

ROMAN ARCHITECTURE & ENGINEERING (A&E), 753 BC to 476 AD



Joseph T Wunderlich PhD

BS Architectural Engineering, U Texas (Austin) 1984
Urban Design, UCSD 1986-87

Full-time A&E in PA, TX, and CA in 1980's; part time to present
Hi-tech in 90's to present (M.Eng, PhD, IBM Research, Purdue Prof, etc.)

Six trips to Italy as of 2020, including teaching a PhD course at U Trento

ROMAN A&E

spanned 1,229 years
(753 BC to 476 AD)

Initially a ROMAN **KINGDOM**, then a
ROMAN **REPUBLIC** (with elections, but not a democracy) from 509BC

Then the ROMAN **EMPIRE**, with EMPERORS, from 27BC

Unlike the Greeks, Roman expansion spread their power and control to many places throughout Europe, the Middle East, and Africa.

The Romans had conquered all of the Greek city-states by 146BC



Roman CONCRETE

SOURCE: <https://www.asme.org/engineering-topics/articles/technology-and-society/ancient-roman-concrete-stands-test-time>



Roman concrete mixed lime, VOLCANIC ASH, and VOLCANIC ROCK (the aggregate) to build structures lasting over 2000 YEARS:

- Large buildings
- Bridges and Roads
- Sewers and Aqueducts
- Piers and breakwaters
 - Along coastline to protect busy shipping harbors
 - Modern-day concrete, even when reinforced with rebar, might only last 100 YEARS in a marine environment

STOP here and learn more about concrete in Wunderlich lecture on “**Concrete**” in Materials & Methods course:

[PPTX-audio](#) [PDF](#) [CLOUDw/transcript](#) [MP4](#) [YouTube](#)

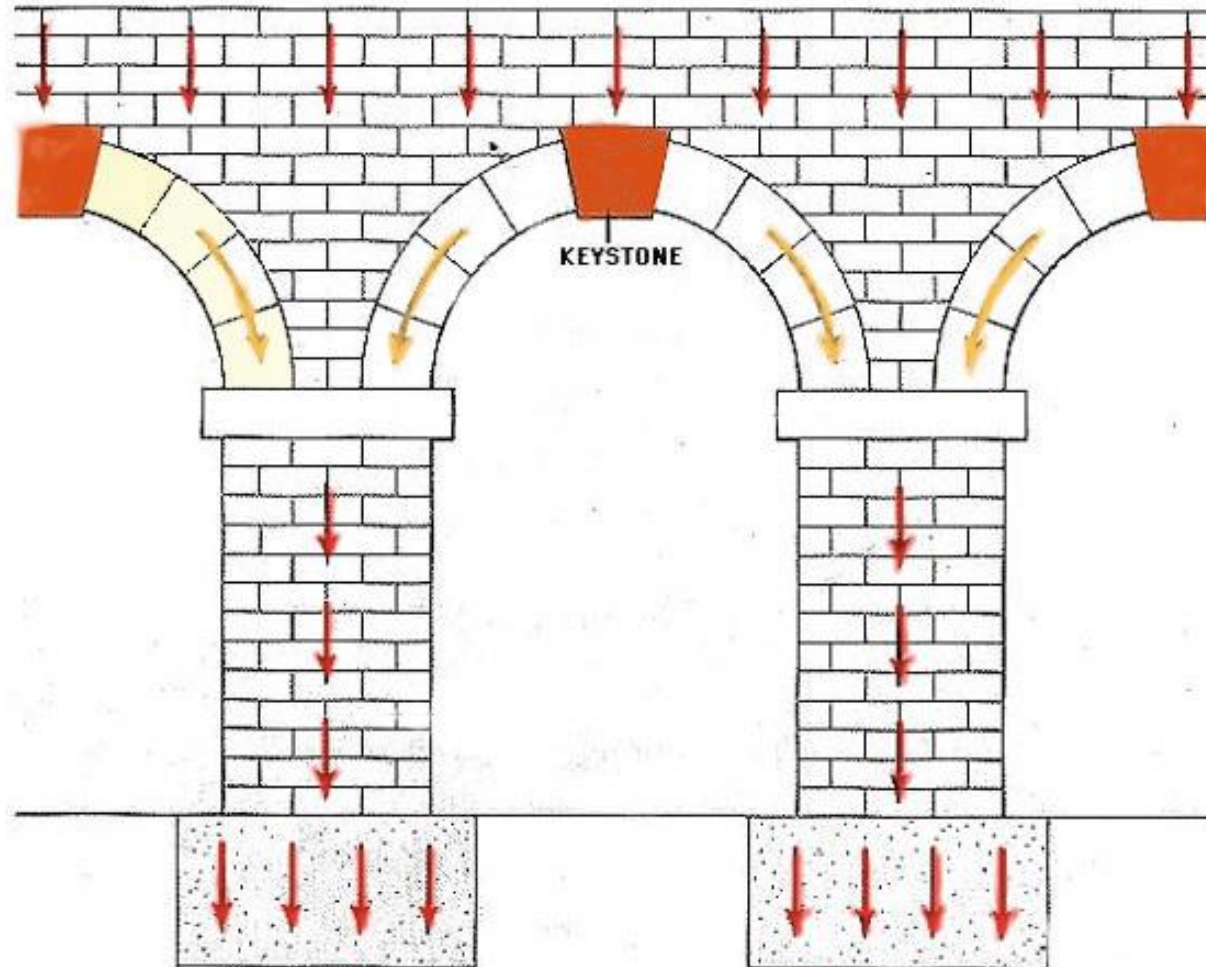


>2500 years ago

Roman ARCH

Distribution of Forces shown by arrows in the figure

SOURCE: <http://aventalearning.com/content168staging/2008Latin1A/unit3/section5f.html>



>2500 years ago

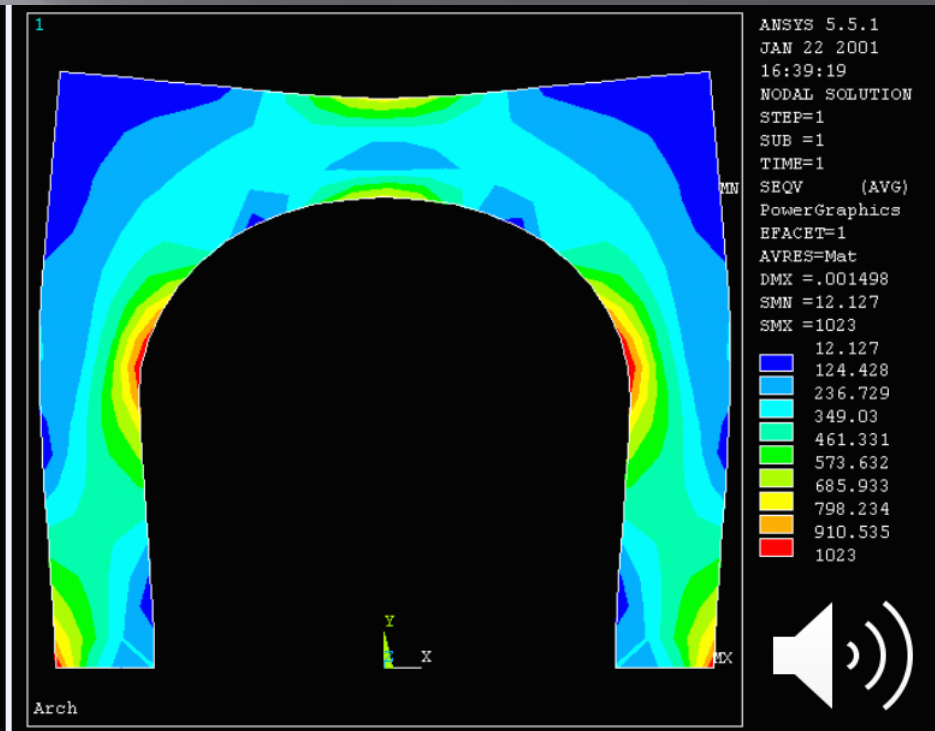
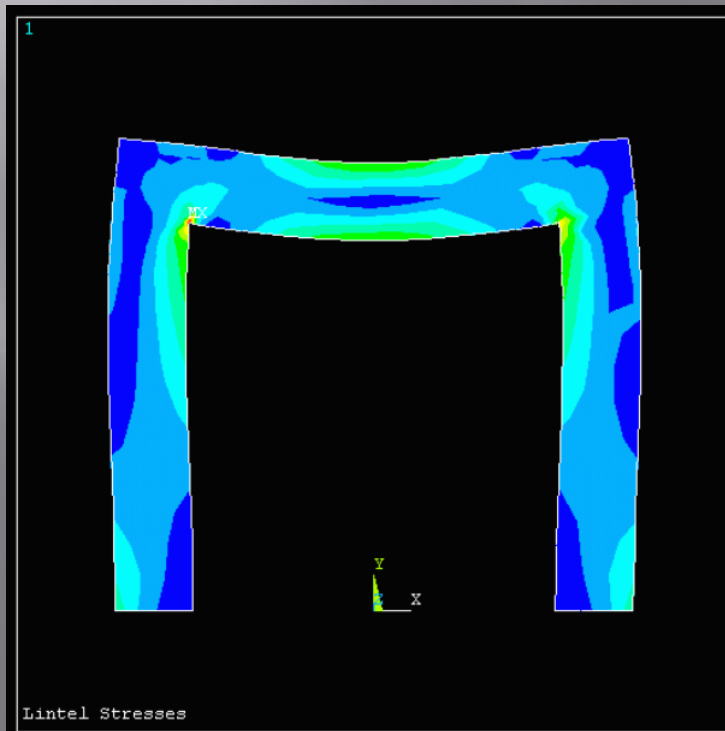
Roman ARCH

SOURCE: <http://infohost.nmt.edu/~es421/ansys/archfull.htm>

Figure 1 shows **internal stress** in a **post-and-beam lintel** while Fig. 2 shows stresses in an arch

Legend on lower right shows maximum stresses in arch are half those in lintel..

Red areas delineate highest relative stresses, blue show lowest.



>2500 years ago

~600BC Roman SEWERS (still function today)

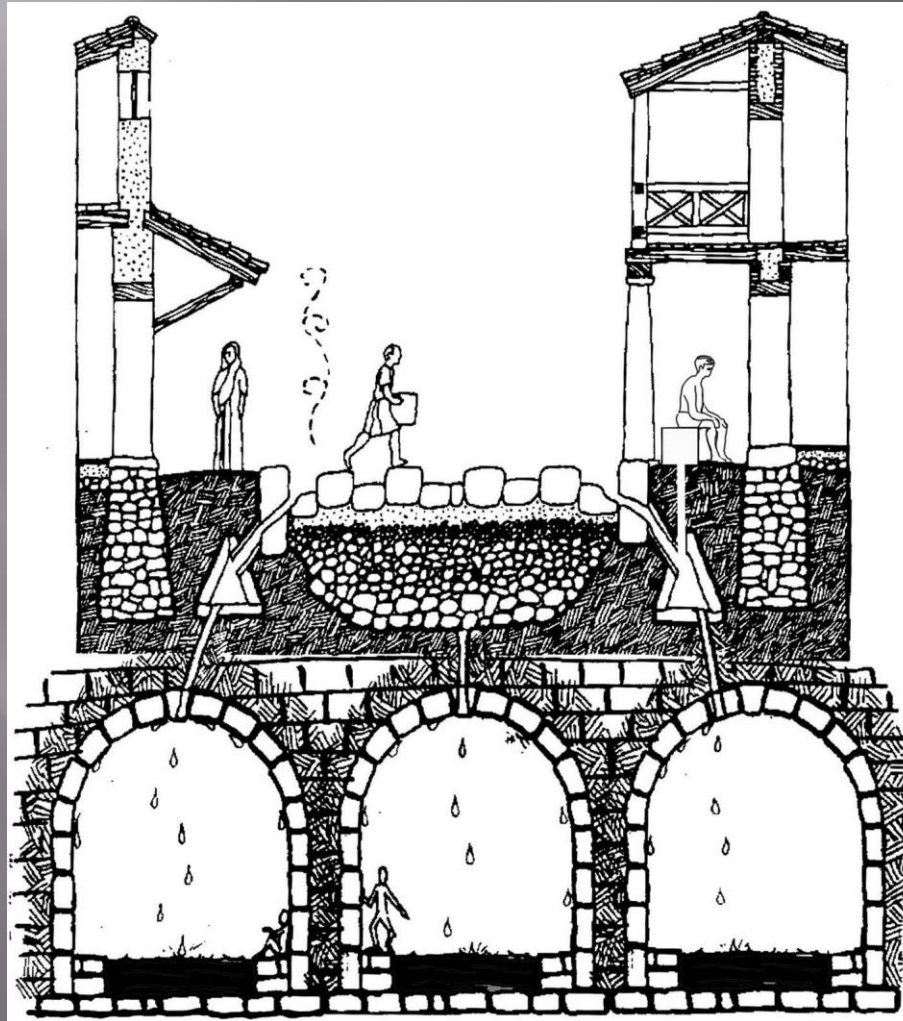


The inside of the tunnel that drains water from the Roman Forum – the Cloaca Maxima.



>2500 years ago

Roman SEWERS (SEWAGE and STORMWATER RUNOFF combined)



>2500 years ago

Roman SEWERS (SEWAGE and STORMWATER RUNOFF combined)



>2500 years ago, and still working !

Roman SEWERS

Photo by J Wunderlich in Rome in 2011 of working sewer from Roman times
(but just for STORMWATER RUNOFF now – dumping into river)



>2500 years ago

Roman SEWERS

In Roman times, raw sewage was also dumped into the Tiber River
(Photo by J Wunderlich in Rome, 2011)



>2500 years ago

Roman SEWERS (“Cloaca Maxima”)

Allowed draining swamp that became the “FORUM”,
Consolidating the tribes on the surrounding hills into a unified culture



Photos by J Wunderlich in 2011



2300 years ago

Romans built over 53,000 miles of ROADS

SOURCE: <https://www.amusingplanet.com/2017/09/appian-way-first-roman-road.html>

Appian Way, 312 BC

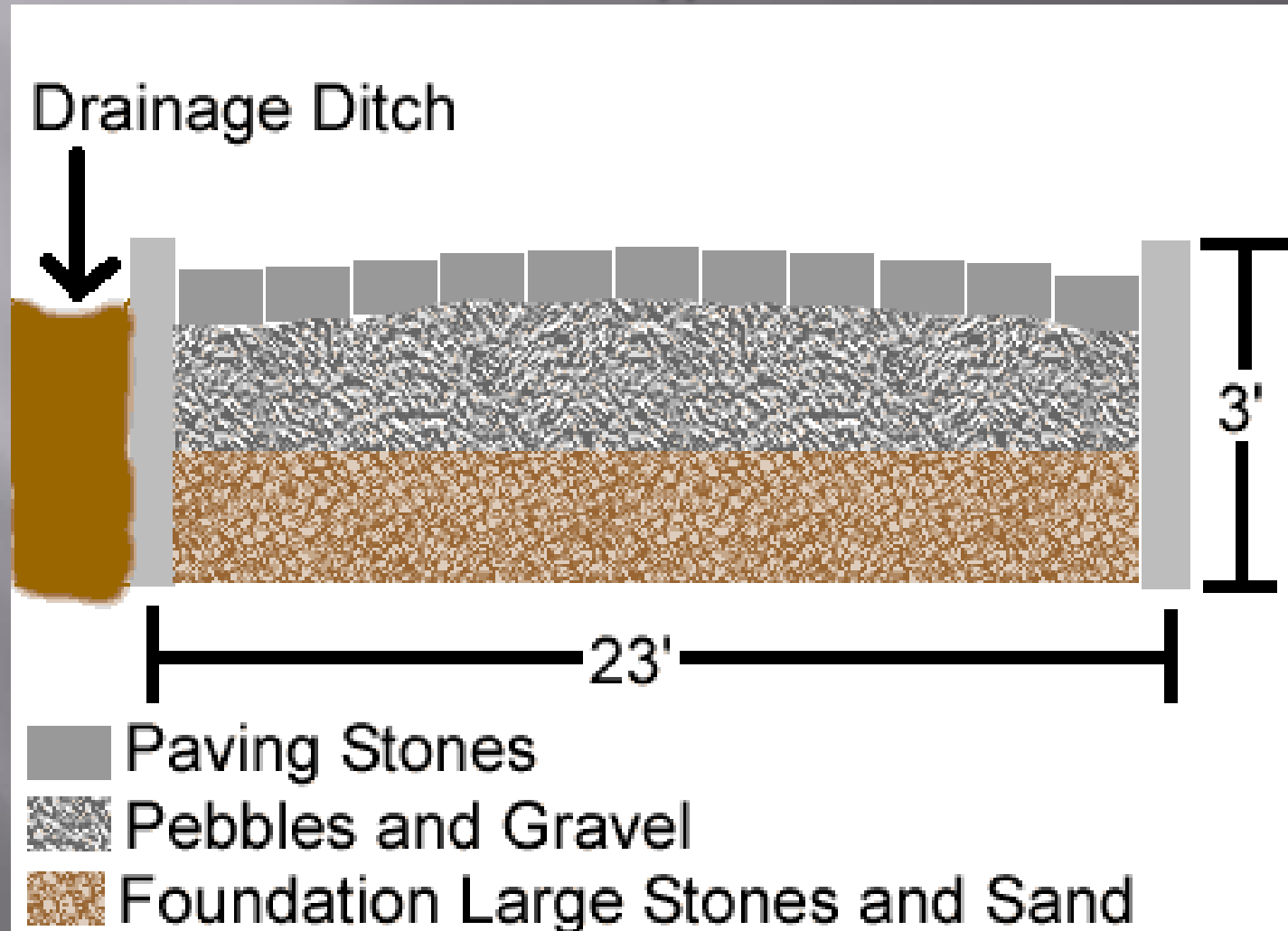


2300 years ago

The ROADS were first surveyed to keep them straight, and then built by hand. Roads were sloped from the center so rainwater would drain off into ditches

SOURCE: <http://historylink101.com/2/Rome/roman-roads.htm>

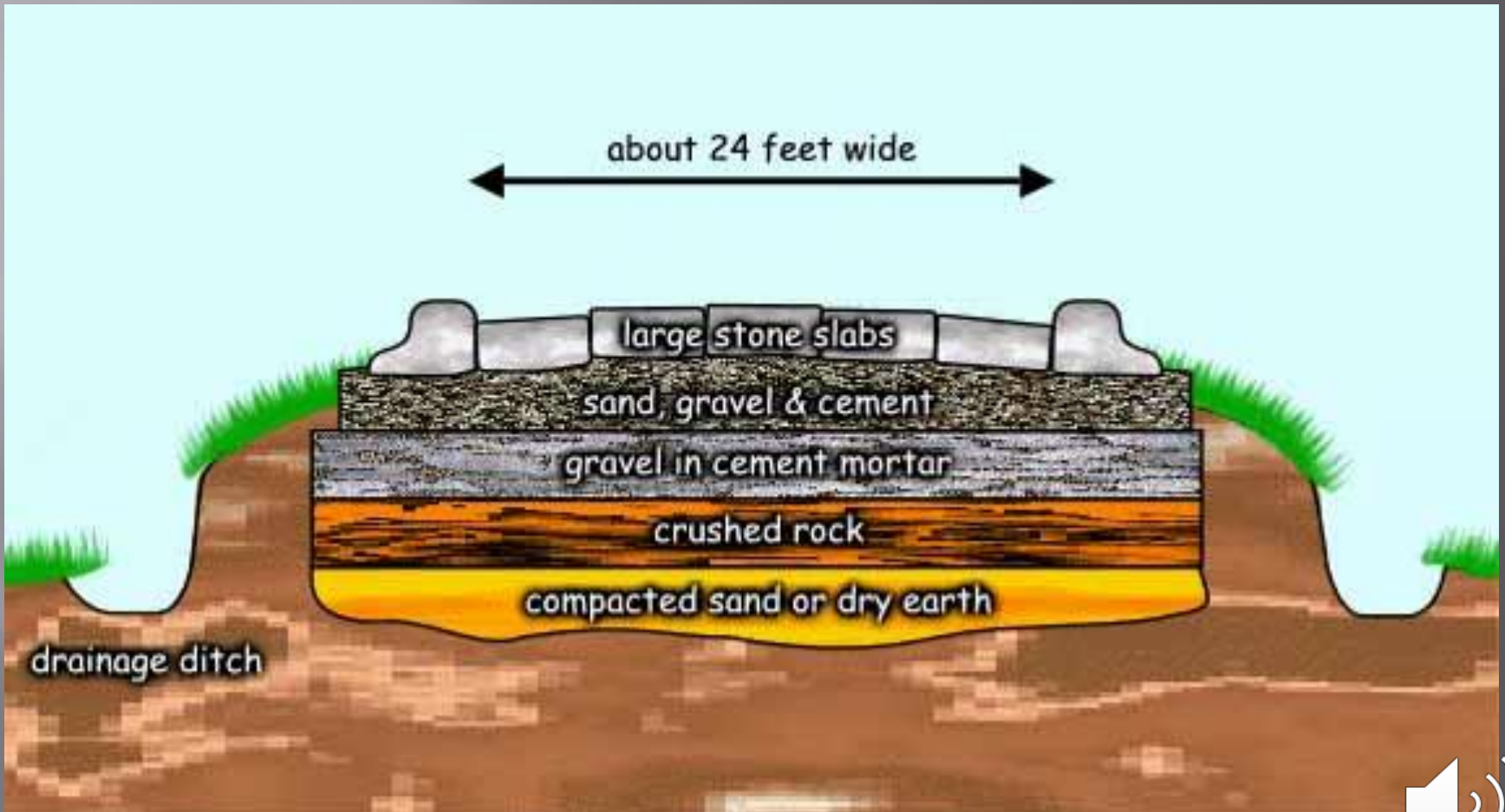
ROAD Type #1



2300 years ago

SOURCE: <http://www.crystalinks.com/romeroads.html>

ROAD Type #2



2300 years ago

Romans built over 53,000 miles of ROADS

A unit of Roman officers called chief builders (“architecti”) were in charge; Educated in Geometry, they had a staff of land surveyors (“agrimensores”) and levelers (“libratores”).

Construction workers taken from the ranks carried weapons, rations, and utensils; And possibly a saw, hatchet, sickle, pick, or spade for road construction work.

SOURCE: <http://www.crystalinks.com/romeroads.html>

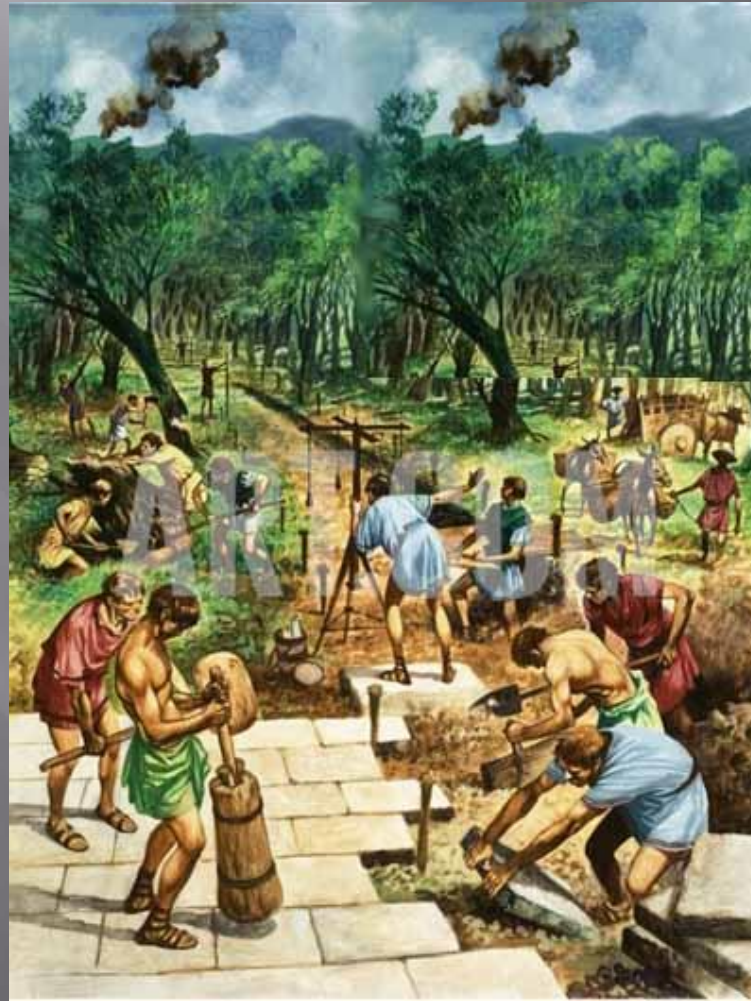


2300 years ago

Romans built over 53,000 miles of ROADS

Slaves, prisoners of war, and convicted criminals performed the quarrying and transporting of stone.

SOURCE: <http://www.crystalinks.com/romeroads.html>



2300 years ago

Romans built over 53,000 miles of ROADS

Stone mile markers placed along roads

SOURCE: <http://historylink101.com/2/Rome/roman-roads.htm>



2200 years ago

Roman BRIDGES



“Ponte Rotto“ (*Broken Bridge*) in Rome. Built in 141 BC. Photo by J Wunderlich 2011

<https://www.througheternity.com/en/blog/hidden-sights/ponte-rotto-romes-broken-bridge.html>



2100 years ago

Roman BRIDGES



Pons Fabricius is oldest Roman bridge in Rome in its original state.
Built in 62 BC

https://en.wikipedia.org/wiki/Pons_Fabricius

<https://fineartamerica.com/featured/pons-fabricius-fabrizio-ruggeri.html>



1900 years ago

Roman BRIDGES



“Alcantara “ Roman Bridge in Spain. Built in 106 AD

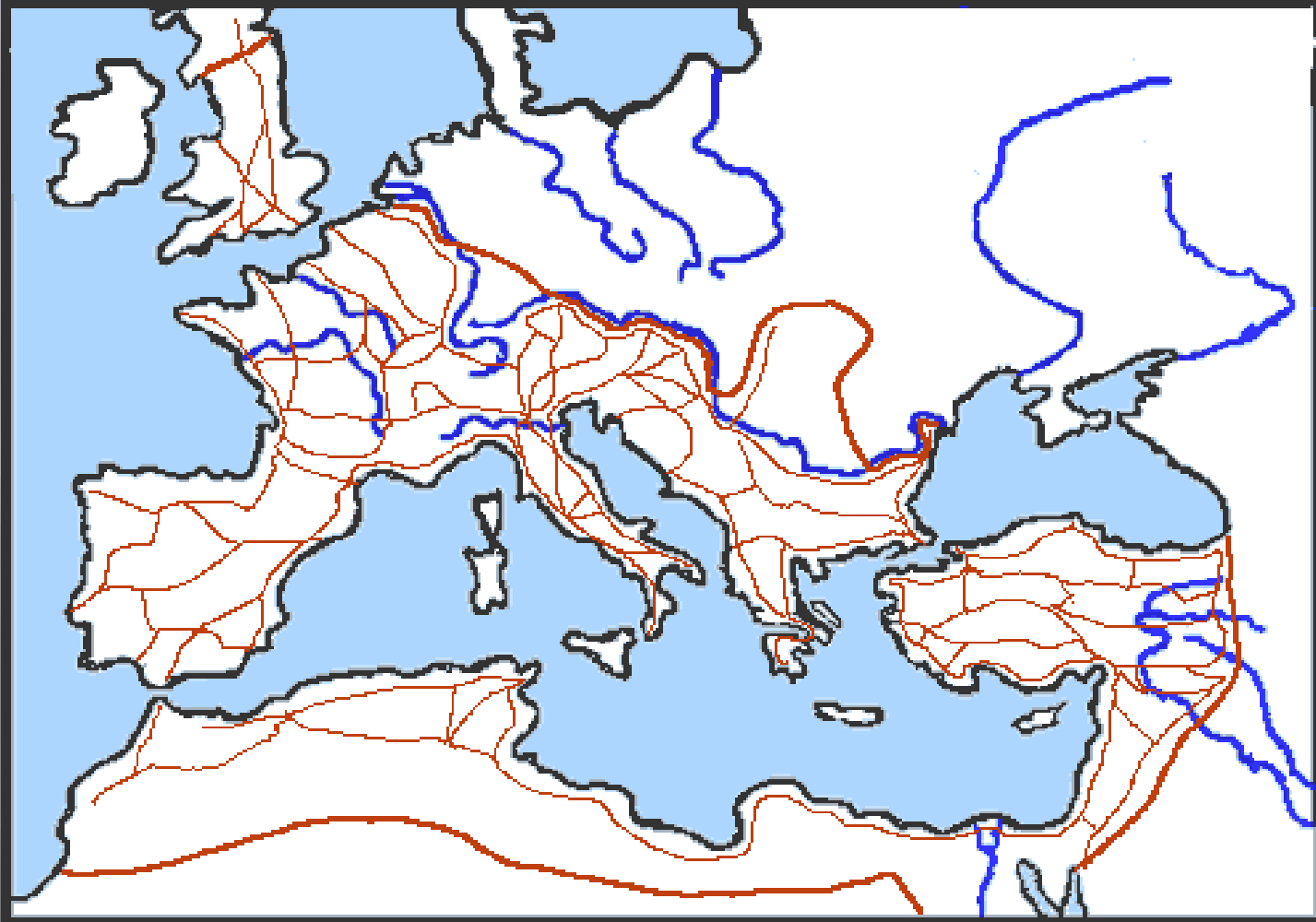
<https://www.istockphoto.com/photos/alcantara-bridge?page=2&sort=mostpopular&mediatype=photography&phrase=alcantara%20bridge>



~2000 years ago

Romans built over 53,000 miles of roads to connect every part of their empire.
They had a saying "All roads lead to Rome."

SOURCE: <http://historylink101.com/2/Rome/roman-roads.htm>



~2000 years ago

Romans built over 53,000 miles of ROADS

Roman Legions of soldier/builders
didn't need WAY-STATION's
since they had a baggage train,
and they constructed their own camp every evening

Others did, and PASSPORTS were required
Carts could travel 8 miles per day, pedestrians a little more

Way-stations were 15 to 18 miles apart

Often a permanent military camp or town grew there

Private systems of refreshments also grew there

SOURCE: <http://historylink101.com/2/Rome/roman-roads.htm>



~2000 years ago

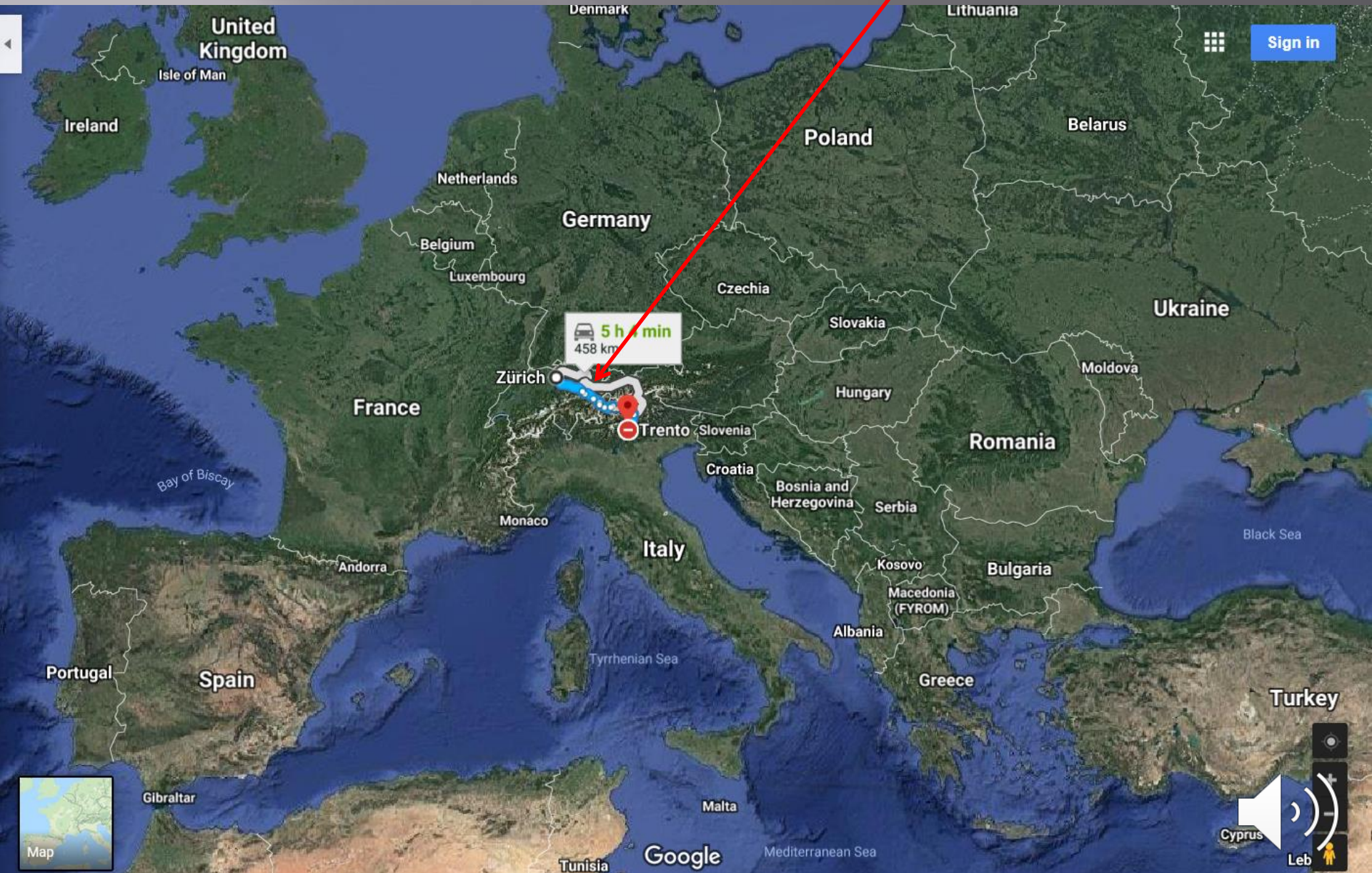
Romans built over 53,000 miles of ROADS

Government maintained way station (“mansiones”)

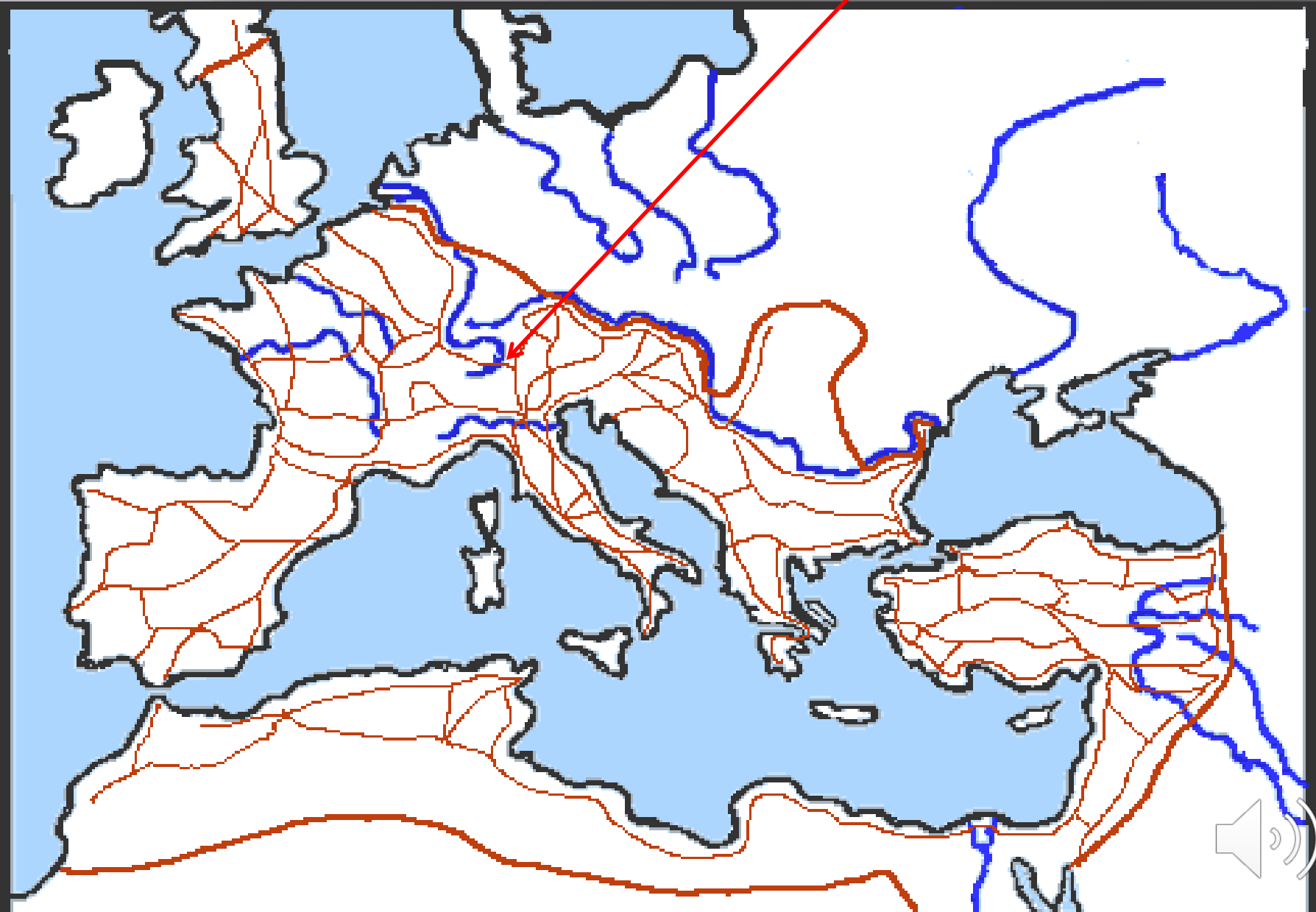
SOURCE: <http://historylink101.com/2/Rome/roman-roads.htm>



J Wunderlich story (listen to audio)



J Wunderlich story (listen to audio)



J Wunderlich story (listen to audio)



J Wunderlich story (listen to audio)



J Wunderlich story (listen to audio)



Val Blu Sporthotel & Spa

Photo from <http://www.valblu.at/de/hotel-wellness-vorarlberg-bludenz-valblu.html>



2300 years ago

WATER SUPPLY for cities by Roman AQUEDUCTS

Aqua Appia, Rome 312 AD



2000 years ago



“Pont du Gard”
Aqueduct
bridge
in
southern France

40-60 AD

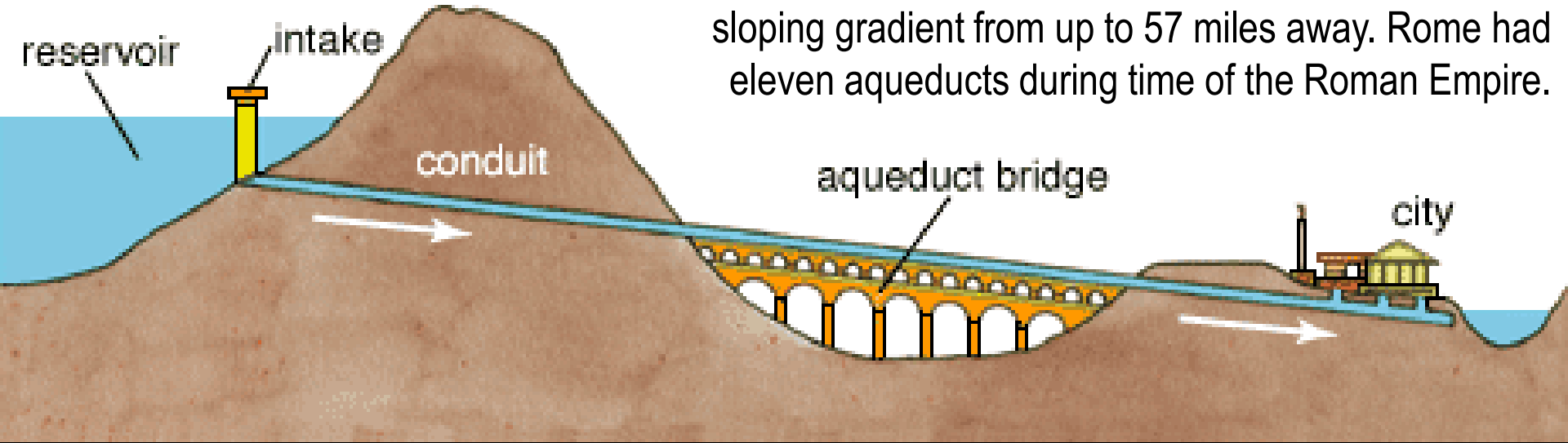


>2000 years ago

Roman AQUEDUCTS

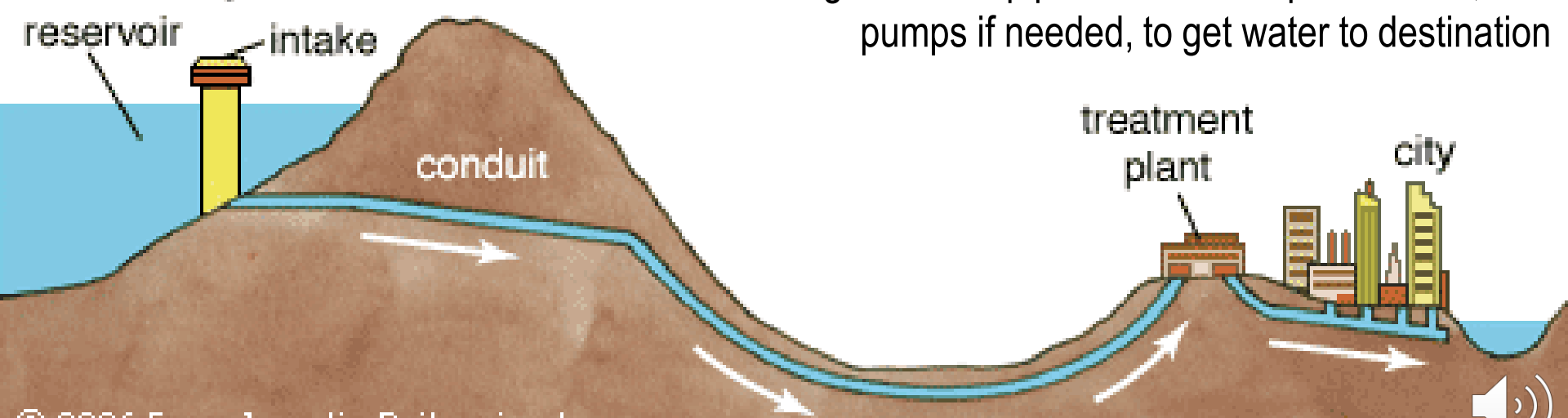
SOURCE: <https://www.britannica.com/technology/aqueduct-engineering> <http://www.crystalinks.com/romeroads.html>

Roman Aqueduct



Often using only gravity to lead water along a continuous sloping gradient from up to 57 miles away. Rome had eleven aqueducts during time of the Roman Empire.

Modern Aqueduct



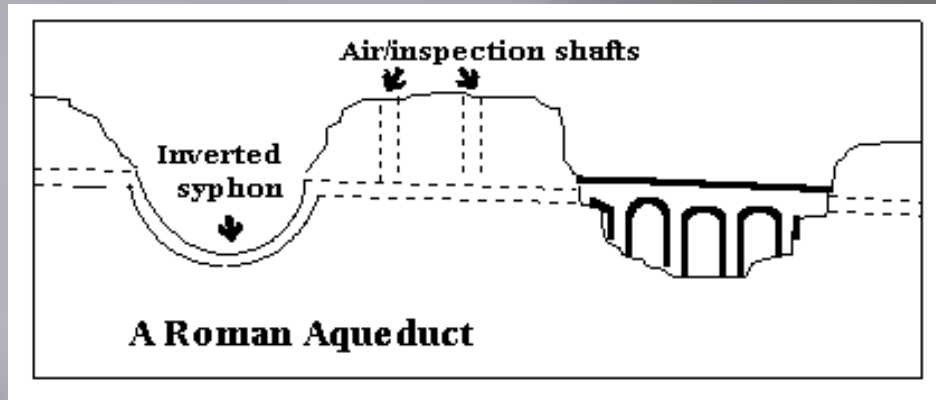
Using enclosed pipes that can be pressurized, and pumps if needed, to get water to destination



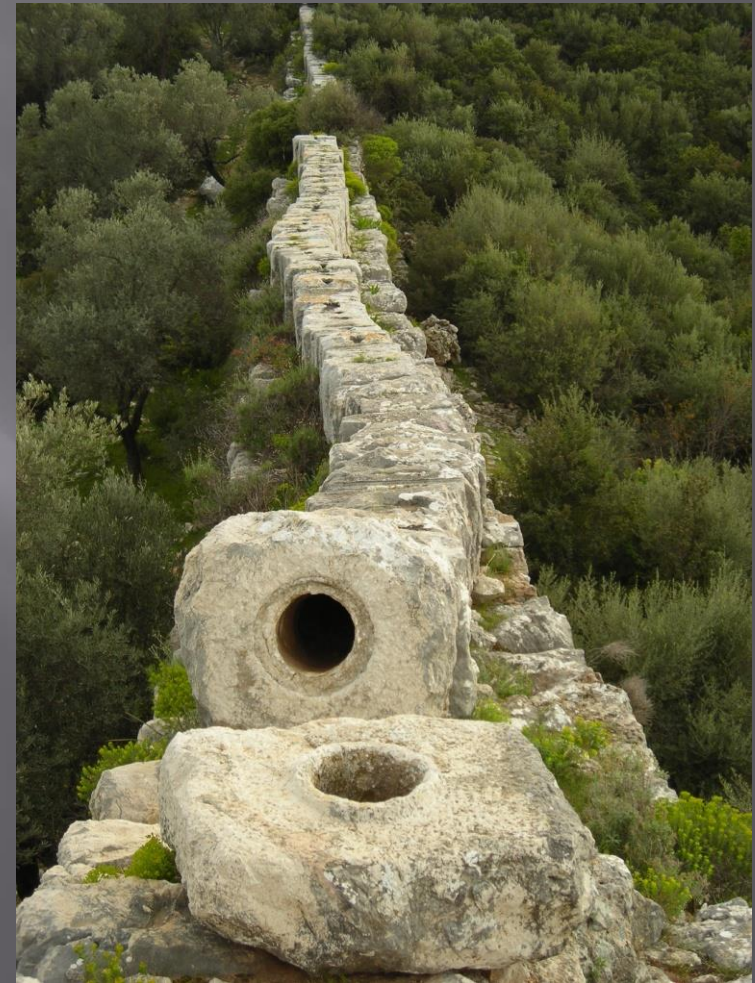
>2000 years ago

WATER SUPPLY for cities by AQUEDUCTS

Parts of some Roman Aqueducts could however span large valleys by using “Inverted Siphons”

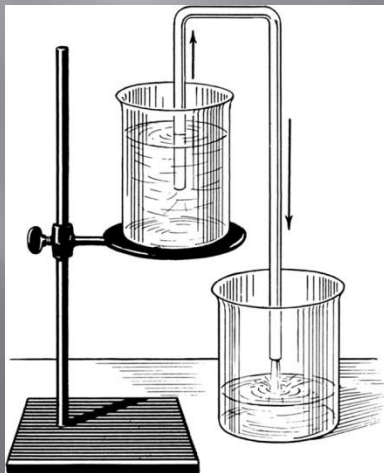


<https://sites.google.com/site/theromanaqueducts/design>



“Patera” Siphon Aquaduct in Turkey

<http://www.romanaqueducts.info/aquasite/index.html>



A Siphon

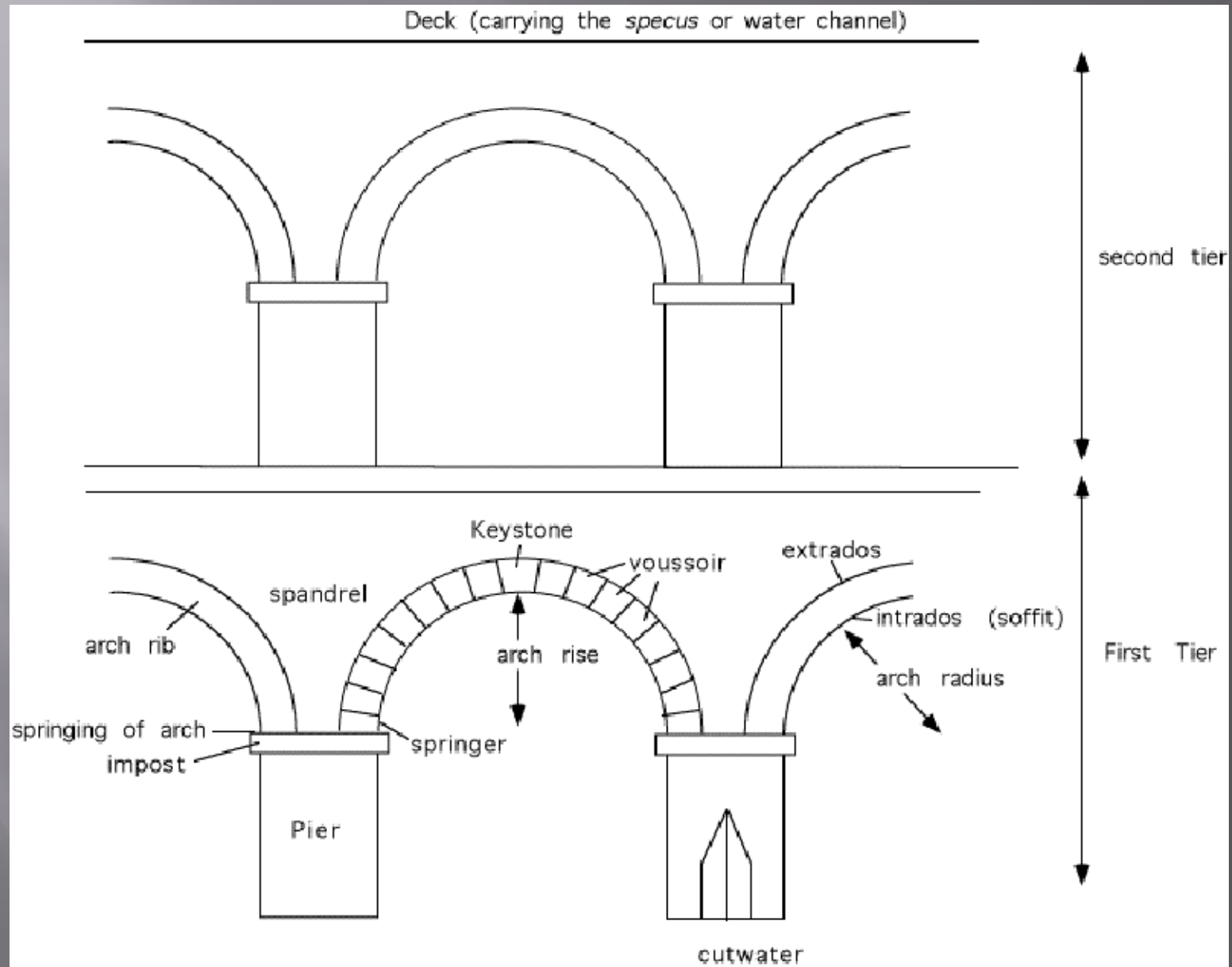
<https://www.britannica.com/technology/siphon-instrument/media/546445/129487>



>2000 years ago

AQUEDUCT BRIDGES

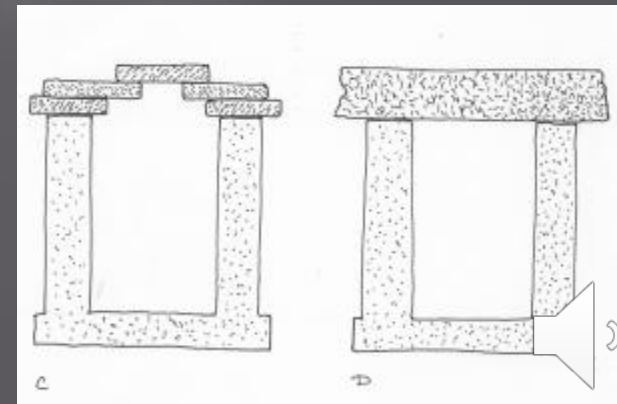
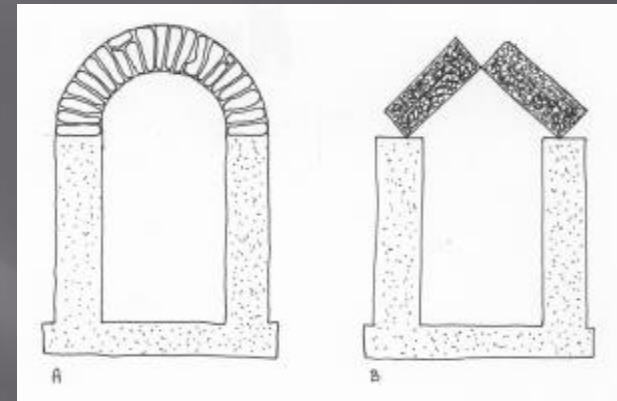
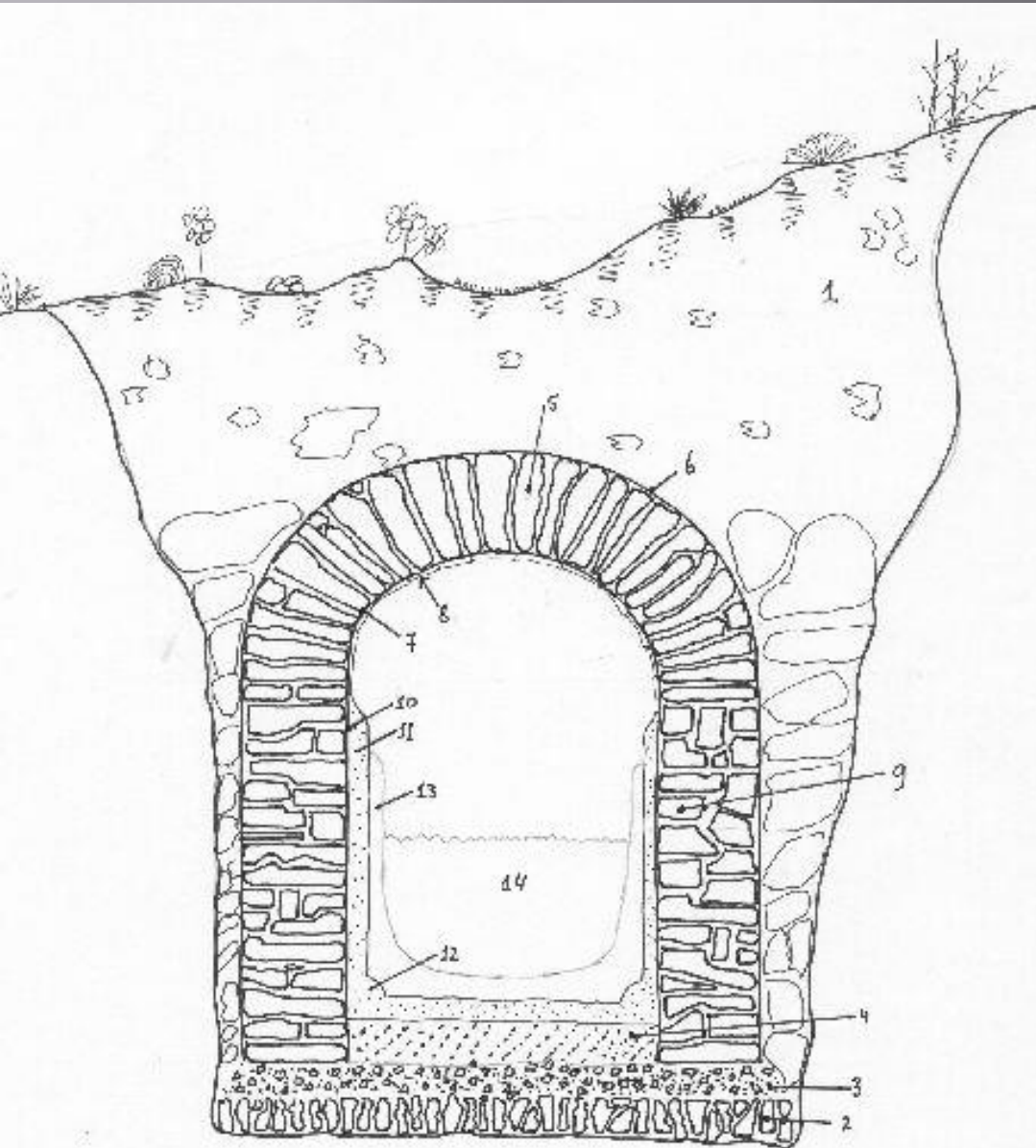
SOURCE: <http://www.romanaqueducts.info/introduction/>



>2000 years ago

AQUEDUCT CHANNELS (underground conduits)

SOURCE: <http://www.romanaqueducts.info/introduction/>



>2000 years ago

AQUEDUCTS

SOURCE <http://www.romanaqueducts.info/aquasite/>

INTRODUCTION

This website on over 100 selected Roman aqueducts and related items is a joint effort of Cees Passchier (Mainz, Germany) and Wilke Schram (Utrecht, the Netherlands). Almost all information is based on open literature and own experiences. Most pictures are our own and may be used free only for non-commercial purposes and with the name(s) of the copyright owner(s): Cees W. Passchier, Driek van Opstal, and/or Wilke D. Schram

The information in these pages has been assembled from a large number of sources, some of which contain contradictory information. It is therefore impossible for us to know if all the information given is correct and up to date (except where we were able to visit the sites). We welcome any comments on errors or incomplete information, so that we can improve this site further. It is not so much our website, it belongs to all who are enthusiastic about roman aqueducts, architecture and engineering.

Please use the entries at the left side of this screen.

If you want to know more about other items, related to Roman aqueducts, please use [HOME](#)

"Roman aqueduct"

We went to see the aqueduct, the one sight of a surly village near the Pyrenees -

surky because there're Cathars? or because they know they've tricked the

Dear Wilke Schram,

My very heartiest congratulations on your

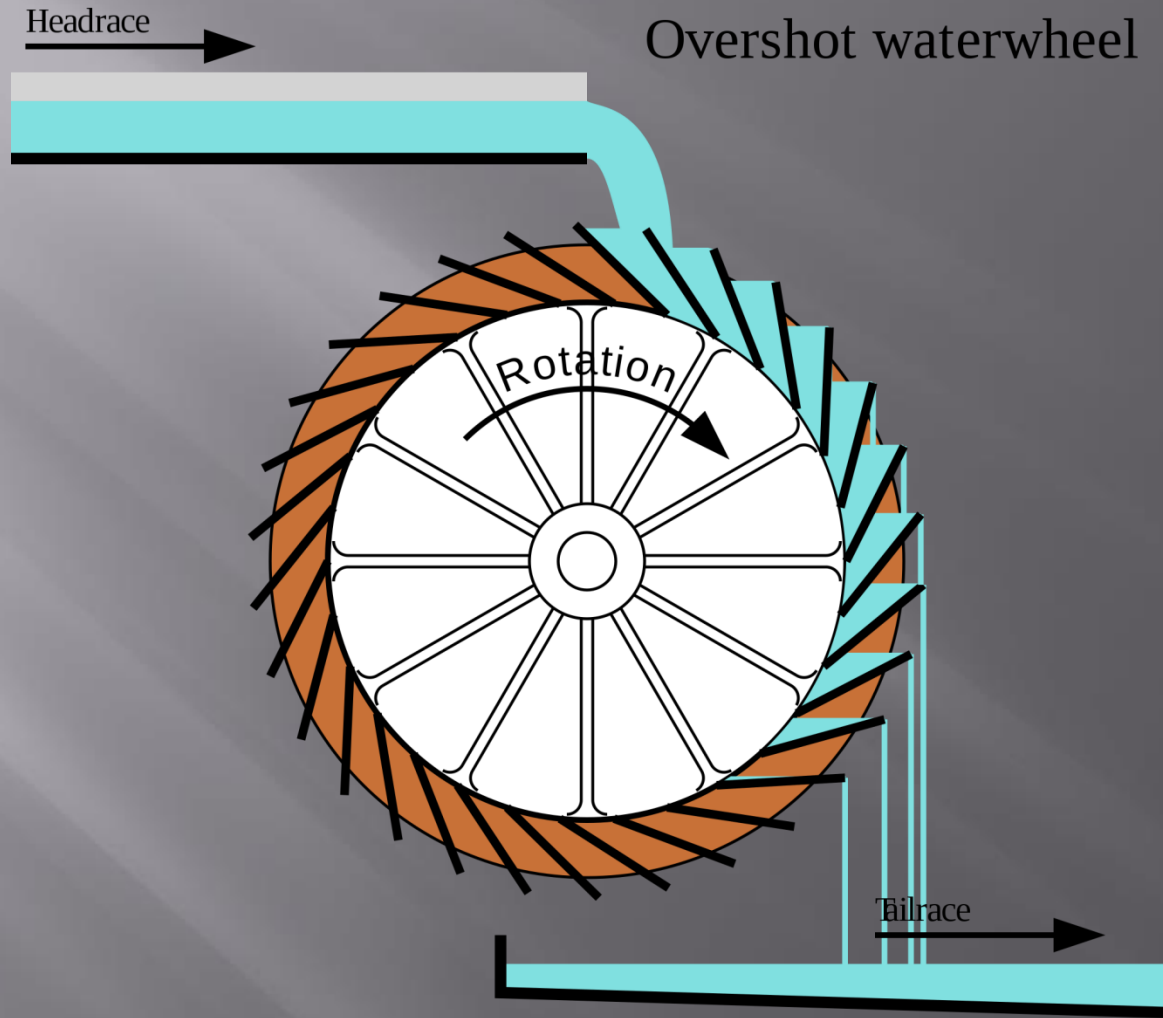
WATER MILLS

The earliest instance of a machine harnessing natural forces to replace human muscular labor (apart from the sail). [[source](#)]

Date ⇄	Water-powered mill types ⇄	Reference (or find spot) ⇄	Modern Country ⇄
Possibly first half of 3rd century BC	Horizontal-wheeled mill ^[5]	Byzantium (assigned place of invention)	Turkey
Possibly c. 240 BC	Vertical-wheeled mill ^[5]	Alexandria (assigned place of invention)	Egypt
Before 71 BC?	Grain-mill ("watermill") ^[14]	Strabon , XII, 3, 30 C 556	Turkey
40/10 BC	Undershot wheel mill ^[15]	Vitruvius , X, 5.2	Unspecified
40/10 BC	Possible kneading machine ^[16]	Vitruvius , X, 5.2	Unspecified
20 BC/10 AD	Overshot wheel mill ^[17]	Antipater of Thessalonica , IX, 418.4–6	Unspecified
c. 70 AD	Trip hammer ^[7]	Pliny , <i>Naturalis Historia</i> , XVIII, 23.97	Italy
73/4 AD	Possible fulling mill ^[18]	Antioch	Syria
2nd century AD	Multiple mill complex ^[19]	Barbegal mill	France
Late 2nd century AD	Breastshot wheel mill ^[20]	Les Martres-de-Veyre	France
Second half of 3rd century AD	Sawmill ; crank and connecting rod system with gear train ^[21]	Hierapolis sarcophagus	Turkey
Late 3rd or early 4th century AD	Turbine mill ^[22]	Chemtou and Testour	Tunisia
Late 3rd or early 4th century AD	Possible tanning mill ^[23]	Saepinum	Italy
?	Possible furnace ^[8]	Marseille	France



WATER MILLS

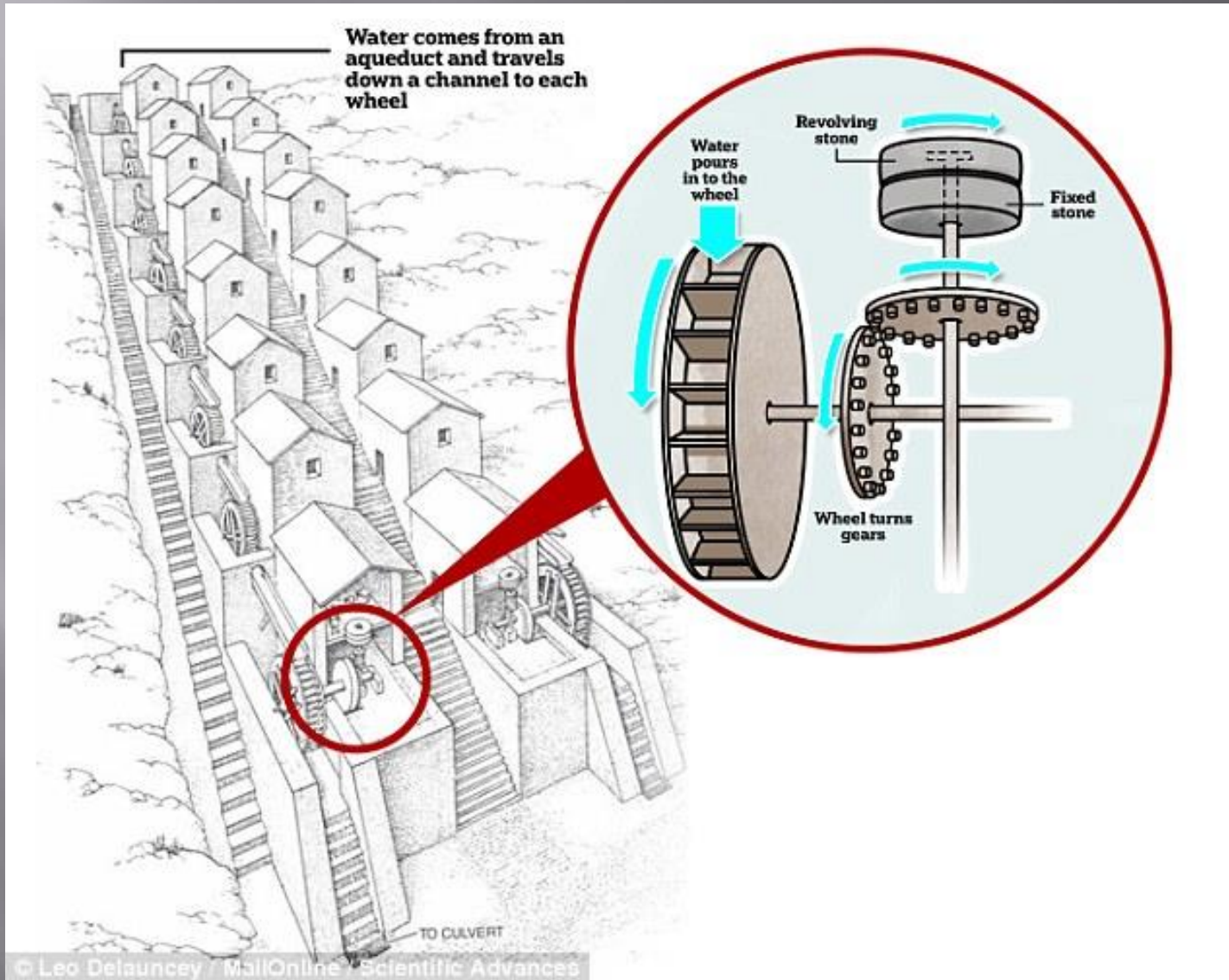


The Roman OVERSHOT WHEEL was more powerful than previous waterwheels

<https://www.dailymail.co.uk/sciencetech/article-6138001/Enormous-Roman-biscuit-factory-powered-16-water-wheels-used-make-food-sailors.html>

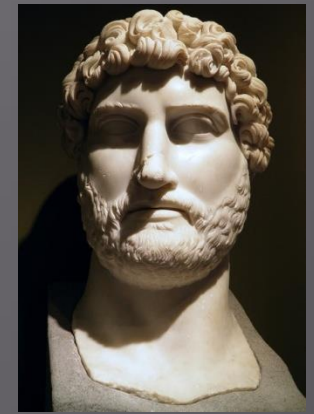


WATER MILLS



~2000 years ago

WATER MILLS



Emperor Hadrian
117 to 138 AD

<https://www.ancient.eu/hadrian/>



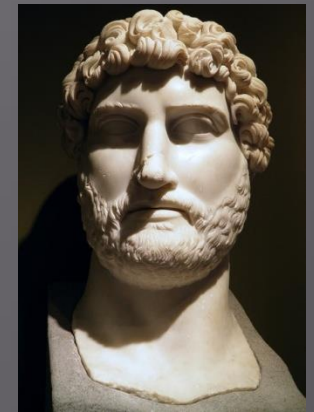
The Roman Barbegal Mill / Aqueduct (100-200 AD)
FLOUR FACTORY could feed 12,000 people per day

<https://advances.sciencemag.org/content/4/9/eaar3620>



~2000 years ago

WATER MILLS



Emperor Hadrian
117 to 138 AD

<https://www.ancient.eu/hadrian/>

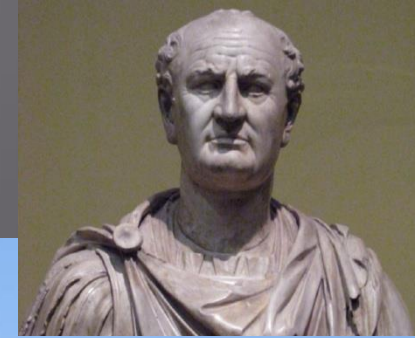
The Roman Barbegal Mill / Aqueduct (100-200 AD)
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<https://advances.sciencemag.org/content/4/9/eaar3620>



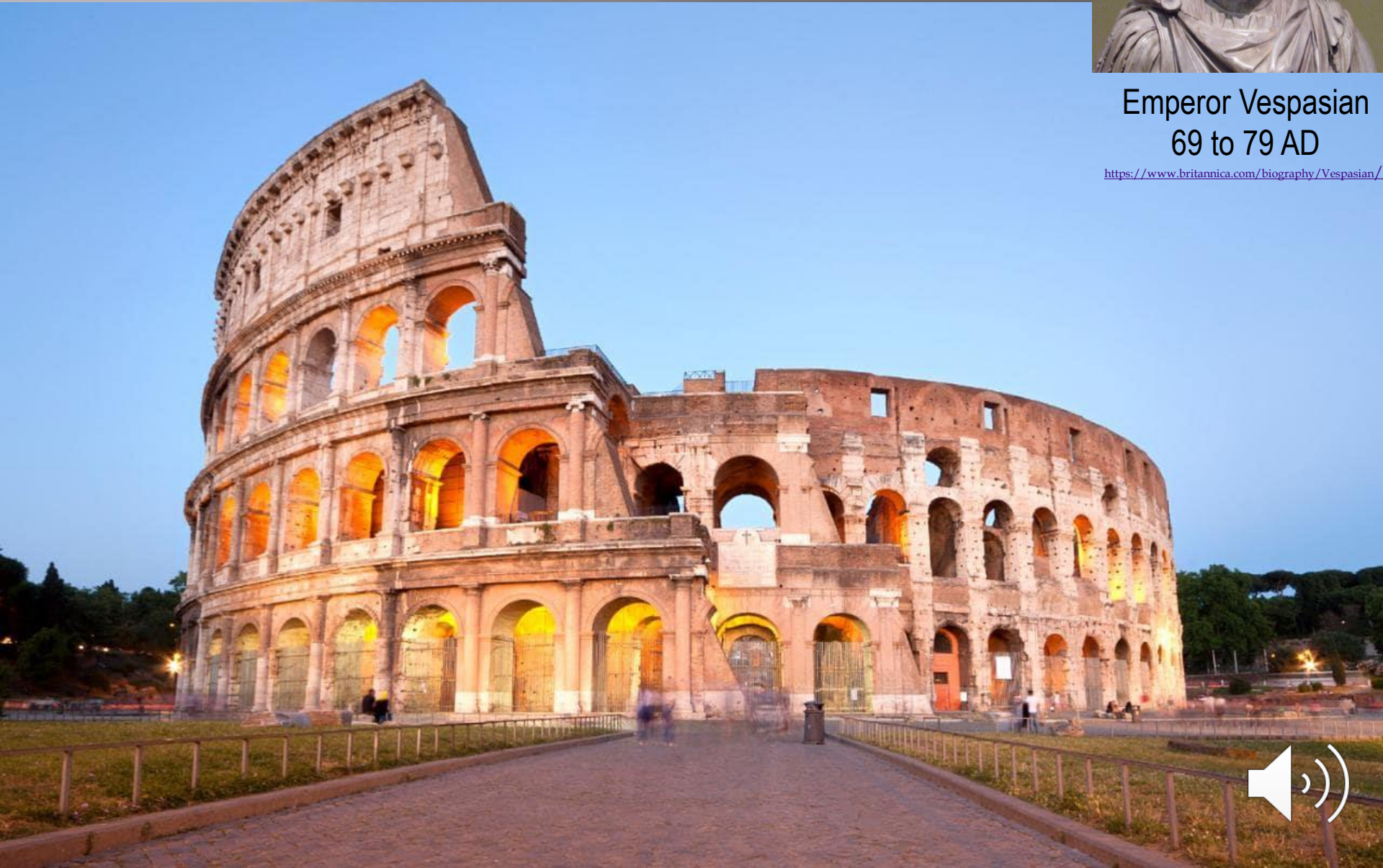
2000 years ago

Coliseum in Rome built 70 to 80 AD held ~50,000 people



Emperor Vespasian
69 to 79 AD

<https://www.britannica.com/biography/Vespasian/>



2000 years ago

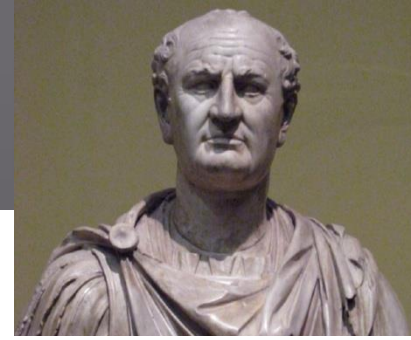


J Wunderlich at the
gate to the
COLISEUM in
Rome in 2011



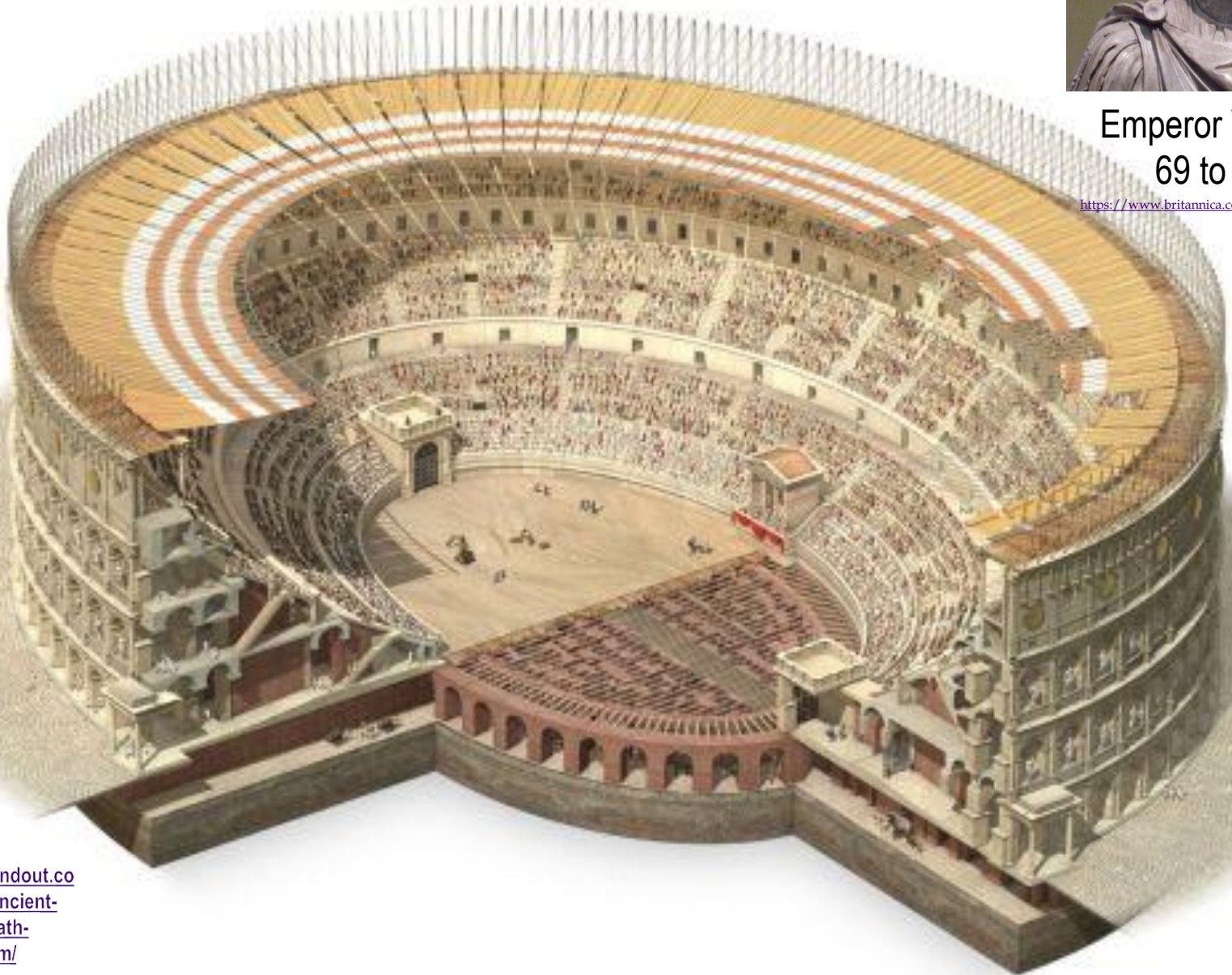
2000 years ago

COLISEUM



Emperor Vespasian
69 to 79 AD

<https://www.britannica.com/biography/Vespasian/>



Source:

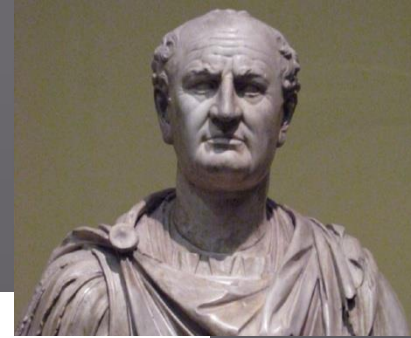
<https://www.dkfindout.com/us/history/ancient-rome/beneath-colosseum/>



2000 years ago

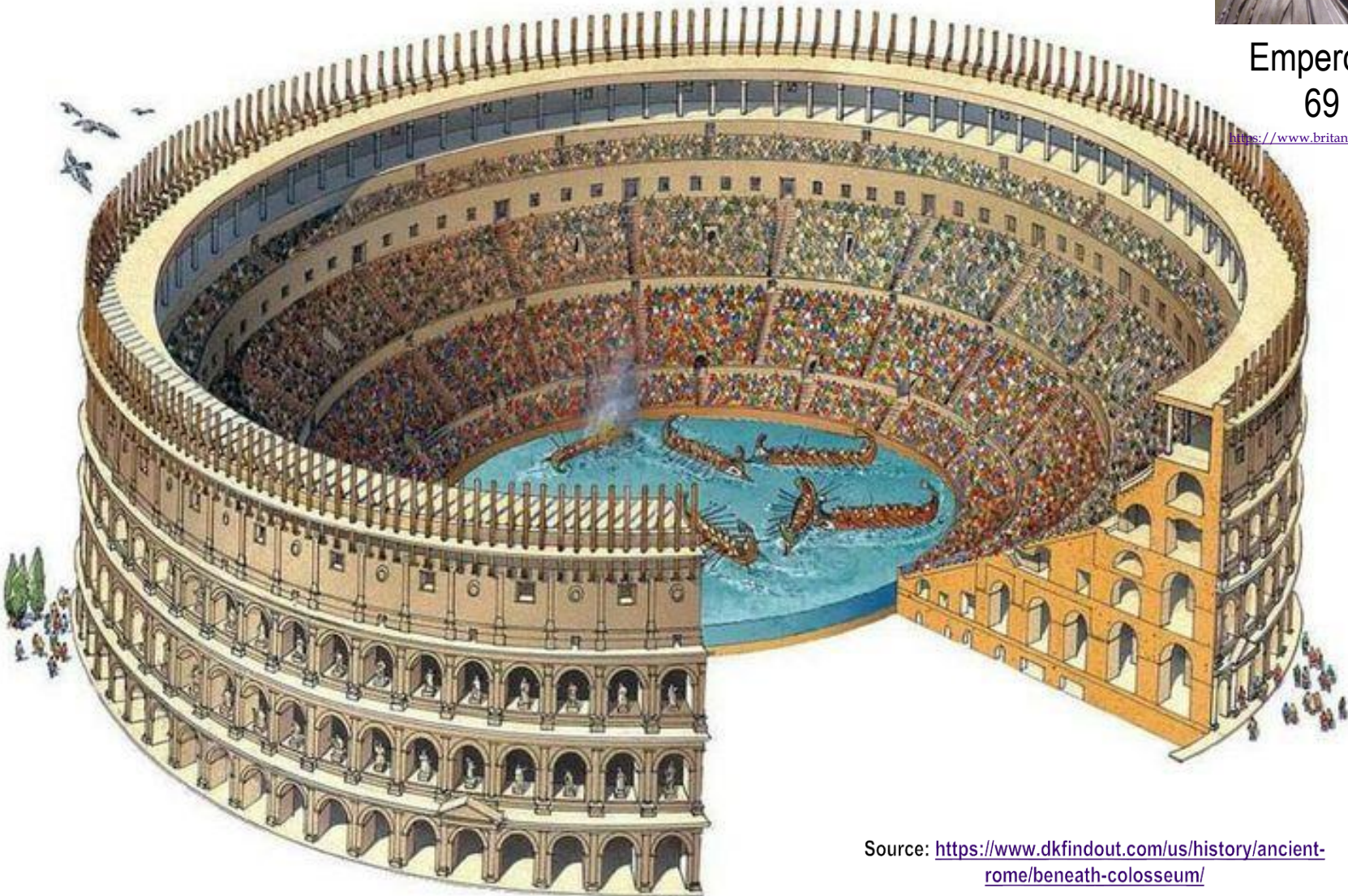
COLISEUM

Initially it could be flooded for sea battles



Emperor Vespasian
69 to 79 AD

<https://www.britannica.com/biography/Vespasian/>

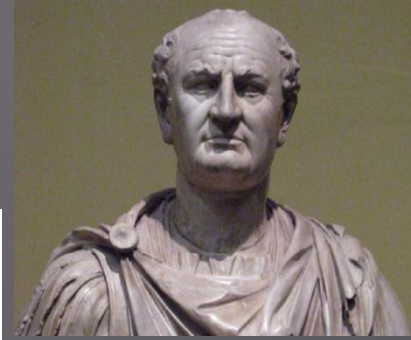


Source: <https://www.dkfindout.com/us/history/ancient-rome/beneath-colosseum/>



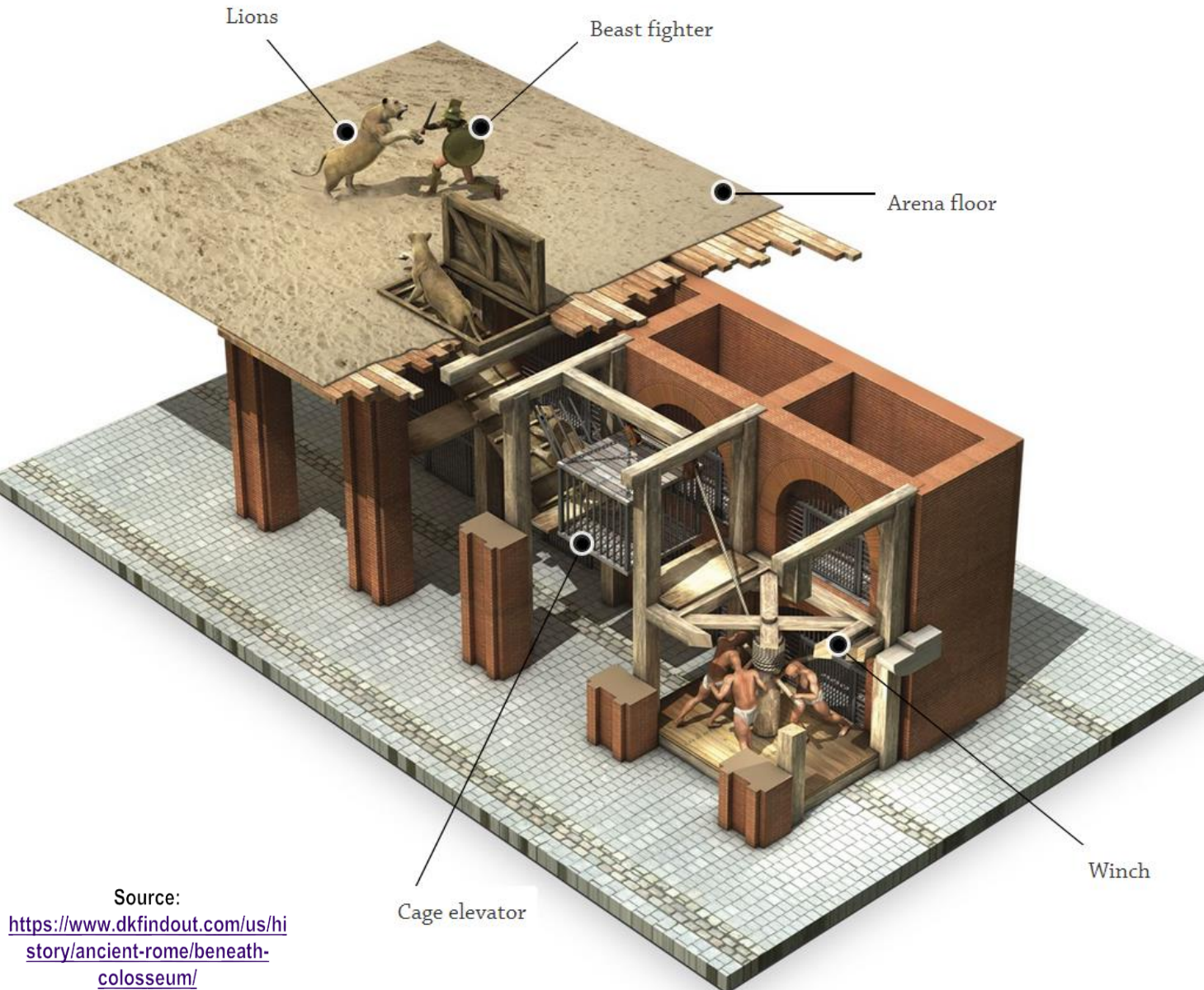
2000 years ago

COLISEUM



Emperor Vespasian
69 to 79 AD

<https://www.britannica.com/biography/Vespasian/>



ELEVATORS
later added to
lift animals
into battles in
the arena

Source:

<https://www.dkfindout.com/us/history/ancient-rome/beneath-colosseum/>



Roman PASSIVE SOLAR HEATING and NATURAL DAYLIGHTING

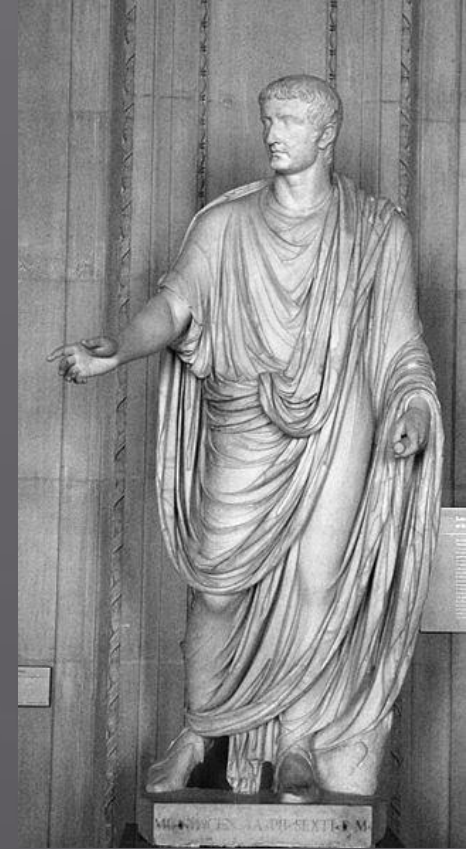
- **Used the “GREENHOUSE EFFECT”** to admit sunlight into a desired space, and holding in the heat so it accumulates inside
- The **earliest known greenhouse** in **30 AD** for Roman Emperor
 - **Called a specularium**, fabricated from small translucent sheets of mica
 - Built to satisfy the emperor's craving for cucumbers out of season
- Large windows of transparent stone like mica, or clear glass
 - They **invented first glass cast windows in 100 AD**
- **Sun-right laws** made it a civil offense to block one's access to the south
- Emphasis on **proper solar orientation** for buildings
 - Baths faced the afternoon sun in wintertime when they had maximum use



2000 years ago

Roman GREENHOUSE, 37 AD

A residence for Emperor Tiberius on the island of Capri in Italy



Emperor Tiberius
14A to 37 AD

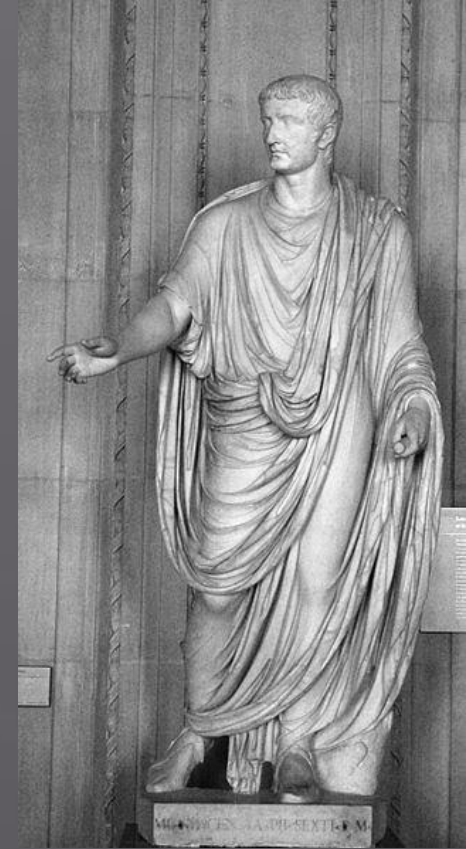
Villa Jovis



2000 years ago

Roman GREENHOUSE, 37 AD

- **Earliest known greenhouse** in 30 AD, for Emperor Tiberius
 - Built to satisfy his craving for cucumbers out of season



Emperor Tiberius
14A to 37 AD

Villa Jovis

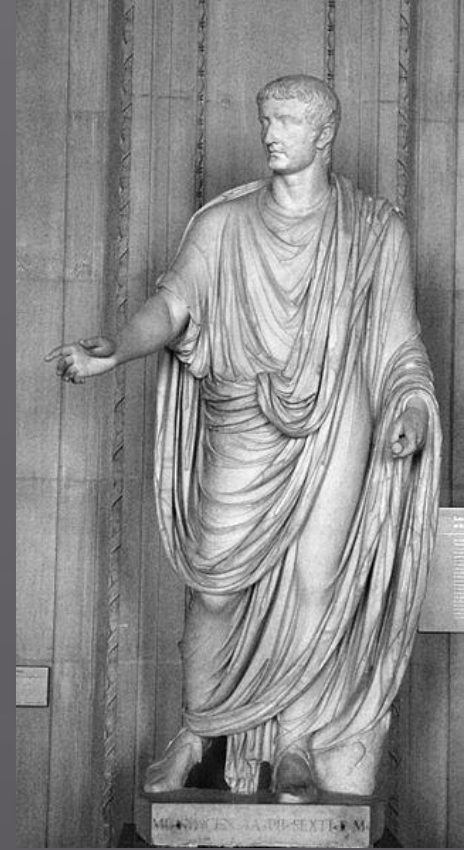


2000 years ago

Roman RAINWATER COLLECTION

The villa set around four huge cisterns with barrel vaults that satisfied water requirements

- Sophisticated rainwater collection system.



Emperor Tiberius
14 to 37AD

Villa Jovis



2000 years ago

Roman GLASS, 100 AD



First cast GLASS WINDOWS

“Window glass produced based on archeological evidence of ancient Roman glass-making technology”

Source <https://www.pinterest.com/pin/304767099771476698/>

The Romans also greatly increased the rapid production of glass through their invention of Glass Molds

https://www.metmuseum.org/toah/hd/rqls/hd_rqls.htm



CITIES of Roman Empire second century AD

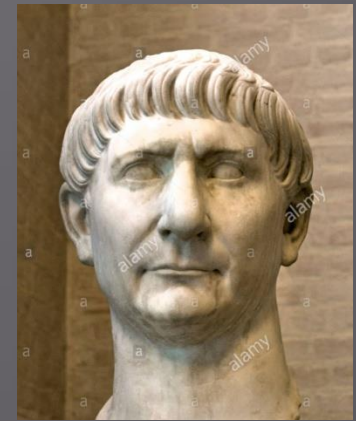


1900 years ago

FORUM (TOWN CENTER), 117 AD

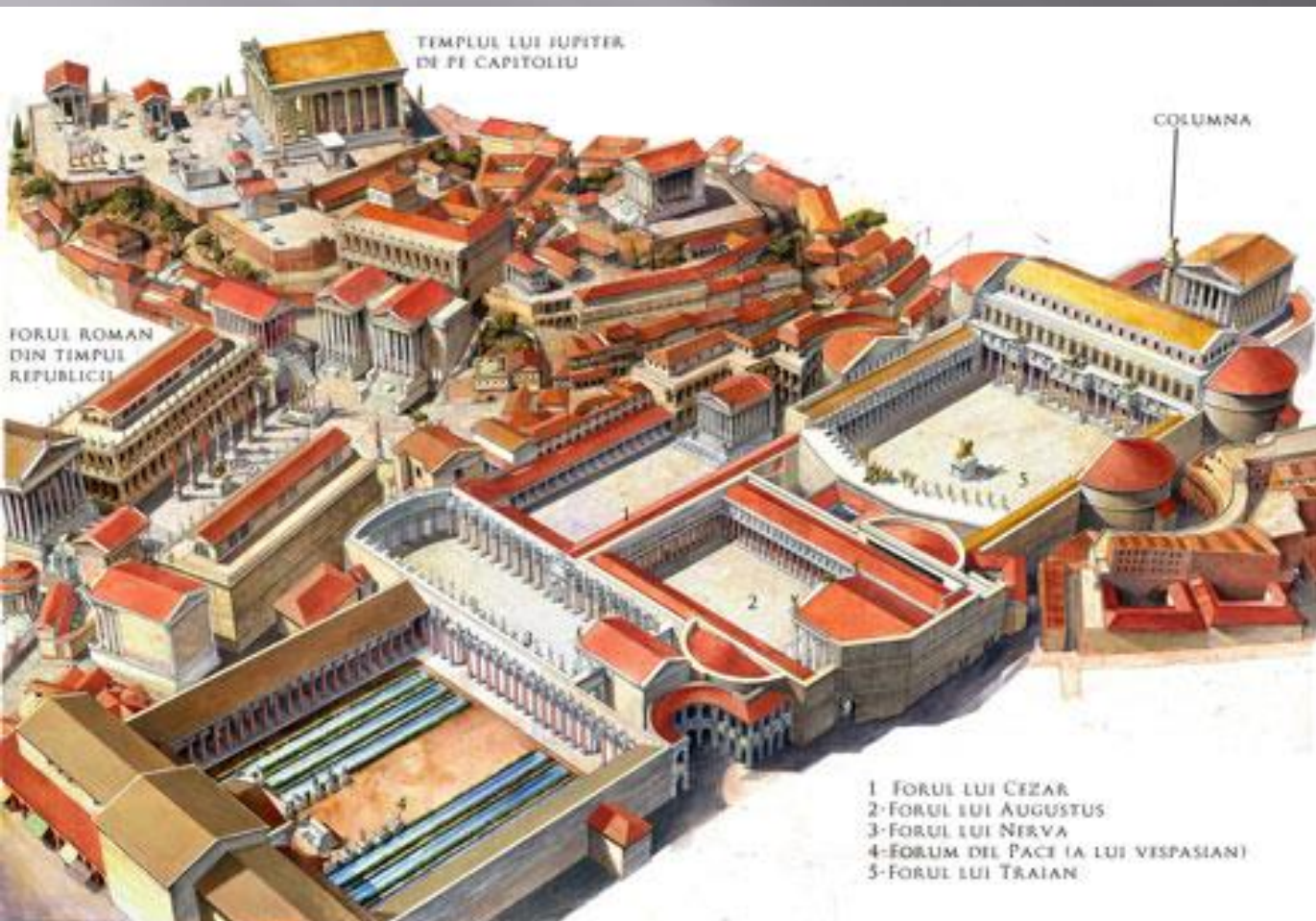
The empire thrived during time of Emperor Trajan 98-117AD,
and Rome had a **new complex Forum**

Trajan's FORUM



Emperor Trajan
98 to 117 AD

<https://www.ancient.eu/hadrian/>



Rendering

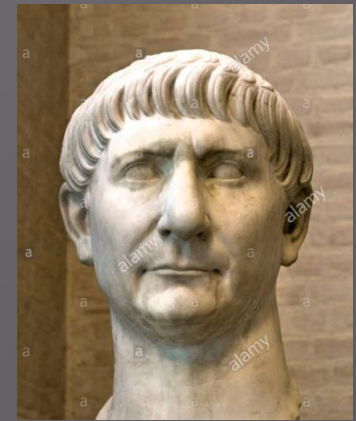
<http://www.ancientvine.com/hadrianswall.html>

1900 years ago

Roman SHOPPING MARKET (MALL), 117 AD

The empire was thriving at the time of Emperor Trajan 98-117AD and Rome had a **new large shopping Market**

Trajan's Market



Emperor Trajan
98 to 117 AD

<https://www.ancient.eu/hadrian/>

A HEMICYCLE
Built into chisel-
away 125 foot
cliff face – this
allowed it to
survive later
earthquake that
destroyed
Trajan's Forum



<http://www.ancientvine.com/hadrianswall.html>

1900 years ago

Roman SHOPPING MARKET (MALL), 117 AD

Trajan's MARKET



Emperor Trajan
98 to 117 AD

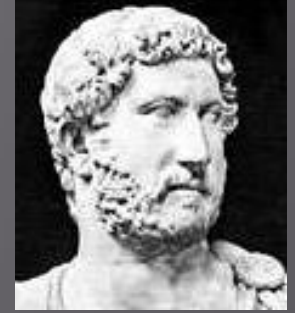
<https://www.ancient.eu/hadrian/>



<https://www.rome.net/trajans-market>

1900 years ago

The Pantheon, 126 AD



Emperor Hadrian
117-138 AD

<https://www.britannica.com/biography/Hadrian>

Source: <https://sites.google.com/site/activity21site/f-development-of-the-dome>



1900 years ago

The Pantheon, 126 AD



Emperor Hadrian
117-138 AD

<https://www.britannica.com/biography/Hadrian>



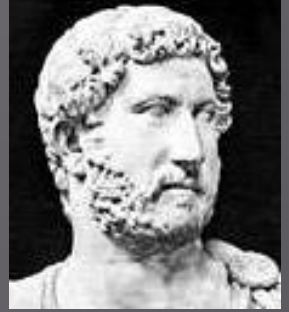
Originally, stairs led ten feet up to the entrance, however the simple accumulation of *dust* accumulated to ten feet over ~2000 years

Source: <http://romancolosseum.org/pantheon-in-rome/>



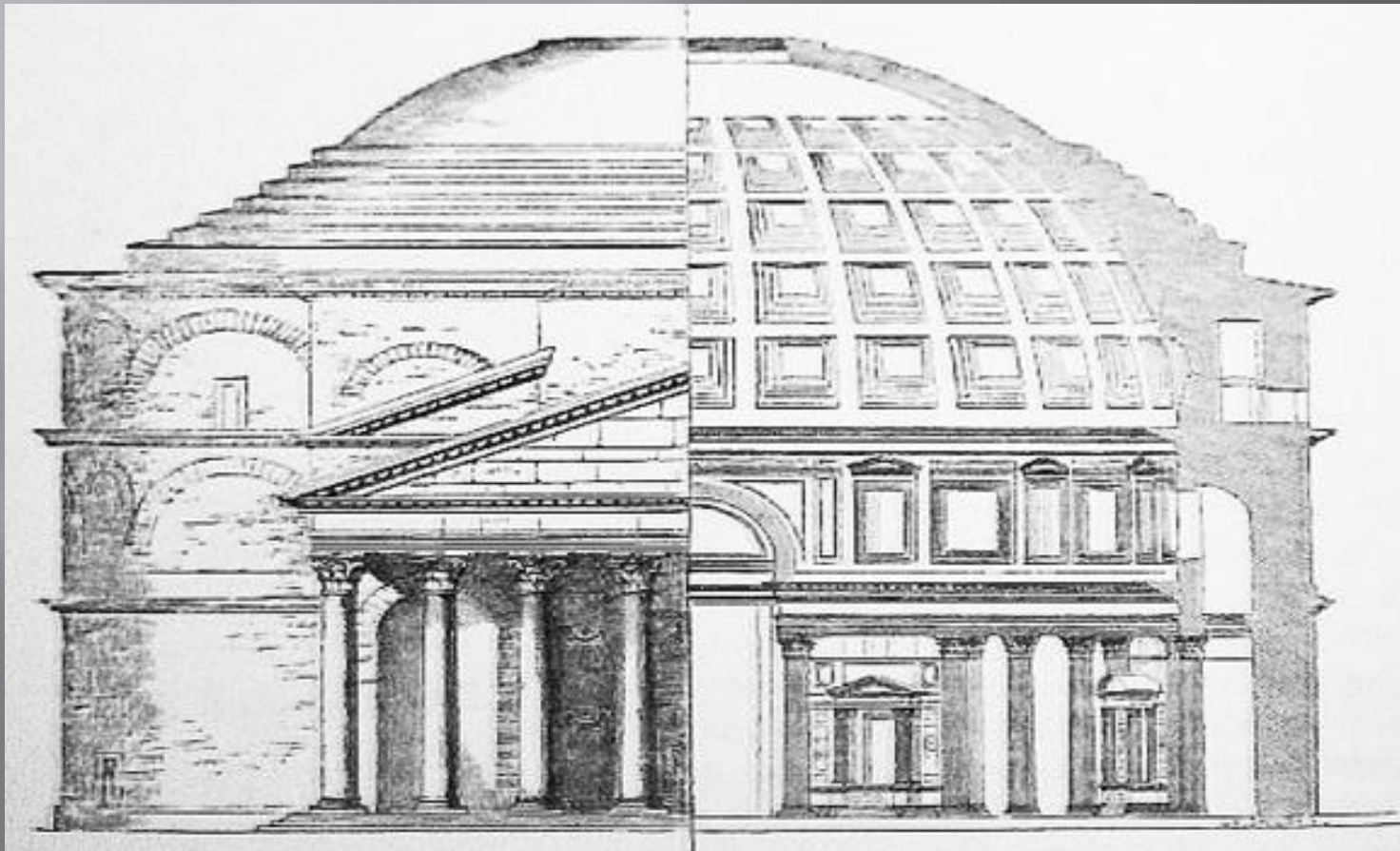
1900 years ago

The Pantheon, 126 AD



Emperor Hadrian
117-138 AD

<https://www.britannica.com/biography/Hadrian>



Source: <http://romeonsegway.com/10-facts-about-the-pantheon/>



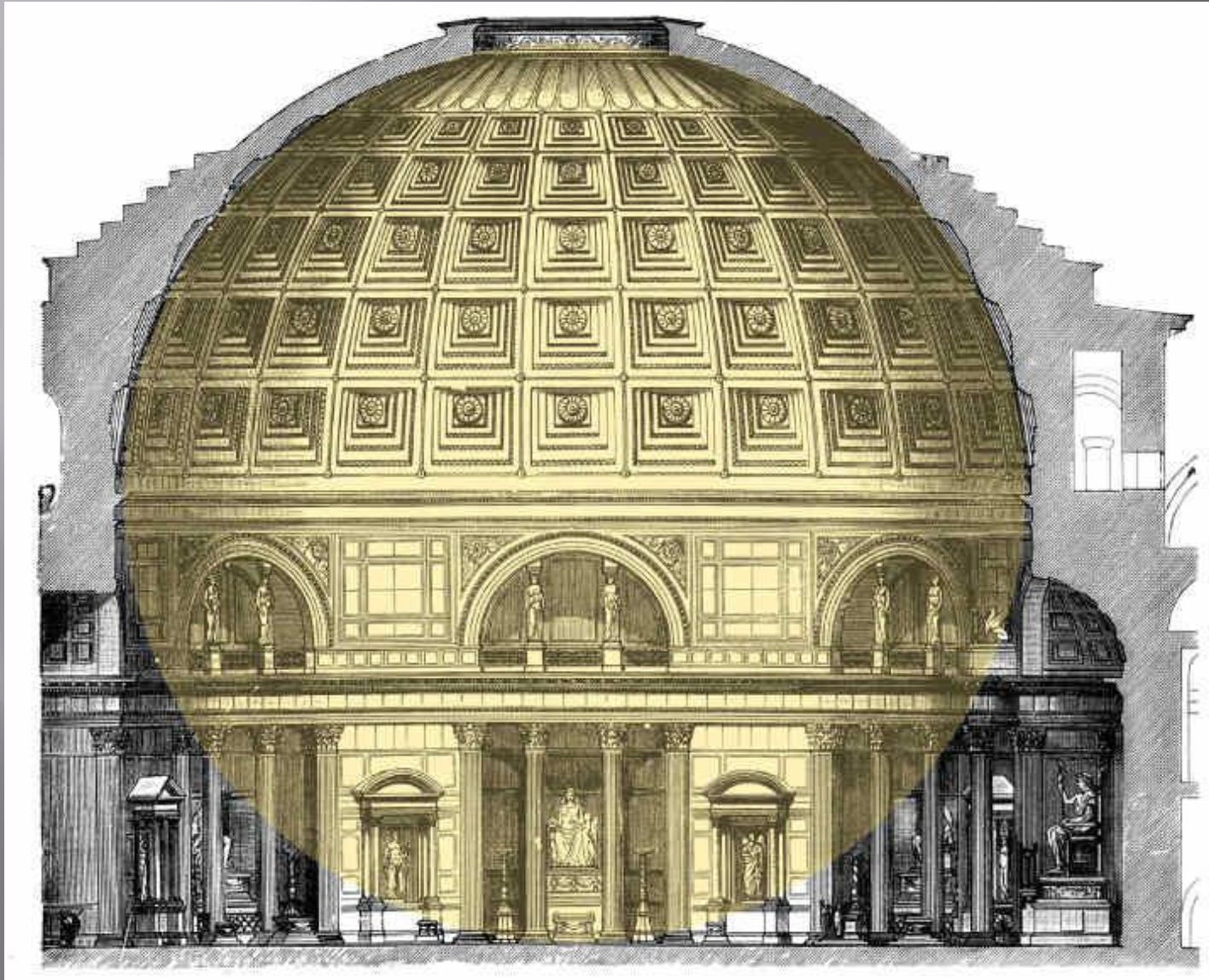
1900 years ago

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Source: <http://www.aroundrometours.com/30-interesting-facts-about-the-pantheon-in-rome-art54-uid1.htm>



1900 years ago

The Pantheon, 126 AD

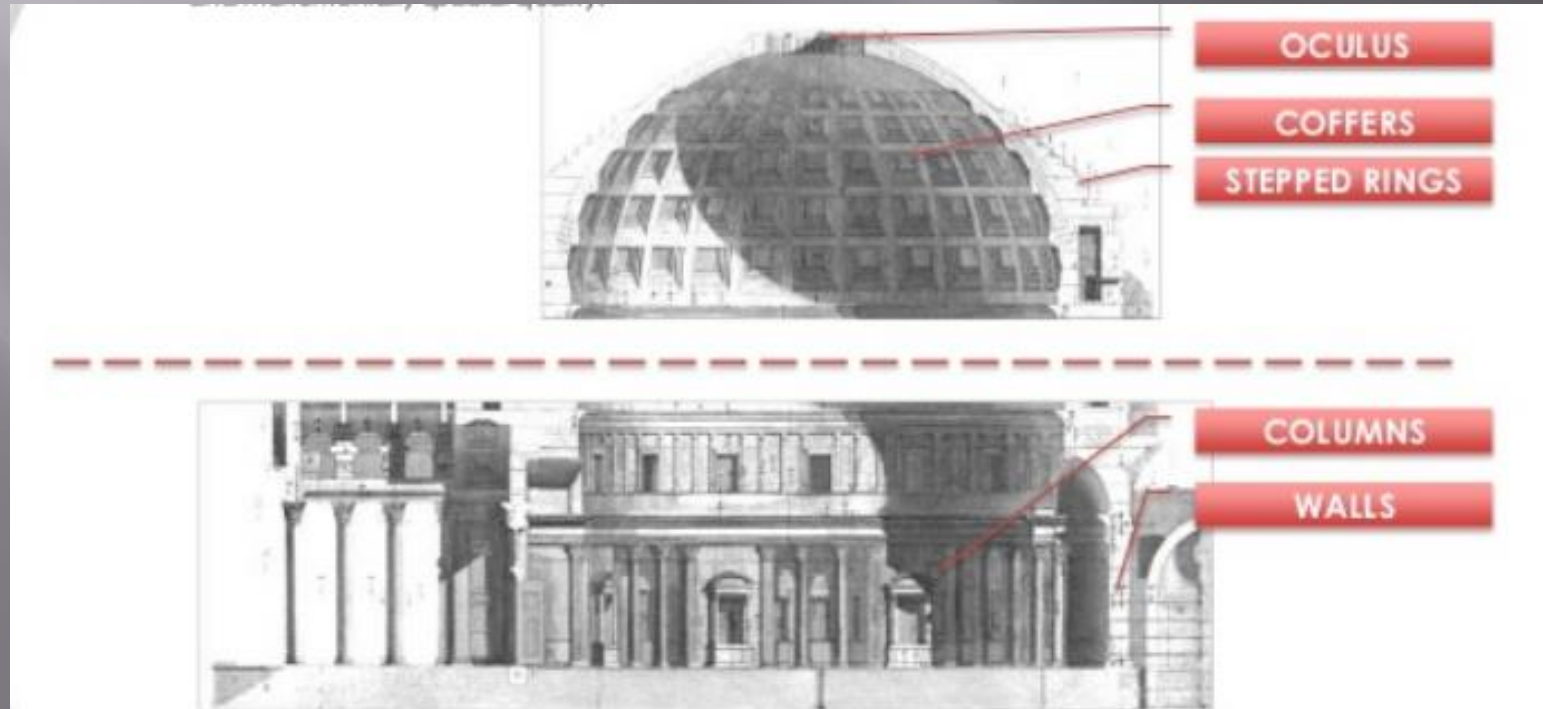
A **COFFER** is space between elements of a structural grid that distribute loads. In a dome, this forms a series of ribs and stabilizing **TENSION** rings that distribute forces evenly to the base. The ring that creates the oculus hole at the top of the Dome is in **COMPRESSION**

Coffers also significantly lessen the weight and material required.



Emperor Hadrian
117-138 AD

<https://www.britannica.com/biography/Hadrian>



1900 years ago

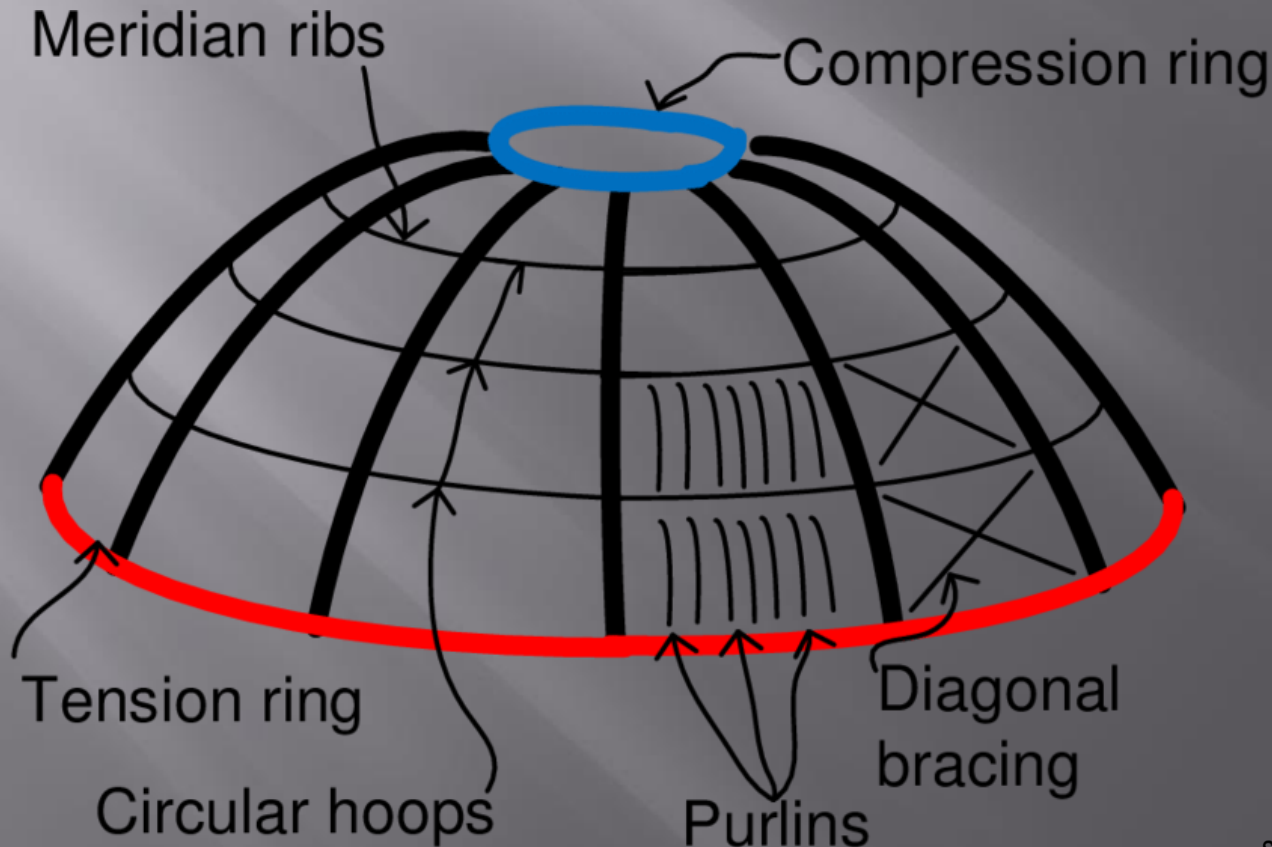
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Source: <http://www.angelfire.com/super/tyvernon/>

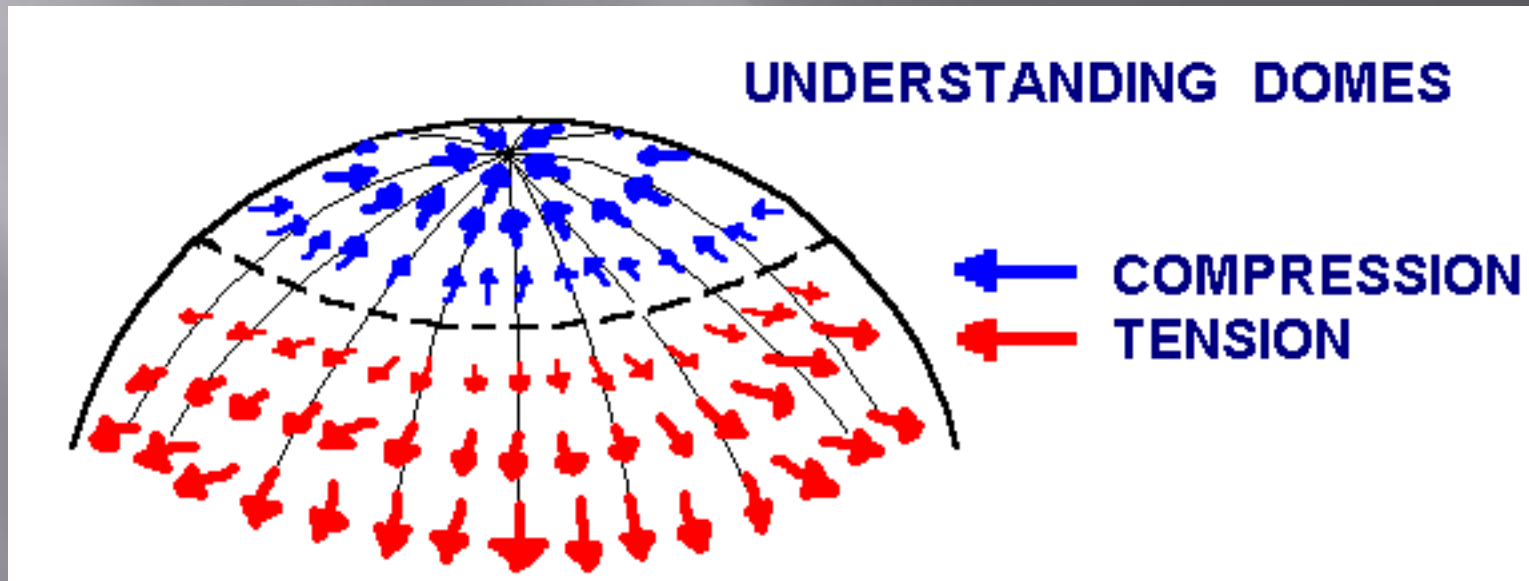
1900 years ago



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Source: <http://www.angelfire.com/super/tyvernon/>

1900 years ago

The Pantheon, 126 AD

Special **LIGHT-WEIGHT CONCRETE** also reduced weight of dome



Emperor Hadrian
117-138 AD

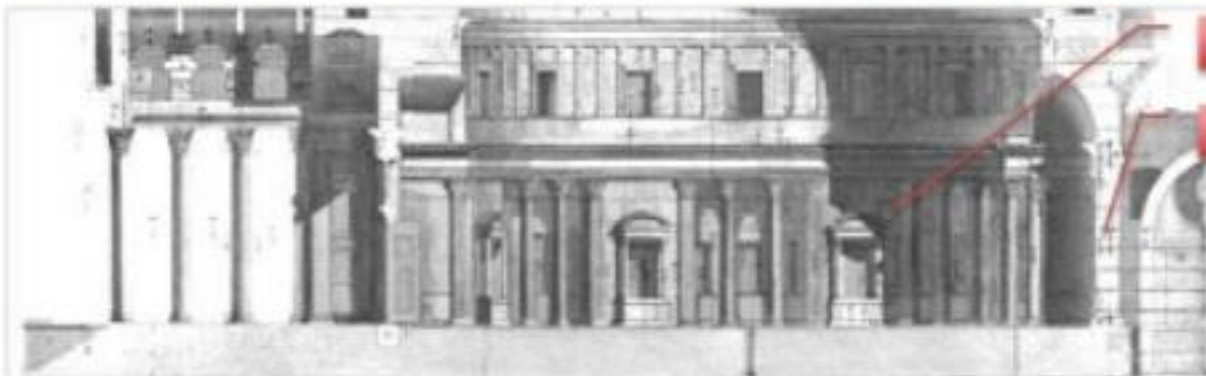
<https://www.britannica.com/biography/Hadrian>



OCULUS

COFFERS

STEPPED RINGS



COLUMNS

WALLS



1900 years ago

The “Oculus” of the Pantheon is for **NATURAL LIGHTING**



Emperor Hadrian
117-138 AD

<https://www.britannica.com/biography/Hadrian>



Source: <http://www.aroundrometours.com/30-interesting-facts-about-the-pantheon-in-rome-art54-uid1.htm>

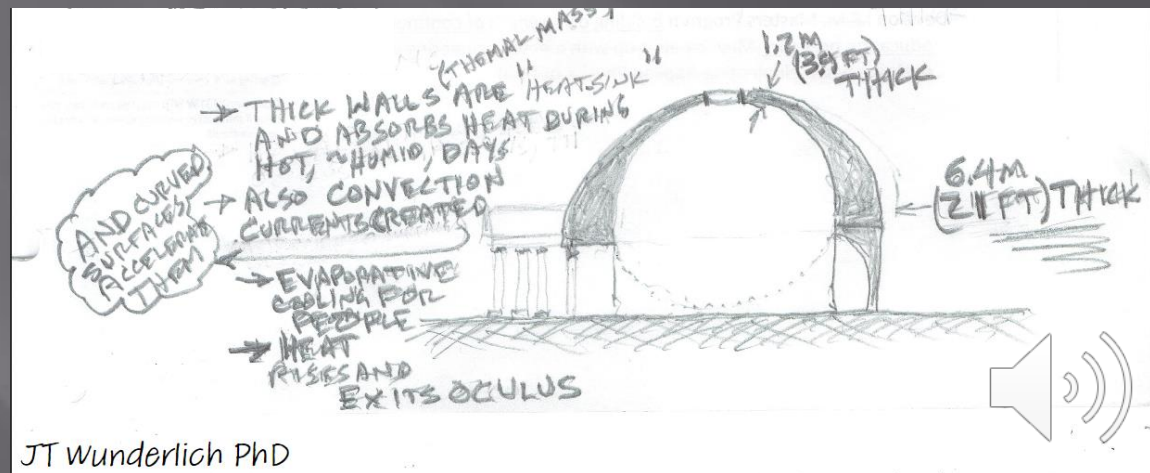
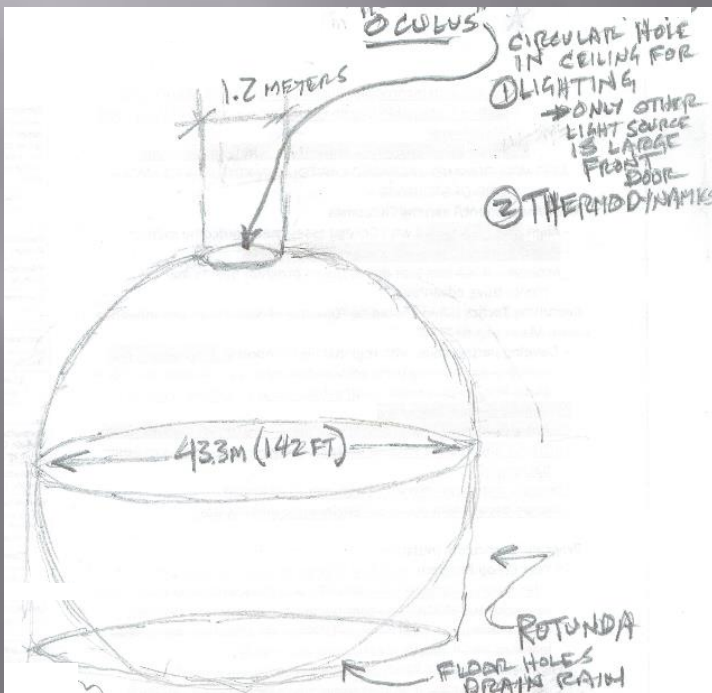
1900 years ago

The “Oculus” of the Pantheon is for NATURAL LIGHTING and NATURAL (PASSIVE) COOLING



from Wunderlich PASSIVE COOLING lecture in course:
EGR353 Green Architectural Engineering

- Part of Architectural Studies Minor and Individualized Major
- Part of Engineering Major Concentration in Civil Engineering
- Part of Engineering Major Concentration in Environmental Engineering



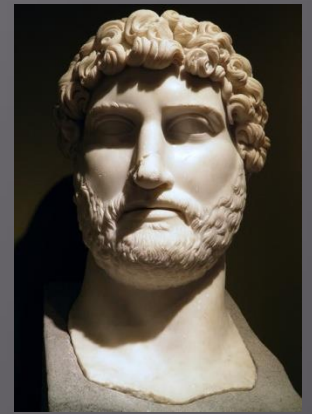
JT Wunderlich PhD



1900 years ago

Roman WALLS in 138 AD

The Empire had gotten so large that Emperor Hadrian was more concerned with keeping what empire he had, rather than conquering new lands



Emperor Hadrian
117 to 138 AD

<https://www.ancient.eu/hadrian/>



A “MILECASTLE”
was built every mile
along 73 miles of
HADRIAN’S WALL
across Britannia
(to stop Scottish
attacks)

Rendering

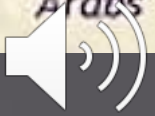
<http://www.ancientvine.com/hadrianswall.html>



Roman Empire (200 AD)



THE ROMAN EMPIRE

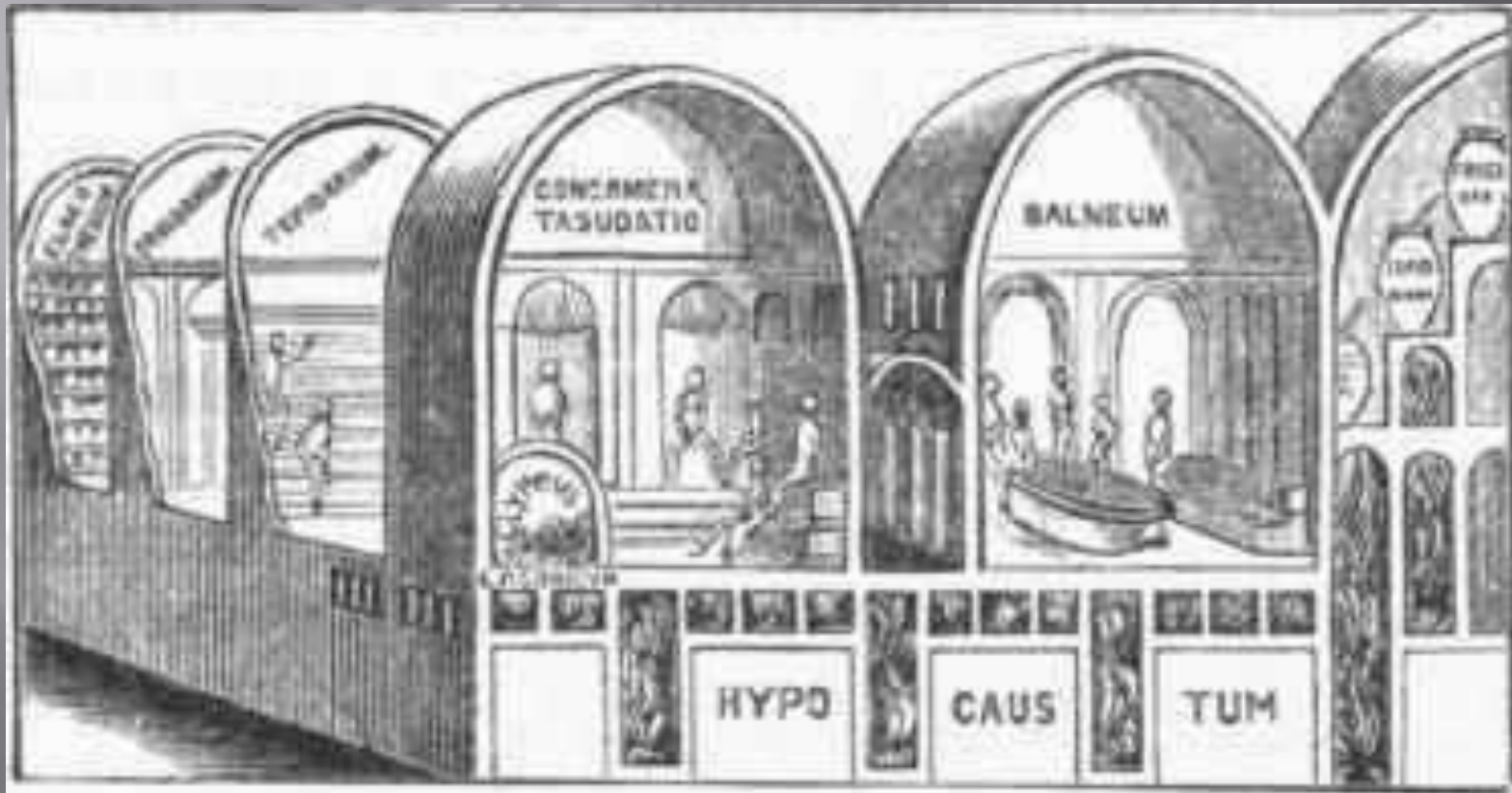


1900 years ago

Roman HOT WATER HEATING

Public Baths

“Bathing occupied an important place in the life of the Greeks,
The standardized architectural type of the THERMAE, however,
was not developed until the Romans ; Baths of Titus (81 AD)”:



1900 years ago

Roman HOT WATER HEATING

Public Baths



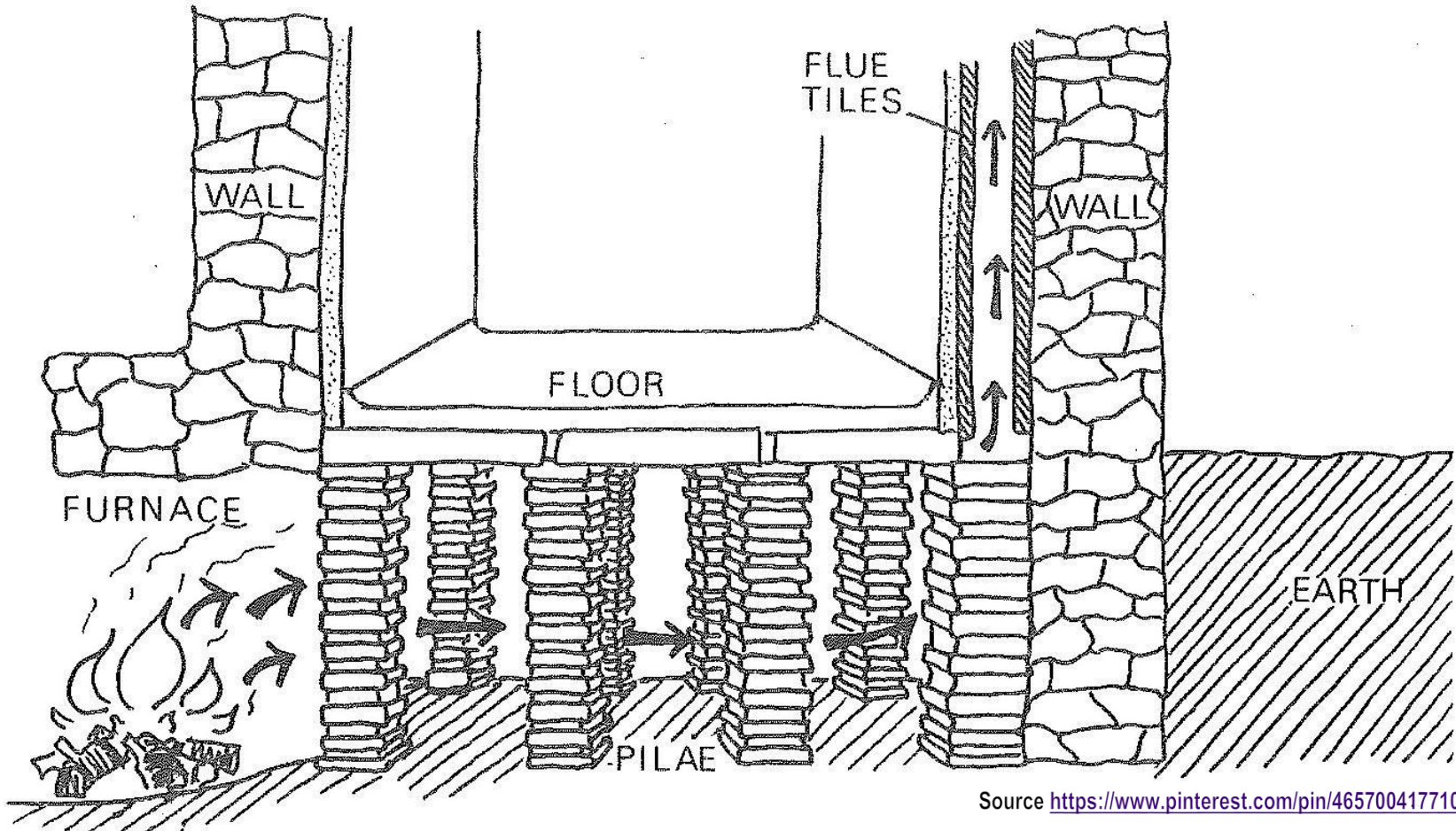
Roman Bath in Bath, England from 70 AD

Source <https://visitbath.co.uk/listings/single/roman-baths/>



Roman HOT WATER HEATING

Public Baths



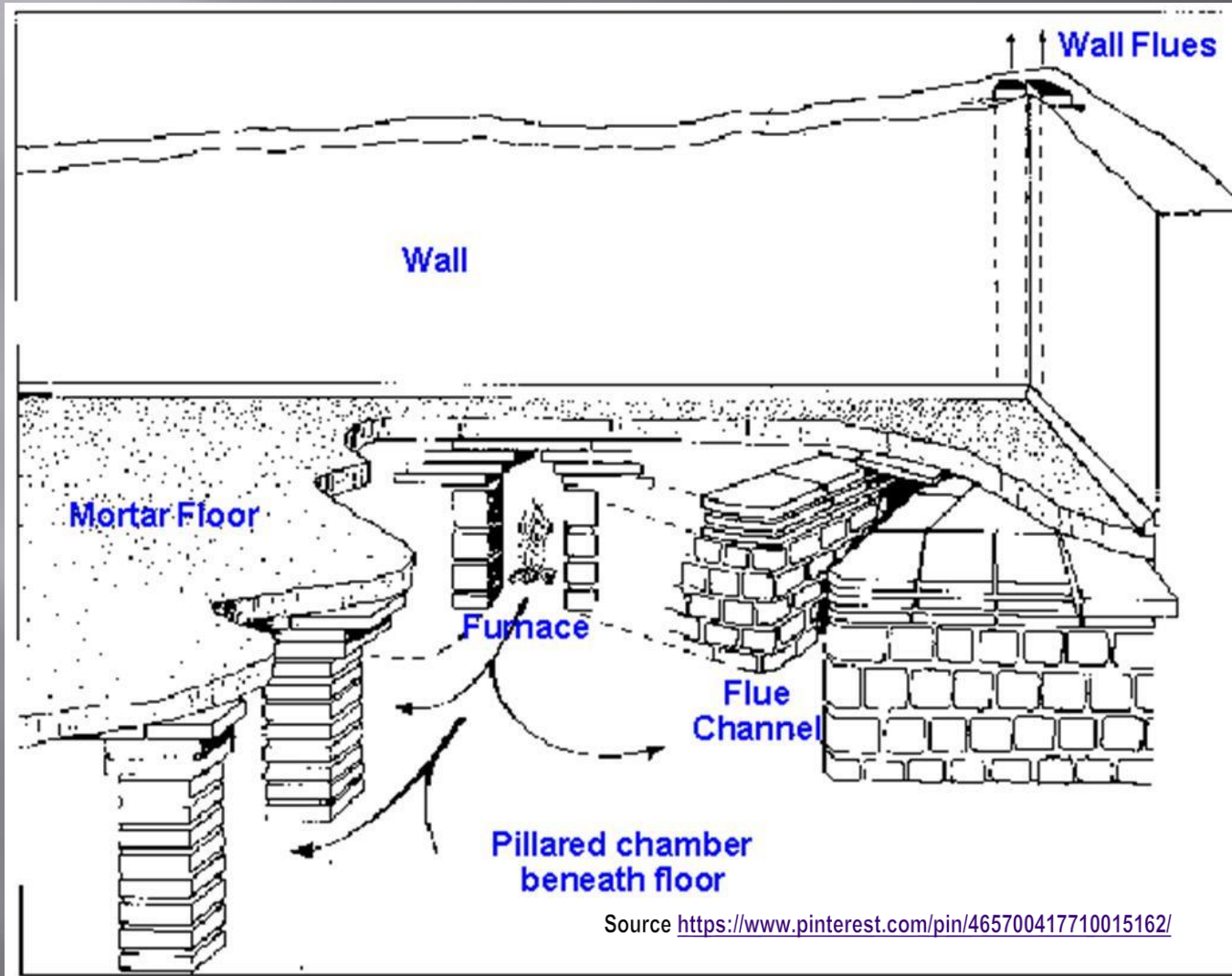
Source <https://www.pinterest.com/pin/465700417710015162/>

The heating system ("Hypocaust")



Roman HOT WATER HEATING

Public Baths



The heating system (“Hypocaust”)



Roman HOT WATER HEATING

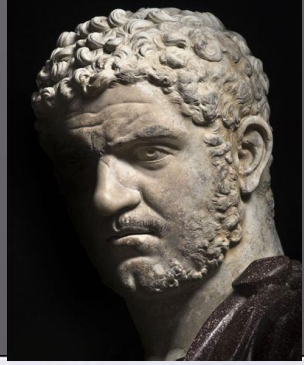
Public Baths



1800 years ago

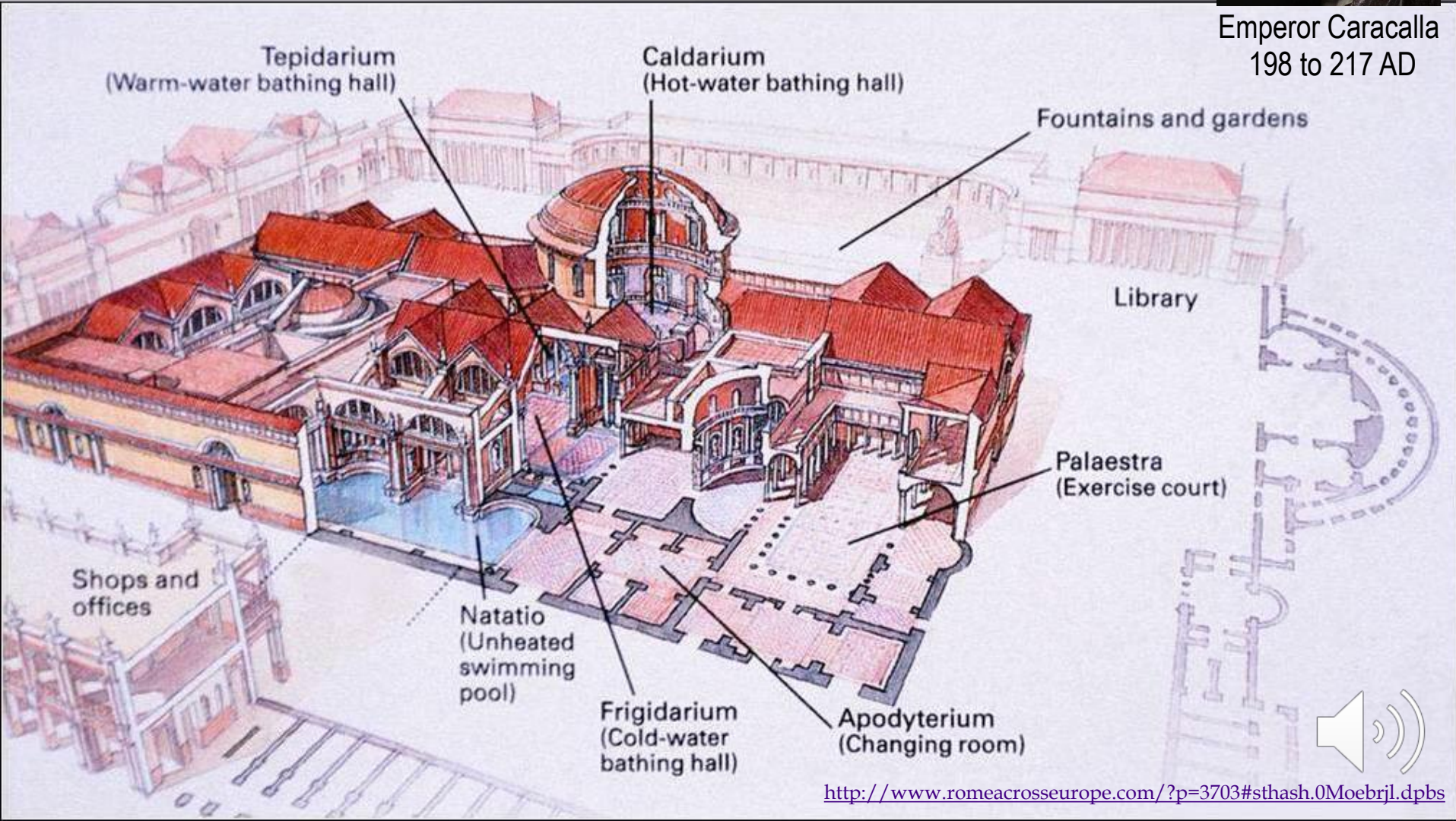
Roman HOT WATER HEATING

Public Baths



Emperor Caracalla
198 to 217 AD

Baths of Caracalla in Rome, circa 216

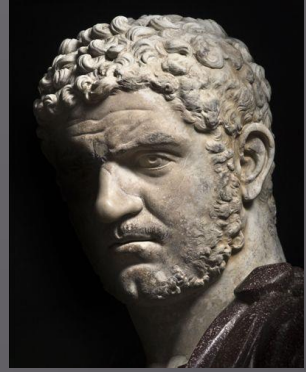


1900 years ago

Roman HOT WATER HEATING

Public Baths

Baths of Caracalla in Rome, circa 216



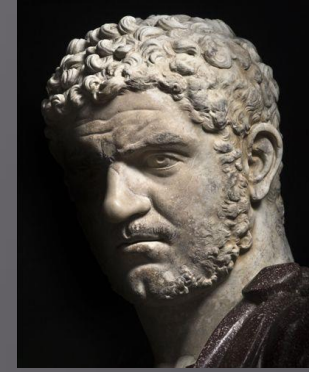
Emperor Caracalla
198 to 217 AD



1900 years ago

Roman HOT WATER HEATING

Public Baths



Emperor Caracalla
198 to 217 AD

Baths of Caracalla in Rome, circa 216



1700 years ago

Rome simulation of 320 AD

https://www.youtube.com/watch?v=T_L8g1R58BU



"HISTORY IN 3D" - ANCIENT ROME 320 AD - 1st trailer

165,422 views

1.1K 34 SHARE SAVE ...



EXTRA

- Elizabethtown College Architectural Studies Minor
https://catalog.etown.edu/preview_program.php?catoid=15&poid=1392&returnto=757
- Elizabethtown College Individualized Major in Architecture (contact J Wunderlich)
- The Pantheon Institute (Architecture School) in Rome
 - J Wunderlich has a relationship with this school
<http://www.pantheon-institute.com/nbpantheon/academics-courses/academic-programs/architecturelandscape-arch/>
- The University of Trento
 - J Wunderlich has a relationship with this school (taught PhD course there in 2009)
<https://www.unitn.it/en>
- J Wunderlich travels in Italy (six trips as of 2020) and other parts of what was the Roman Empire
http://users.etown.edu/w/wunderjt/home_personal_ITALY_ALL.html
- J Wunderlich personal language Dictionaries:
 - Version 7: http://users.etown.edu/w/wunderjt/ITALIAN_WEB7.htm
 - Version 8: http://users.etown.edu/w/wunderjt/ITALIAN_WEB8.htm

