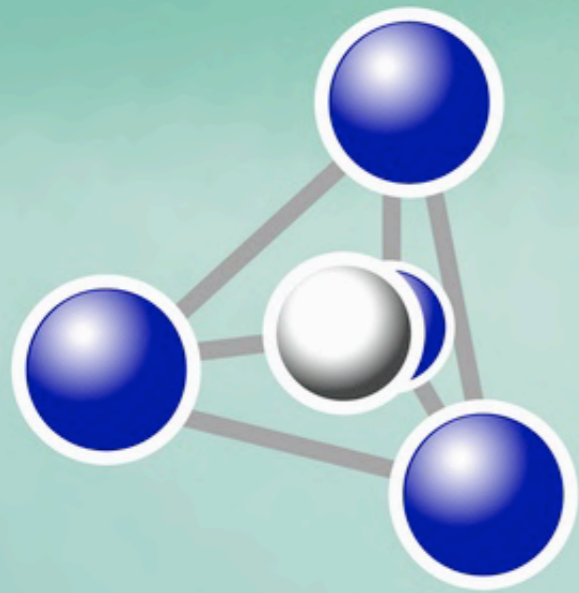


**Geological origin of the reagents  
constituting the Roman mortar,  
according to Vitruvius**



**INSTITUT**

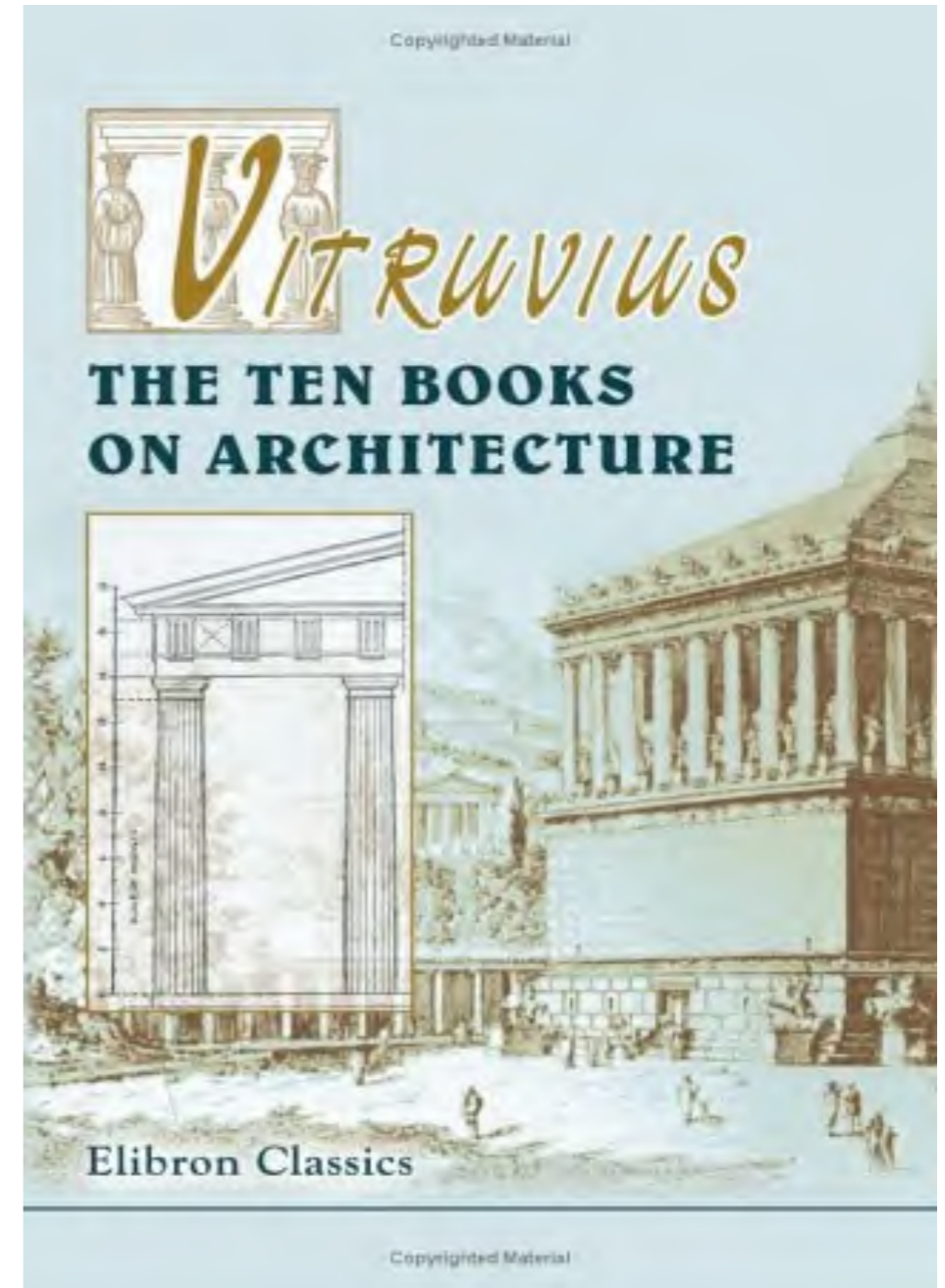
**GÉOPOLYMÈRE**

**Frédéric Davidovits, Ph. D.**

**[www.geopolymer.org](http://www.geopolymer.org)**

# Vitruvius

- Roman architect, author of *De architectura* (25 B.C.).
- The only complete architectural treatise to survive from classical antiquity
- His treatise has recipes for making cement and concrete



# Study of 53 latin and greek words in Vitruvius' work

- stone, rubble, sand, pozzolana,
- adobe, baked brick, lime, plaster,
- Pigments, mortars and coating
- Concrete: *opus caementicium*, *opus signinum*



UNIVERSITÉ DE CAEN/BASSE-NORMANDIE  
U.F.R. : SCIENCES DE L'HOMME  
ECOLE DOCTORALE LITTÉRATURE,  
CULTURES ET SCIENCES SOCIALES

THÈSE

présentée par

Mr Frédéric DAVIDOVITS

et soutenue

le 28 mars 2007

en vue de l'obtention du

DOCTORAT de l'UNIVERSITÉ DE CAEN

Spécialité : Langues et Littératures Anciennes

Arrêté du 07 avril 2006

Titre : Géologie et construction  
dans le *De architectura* de Vitruve

MEMBRES du JURY

Mr Pierre Gros, Professeur émérite, Université de Provence et Institut Universitaire de France (*rapporteur*)

Mme Agnès Rouveret, Professeur, Université de Nanterre (*rapporteur*)

Mme Carmen Codoñer, Catedratica, Université de Salamanque

Mr Philippe Fleury, Professeur, Université de Caen

Mr Pierre Savaton, Maître de Conférences, Université de Caen

Mr Louis Callebat, Professeur émérite, Université de Caen (*Directeur de thèse*)

# Study through 3 research perspectives

THÈSE

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## 1. Lexicography (latin translation)

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## 2. Archaeology

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## 3. « Hard sciences »: geology, civil engineering, science materials...

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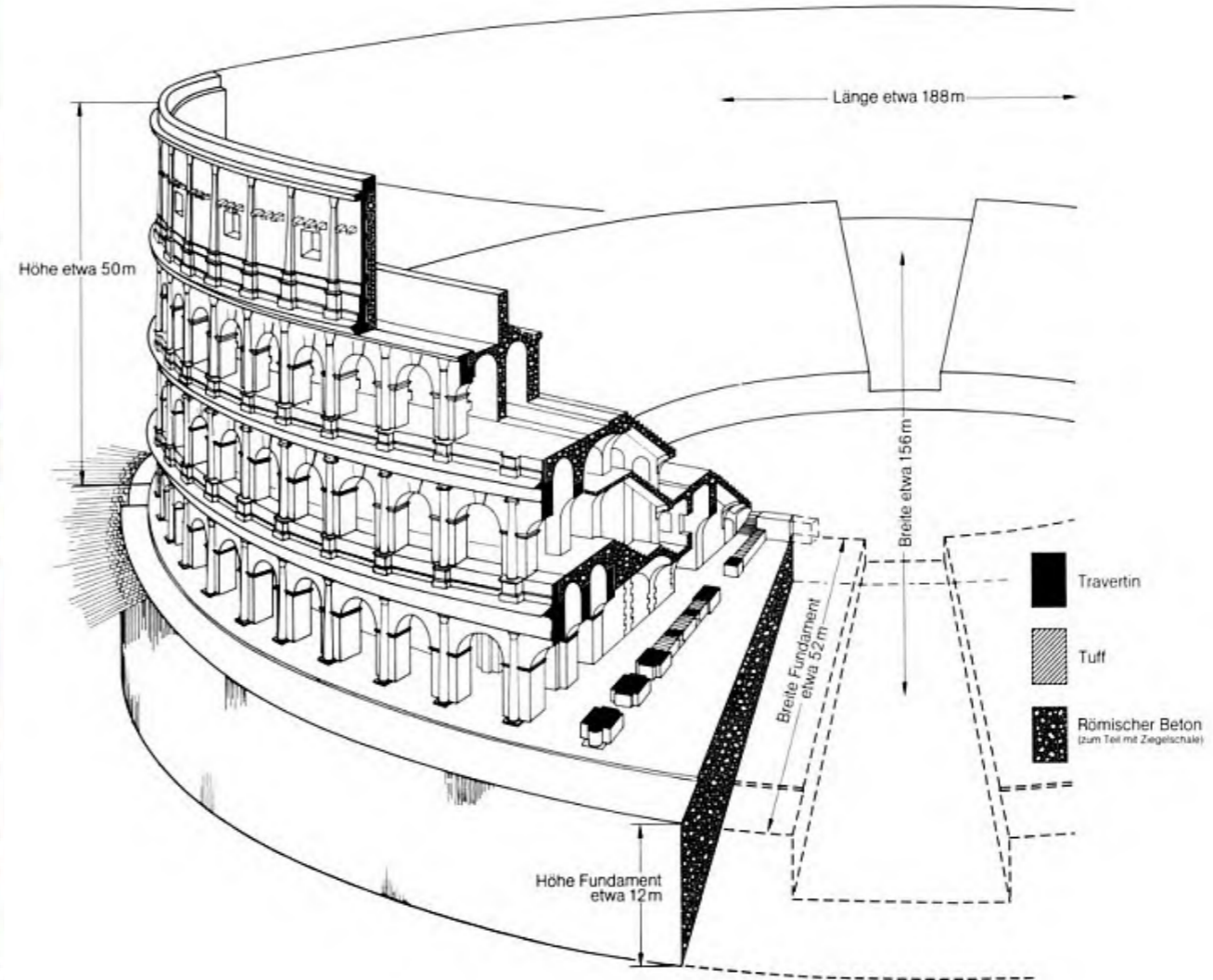
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# Roman Concrete



Roman Pantheon



Colosseo

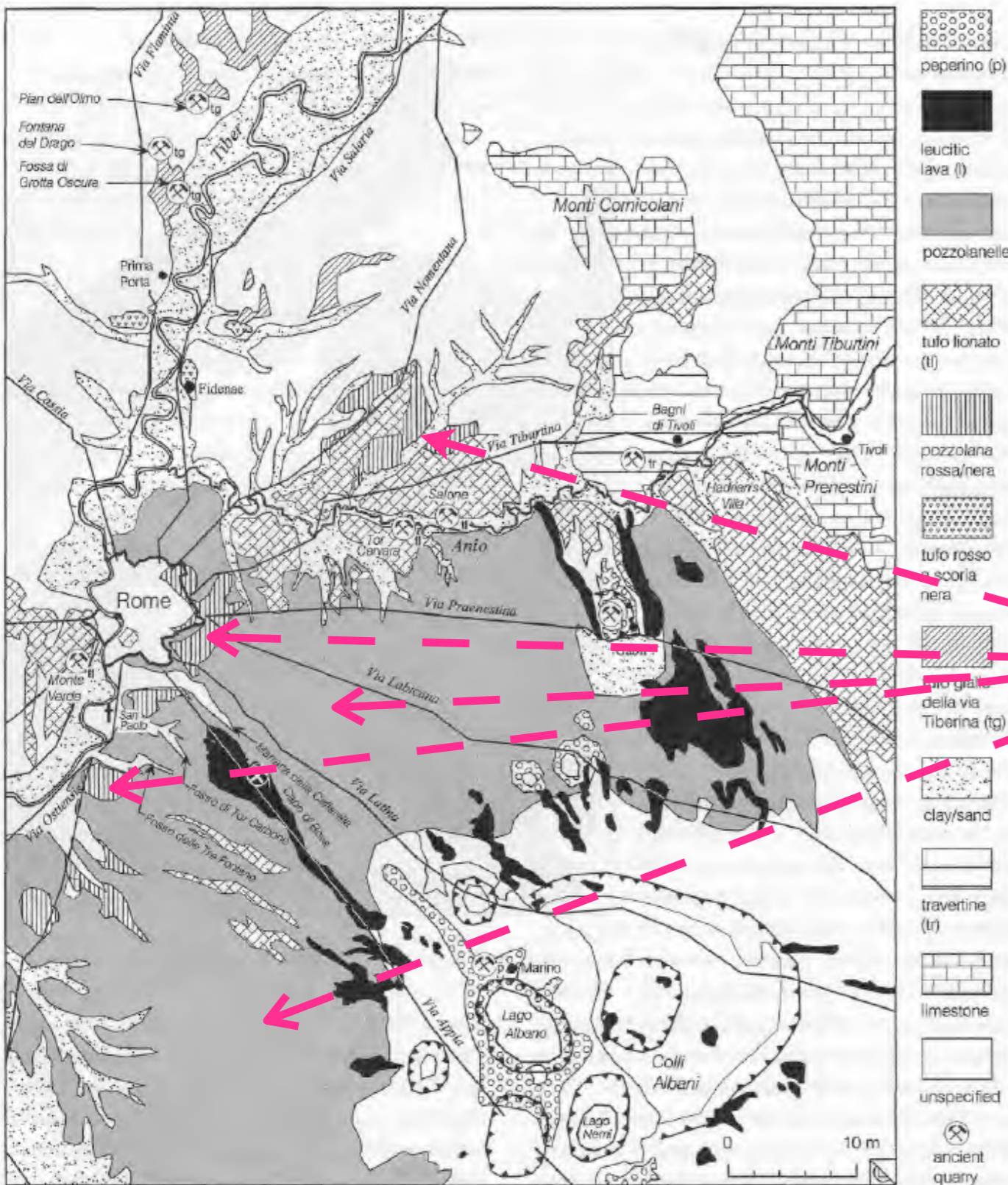
# Keywords of Roman concrete according to Vitruvius

- Lime, hydraulic lime: *calx*
- Sand for concrete : *harena fossicia*  
« volcanic sand »
- Sand for coatings: *harena fluviatica*  
« river sand »

# Key words of roman concrete for Vitruvius

- *Caementum* « rubble »
- *Testa* « crushed metakaolin (kaolinitic clay, calcined at 750 °C) »
- *Pulvis* « pozzolana »

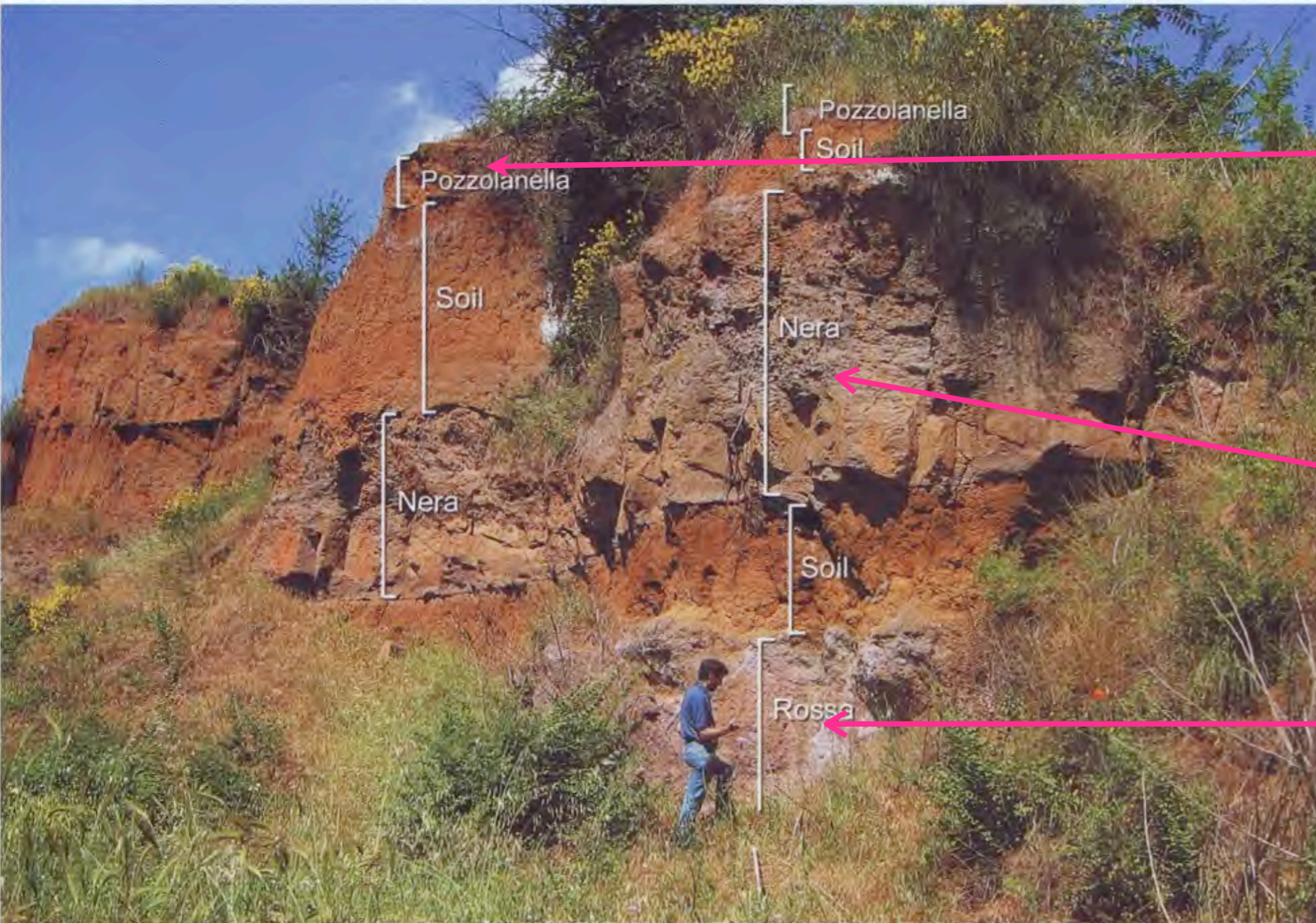
Volcanic sand/pozzolana and rubble came from Rome surroundings.



Volcanic sand/  
pozzalana

MAP 3. Geological map of Rome and environs showing locations of major building materials used in concrete vaulting. Deposits of materials not used by Roman builders are not shown.





*pozzolanella*  
(grayish,  
1360-1670 kg/m<sup>3</sup>)

*pozzolana nera*  
(black, 1340 kg/m<sup>3</sup>)

*pozzolana rossa*  
(red, 1600-1900  
kg/m<sup>3</sup>)

PLATE IV. Section through an abandoned pozzolana quarry on Via Nesazio (near Largo Martiri delle Fosse Ardeatine) showing the stratigraphy of the three different types of Colli Albani pozzolana.

Volcanic quarry (Lancaster 2005)

Campi Flegrei Pozzolana

Pozzolana Rossa



Pozzolanelle

Pozzolana Nera

*Harena fossicia rubra:*  
reddish volcanic sand

*Pulvis* « true pozzolana »

*Harena fossicia nigra:*  
reddish volcanic sand

*Harena fossicia cana:*  
grayish volcanic sand

PLATE III. Four types of pozzolana showing the difference in color between them. The Campi Flegreian pozzolana (*pulvis puteolanus*) at upper left is easily distinguishable from the other pozzolanas quarried near Rome. (Euro = 2.3-cm dia)

# Vitruvius' volcanic sands

Vitruvius (II, 4, 1) describes the characteristics of harena fossicia: *Genera autem harenae fossiciae sunt haec: **nigra, cana, rubra, carbunculus.*** Now the kinds of volcanic sand are these: **black, white, red, and the carbuncle.** Of these, that which makes a noise when rubbed in the hand will be best; but that which is earthy will not have a like roughness. Also, if it is covered up in a white cloth, and afterwards shaken up or beaten, and does not foul it, and the earth does not settle therein, it will be suitable.

# Properties of *harena fossica*

Vitruvius II, 4, 3: “But quarry volcanic sand quickly dries in buildings, and the surface lasts; and it admits of vaulting, but only that which is fresh from pit. For if after being taken out it lies too long, it is weathered by the sun and the moon and the hoar frost, and is dissolved and becomes earthy. [...] But while fresh volcanic sand has such virtues in buildings, it is not useful in plaster work; because owing to its richness, the lime when mingled with straw cannot, because of its strength, dry without cracks.”

# Distinction between true pozzolana and volcanic sand

Vitruvius II, 6, 1: *Utraque autem sunt egregia in structuris, sed alia in terrenis aedificiis, alia etiam in maritimis molibus habent virtutem.*

“Pozzolana and volcanic sand are excellent in walling. But the latter have advantages in buildings on land, and pozzolana in piers built into the sea. »

# Vitruvius' sand

- *harena fossicia, carbunculus*:  
« volcanic sand » for buildings
- Pulvis « pozzolana of Puteoli » for  
piers
- *harena fluviatica*: « river sand »,  
*harena marina* « sae sand » for  
coatings

# The *carbunculus*

- Vitruvius (II, 6) states: « the best of volcanic sand »
- It is extracted from a volcanic tuff called *carbunculus* or *materia excocta*,
- It is a “soft volcanic tuff calcined by underground fire”.
- He also claims that it is found geologically in Etruria, in the volcanic area located in the north of Rome.

Vitruvius II, 6, 6: « Therefore where ever mountains are not of earth but of a stony kind, the force of fire escaping through the veins burns it up. It burns out what is soft and tender, but leaves what is rough. The nature of this volcanic stone (*carbunculus*) is softer than tufa, more solid than the earth; and when this is burnt deep down by the violence of vapour, there is generated in some places that kind of volcanic sand which is called *carbunculus*. »



# This text is crazy

- *Carbunculus* « is softer than tuff, more solid than the earth » !
- What does that mean ? How to translate it ?
- We know that Vitruvius' geological description relates to a geological reality.

# Vitruvian theory of 4 elements

- Each substance in Nature has four elements:  
*terra* "earth", *aqua* "water", *aer* "air" and *ignis* "fire »
- Their proportions determine their physical properties (hardness, softness, etc.)

# Vitruvian theory of 4 elements

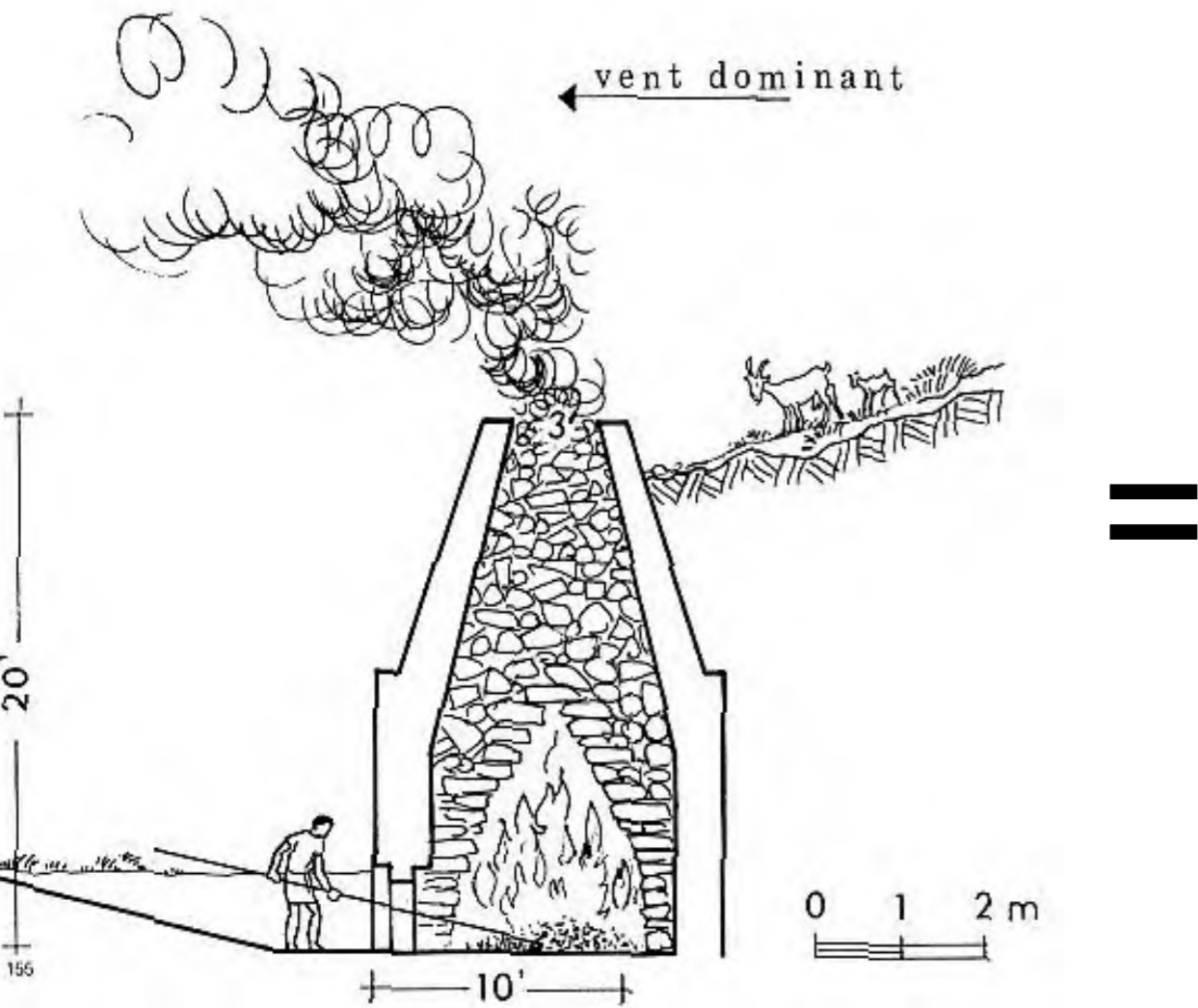
- The volcanic/artificial fire destroys the coherence of any stone,
- Lime is the result of expelled air and water from limestone (Vitr. II, 5) whereas Roman lava containing more earth and water than air and fire, withstands better fire and weathering (Vitr. II, 7, 2).

# Vitruvian theory of 4 elements

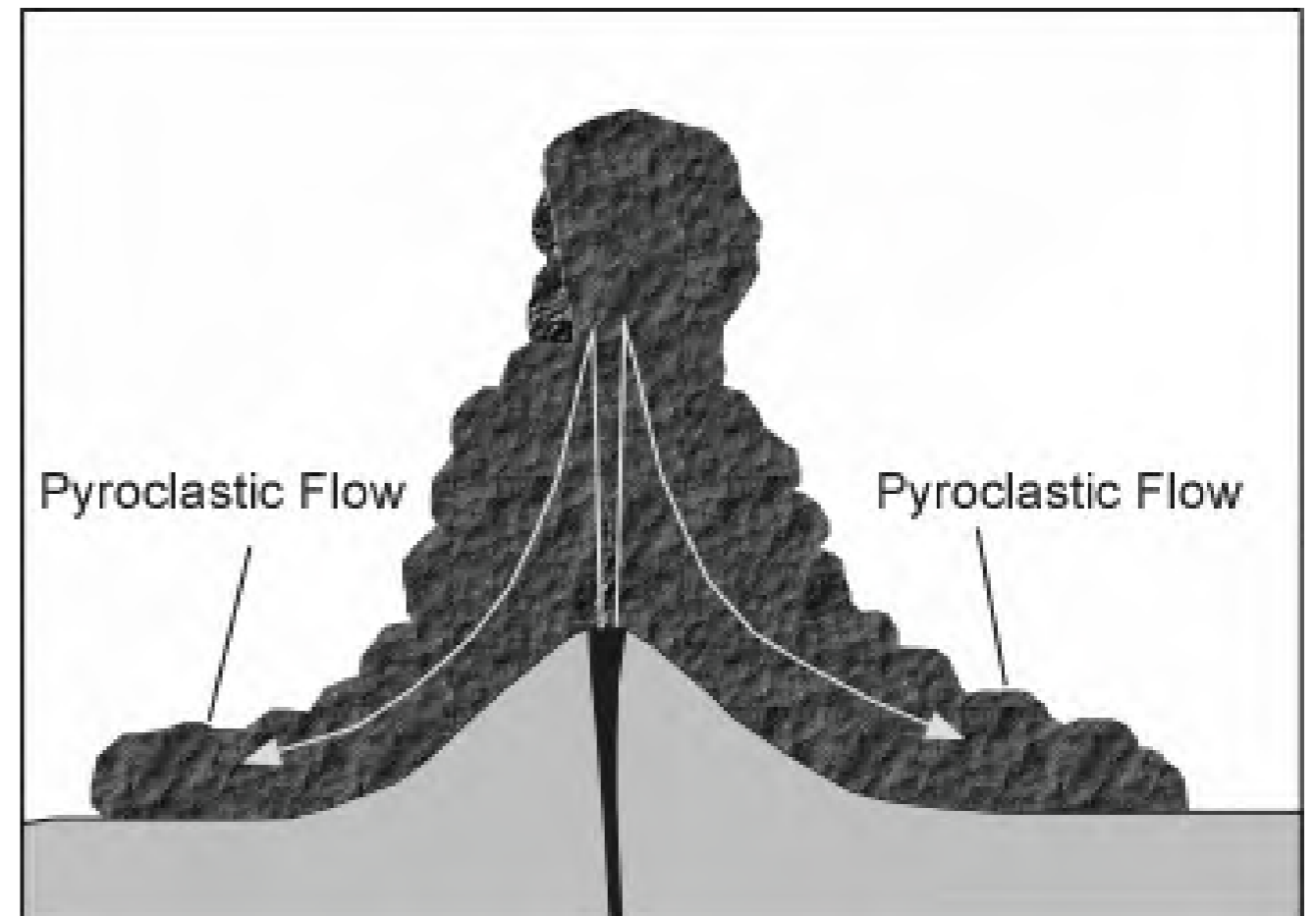
For Vitruvius, any substance (stone, mineral, metal) which has been fired in a kiln such as lime or has undergone the volcanic fire gets new physical or chemical properties for architecture and engineering (Davidovits 2003; Davidovits 2007).

**Kiln = volcanism**

# How does materials gain their physical properties ?



=



**Limekiln = Volcano**

# List of natural material for mortar/concrete

- Pozzolan: *cinis* “ash”, *terra exusta* “burnt out earth”
- Pumice of Pompeii: *genus lapidis excoctum* “a kind of calcined rock”
- Carboncle: *materia excocta* “calcined rocky material”
- Volcanic sand: *harena fossicia* “extracted volcanic sand”

# List of artificial materials for mortar/concrete

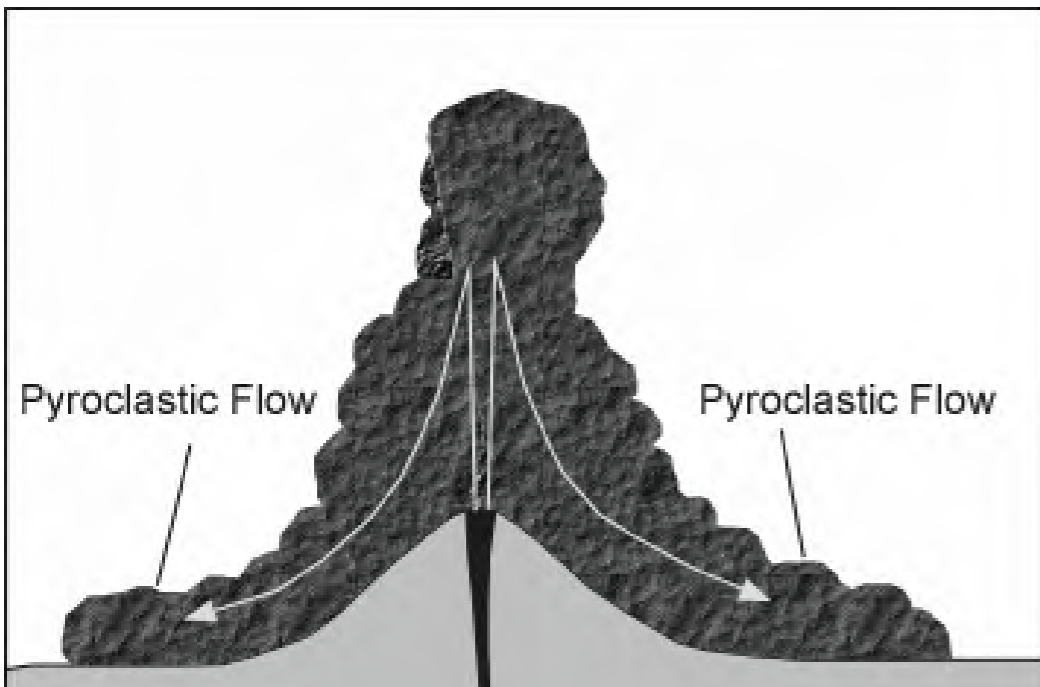
- *Calx* « lime »
- *Testa* « calcined kaolinitic clay at 750 °C »
- All those materials have been charred by natural (volcanism) or artificial fire (kiln)

# How to recognise good volcanic tuff for concrete

- *Carbunculus* tuff for sand is not indurated (*mollior quam tofus*) and has pores and veins (created by volcanism) that run through the stone (Vitruvius II, 6, 5-6)
- Geologically, it is a pyroclastic stone (ignimbrite) which has fluidisation pipes.
- The gas contained in the ignimbrite escape through pipes and the stone become soft
- Volcanic sand can be extracted by hand.



# Pyroclastic flow



Pompei, Italy, 79 A. D.

# Gas pipes = “the force of fire escaping through the veins” (Vitruvius)

- Gas segregation structures that provide direct routes for the degassing of the ignimbrite.
- pipes are ~20 cm in diameter
- The escaping gases cause different induration in stone



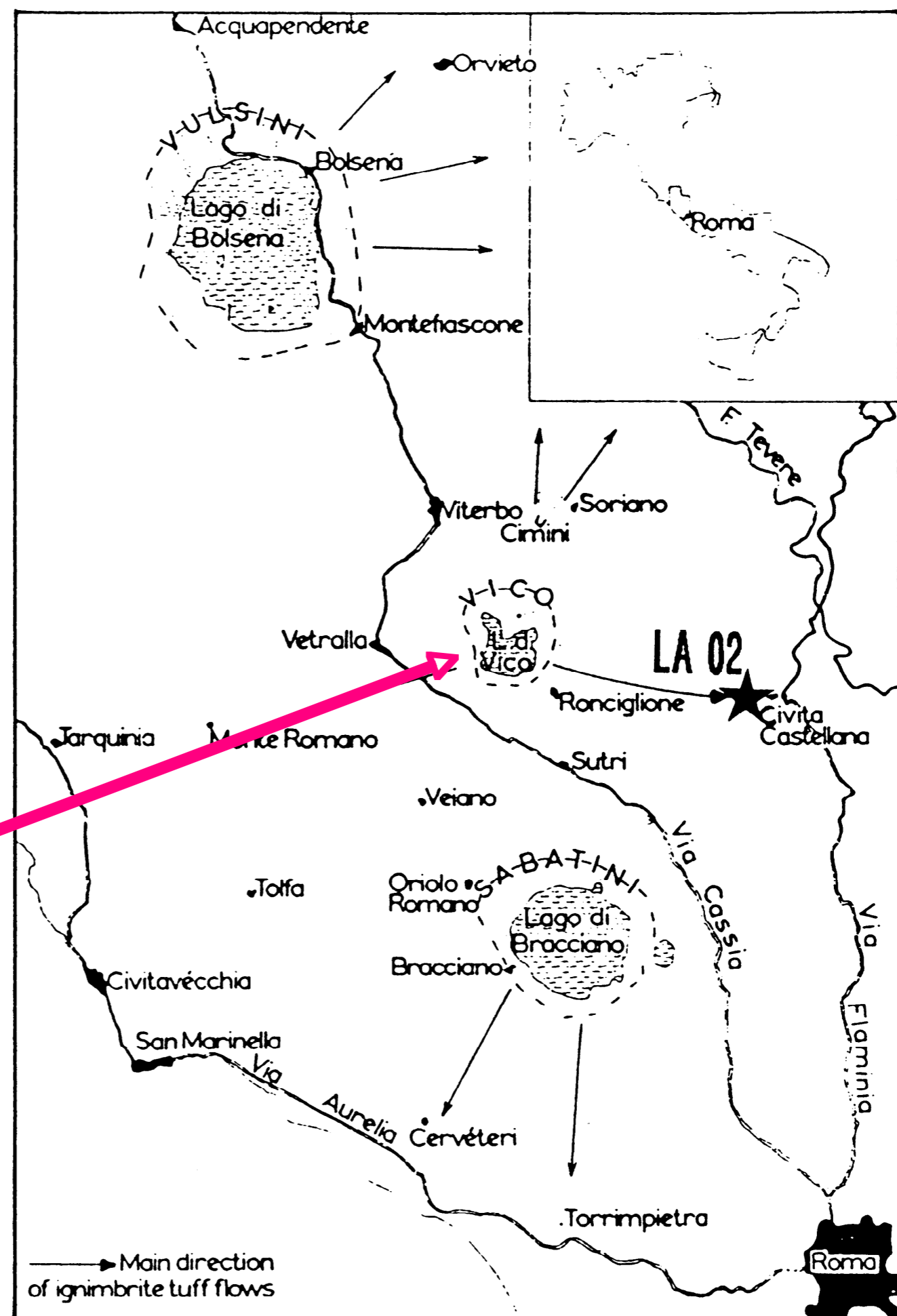
Fumarole pipes, Real Grande ignimbrite, Argentina

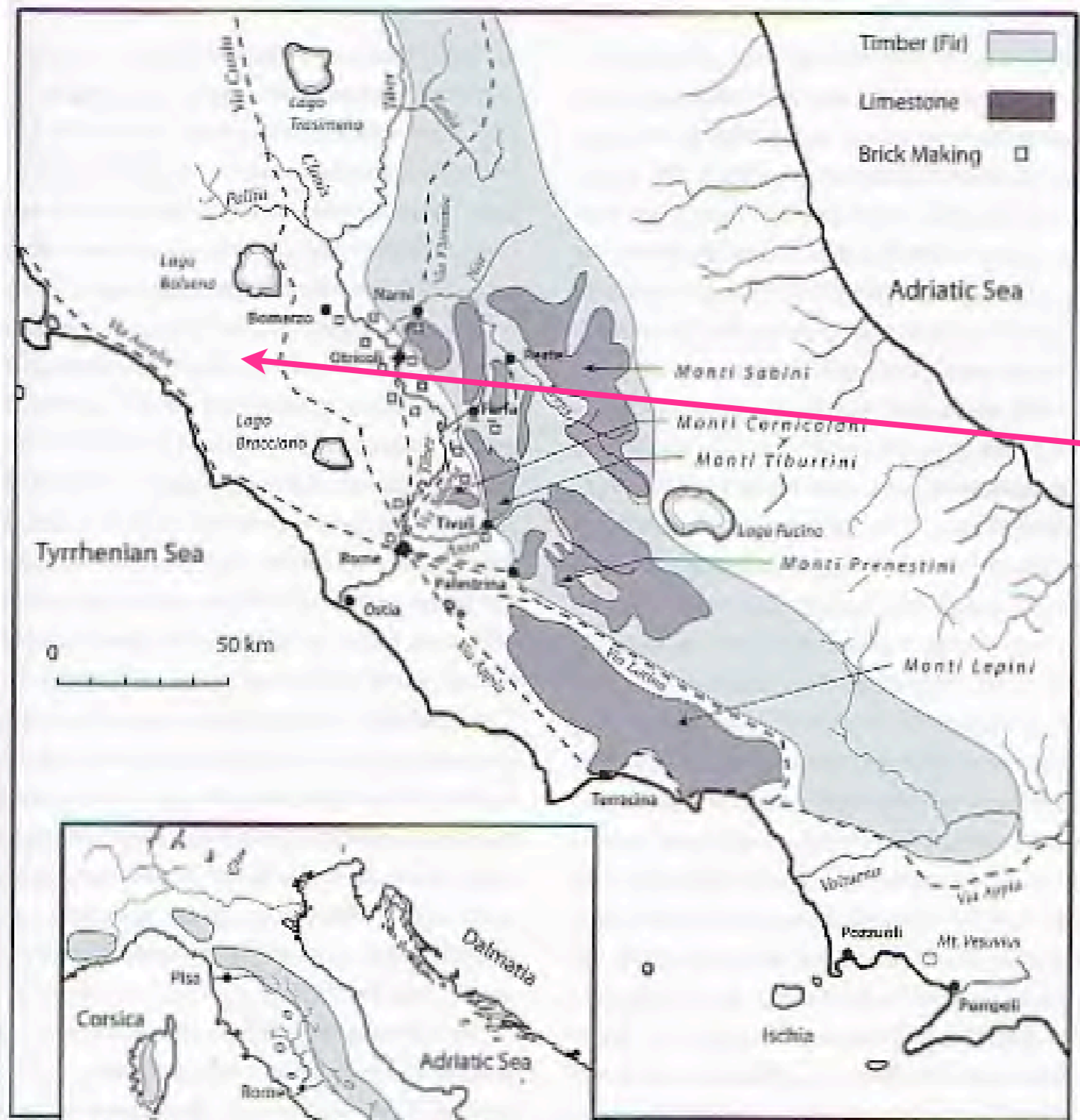
Gas pipes = “the force of fire escaping through the veins” (Vitruvius)



Gas pipes in ignimbrite of strato-volcano of Vico (Italy) in Etruria, where Vitruvius situated the *carbunculus*

# Volcano of Vico in Etruria





**Volcanic  
Etruria**



Major Timber (Fir) Source Areas Shaded

MAP 4. Map of Italy showing locations of major sources of timber and limestone.

# Conclusion

- Vitruvius exposes his volcanism theory in order to provide the necessary information for the civil engineers
- How to recognise the best volcanic materials for making mortar
- His description of volcanic tuff/sand relates to a geological reality