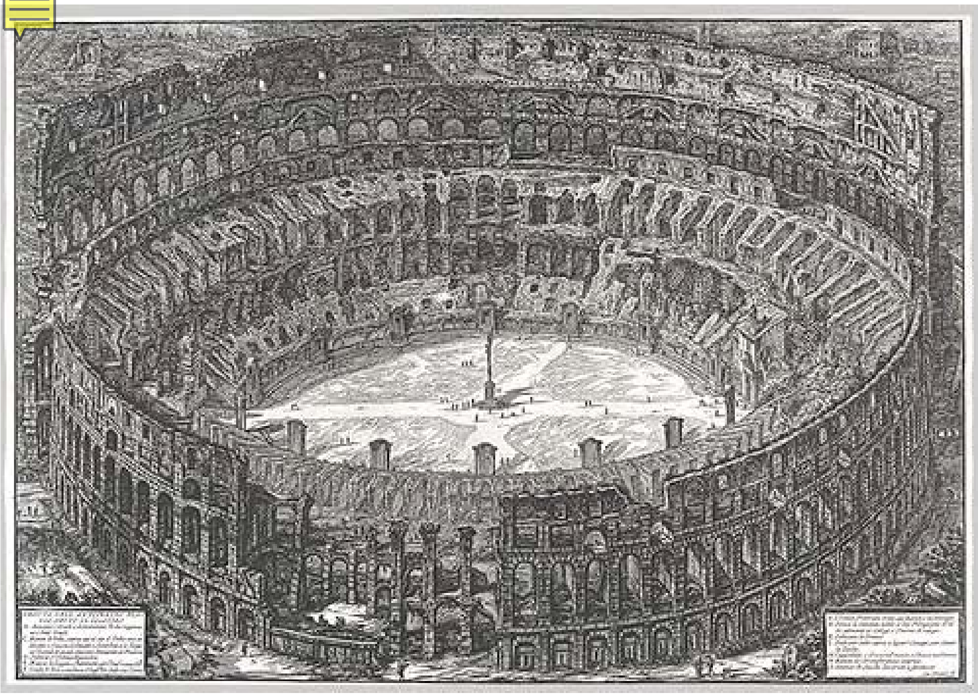
- Os romanos não foram os primeiros a usar pozolana:
- Civilização em Creta
- Construções gregas desde 500–400 AC: Kameiros, Rhodes

Prioridades diferentes

Arquimedes recusou escrever um livro sobre engenharia porque ***o trabalho do engenheiro e, mesmo, qualquer atividade de faça a vida mais fácil e’ vulgar.***

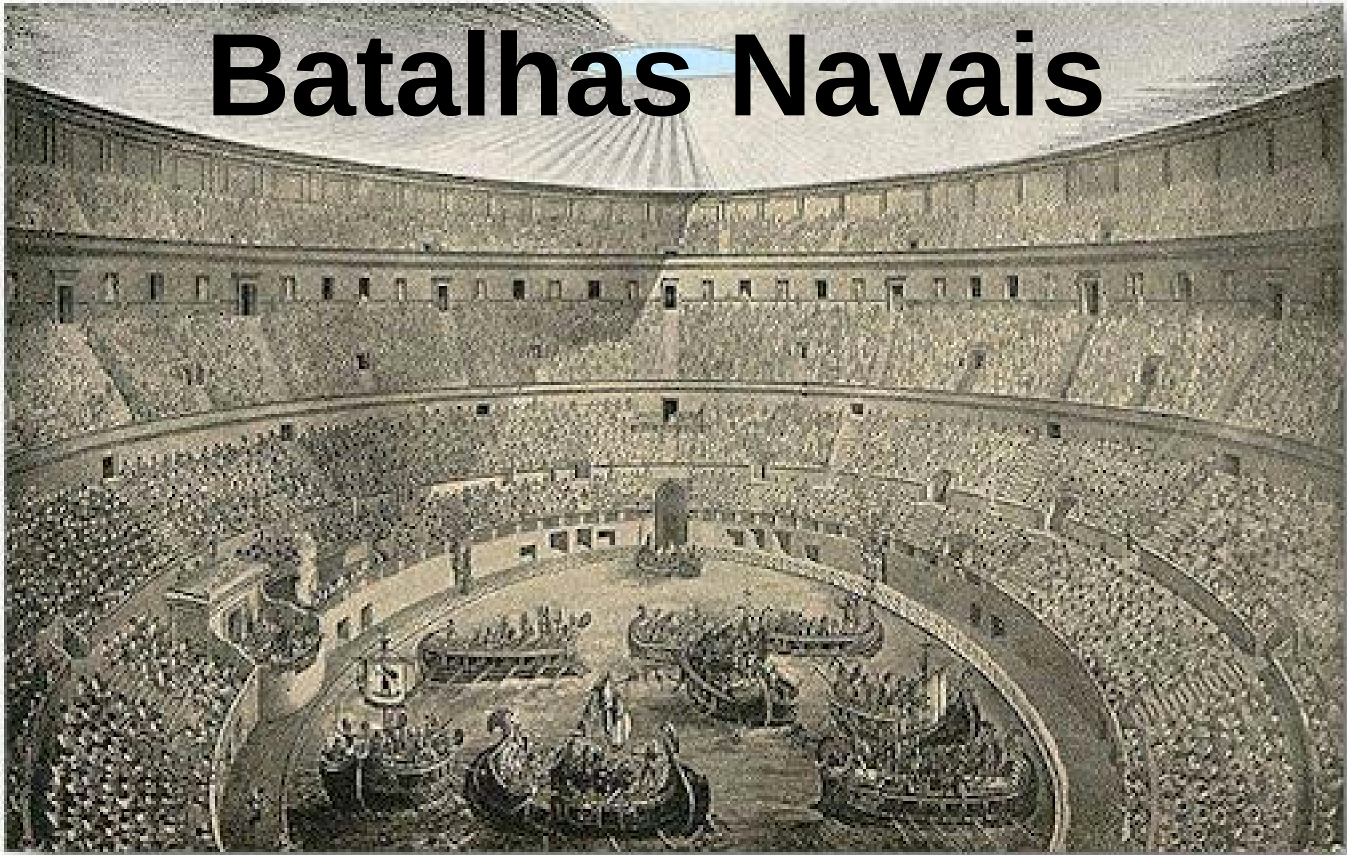
Os Romanos tiveram Vitruvius (80AC (?) – depois de 15 AC)

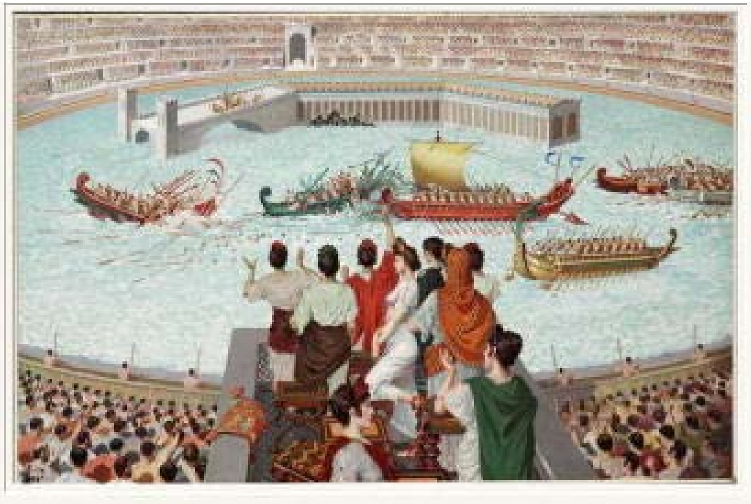
Esta substância, quando misturada com cal e pedras, não apenas origina resistência às edificações e mesmo quando piers são construídos no mar, eles podem endurecer debaixo d'água.



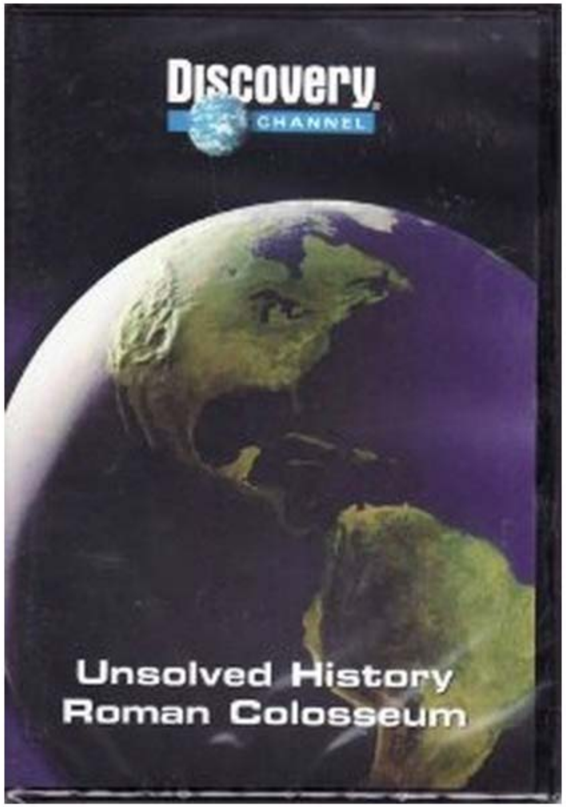
Coliseum Romano

Batalhas Navais





Discovery Channel

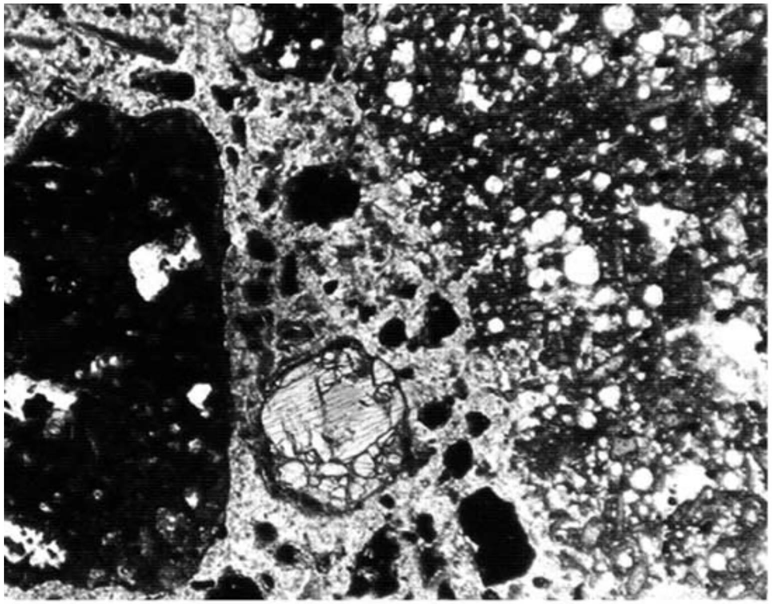


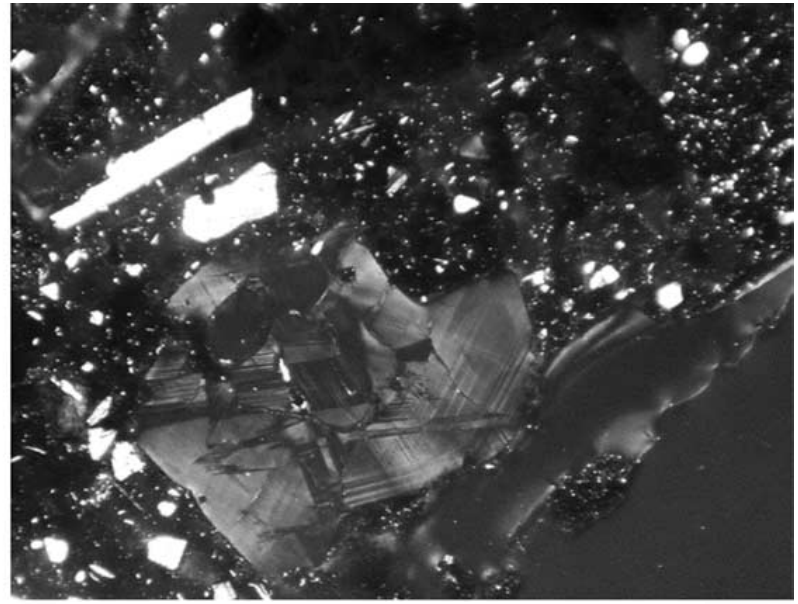
Season 1

1. Gettysburg: Pickett's Charge
2. The Death of the U.S.S. Maine
3. Inside Hitler's Bunker
4. Forensics in the White House
5. Custer's Last Stand
6. The Alamo
7. The Iceman Mystery
8. Pearl Harbor: Death of the Arizona
9. The Death of the Red Baron - produced by Termite Art Productions
10. Shoot-Out at the O.K. Corral
11. The Boston Massacre
12. JFK: Death in Dealey Plaza - produced by Termite Art Productions
13. The Roman Colosseum
14. Wilhelm Gustloff: World's Deadliest Sea Disaster
15. Who Killed Julius Caesar?
16. The Assassination of King Tut
17. Escapes from Alcatraz
18. JFK: Altered Statesman
19. Death of Princess Diana
20. San Francisco's Earthquake of 1906

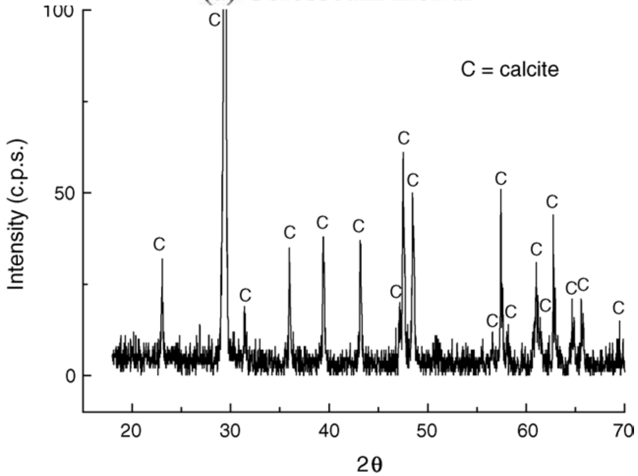
Meus 15 segundos de fama

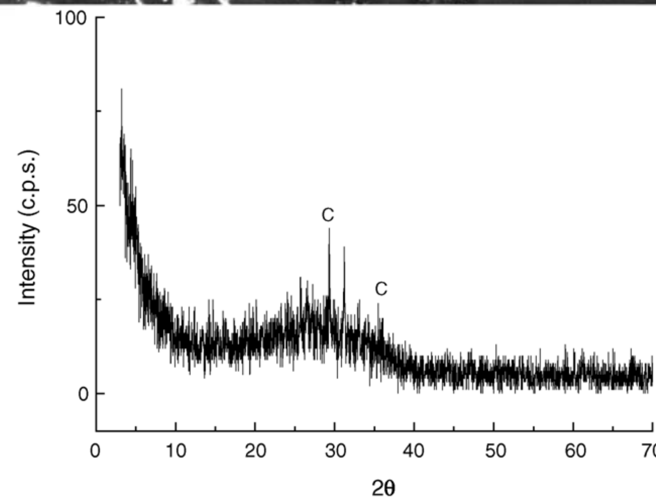
De volta aos romanos:O que descobrimos





(a) Colosseum mortar





.Silva et al., Thermochimica Acta v 438, n 1-2, Nov 1, 2005

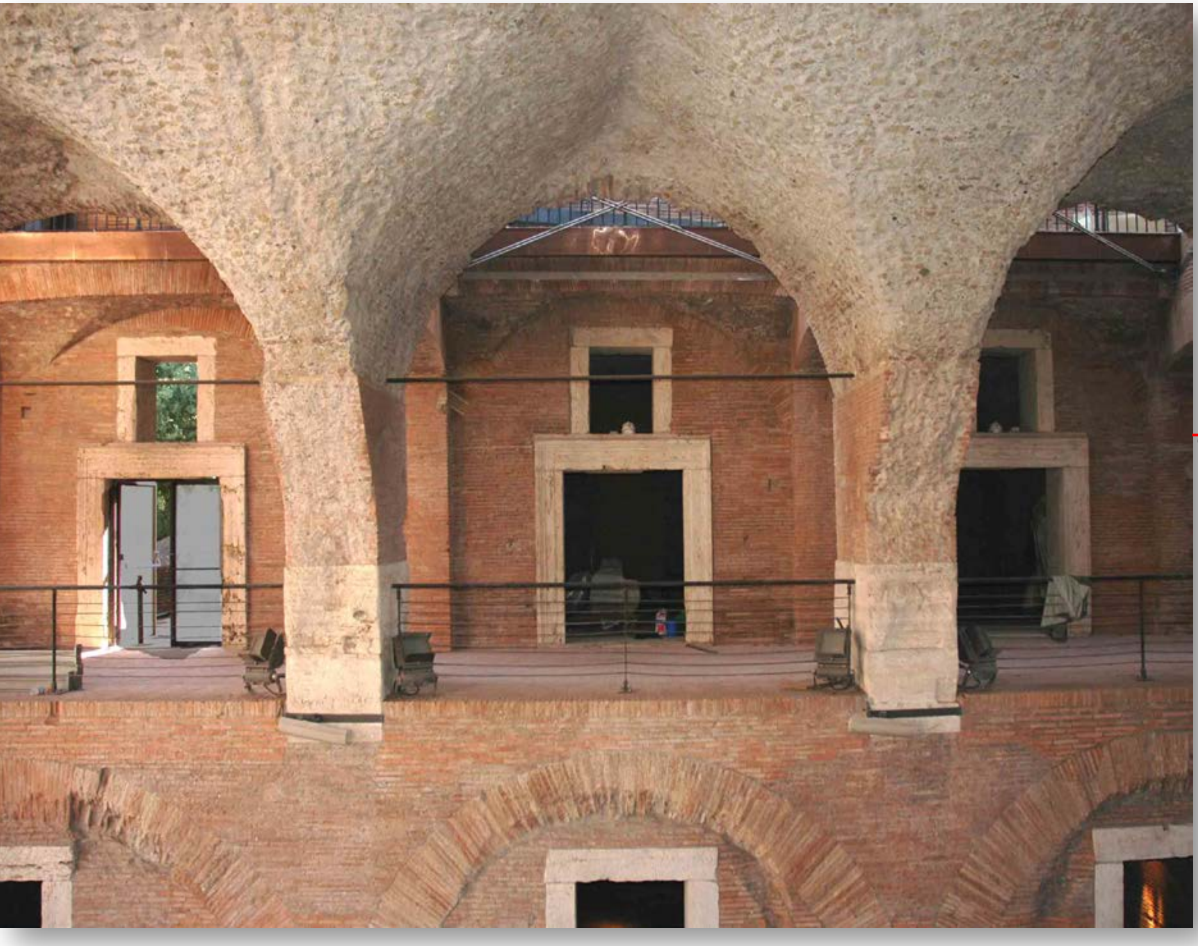
Pergunta:

O concreto romano sobreviveu mais de 2000 anos. Podemos descobrir o seu segredo usando métodos modernos de caracterização?

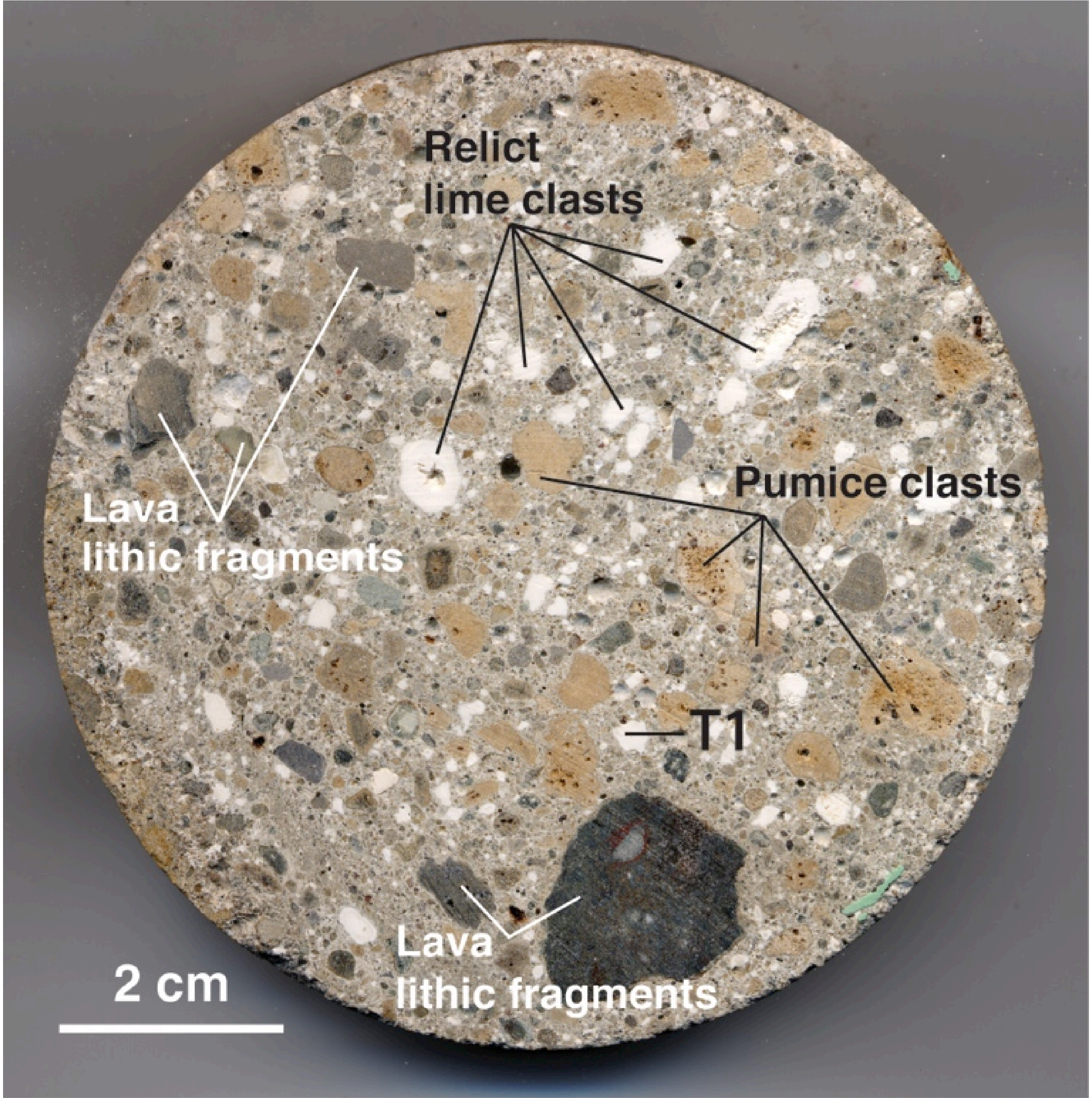
Mais que uma curiosidade acadêmica

- Estabilidade dos produtos de hidratação;
- Melhoria do desempenho em estruturas marítimas;
- Novas informações sobre o uso de pozolanas;
- Projeto de lixo nuclear que deve ser estável por milhares de anos.

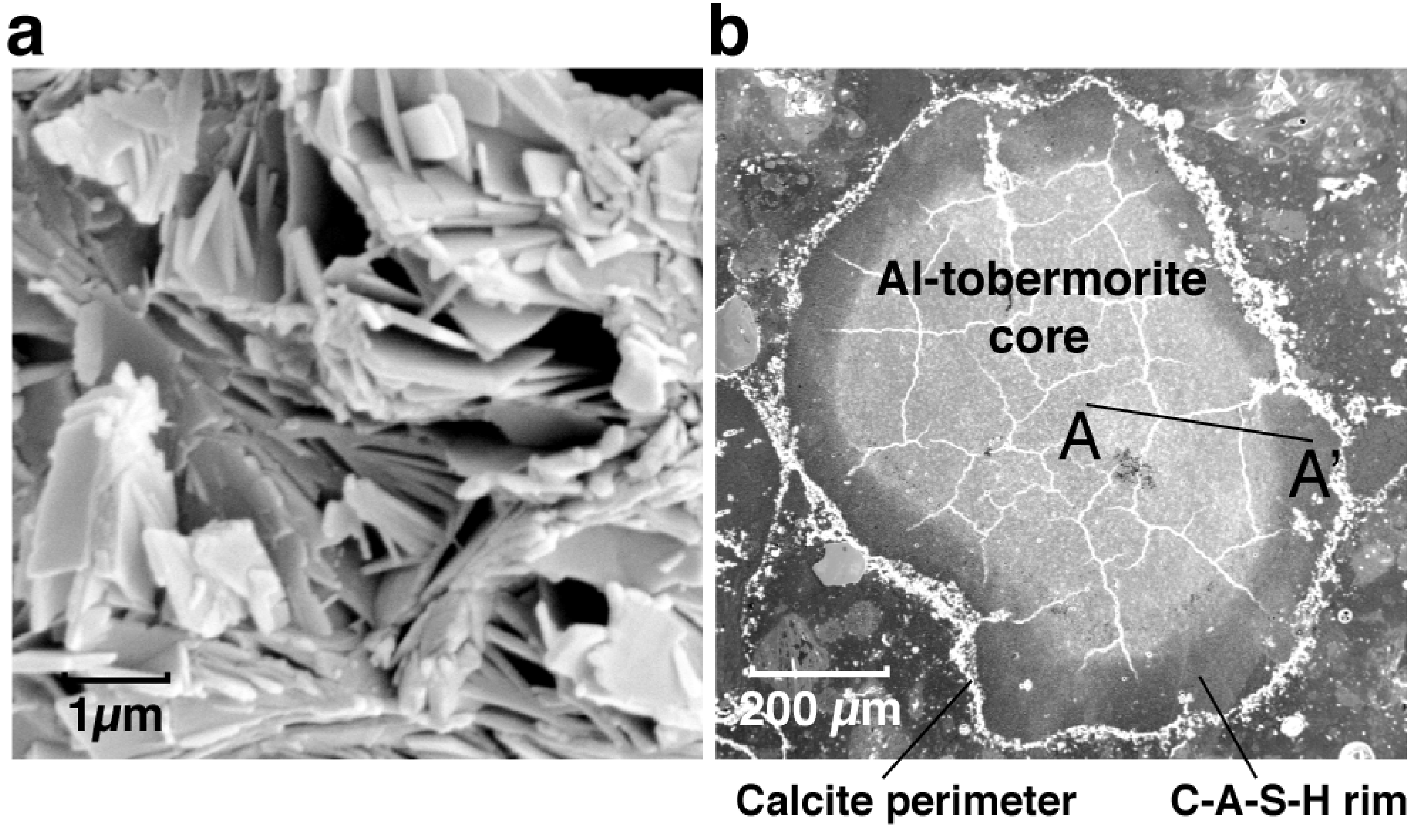
Concreto dos monumentos



Concreto das estruturas marítimas


Relict
lime clasts
Pumice clasts
Lava
lithic fragments
T1
Lava
lithic fragments
2 cm

Caracterização clássica

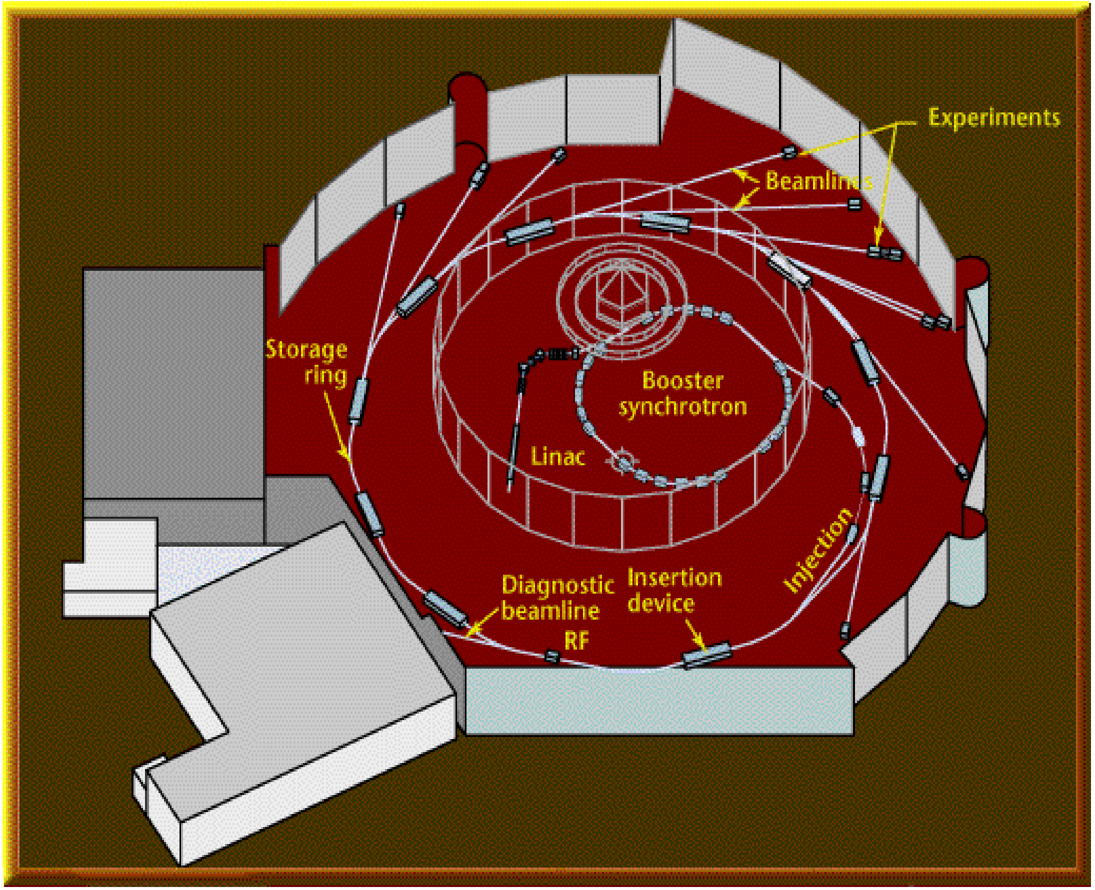


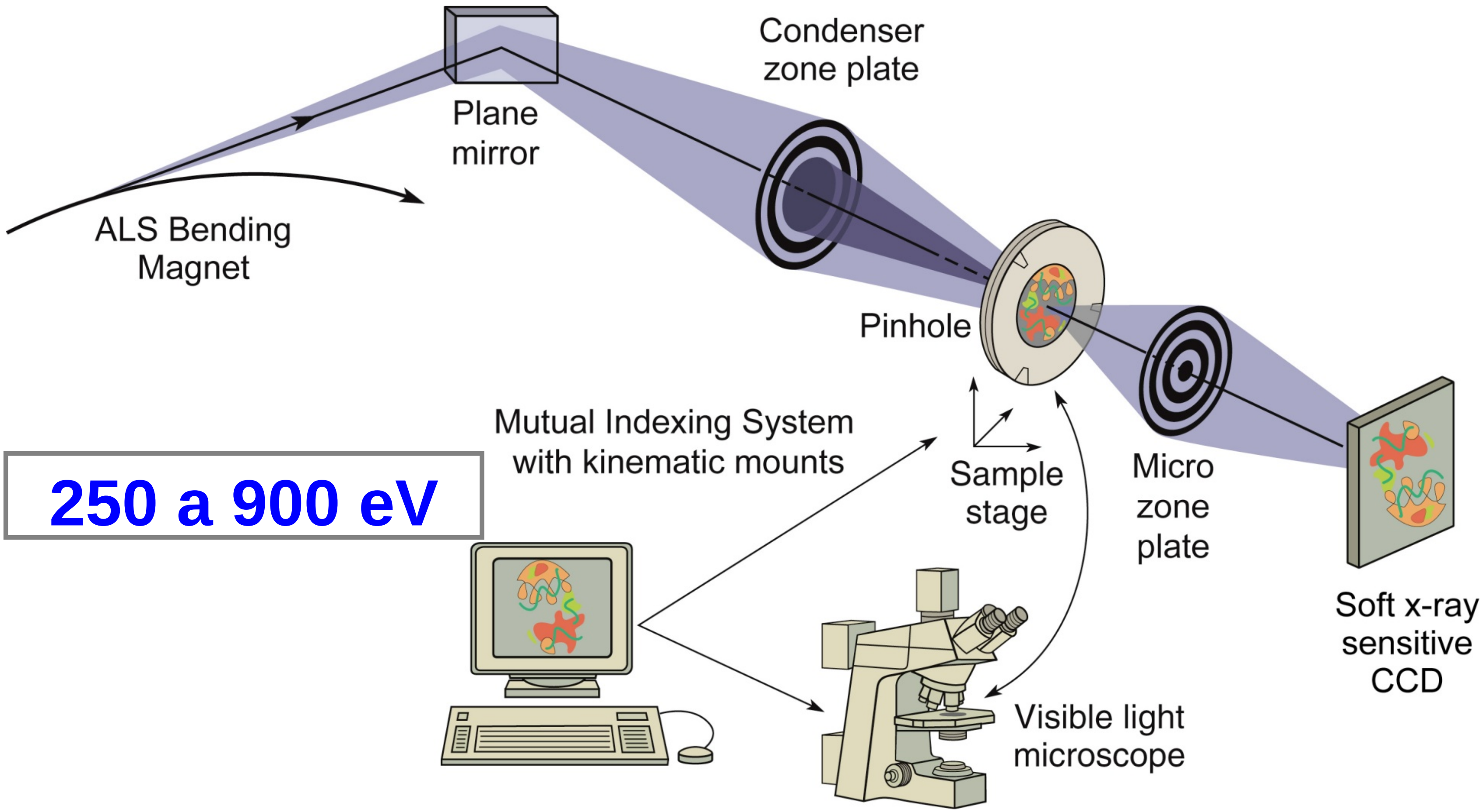
Jackson et al., American Mineralogist, Volume 98, pages 1669–1687, 2013

Advanced Light Source

the world's first third-generation synchrotron light source in its energy range

Advanced Light Source at Berkeley



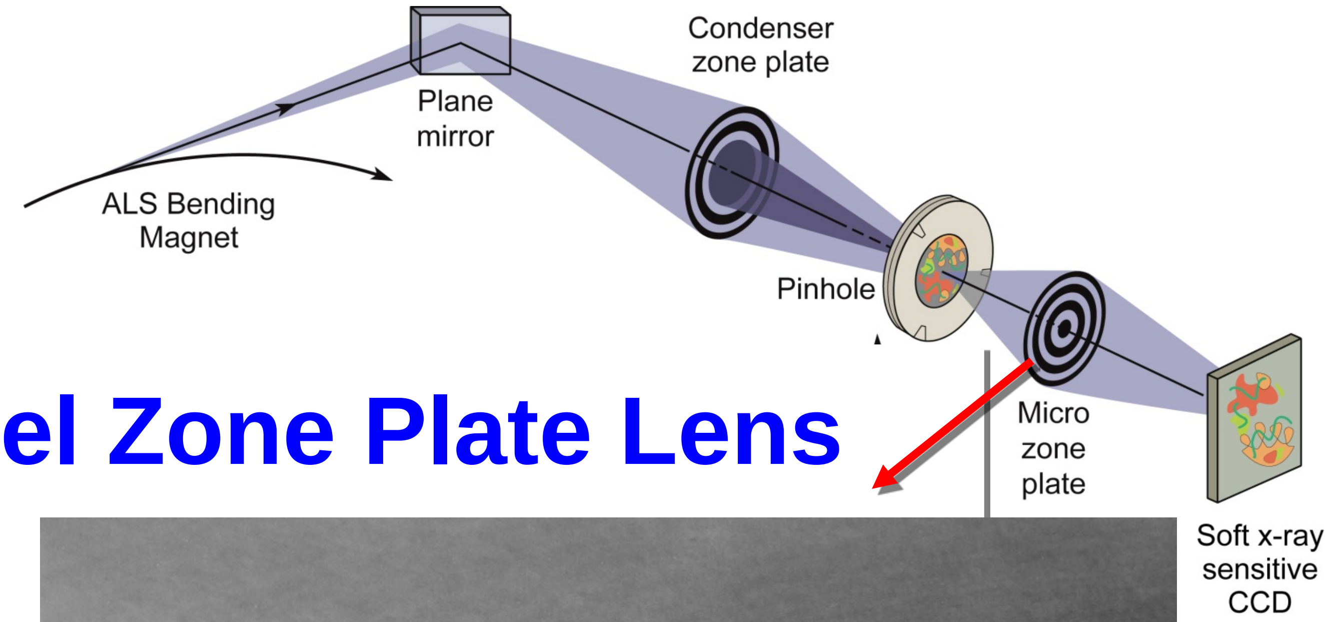


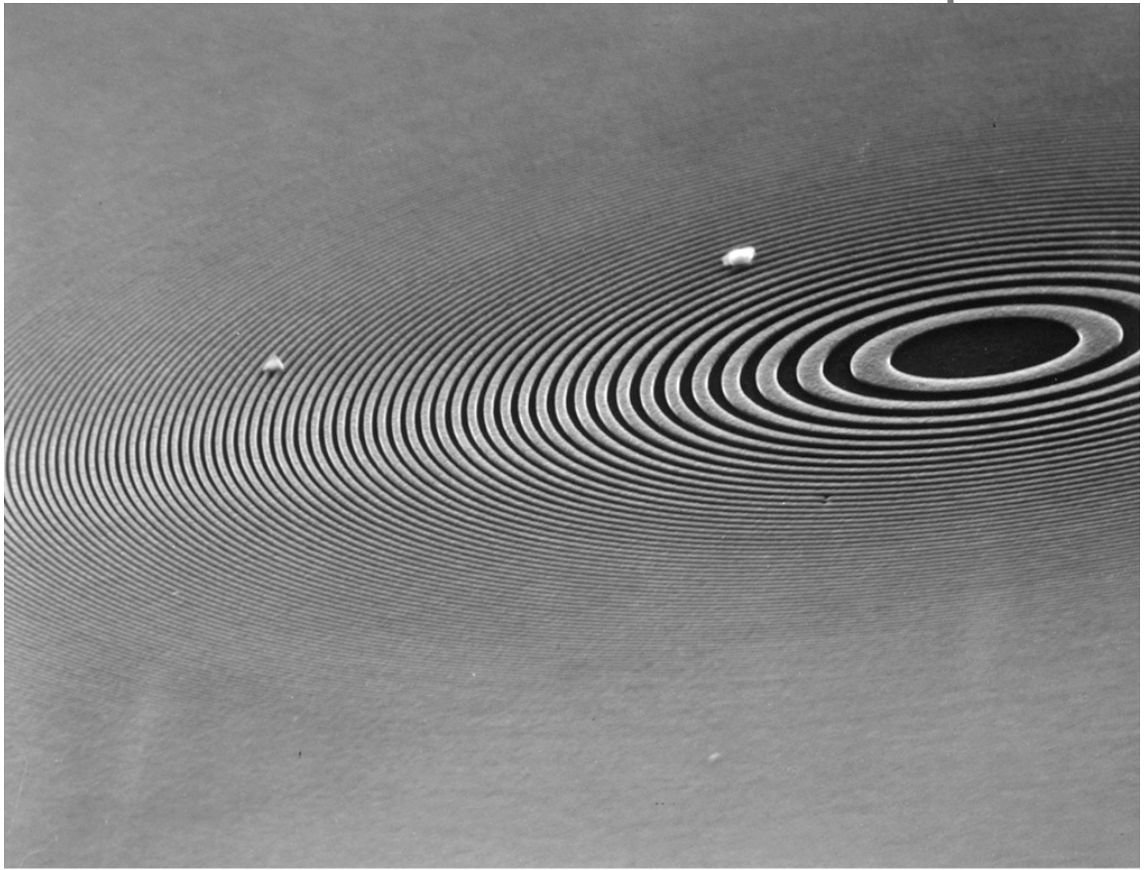
250 a 900 eV

Resolução: 15 nm

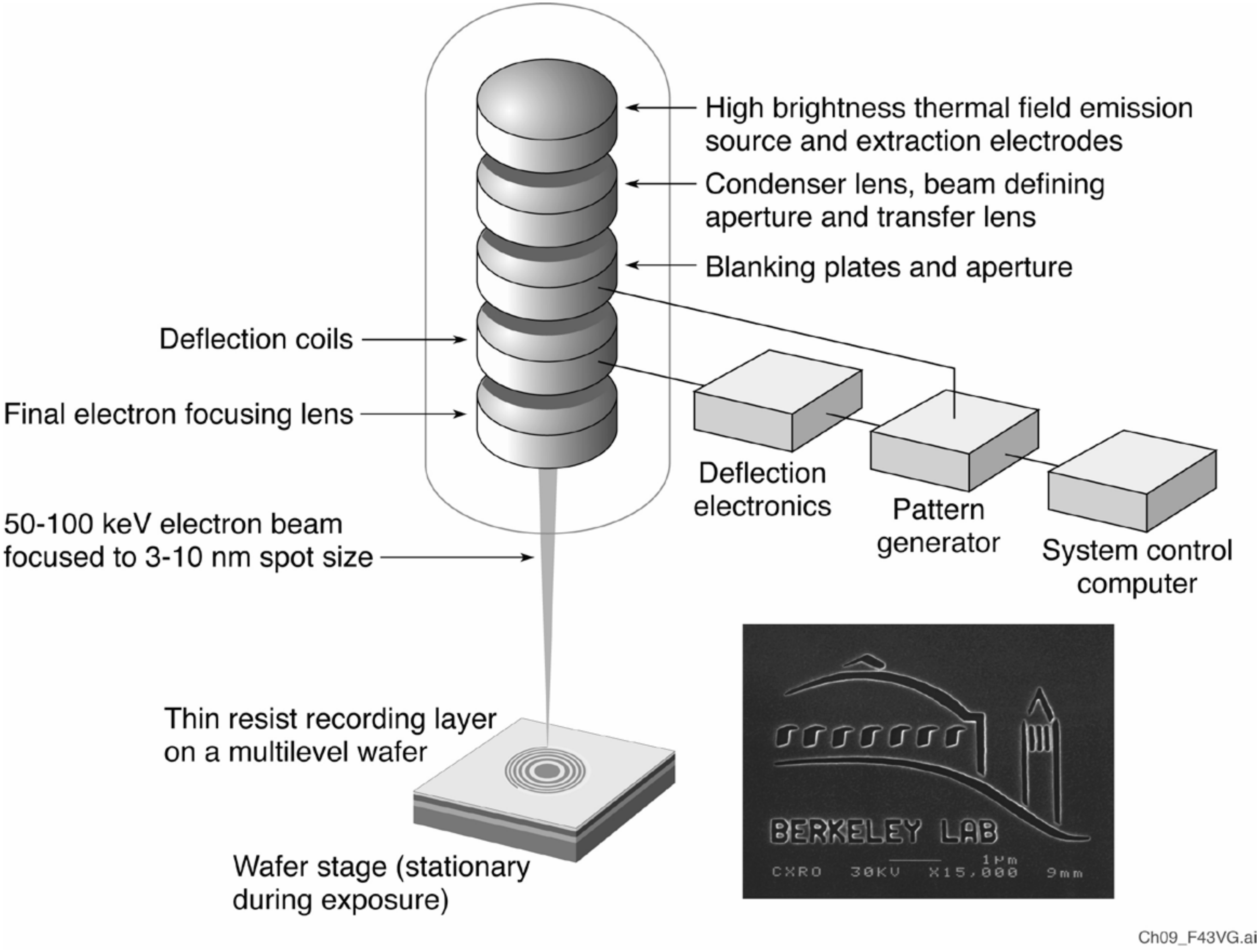
Magnificação: 1600 a 2400 vezes

Fresnel Zone Plate Lens





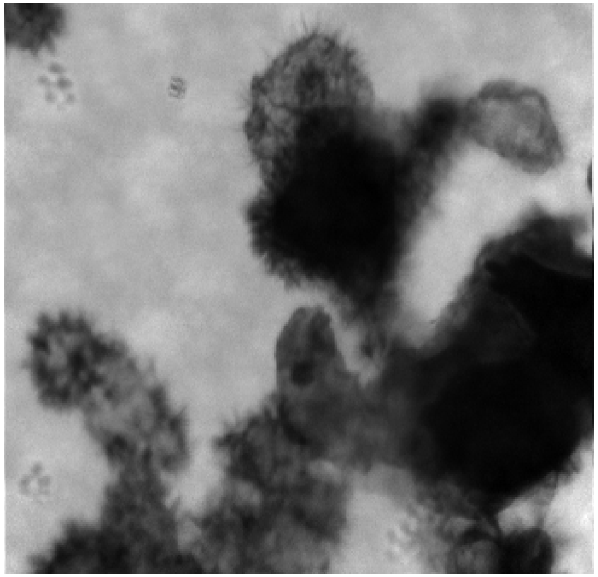
The Nanowriter: High Resolution Electron Beam Writing With High Placement Accuracy



Courtesy of E. Anderson (LBNL)

C_3S + Aceleradores ($CaCl_2$)

Imagens em 2-d



M.C.G. Juenger, P.J.M. Monteiro, E.M. Gartner, G.P. Denbeaux, Cement and Concrete Research 25 (2005) 19-25.

From clivewhite.co.uk


From imgur.com

From reddit.com

http://today.ucf.edu/a-double-take-on-a-double-headed-snake/

Backprojection of Filtered Projections

$$f(x,y)=\int_0^{2\pi}\int_0^{\infty} e^{i2\pi(\omega_x x+\omega_y y)} F(\omega_x,\omega_y)\, d\omega_x d\omega_y$$

Inverse Fourier Transf.

First we do cartesian-to-polar coordinate transform:

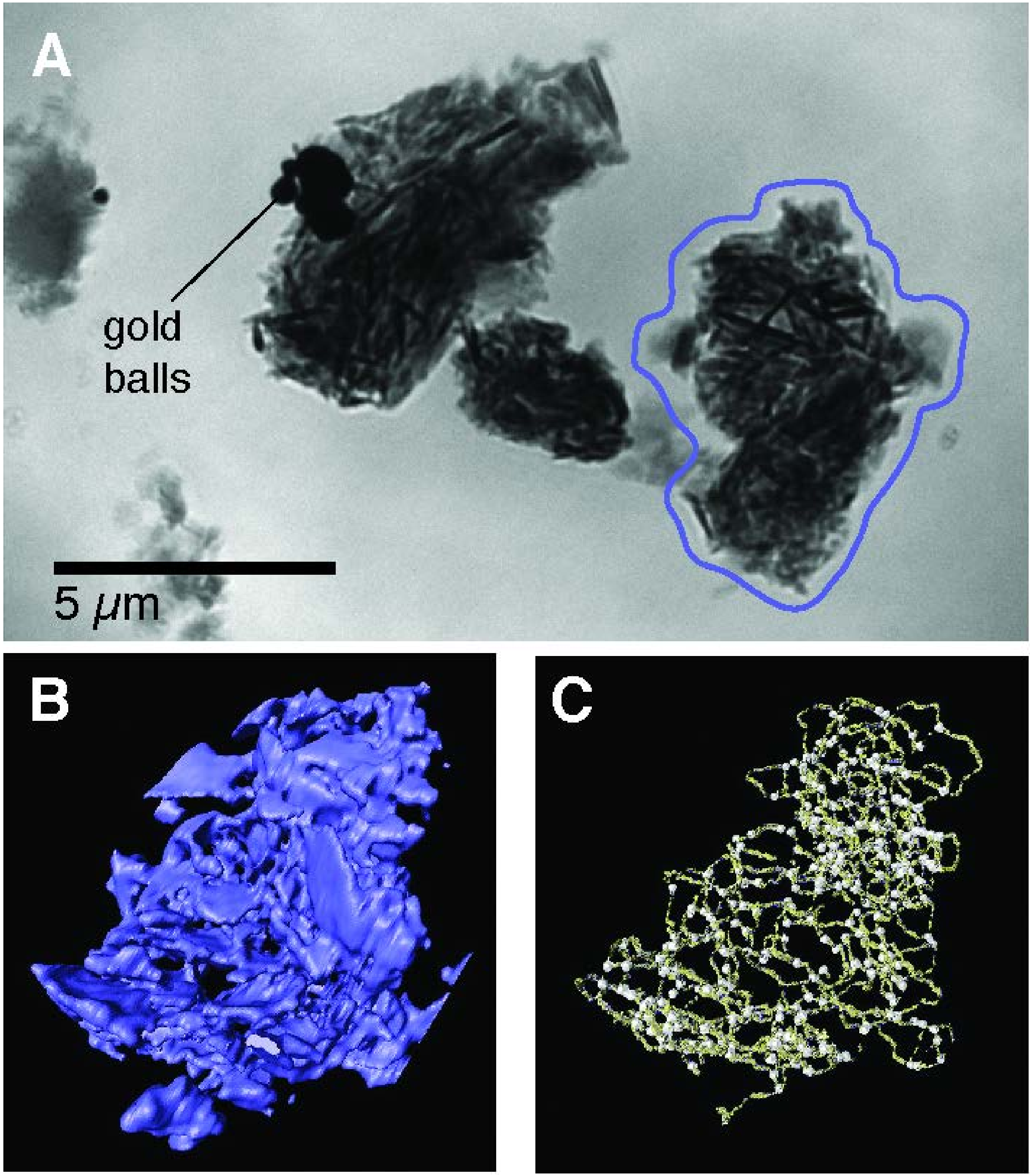
$$\omega_x=\omega_s\cos\theta,\omega_y=\omega_s\sin\theta \qquad d\omega_x d\omega_y=\omega_s d\omega_s d\theta$$

and we get:

$$f(x,y)=\int_0^{2\pi}\int_0^{\infty} e^{i2\pi\omega_s(x\cos\theta+y\sin\theta)} F(\omega_s\cos\theta,\omega_s\sin\theta)\omega_s d\omega_s d\theta$$

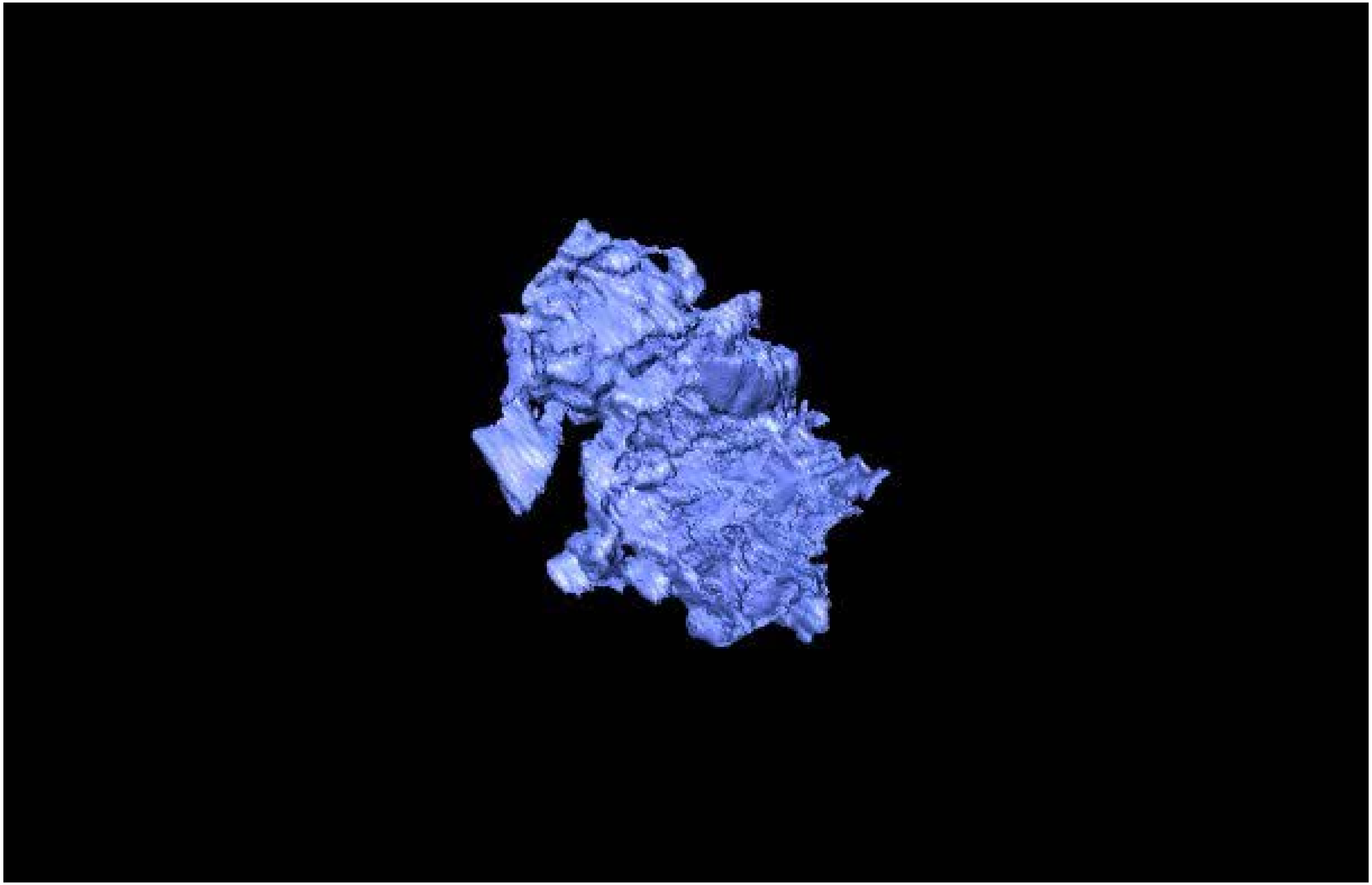
$$=\int_0^{\pi}\int_{-\infty}^{\infty} e^{i2\pi\omega_s(x\cos\theta+y\sin\theta)} P(\omega_s,\theta)\left|\omega_s\right| d\omega_s d\theta$$

Nanotomografia do concreto Romano

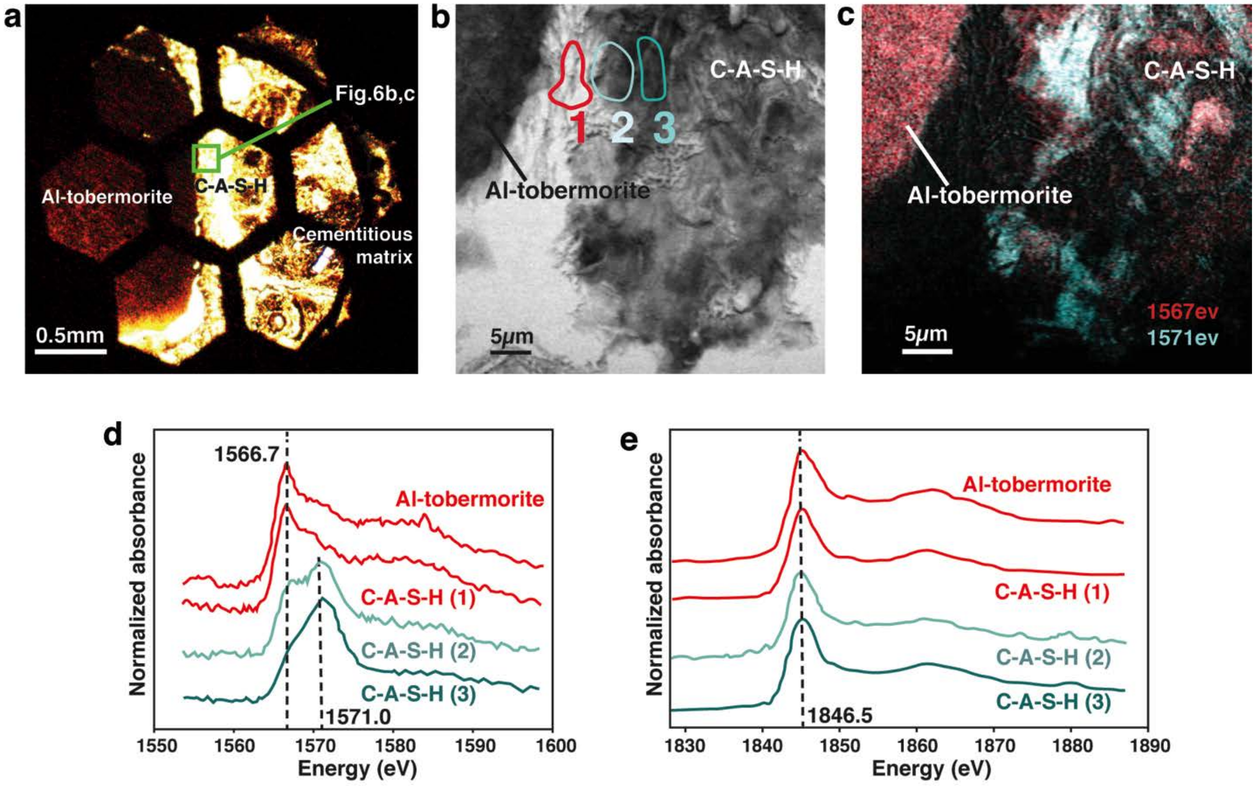


Jackson et al. Journal of American Ceramics Society, AUG 2013.

Animação

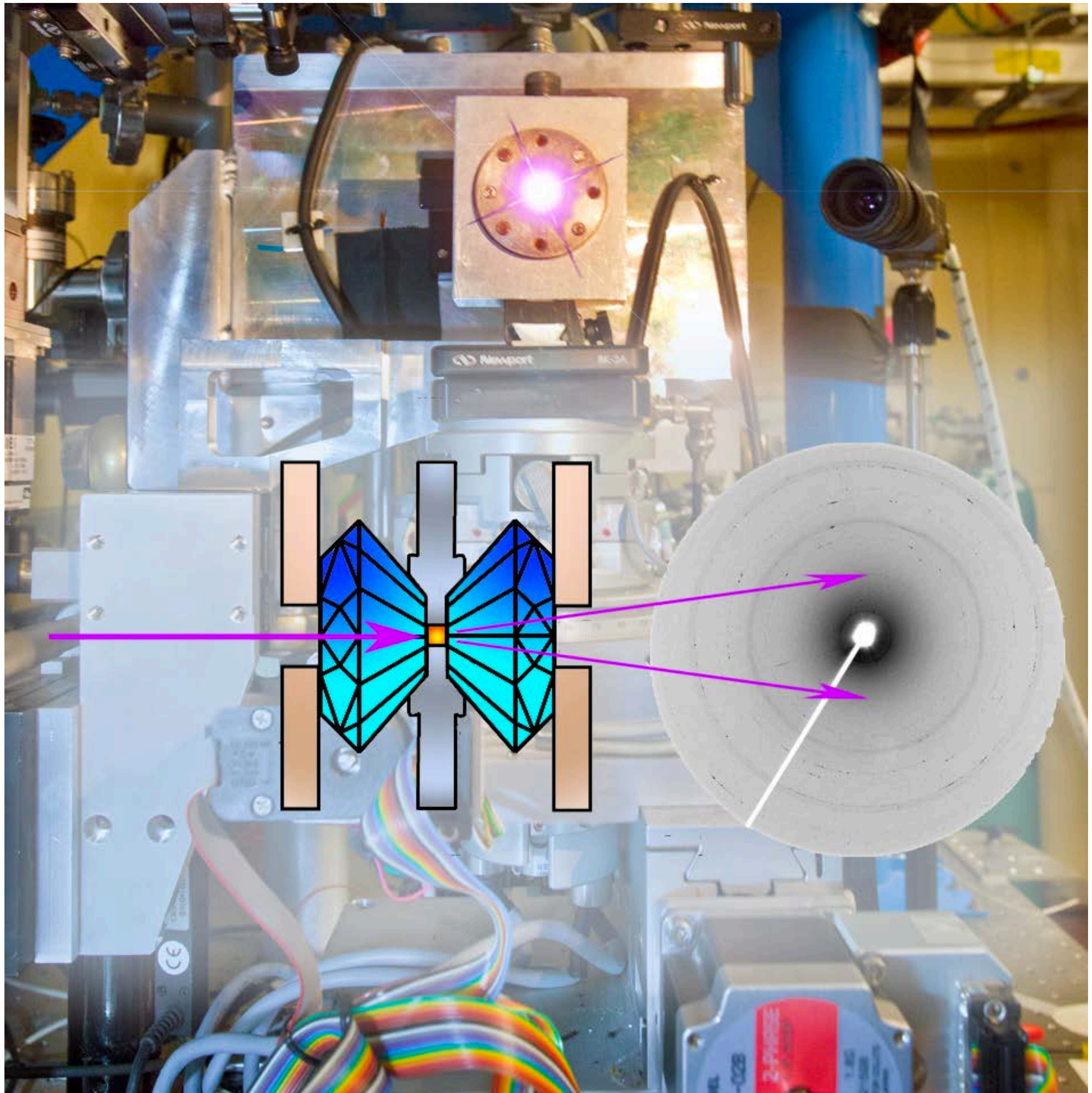


Espectroscopia



Jackson et al., American Mineralogist, Volume 98, pages 1669–1687, 2013

Medindo propriedades mecânicas em pequenos cristais



Procedimento experimental

- **Cálculo da dimensão da rede cristalina (a, b, c, α, β, γ)**

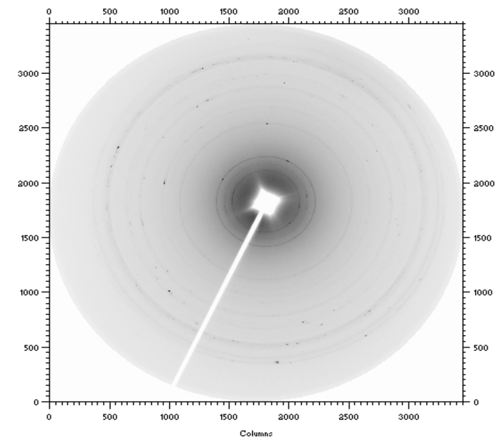
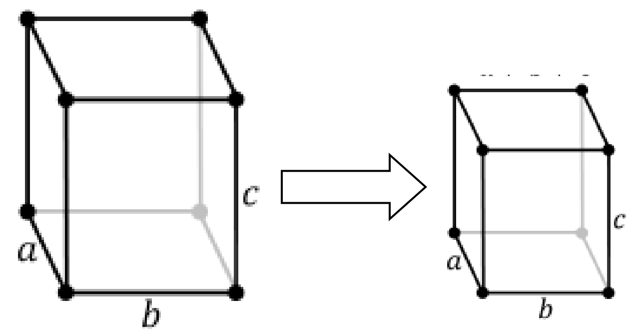


Figure. X-ray diffraction Pattern in beamline 12.2.2 (tobermorite)

- **$P(V/V_o)$ determinado**

- **Bulk modulus =**

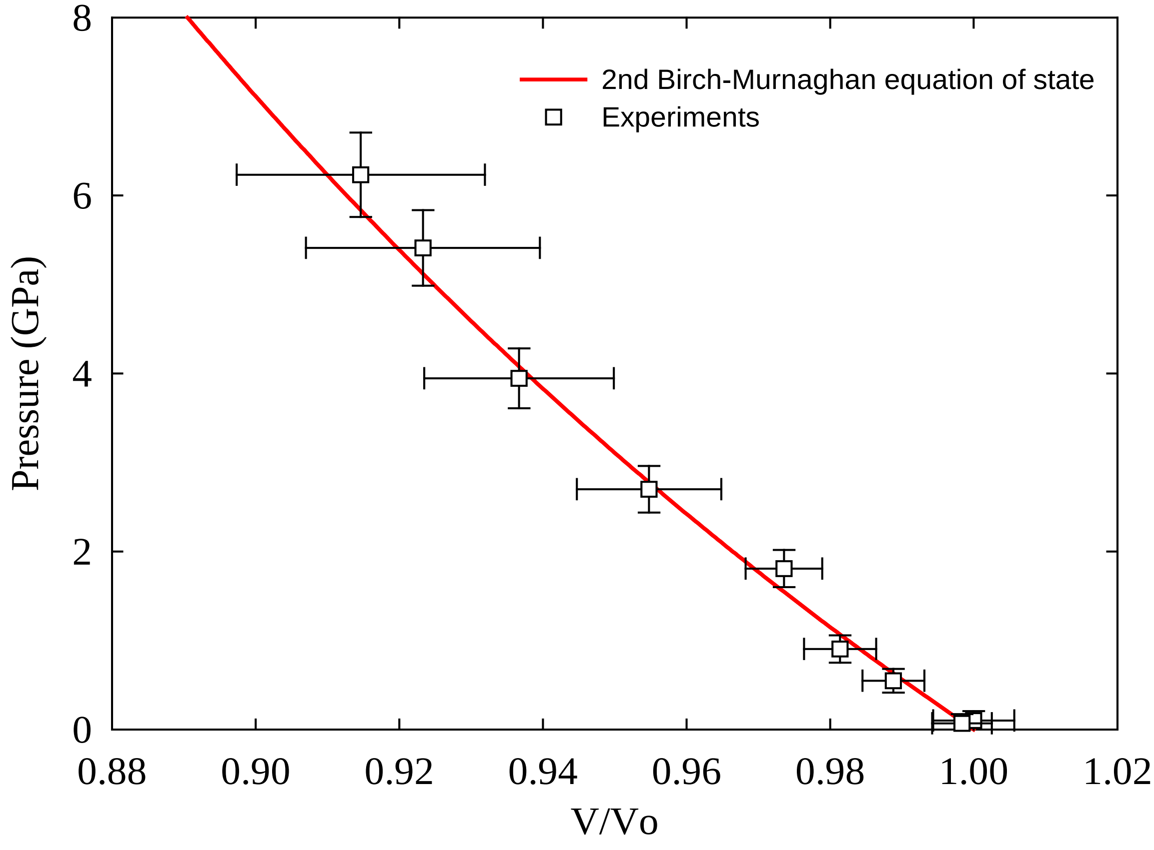
$$K_T = -V\frac{dP}{dV}$$



At low pressure **At high pressure**

$$P = \frac{3}{2}K_o\left[(V/V_o)^{-\frac{7}{3}} - (V/V_o)^{-\frac{5}{3}}\right]\left[1+\frac{3}{4}(K_o' - 4)\left((V/V_o)^{-\frac{2}{3}} - 1\right)\right]$$

Propriedades mecânicas ao nível atômico



K_o= 54.7±5.5 GPa

Jackson et al. Journal of American Ceramics Society, AUG 2013.

O que aprendemos?

- Identificamos a presença de Al-tobermorite e C-A-S-H poucamente cristalizado.

Conclusões

- **Sílica e alumínio são muito estáveis tanto na Al-tobermorite e C-A-S-H.**

HISTORY IN THE HEADLINES

June 21, 2013

The Secrets of Ancient Roman Concrete

www.sefindia.org

STRUCTURAL ENGINEERING FORUM OF INDIA [SEFI]

The American Ceramic Society

To improve today's concrete, do as the Romans did

By Sarah Yang, Media Relations | June 4, 2013

BERKELEY — In a quest to make concrete more durable and sustainable, an international team of geologists and engineers has found inspiration in the ancient Romans, whose massive concrete structures have withstood the elements for more than 2,000 years.

Using the Advanced Light Source at Lawrence Berkeley National Laboratory (Berkeley Lab), a research team from the University of California, Berkeley, examined the fine-scale structure of Roman concrete. It described for the first time how the extraordinarily stable compound – calcium-aluminum-silicate-hydrate (C-A-S-H) – binds the material used to build some of the most enduring structures in

Eco Books 4 Kids!

NATURE WORLD NEWS

Science

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Ancient Romans could inspire durable modern concrete

The Ancient Romans Were Better At Making Sustainable Concrete Than We Are

An ancient concrete mixture could be better for the environment and just as strong as modern mixtures

Roman Seawater Concrete Holds the Secret to Cutting Carbon Emissions

Berkeley Lab scientists and their colleagues have discovered the properties that made ancient Roman concrete sustainable and durable

JUNE 04, 2013

now What's Trending on Money

How Roman concrete could build better buildings now

Long regarded for a far more durable product, the 2,000-year-old recipe is also better environmentally than current processes.

By Bruce Kennedy Mon 2:34 PM

Standing the tests of time, Roman concrete is very resilient. One only has to look at structures like the Pantheon in Rome or the harbor at Caesarea Maritima in Israel to see that this is true, but is it as durable as modern concrete? According to findings by Paulo Monteiro and his team at the U.S. Department of Energy's Lawrence Berkeley National Laboratory, it is. As well as being just as durable, Roman concrete was also more eco-friendly than our modern recipe, which consists of lime and clay. This mixture requires that it be heated at high temperatures and results in significant carbon dioxide emissions. Roman hydraulic concrete, on the other hand, was made from pumice, mortar, lime and volcanic ash from Italy—*pozzolana*—and fired at much lower temperatures, thereby creating the more

This artist's drawing of Caesarea Maritima shows the glory and power of the Roman capital of Jud... manmade harbor (the largest in the ... largely constructed with Ro... Robert Teringo/Nati...

inhabitat

Researchers Discover Key to Super-Durable Ancient Roman Concrete

by Tafline Laylin, 06/17/13

CALIFORNIA ACADEMY OF SCIENCES

PASTHORIZONS adventuresinarchaeology

Sustentabilidade

Objetivo:

Eliminar 1 bilhão t de CO_2

Desafio:

Mais de bilhão t de materiais alternativos

Oferta:

607-670 milhões t de cinza volante

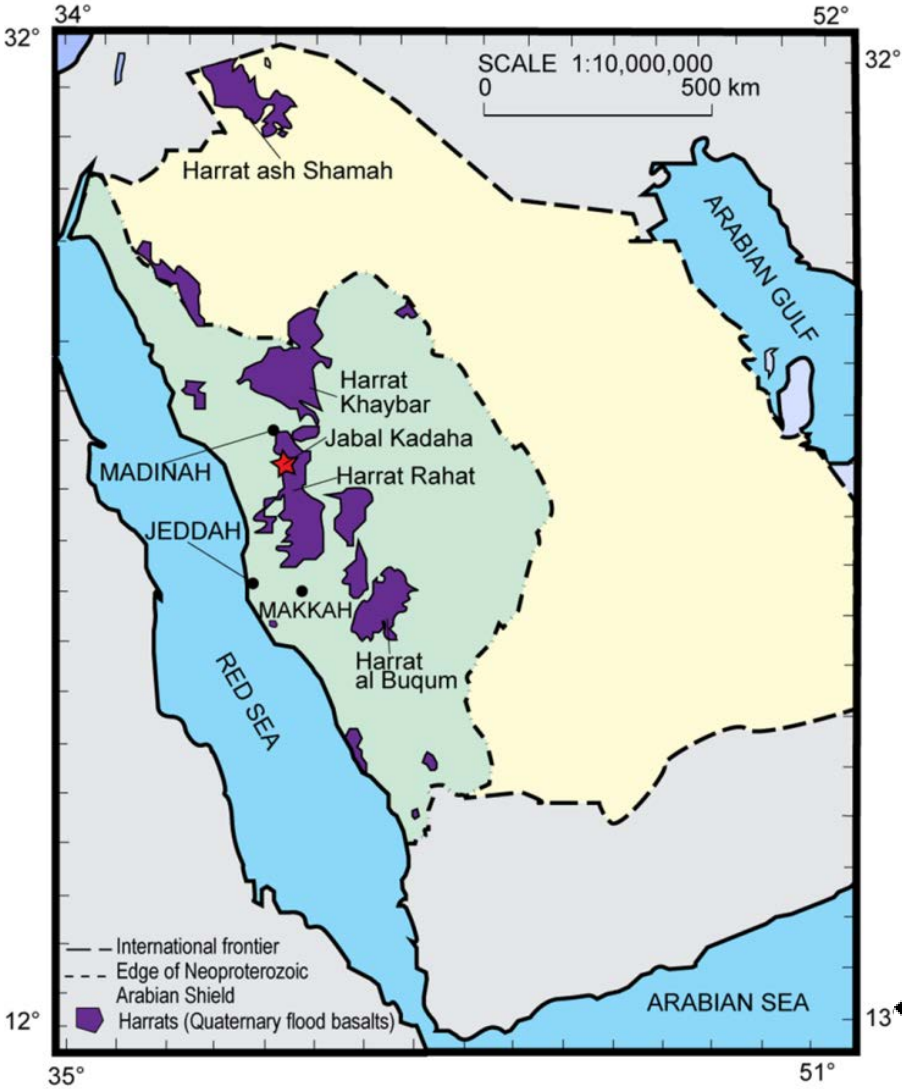
220 milhões t de escória

Podemos nos inspirar nos Romanos?

Uma nova metodologia

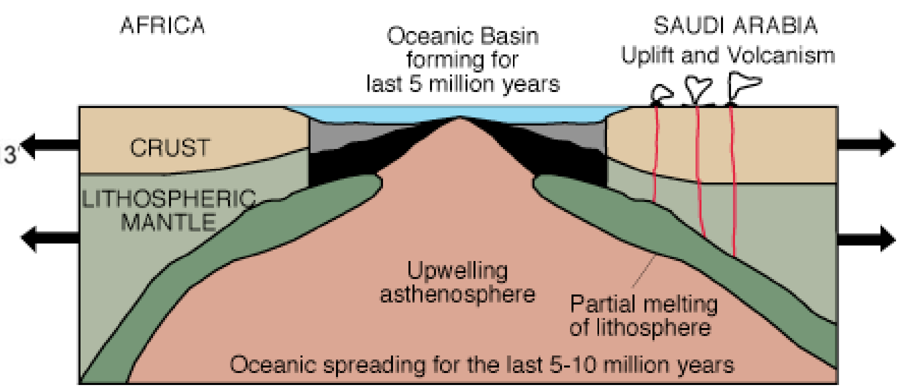
Uso de altos consumos de pozolana e pó calcário

Formação geológica



Natural pozzolanic material is available in Saudi Arabia from basalt plateaus (Harrat) spread within the "Edge of Arabian Shield".

The volcanoes of the 600 km Makkah-Madinah-Nafud volcanic line are younger than 10 million years and may represent a completely new N-S crustal rift zone in western Saudi Arabia.



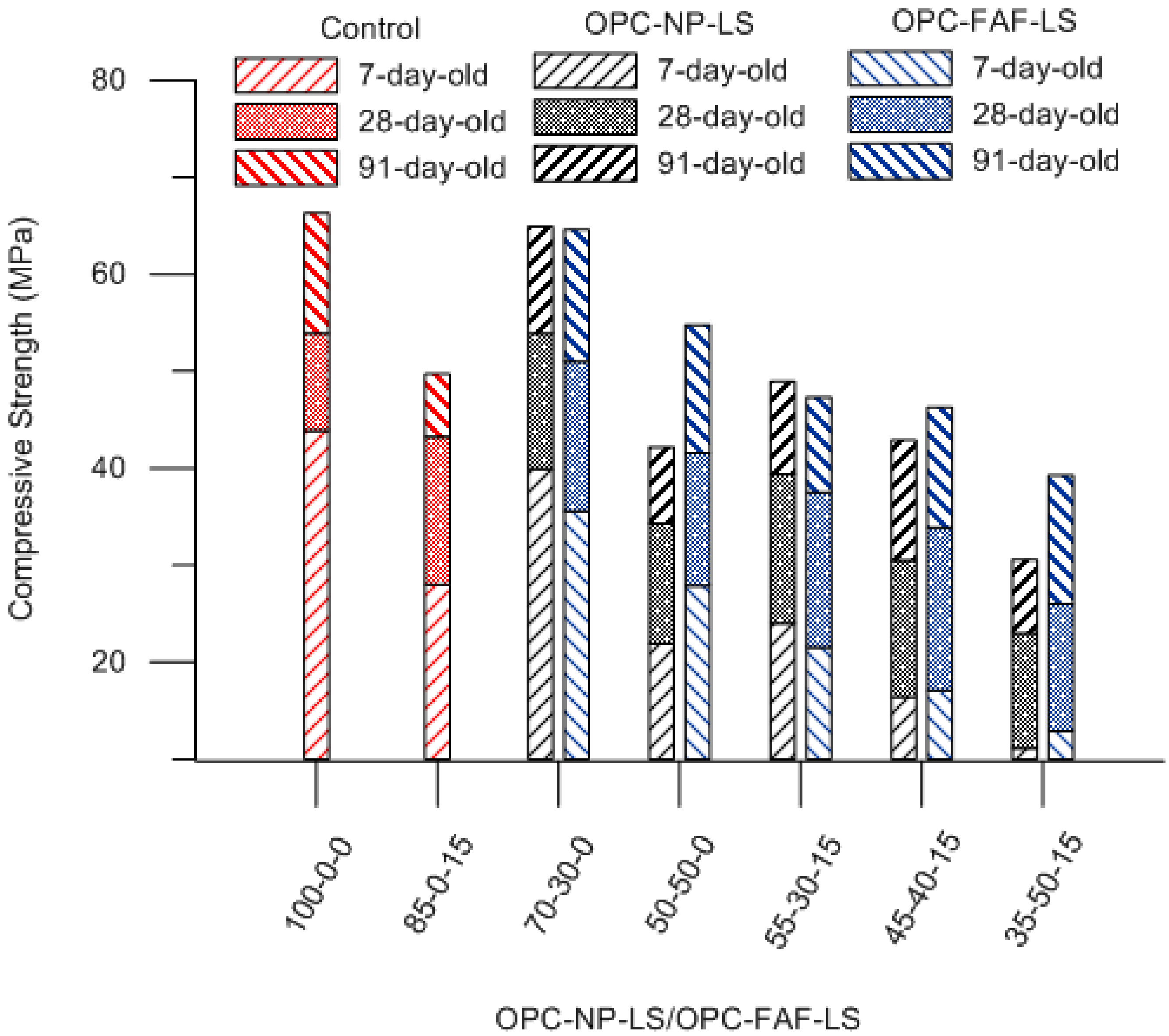
Dosagem do concreto

	OPC-LS-NP/FAF (mass%)	OPC	NP/FAF	LS	FA	CA	W/CM	SP (NP/FAF) (mass%)
Controle	100-0-0	1.00	–	–	2	2	0.35	1.43
	85-15-0	0.85	-	0.15	2	2	0.35	1.43
Binary HVNP/FAF blends	70-0-30	0.70	0.30	–	2	2	0.35	1.08/1.39
	50-0-50	0.50	0.50	–	2	2	0.35	1.03/1.14
Ternary HVNP/FAF-LS blends	55-15-30	0.55	0.30	0.15	2	2	0.35	1.22/1.14
	45-15-40	0.45	0.40	0.15	2	2	0.35	1.22/1.03
	35-15-50	0.35	0.50	0.15	2	2	0.35	1.12/1.00

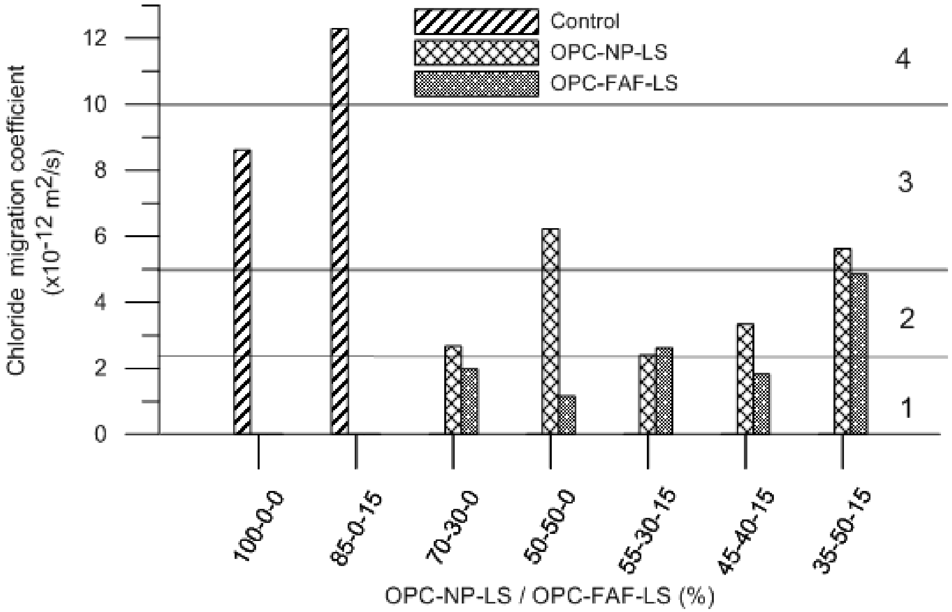
Concreto autoadensável

- The flow diameter and T_{50} time was recorded
- The stability of SCC was observed visually by examining the concrete mass in terms of segregation, bleeding and the mortar halo near the slump flow perimeter

Resistência à compressão



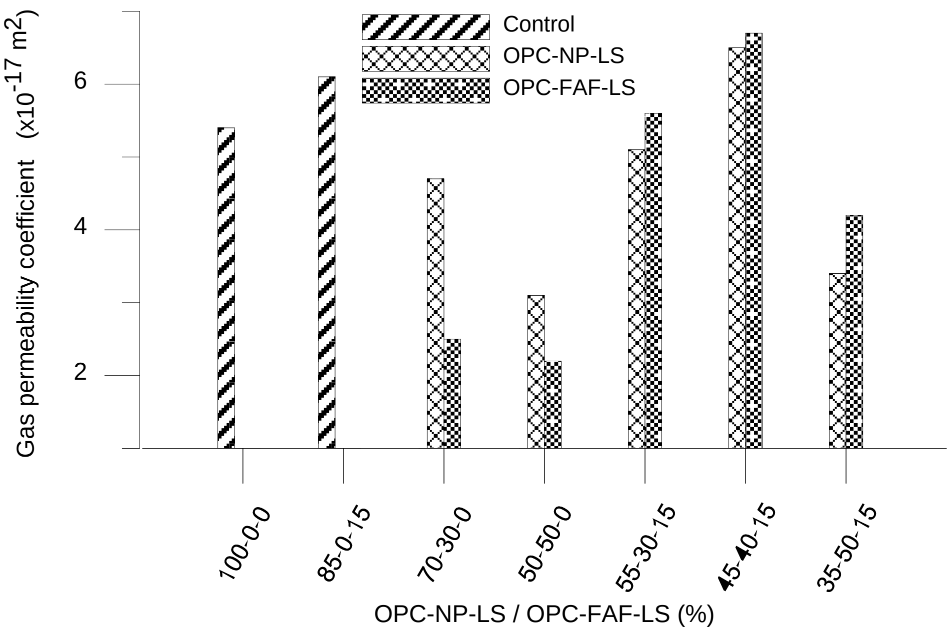
Desempenho de Durabilidade



Coefficient of chloride migration

NT BUILD 492

*Zones **1, 2, 3** and **4** indicate **extremely high, very high, high, moderate resistance** to chloride penetration, respectively according to guidelines presented in (Gjørv, 2009)*



Gas permeability

CEMBUREAU

Quem quer ser um bilionário?

Concreto: 33 bilhões t

Água: 2.7 bilhões t

Agregado: 27 bilhões t

Cimento: 3.7 bilhões t