A Multimodal Analysis of Cement Lines in Human Osteonal Bone

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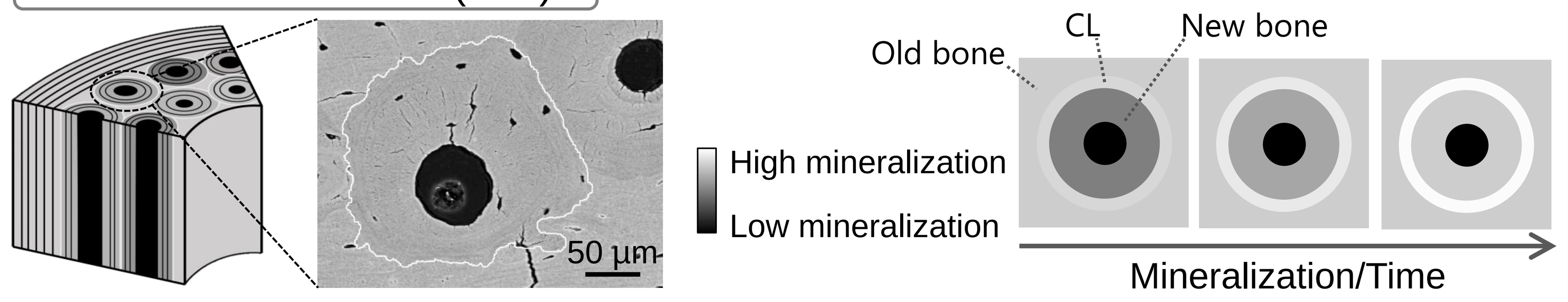
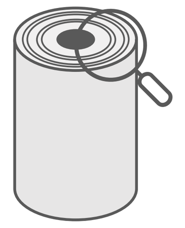
Introduction

What are cement lines (CLs)?





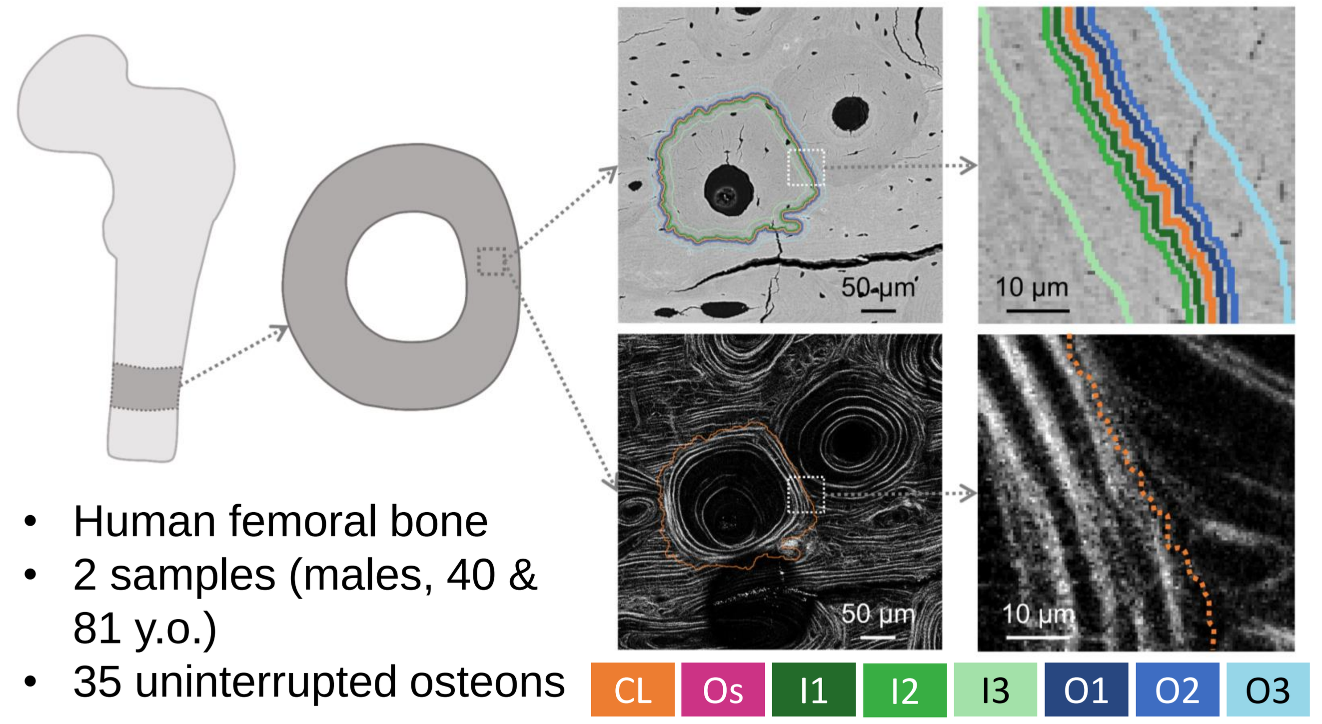
Research questions:
- Composition
- Structure
- Mechanical properties

Outcomes:
- Bone fracture models
- Bone remodeling models
- New bioinspired composites

The goal of this research is to characterize the **mineral content** and **mechanical properties** of CL and its surroundings at micrometer scale.

Methods

Mineral content and lamellar structure



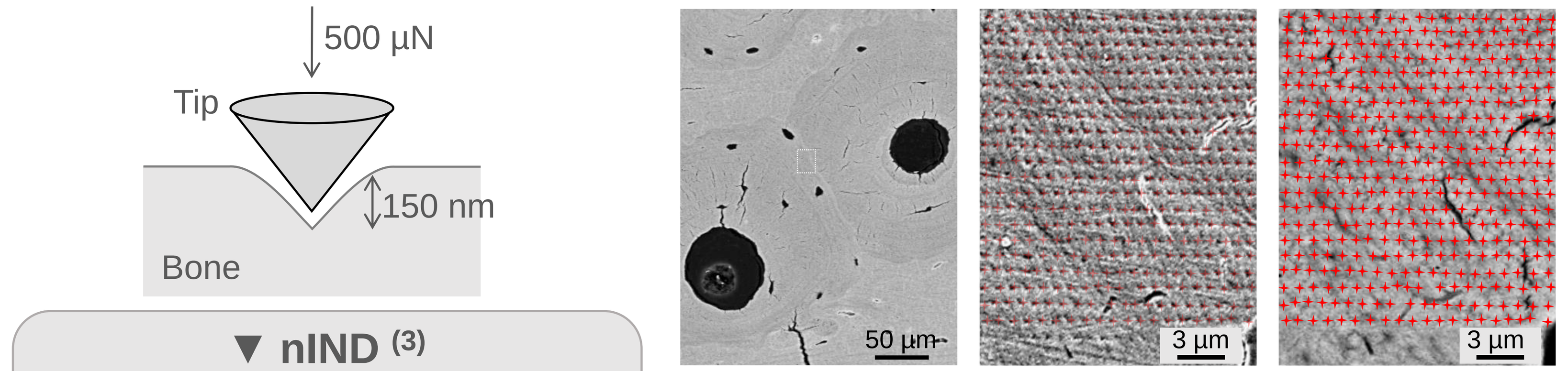
- Human femoral bone
- 2 samples (males, 40 & 81 y.o.)
- 35 uninterrupted osteons

qBEI [1] Pixel size: 570 nm

SHG [2] Pixel size: 380 nm

(1) Quantitative backscattered electron imaging
(2) Second harmonic generation

Mechanical properties



nIND [3]
- Lateral spacing: 1 µm
- Applied force: 500 µN
- Penetration depth: ~150 nm

qBEI Pixel size: 570 nm

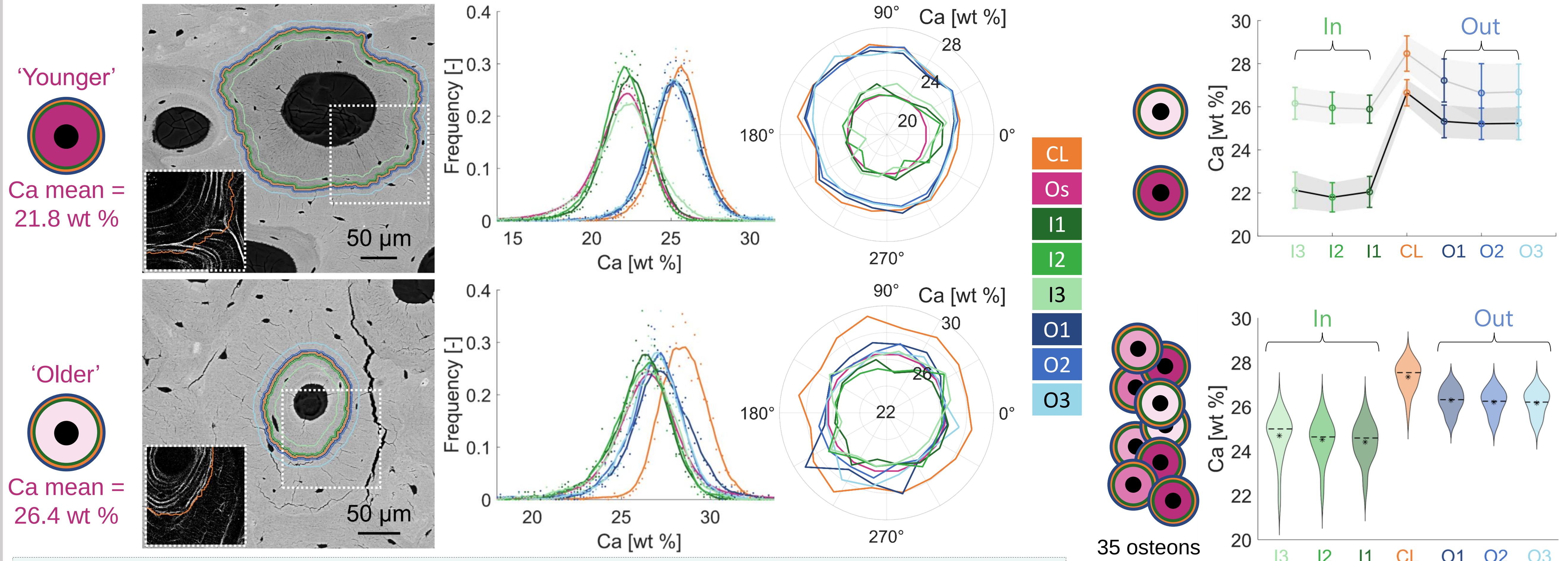
hrSEI [4] Pixel size: 75 nm

hrBEI [5] Pixel size: 75 nm

(3) Nanoindentation
(4) High resolution second electron imaging
(5) High resolution backscattered electron imaging

Results

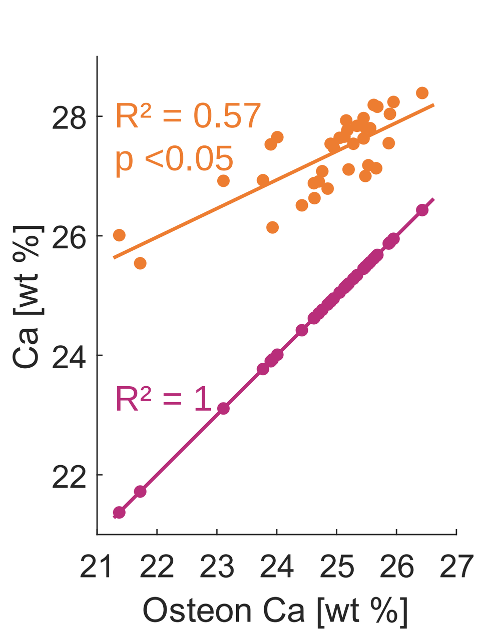
Mineral content: Is there a relationship between the mineral content of CL and of surrounding bone?



- CL **higher** mineral content
- Low mineralized '**young**' osteon: Mineral content of CL follows outer layers polar profile
- High mineralized '**old**' osteon: Mineral content of CL follows much less outer layers polar profile

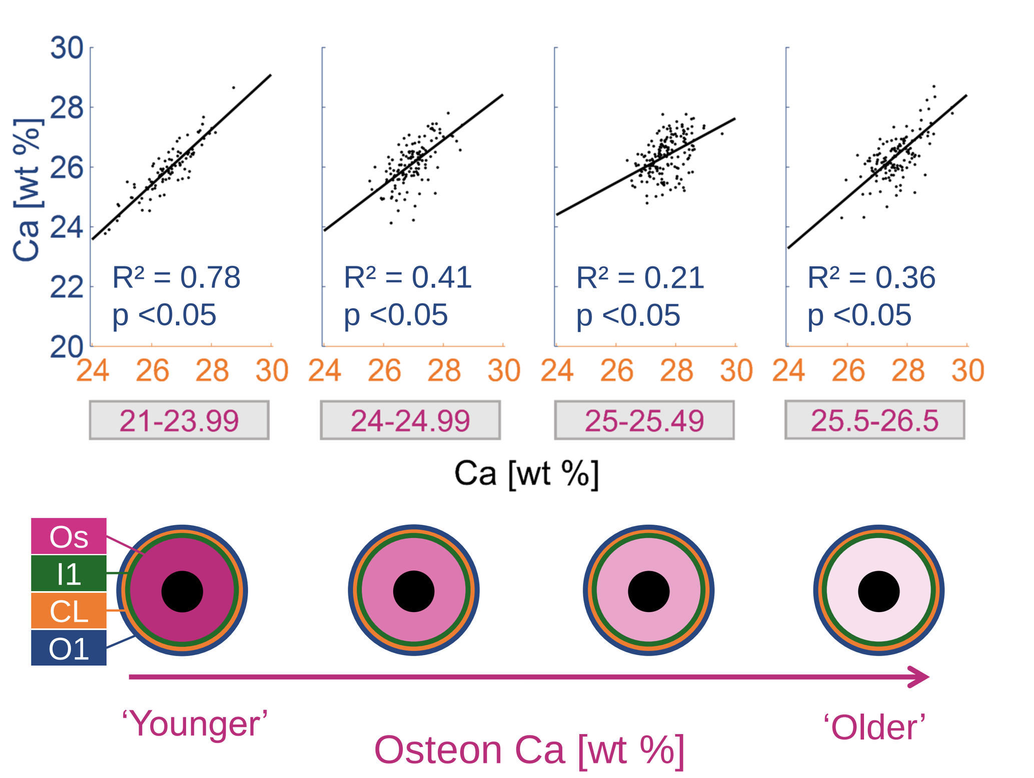
CL ~10% **more mineralized** than corresponding osteon

Mineralization kinetics



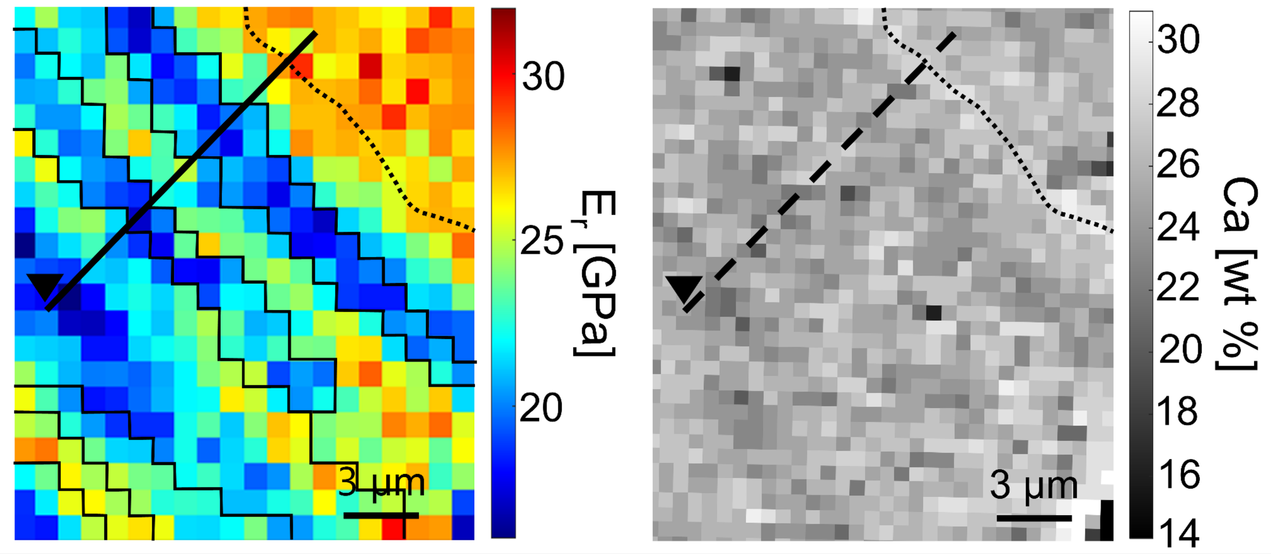
- **Correlation** between Ca content of CL and osteon
- **Different** mineralization kinetics

Impact of surrounding bone

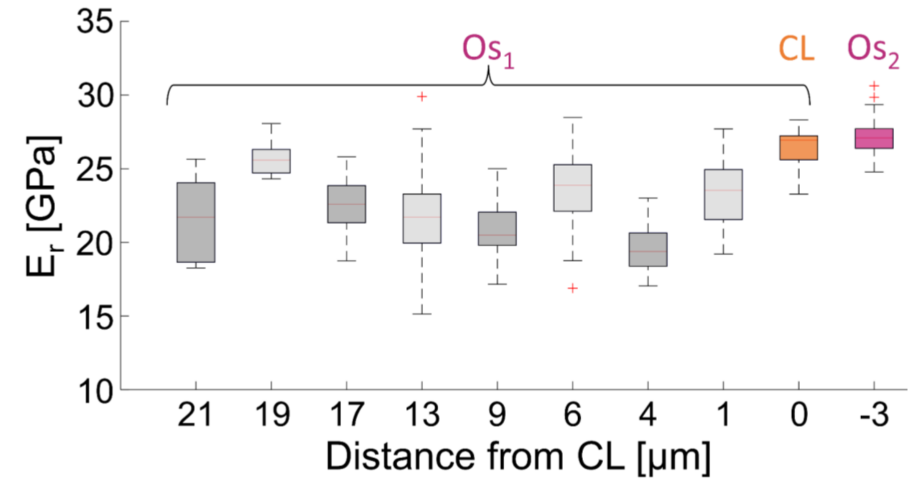


Strong **correlation** between Ca content of CL and of outside environment especially for low mineralized '**young**' osteon

Mechanical properties: Is CL stiffer or more compliant than its corresponding osteonal bone?

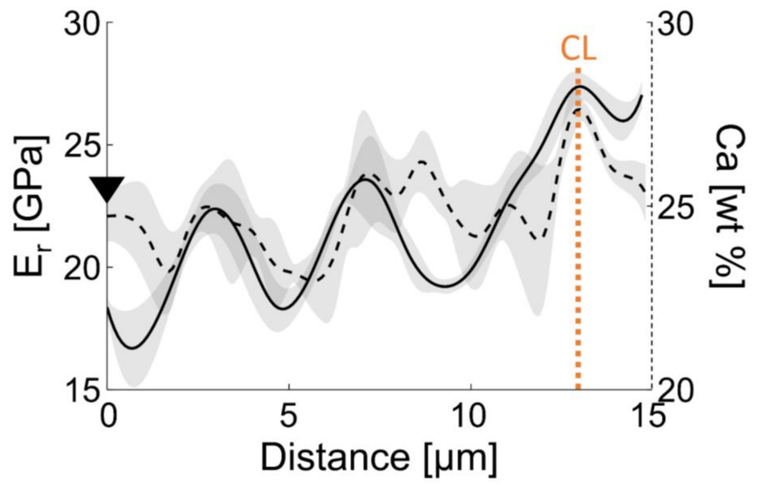


Global analysis



- **Periodic** alternation of:
  - Stiffer (23 ± 2.7 GPa) lamellae
  - Softer (20.7 ± 2.1 GPa) lamellae
- Distinct **peak** for CL (26.5 ± 1.3 GPa) compared to corresponding osteon (p <0.01)

Local analysis

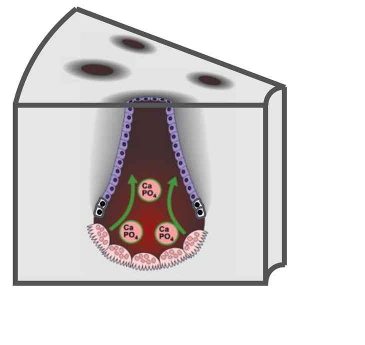


- **Spatial correlation** between periodic variations in stiffness (p <0.01) and in mineral content (p <0.01)
- **Peaks** of mineral content and stiffness at CL

Conclusions and Perspectives

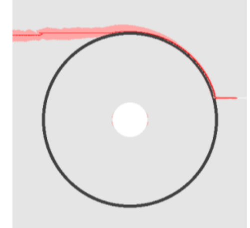
Mineral content:
- CL **hypermineralized**
- **Strong** correlation between mineral content of CL and outside environment within **young** osteon

→ Local recycling of minerals already there to build new CL
→ Consistent with [1]



Mechanical properties:

CL **stiffer** than its corresponding osteon

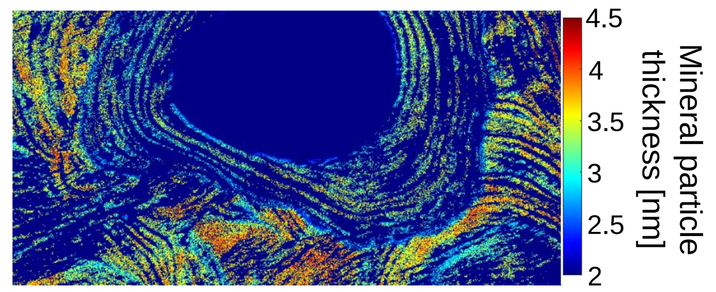


→ Hamper crack propagation
→ In contradiction with softer CL [2,3]

Image from simulation of T. Volders @MBBM lab, ULiège

→ Consistent with reduced nanoporosity of CL [4]

Perspectives:
- Mineral properties of CL measured with X-ray scattering @ESRF
- Interplay between CL and osteocyte lacuno-canalicular network



References

[1] Roschger et al., Acta Biomater., 2020
[2] Zhou et al., EMI, 2020
[3] Montalbano et al. J. Mater. Res., 2011
[4] Tang et al., JBMR,2023

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Social networks

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