

Hierarchical Stratigraphy of Travertine Deposition in Ancient Roman Aqueducts¹

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Ancient Rome's water supply system enabled the development of unprecedented population density. Calcium carbonate (CaCO₃) deposits (travertine) precipitated from flowing water within the system record its hydrology and chemistry, enabling reconstruction of past water management.

Five depositional beds of travertine (fig. 1C) were found along a 140 m flow path transect of the *Anio Novus* aqueduct² at Roma Vecchia (fig. 1A). Only beds 1 and 2 (the lowest and oldest beds) survive at all three sites sampled (fig. 2). Field and microscopic investigation revealed multi-scale bedding charac-

teristics (fig. 2-3). These include: μm - to mm - scale dark-light color variations³, and mm - to cm -scale crystalline ripple bedforms⁴. On the stoss (upstream) side of ripples, there is denser crystallization (labelled vii on fig. 2-3) and fans of longer crystals (iii, mainly in bed 1). On the lee (downstream) side, crystallization is less dense (viii) and there are lag deposits of sand-sized particles (i) and, in larger, asymmetric ripples, voids (ii) and travertine-coated grains and fibres⁵ (iv).

Both uranium-thorium and carbon-14 dating failed to produce useable dates for these deposits. However, at a minimum, the travertine must date be-

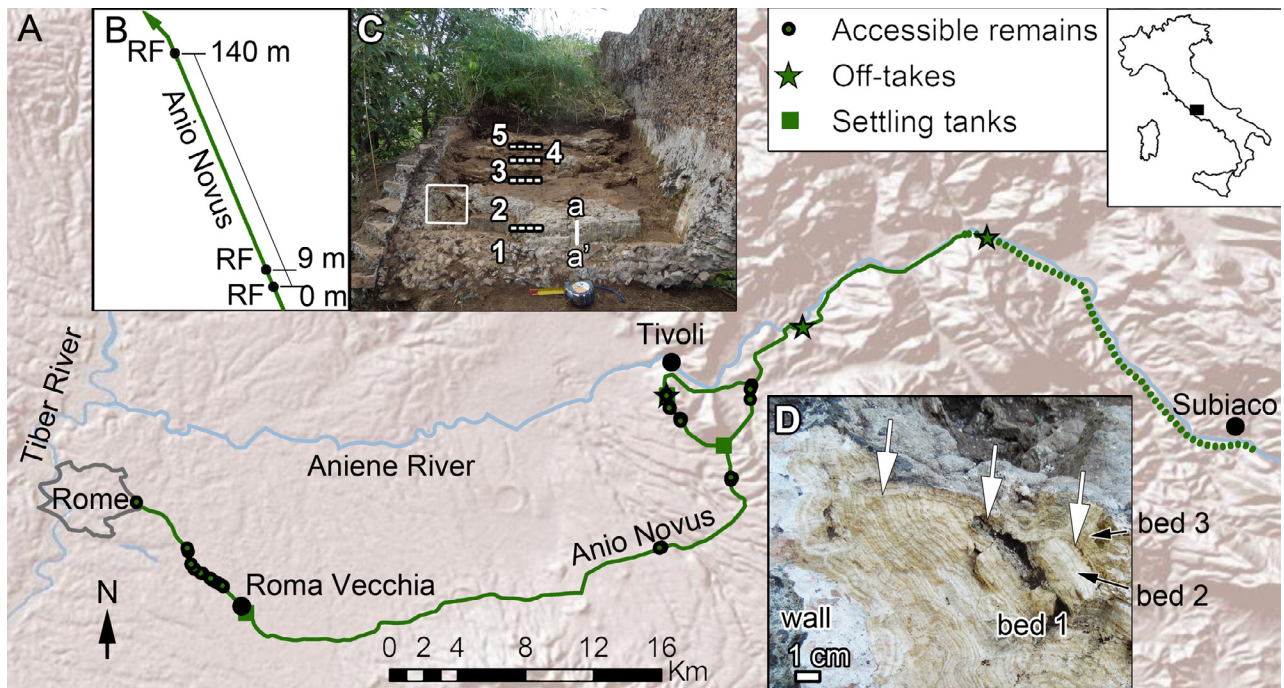


Fig. 1. Study sites. A. The Anio Novus (Reina – Corbellini – Ducci 1917; Ashby 1935; Fiore Cavaliere – Mari 1995). Based on data provided by ESRI Inc. B. Roma Vecchia sampling transect. C. Beds 1 – 5 at RF m 140, facing downstream. Tape measure: cm 10. The sample (fig. 2C) was collected from a-a'. Box shows location of D. D. The 3rd unconformity (white arrows).

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² Rome's highest and furthest-reaching aqueduct.

³ The smallest yet reported in aqueduct travertine.

⁴ These ripple bedforms are previously unreported in aqueduct travertine and will be analyzed in a forthcoming publication.

Fig. 2-3. Flow is to the right. Arabic numerals label unconformities. Other features: lag deposits (i), and associated voids (ii), large crystal fans (iii), coated grains (iv), fractures (v), porous area (vi) more dense, stoss-side fabric (vii), less dense lee-side fabric (viii), micron-scale layers (ix) and concentrations of particles in the area of a dark layer (x). Overlaid colored columns are CL images.

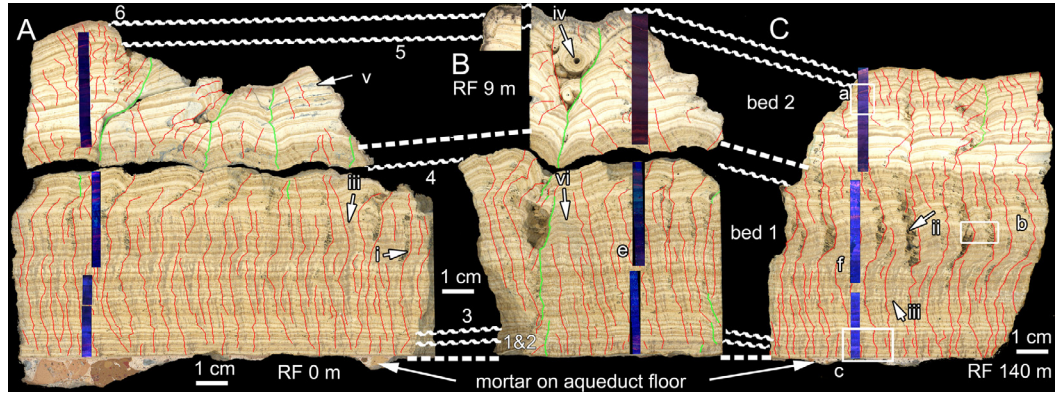


Fig. 2. Correlation of travertine stratigraphy along the transect. Red (small scale) and green (large scale) lines show ripple troughs. Boxes and CL columns show indicative locations only.

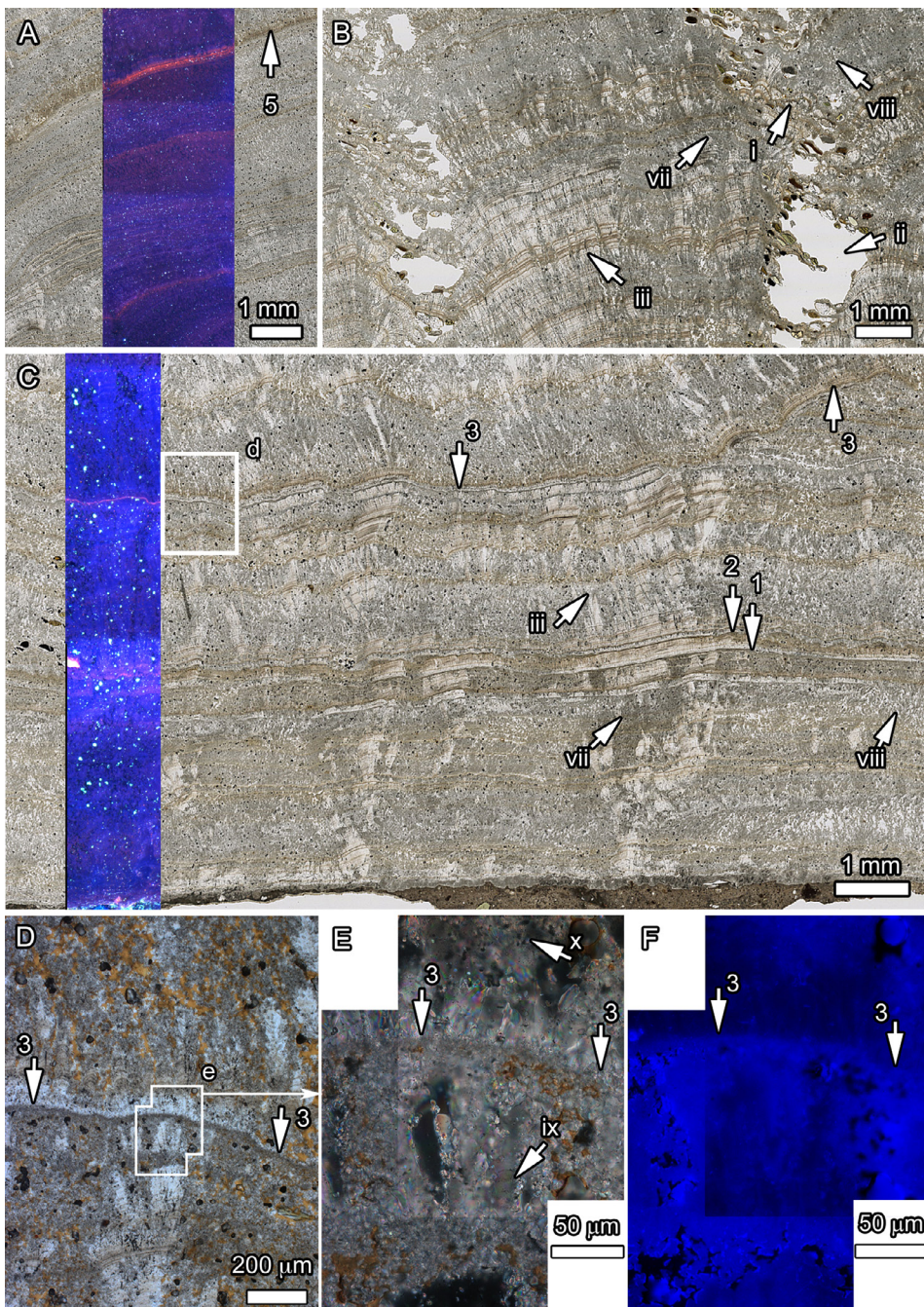


Fig. 3. Microphotographs. A, B, C are Nano Zoomer enlargements of boxes a, b, c from fig. 2. B shows a mid-scale asymmetrical ripple. D Laser confocal image of box d. E Plane-light, and F autofluorescence (432-482 nm emission, 405 nm excitation), confocal images of box e.

tween the *Anio Novus*' commissioning (AD 52)⁶ and final breakdown (sometime between AD 381⁷ and the 11th century AD⁸).

The six erosional unconformities (fig. 2) in beds 1 and 2 may have been caused during the flash-flood restarting of the aqueduct after maintenance or repair. The 3rd (fig. 3C), 5th (fig. 2B) and 6th (fig. 1D) unconformities show cm-scale variation in the travertine layers preserved under them, suggesting they were caused by manual removal of travertine⁹.

Sub-mm layering in both beds has been comprehensively correlated along the transect (fig. 2), a first for aqueduct travertine. This suggests that this aqueduct travertine records aqueduct bulk fluid hydrology rather than merely localized conditions. Darkly colored layers are richer in organic material, including humic and fulvic acids (which autofluoresce under certain wavelengths of light¹⁰) than surrounding travertine (fig. 3F). Aqueous complexation with these humic acids¹¹ might explain the greater concentrations of manganese suggested by the pink cathodoluminescence (CL) of most darker layers (figs 2& 3A, C). These dark layers are also associated with micrometer-scale particles (fig. 3E, x)¹². Significant increases of both organic material and sediment particles during rainstorms have been documented in the *Anio Novus*¹³ and in its source, the modern Aniene River (fig. 1)¹⁴. These increases will have significantly impacted microbial ecology within the

aqueduct, which may also be recorded by travertine layering. It is unclear which scale, if any, of dark-light layering regularly corresponds to annual rainy seasons.

These observations warn against the routine employment of annual layering interpretations of aqueduct travertine and highlight the importance of the context of each sample and aqueduct¹⁵.

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Abstract

Travertine formed from the water of Anio Novus provides a sensitive record of its hydrology and chemistry. The travertine exhibits multi-scale bedding characteristics, including mm- to μm- scale dark-light layering, and previously unreported mm- to cm-scale crystalline bedforms. Optical field and laboratory analyses reveal multiple flow interruptions. The unknown scale of the probable correlation between rainfall events and dark-light layering warns against routine annual layering interpretations.

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⁶ CIL VI, 1256, Frontin., *aq.*, 13. The oldest travertine adjacent to the mortar may date to this period.

⁷ CIL VI, 3865 = 31945.

⁸ Ashby 1935; Coates-Stephens 2003.

⁹ Frontin. *aq.*, 122.

¹⁰ Baker et al. 2008.

¹¹ Lester – Birkett 1999.

¹² Also noticed by Carrara – Persia 2001 in *Anio Novus* travertine km 5 downstream.

¹³ Frontin., *aq.*, 15, 89-91.

¹⁴ Bono – Percopo 1996.

¹⁵ Future work will include travertine precipitation experimentation under controlled water chemistry, flow and microbial conditions.

