Roman aqueducts and its calcareous sinter deposits as a source of data in paleoclimate, tectonics and hydrology

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In Roman times, there were more than 1400 long distance aqueducts that carried water to ancient cities over up to 250 km, such as; Rome, Constantinople, Carthago and many others…
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The Romans used aqueducts
for several reasons;
•public baths,
•latrines,
•fountains,
•private houses
•mining,
•processing,
•agriculture.
SPQR
ACQVA MARCIA

Subject of our work: **Calcareous sinter in Roman aqueducts**

In-situ examples:

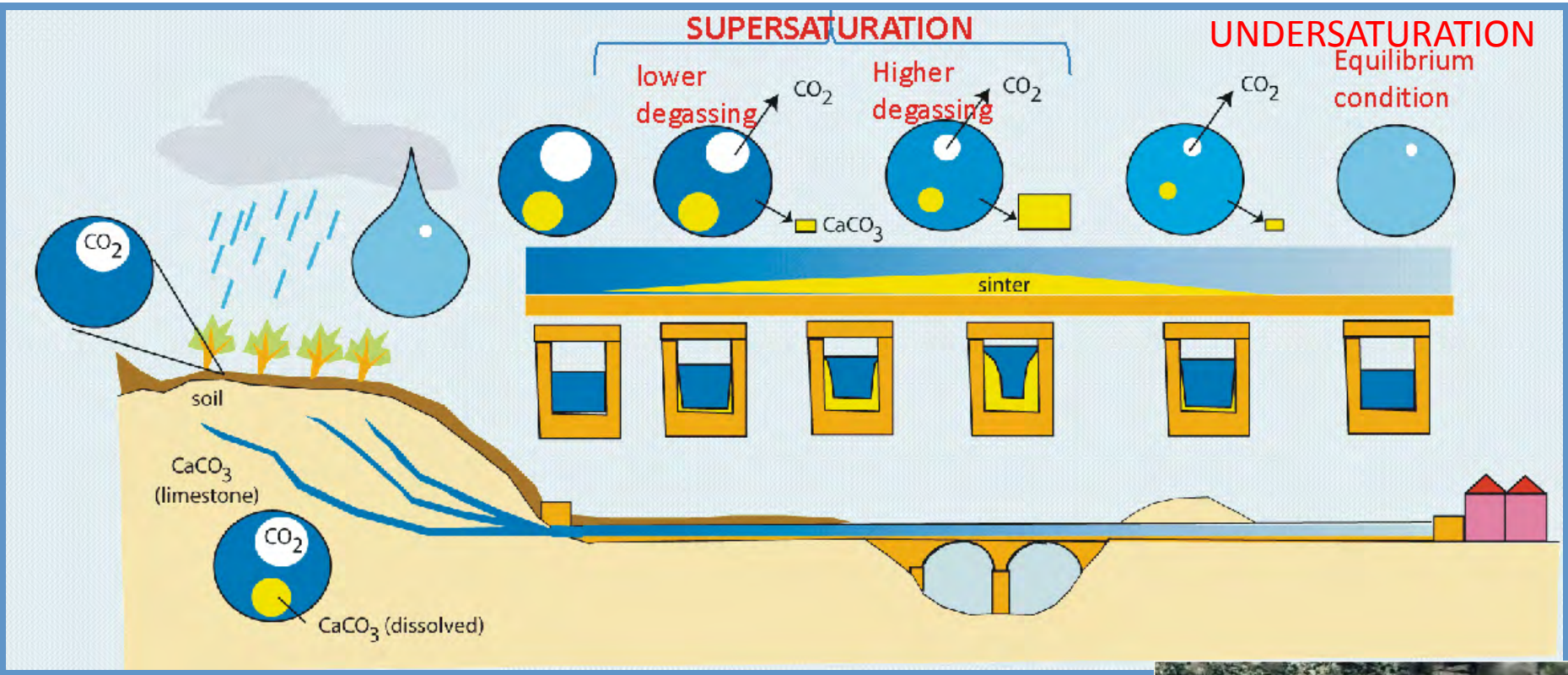

Patara, Turkey


Hierapolis, Turkey

Roman aqueducts commonly contain layered carbonate deposits which can be a valuable data source in archaeology. Such calcareous sinter deposits can be up to 80cm thick and representing a continuous record of up to 800 years.

No calcareous sinter in an aqueduct can be due to;

- Local geology (non-karstic site)
- Intake from a river or a lake
- Cleaning process
- Undersaturation condition

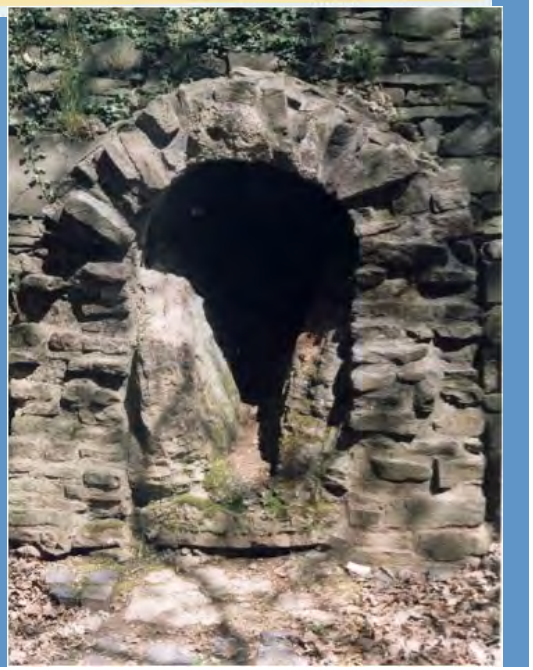


- Most aqueduct used karstic areas as a source water
- Karstic water generally rich in $CaC0_3$ (supersaturation condition)
- By degassing process, calcite precipitation occur as a solid deposit;

$$Ca^{+2}_{(aq)} + 2HCO^{-}_{3\,(aq)} < > CaCO_{3\,(s)} + C0_{2\,(g)} + H_2O_{(l)}$$

✓Evaporation-a minor factor!!

CALCAREOUS SINTER

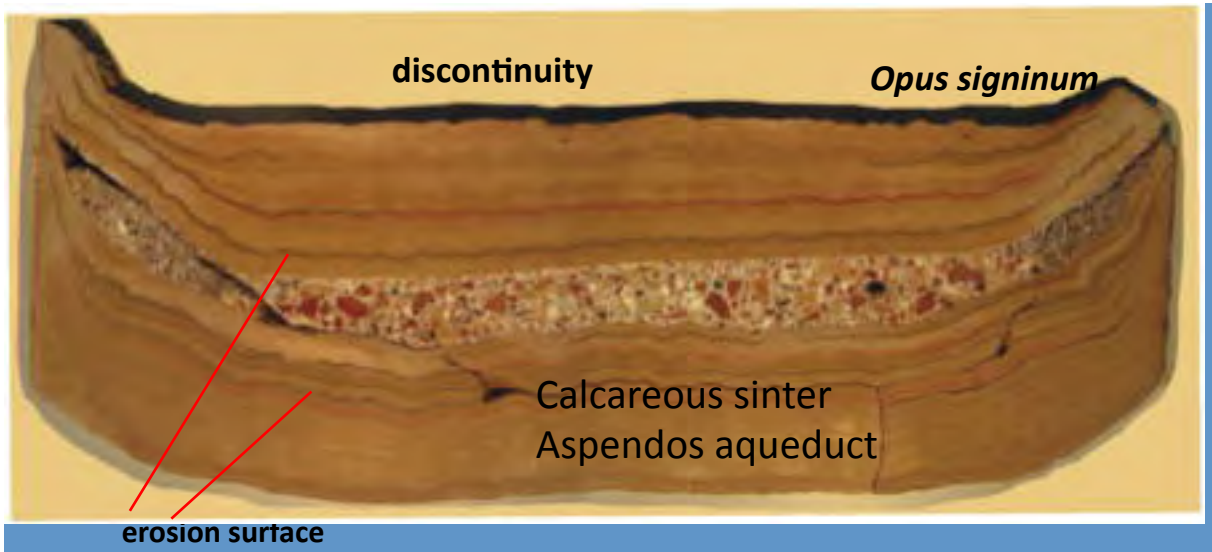


More porous

Calcareous sinter, Cologne aqueduct

STRATIGRAPHY

-Laminated deposits like other terrestrial carbonates; speleothem,tufa, travertine, flowstones,
-Dark brown and light laminae couples in hand specimen,
-By comparison;denser than tufa, more porous than speleothem,
-Start with dense fabric after *opus signinum*, gets more porous close to the top of the deposit.



Calcareous sinter
Aspendos aqueduct

150 years of climate and earthquake and (or) human activity data

Calcareous sinter can be used as data for;

- ✓Paleoclimate
- ✓archaeoseismology
- ✓human activity (anthropological information)

Cologne aqueduct

Nîmes aqueduct (Pont du Gard)
More than 400 years data from the channel calcareous sinter deposit


Aqua Marcia
Sikyon
Argos
Patara
Aspendos
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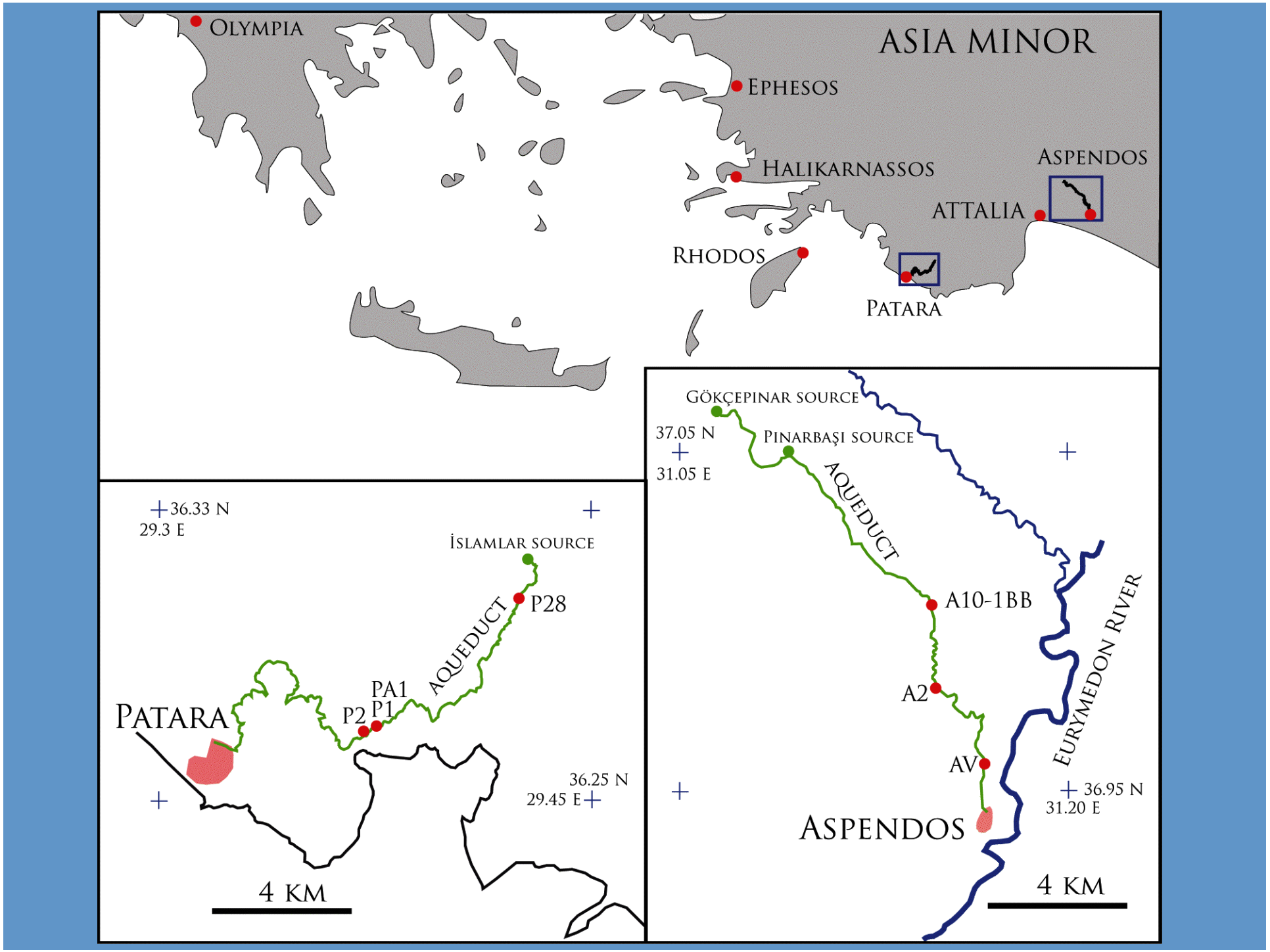

ASIA MINOR
OLYMPIA
EPHESOS
HALIKARNASSOS
ASPENDOS
ATTALIA
RHODOS
PATARA
GÖKÇEPINAR SOURCE
37.05 N
31.05 E
PINARBAŞI SOURCE
AQUEDUCT
A10-1BB
A2
AV
EURYMEDON RIVER
36.95 N
31.20 E
ASPENDOS
4 KM
36.33 N
29.3 E
İSLAMLAR SOURCE
P28
AQUEDUCT
PA1
P2
P1
PATARA
36.25 N
29.45 E
4 KM

METHODS

Laminae couplets: annual or not

- Electron Backscatter Diffraction (EBSD) : crystal shape and orientation
- Electron microprobe (EPMA): major element concentration
- Laser Ablation Inductively Coupled Mass Spectrometry (LA-ICP-MS): trace elements
- Raman Spectroscopy: defining carbonate type (aragonite and calcite)
- Stable Oxygen-Carbon Isotope Analysis:

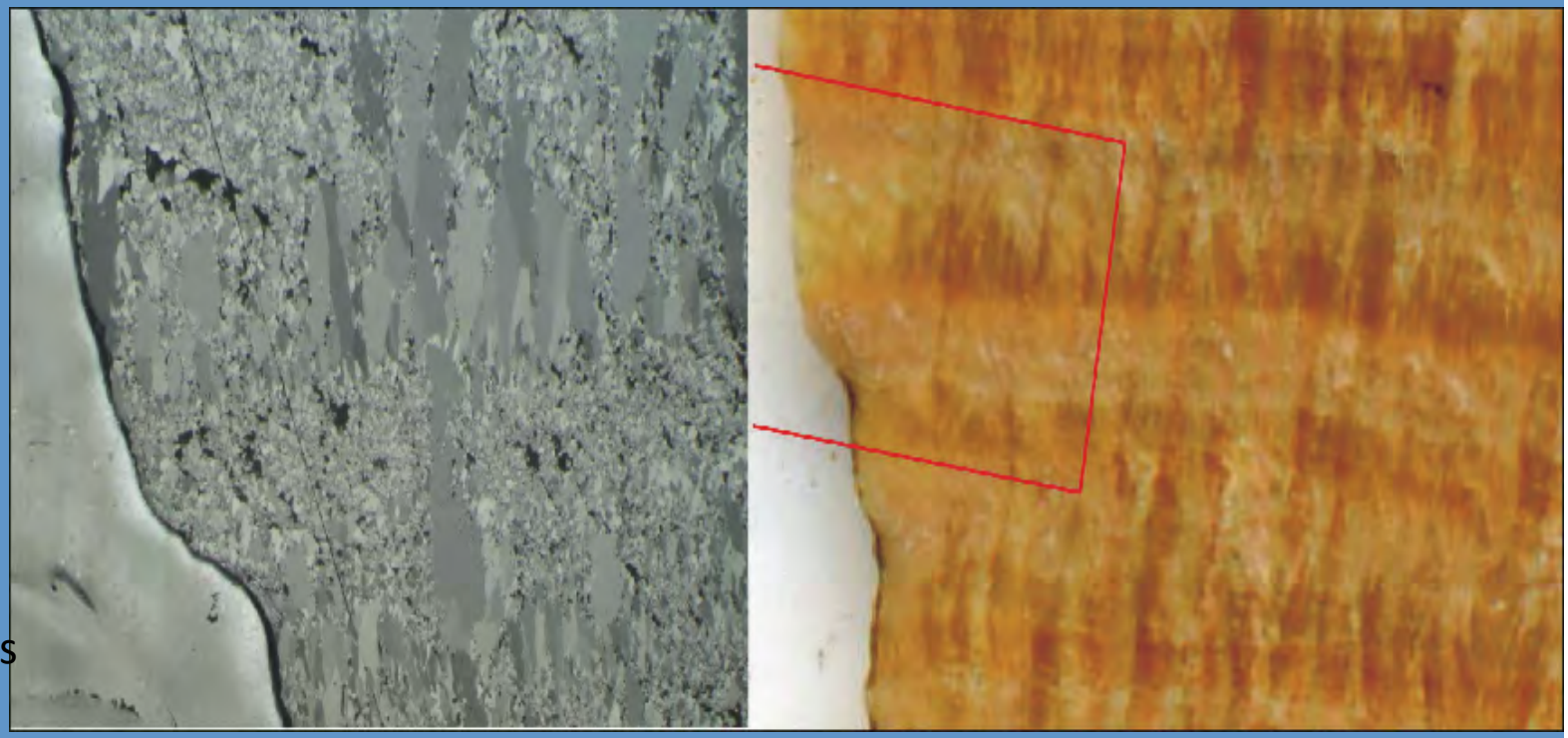
- $\delta\,^{18}O$ (ratio of stable isotopes O_{18}/O_{16}) reflects changes in paleo temperature and rainfall
- $\delta\,^{13}C$ (ratio of stable isotopes C_{13}/C_{12}) reflects biogenic activity, degassing and prior calcite precipitation (pcp)

EBSD analysis Two type of laminae couples

fine grained crystals

high porosity

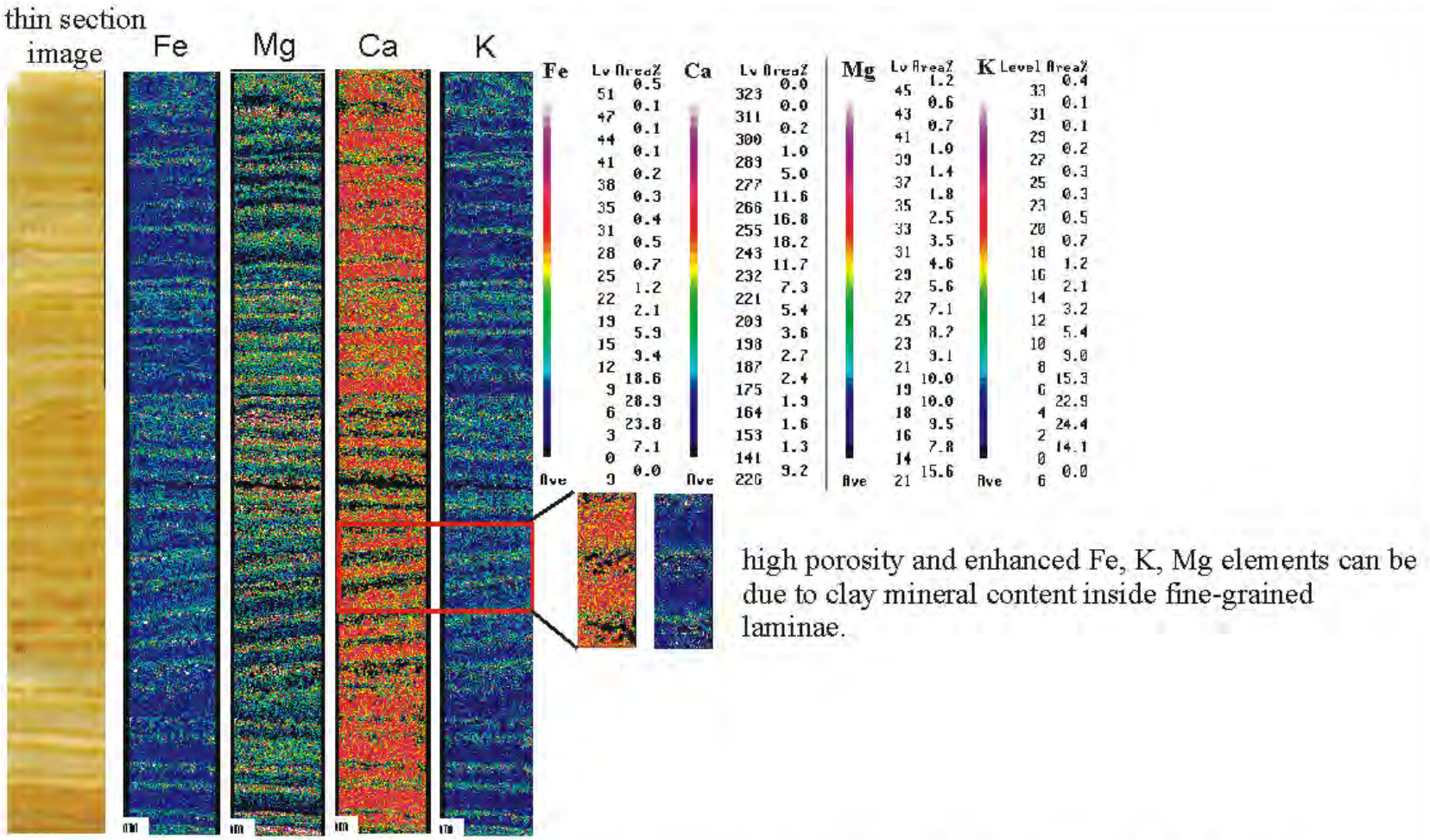
Coarse grained elongated crystals



Aspendos (A10-1BB) EBSD image from thin section. Width of view at left: 3.1 mm

- Dark and light layers in thin section consist of fine and coarse-grained crystals.
- Coarse grained crystals elongated along the growth axis.
- High porosity inside fine-grained crystals

EPMA analysis

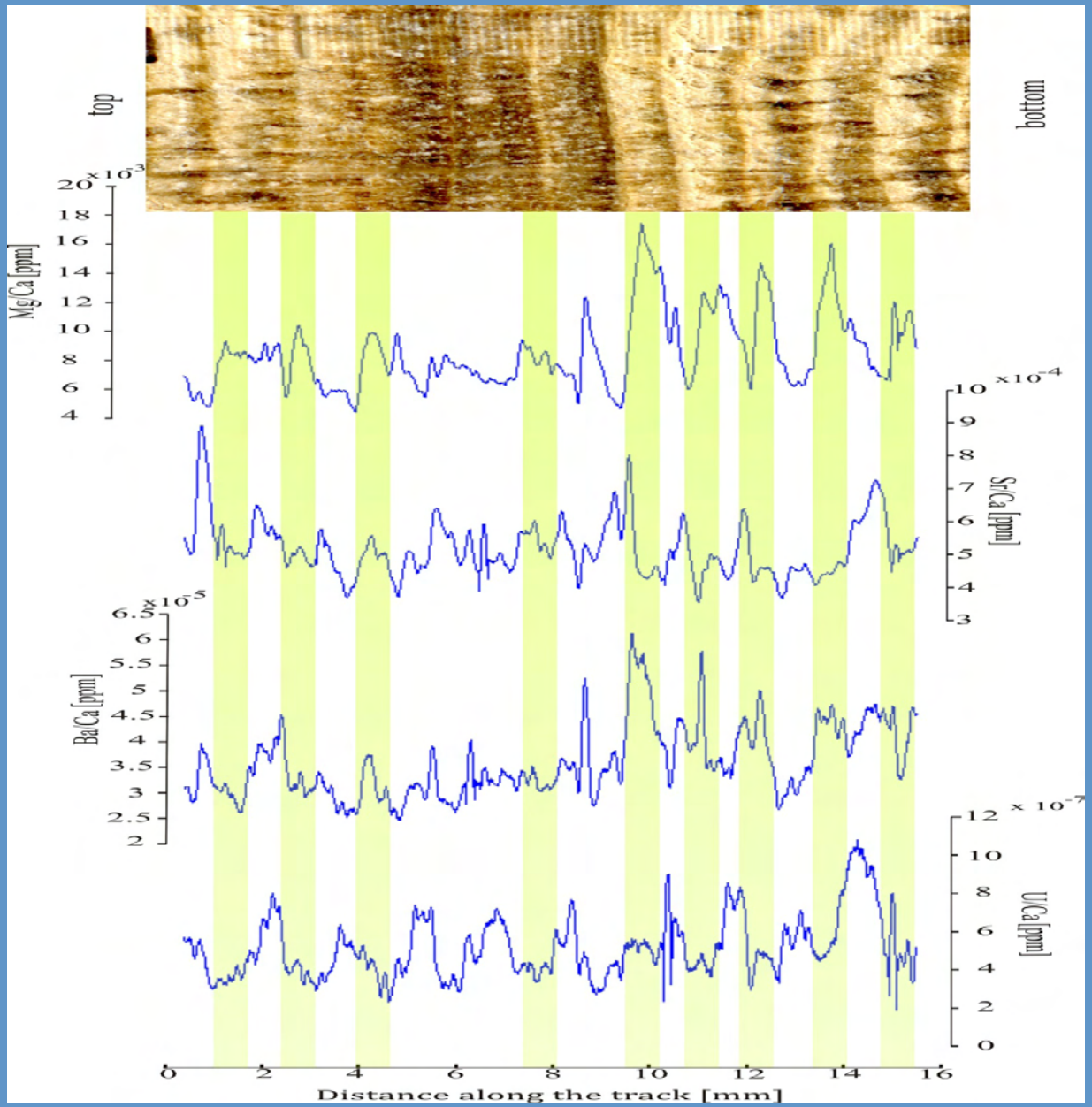


high porosity and enhanced Fe, K, Mg elements can be due to clay mineral content inside fine-grained laminae.

. EPMA elemental distribution map of the Aspendos (A2) sinter sample. Sample height 36 mm.

The higher values of Fe, K, Mg, Al and Si may be due to the presence of sub-microscopic clay minerals or other inclusions in the calcite crystals, seasonal changes in water level or biological activity.

LA-ICP-MS (trace element analysis)



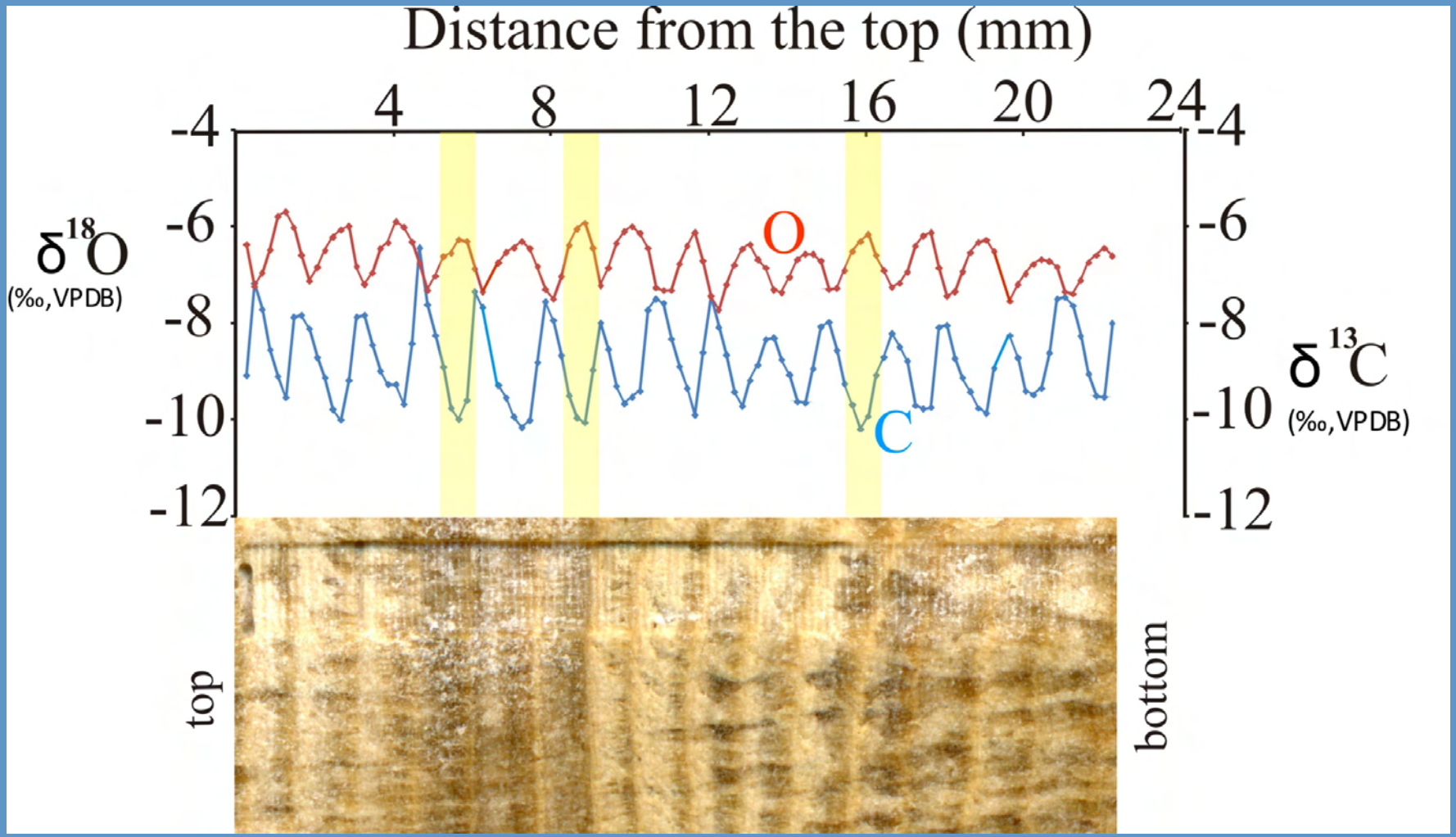
Sample from Aspendos aqueduct

- Mg/Ca ratio is affected by changes in water temperature, rainfall and prior calcite precipitation

Sr/Ca and Ba/Ca is related with crystal growth rate

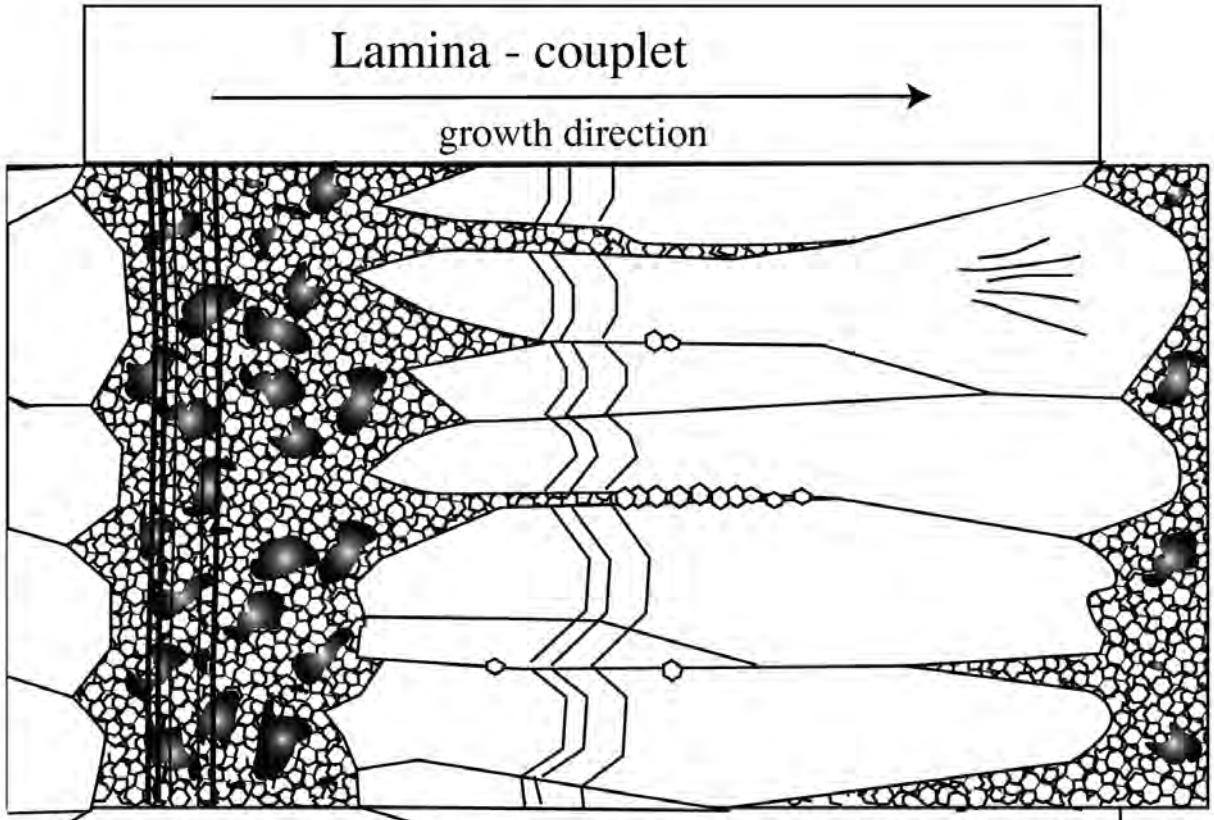
U/Ca is related with organic matter, clay mineral content

The stable isotope analysis



- δ ^{18}O isotope values may reflect temperature in the channel and in original rainfall.
- Higher δ ^{18}O values mostly correspond to fine-grained, more porous summer layers.

- δ ^{13}C isotope values may be affected by degassing, paleo productivity and prior calcite precipitation. Higher δ ^{13}C values can be due to mainly higher degassing during colder period.



PF -lamina	DC-lamina
white-opaque in sample	brown-translucent in sample
dark-opaque in thin section	light-transparent in thin section
fine-crystalline, micritic	coarse-crystalline, sparitic
equidimensional crystals	elongate crystals
porous	dense
high Fe, Mg, Si, Al, K, U	low Fe, Mg, Si, Al, K, U
low δ^{18} O, high δ^{13} C	high δ^{18} O, low δ^{13} C
warm, dry season, slow flow	cold, wet season, fast flow

Monitoring on still working aqueducts

Monitoring on some of the still operating roman aqueducts to see how water temperature and geochemistry varies in regular time intervals to better interpret historical data from the recent conditions, observation of the process depositing the sinter, and the conditions under which it occurs.

pH water conductivity hardness temperature

trace elements stable isotopes

Sicily
November, 2010

Aqua Virgo,
July 2011

Αύτοκράτωρ Καίσαρ Φλάουιος Ούεσπασιανός Σεβαστός
τό του ύδρα[γω]γίου άνάλημμα συμπεσόν σεισμοίς έκθεμε[λ]
1ων άποκατέστησε om τοις *έη* αύτφ λιθίνοις *έκ* τετραπέδου
λίθου σωλπσι προστεθεγτος καΐ ετ[έ]ρου παράτ[όδ]ε άνάλημμα
θλειμματικοΫ ύδραγωγίου δια τριστίχων σωλήνων
όστρακίνων.....

Delikkemer inverted siphon, Patara

Summary

•Calcareous sinter in two Roman aqueducts from the eastern Mediterranean consists of couplets of alternating porous, fine-grained (PF) and dense, coarse-grained (DC) laminae, usually 1-2 mm wide. This layering is interpreted as annual, based on the combined interpretation of the microstructure, oxygen and carbon isotopes, and trace elements.

•The cyclicity seen in crystal structure, porosity, major and trace elements, and stable isotopes is the result of a seasonal pattern, which implies that calcareous sinter in Roman aqueducts is a potentially significant high-resolution data source on climate change over nearly 1000 years during the Roman and Byzantine era.

•Further studies in different climate zones are needed to better understand the factors that play a role in the formation of calcareous sinter in Roman aqueducts. Once these processes are well understood, annually laminated sinter from aqueducts could emerge as a new high-resolution environmental and archaeological proxy.

Delikkemer
Patara, TURKEY

Thanks
for your attention