Fracturing of organic-rich shales

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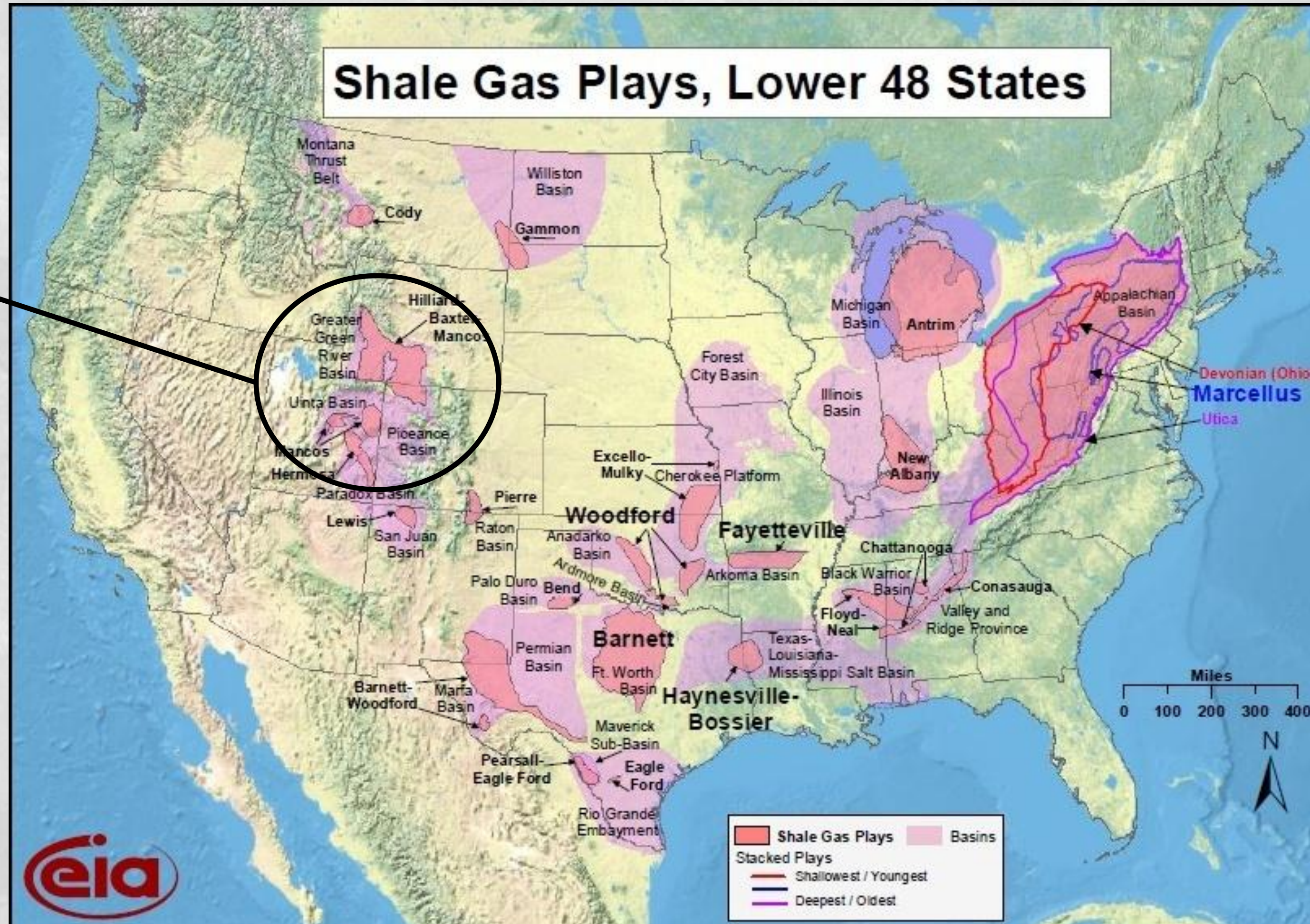
“Organic-rich shales”:

- Sedimentary, fine grained, highly laminated rocks
- 0.2 – 40 wt. % organic matter
- Very small pores $\Rightarrow$ very small matrix permeability
- Source rocks for oil and gas

Primary migration – transport of hydrocarbons from low permeability source rocks to reservoir

How does oil/gas escape from tight shales?

Green River Shale, USA



http://www.eia.doe.gov/oil_gas/rpd/shale_gas.pdf

Immature black shales

Total Organic Carbon (TOC) ≈ 10%

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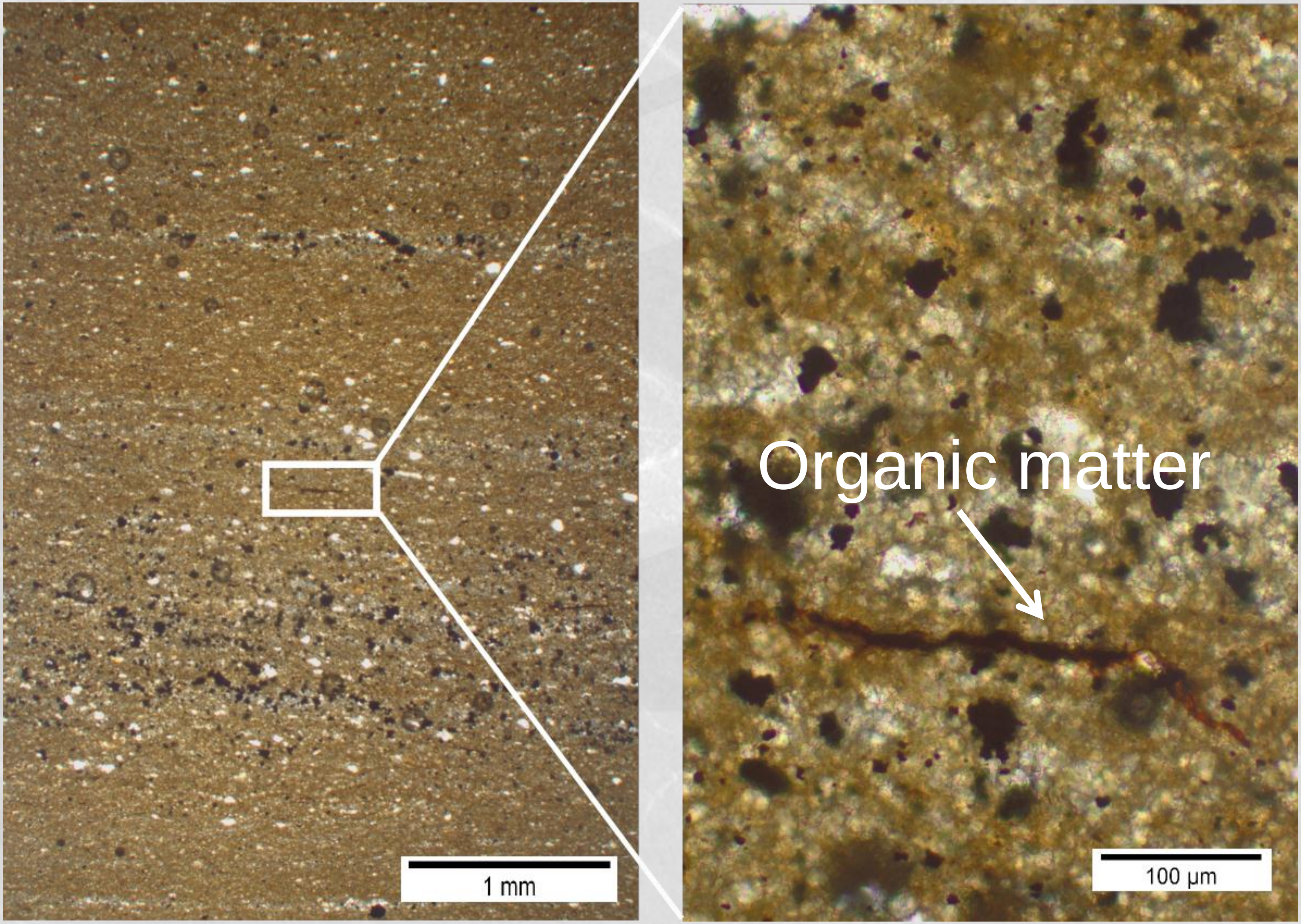
Thin sections – Optical imaging



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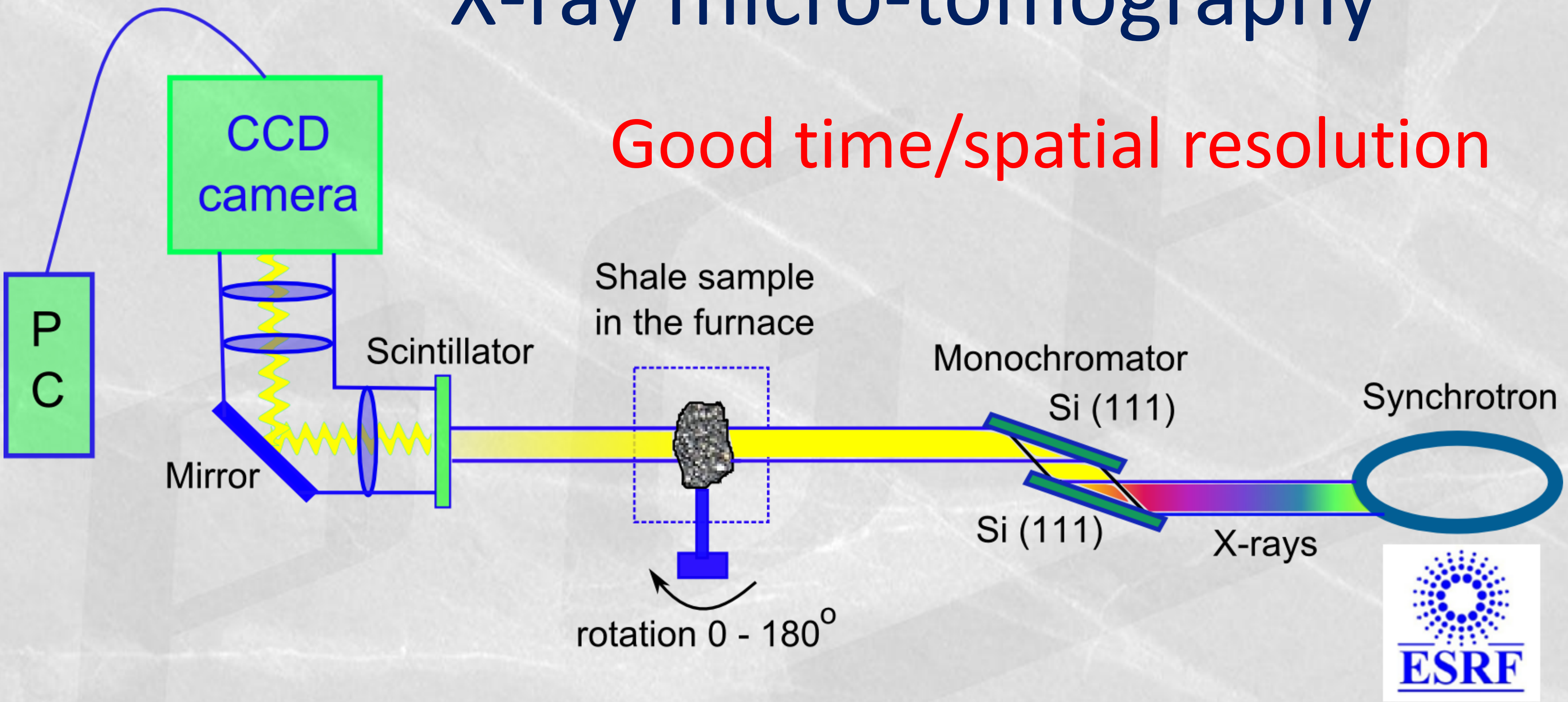
ESRF – European Synchrotron Radiation Facility, beamline ID 19 Grenoble, France

X-ray micro-tomography

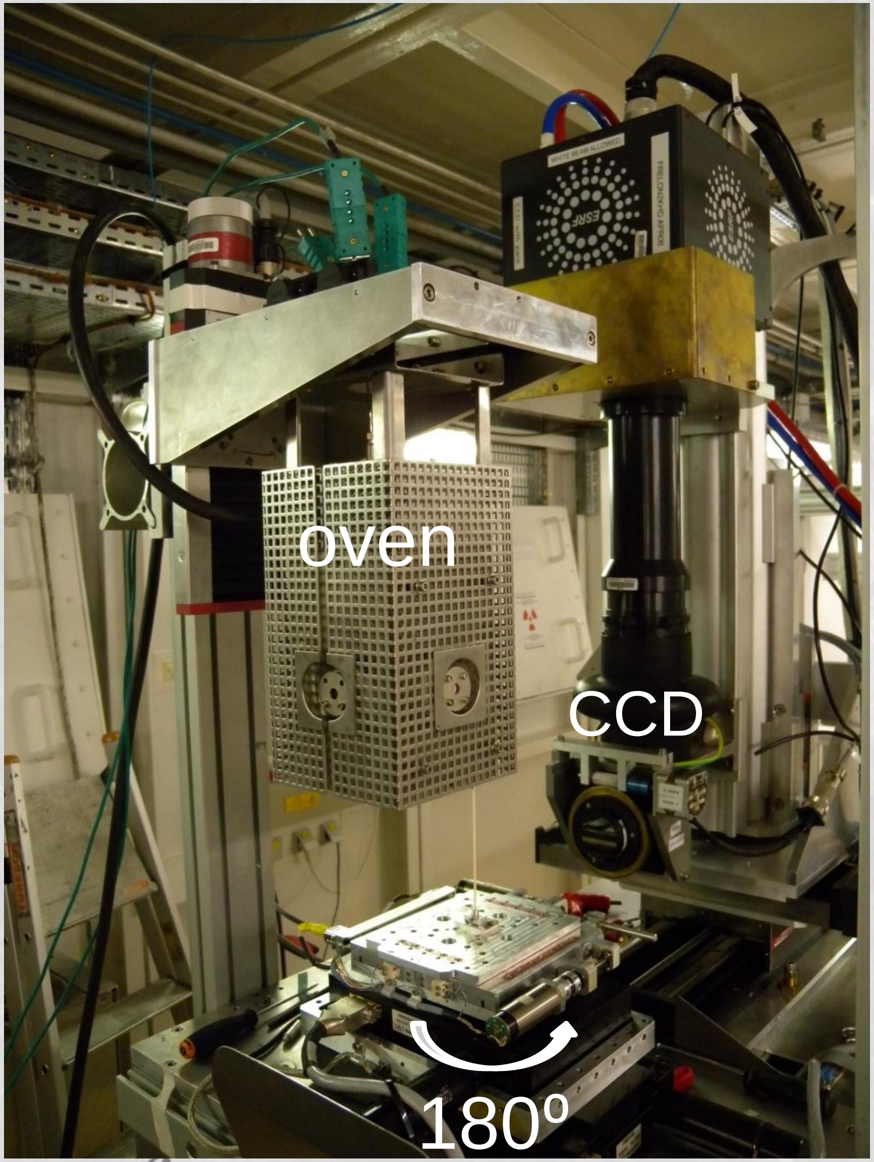


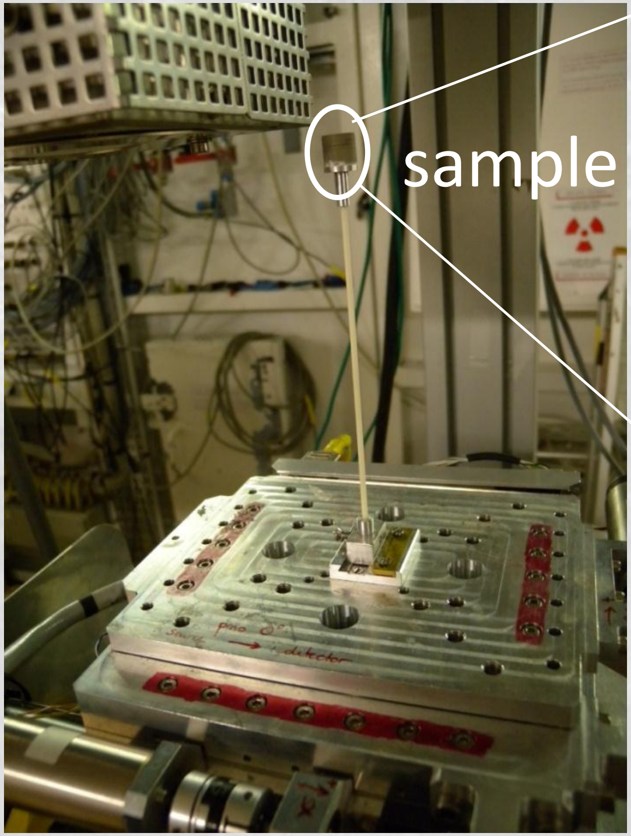
Good time/spatial resolution

- Image – density map
- 1500 projections reconstructed into 3D image
- 5 µm resolution
- 15 minutes for every 3D image

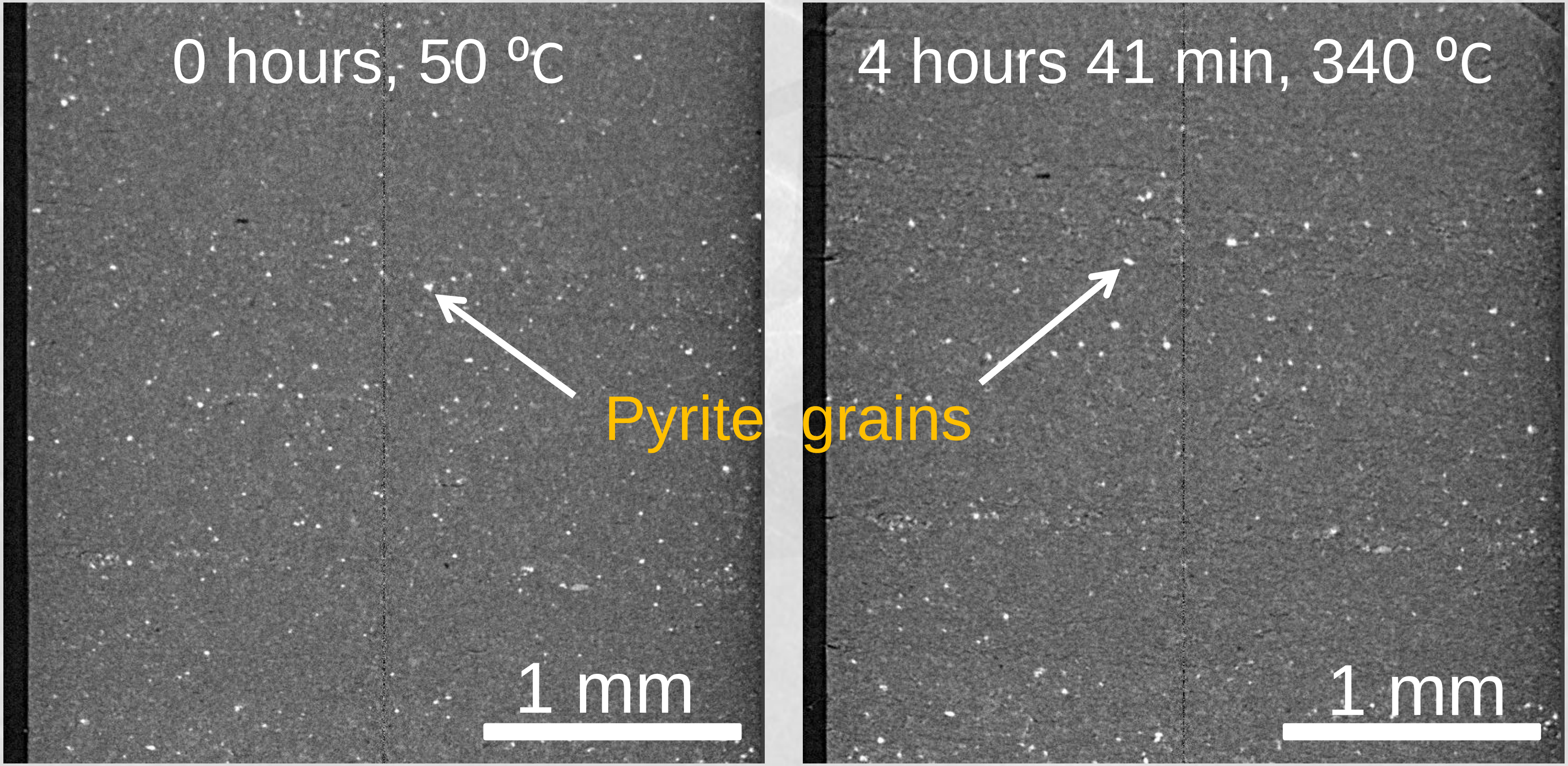
Sample setup

- Heating rate 1°C/min
- In air, atmospheric pressure
- Without confinement



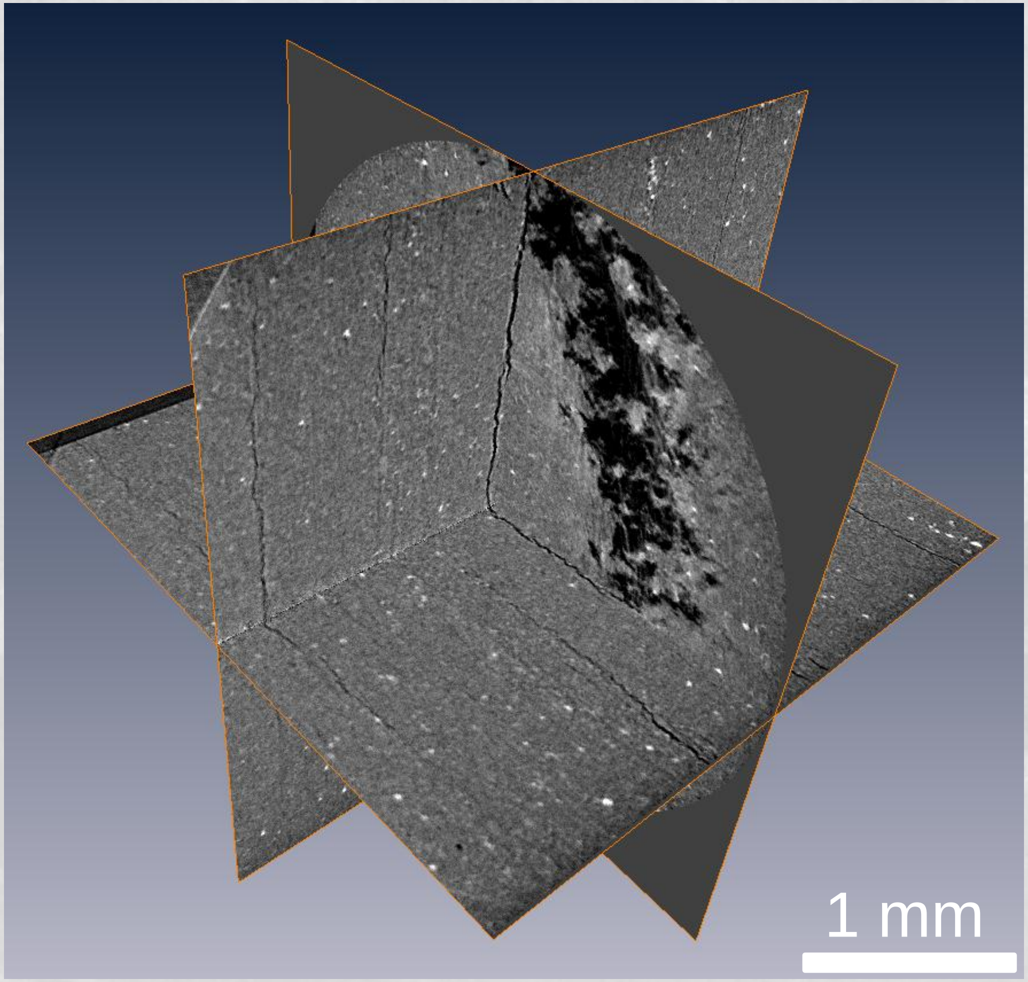


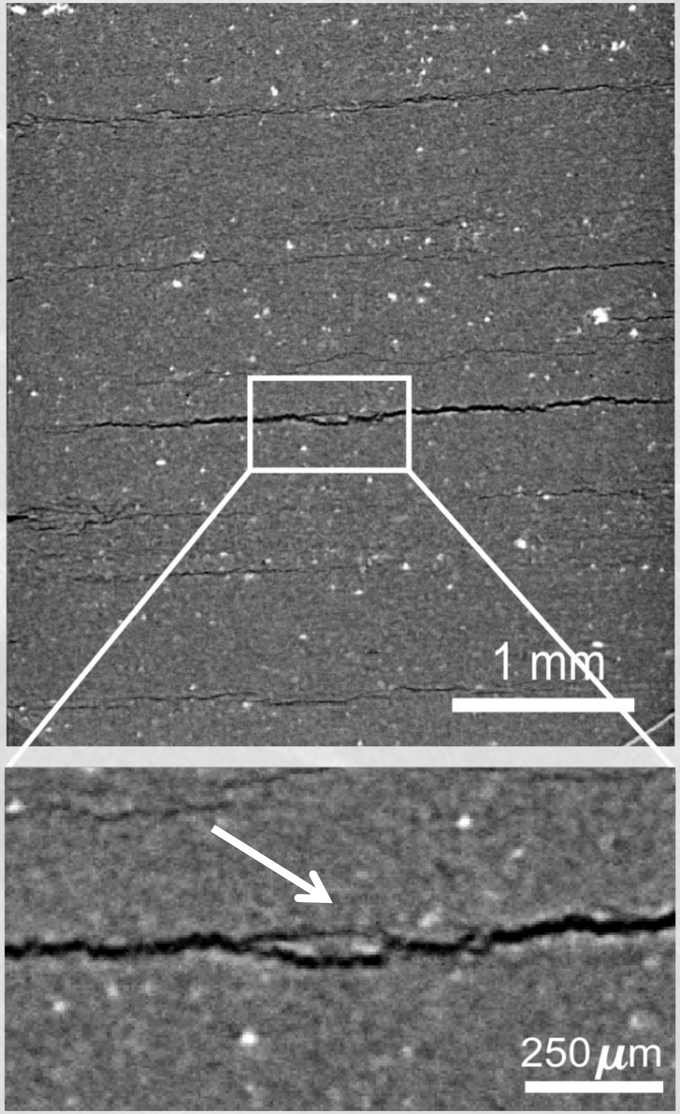
3D X-ray imaging while heating from 50 to 400^{o}C



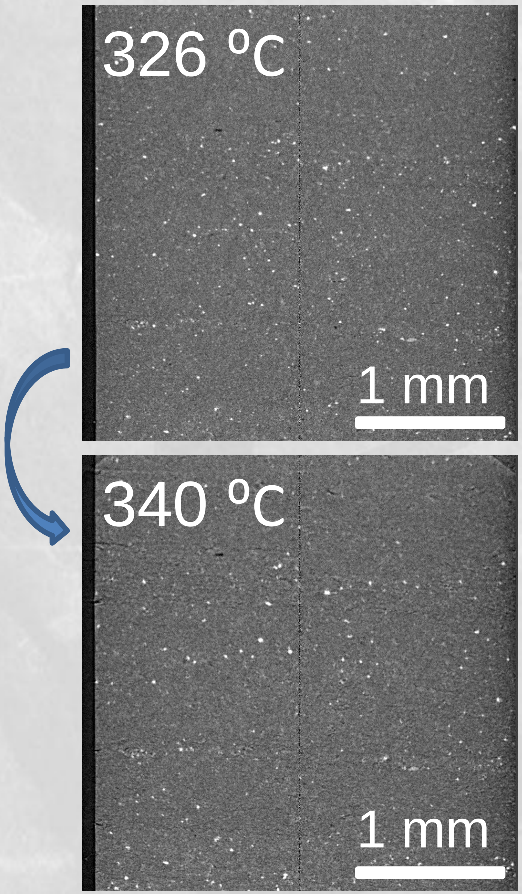
Fracturing at 350ºC

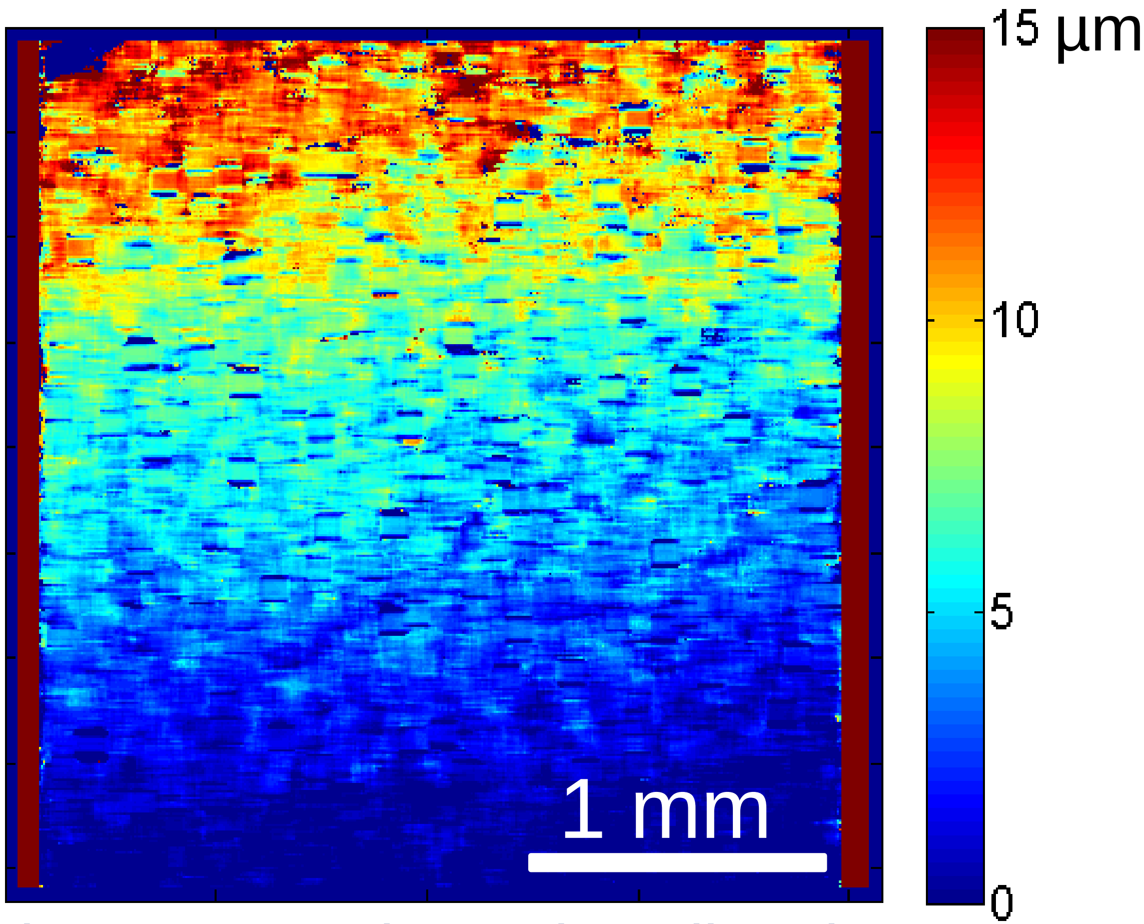
Cracks opening: 15-20 µm





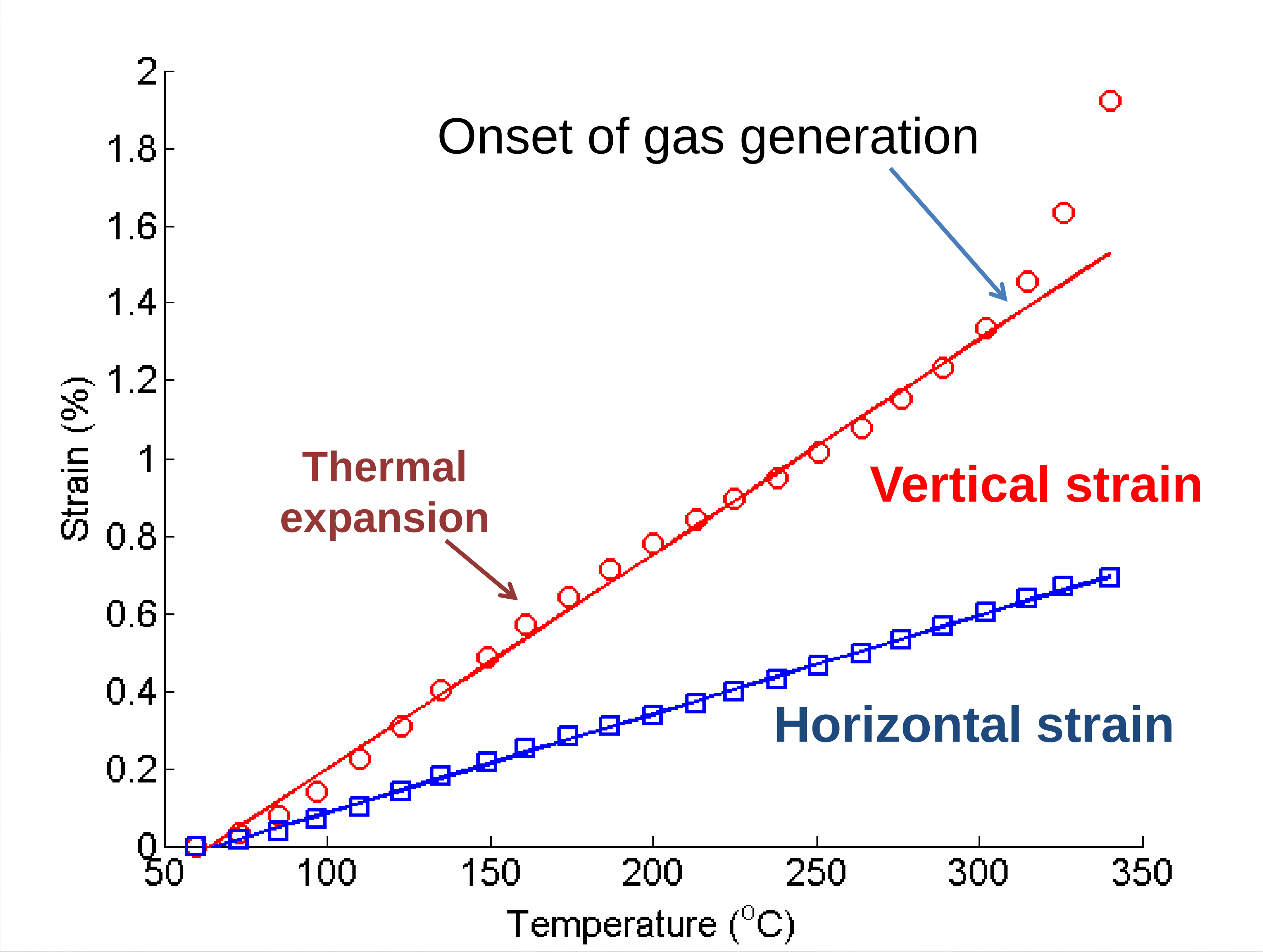
Correlation analysis –
Deformation of the sample before fracturing



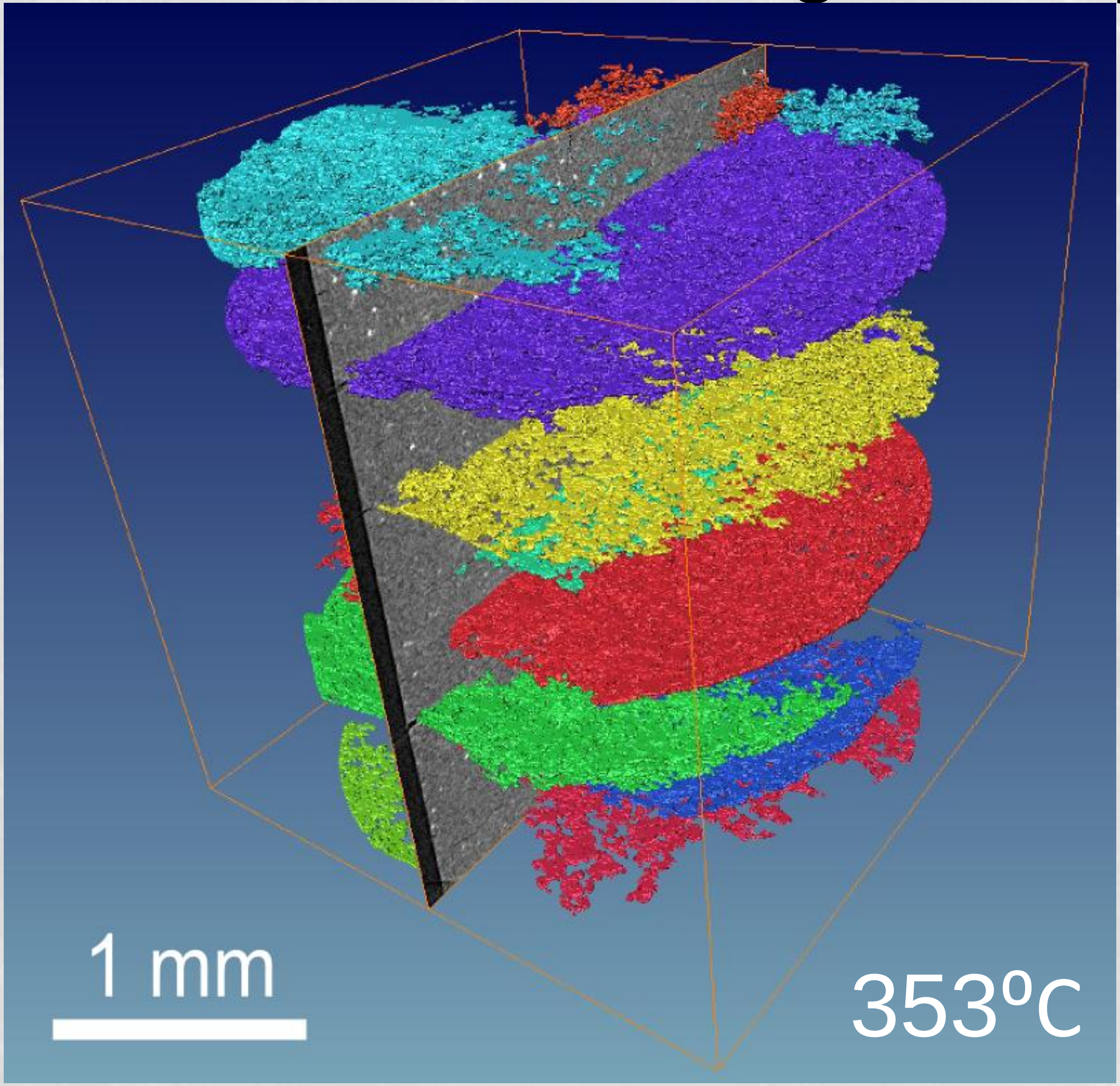


Displacement in vertical direction

Correlation analysis

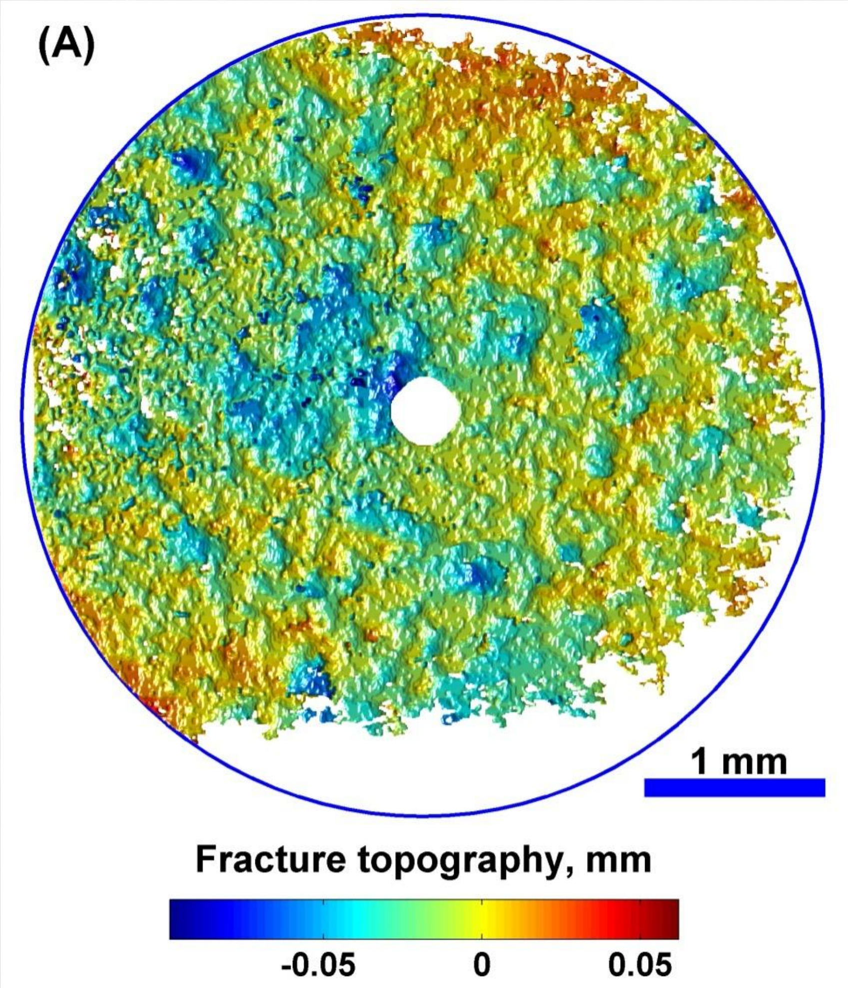


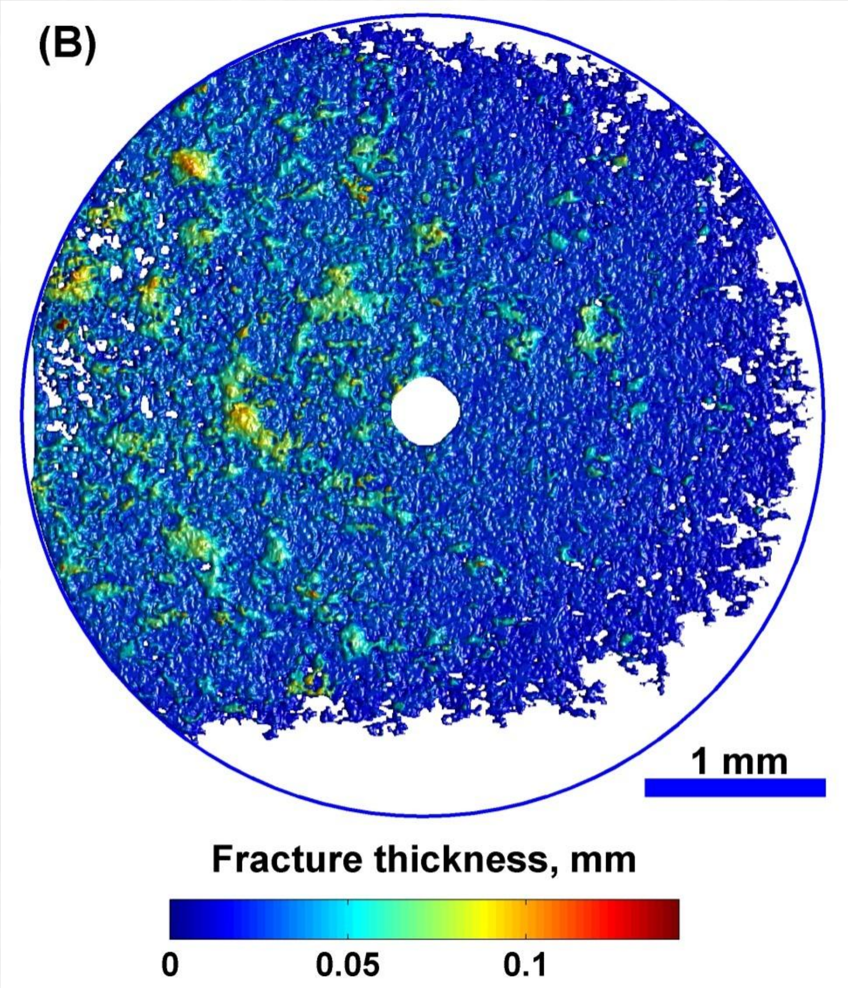
3D image analysis



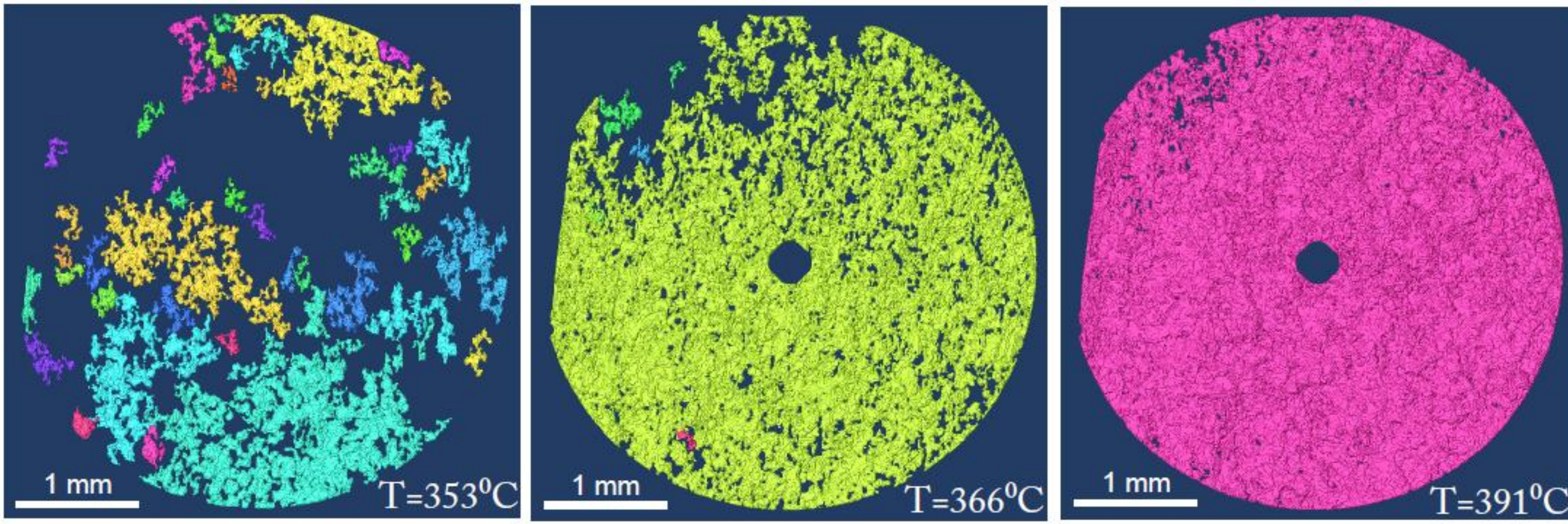
- Cracks are parallel to the lamination
- Rough surface
- Irregular outlines

Out of plane fluctuation

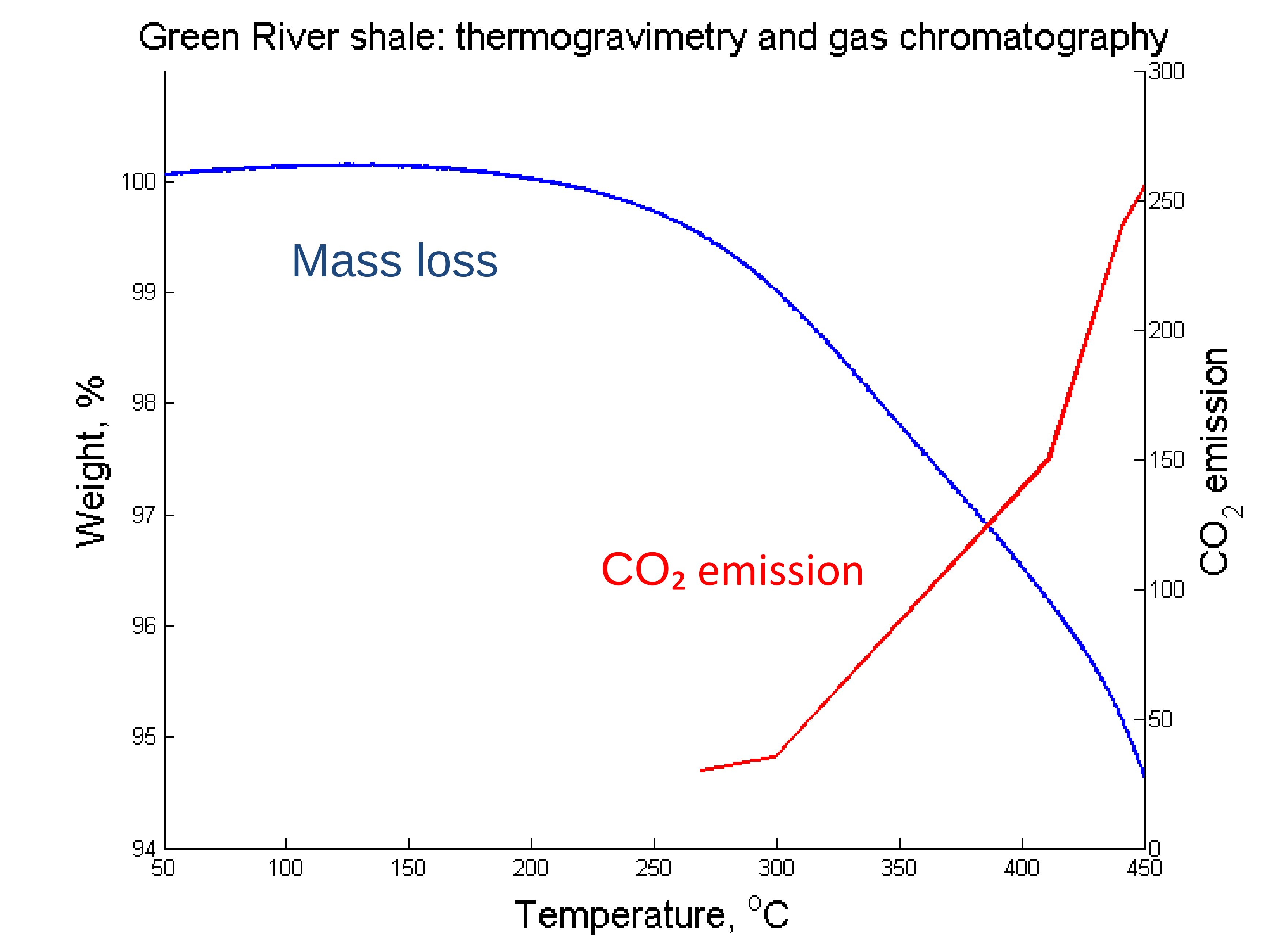




Fracture evolution in time -15 min/^{0}C resolution



- Nucleation of small cracks
- Growth of separate cracks
- Coalescence into one big crack



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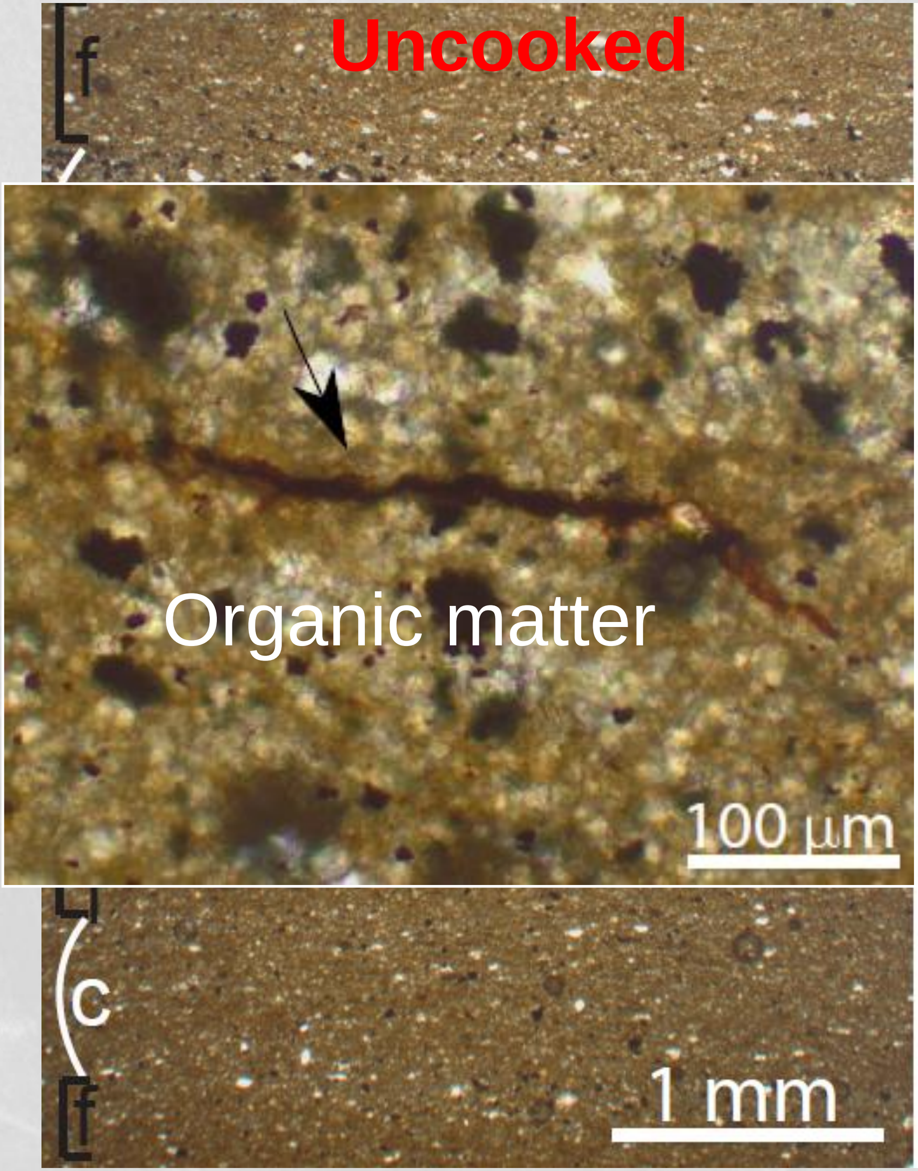
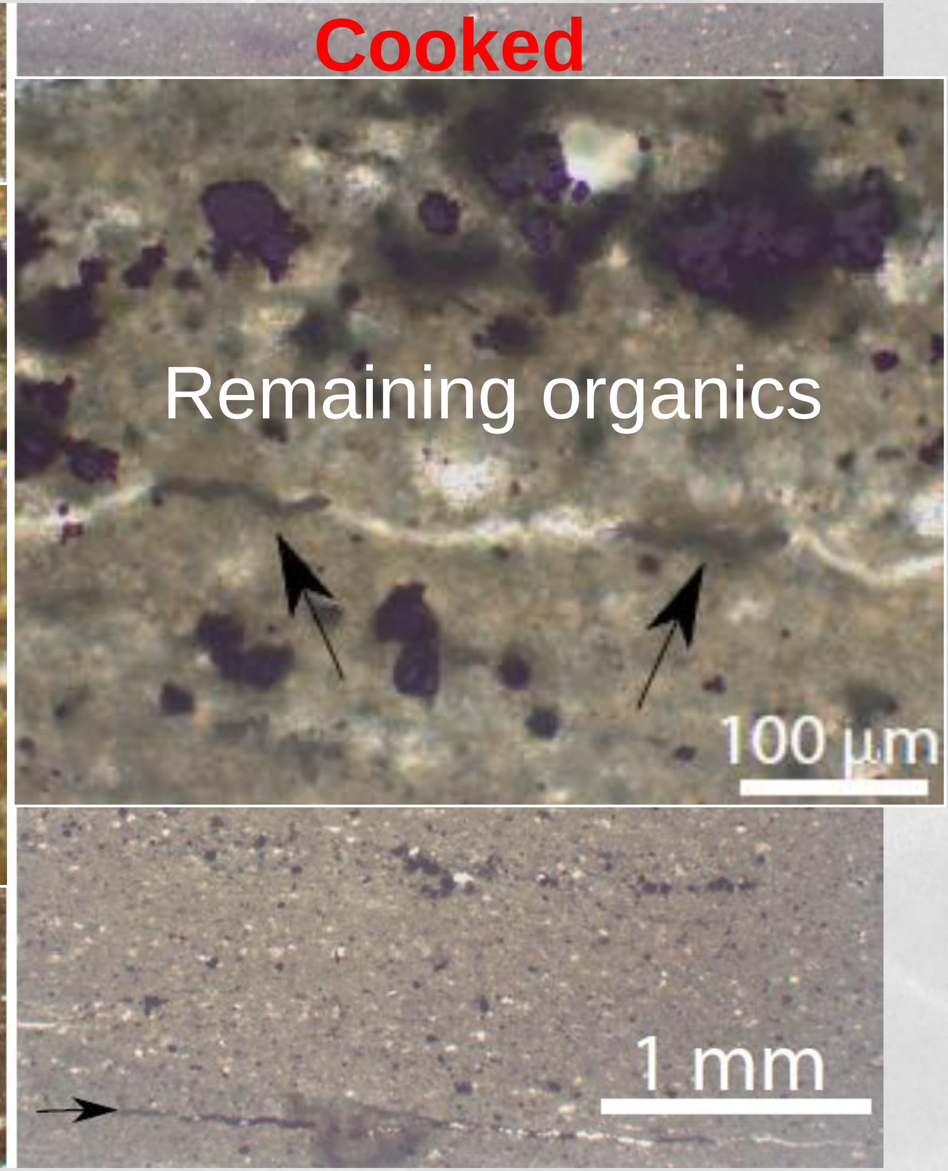
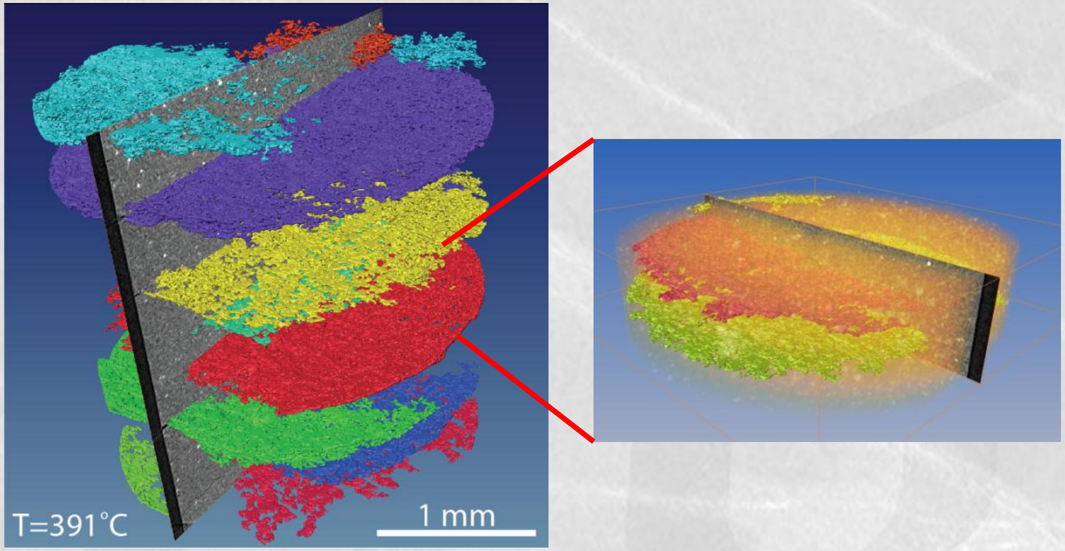
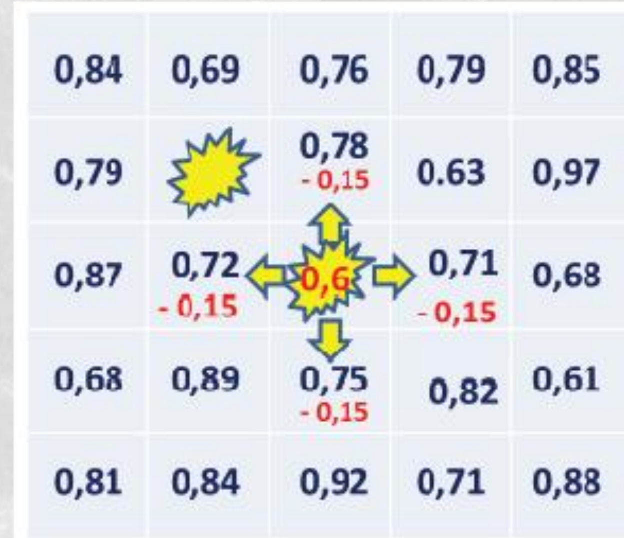
Thin sections – Optical imaging





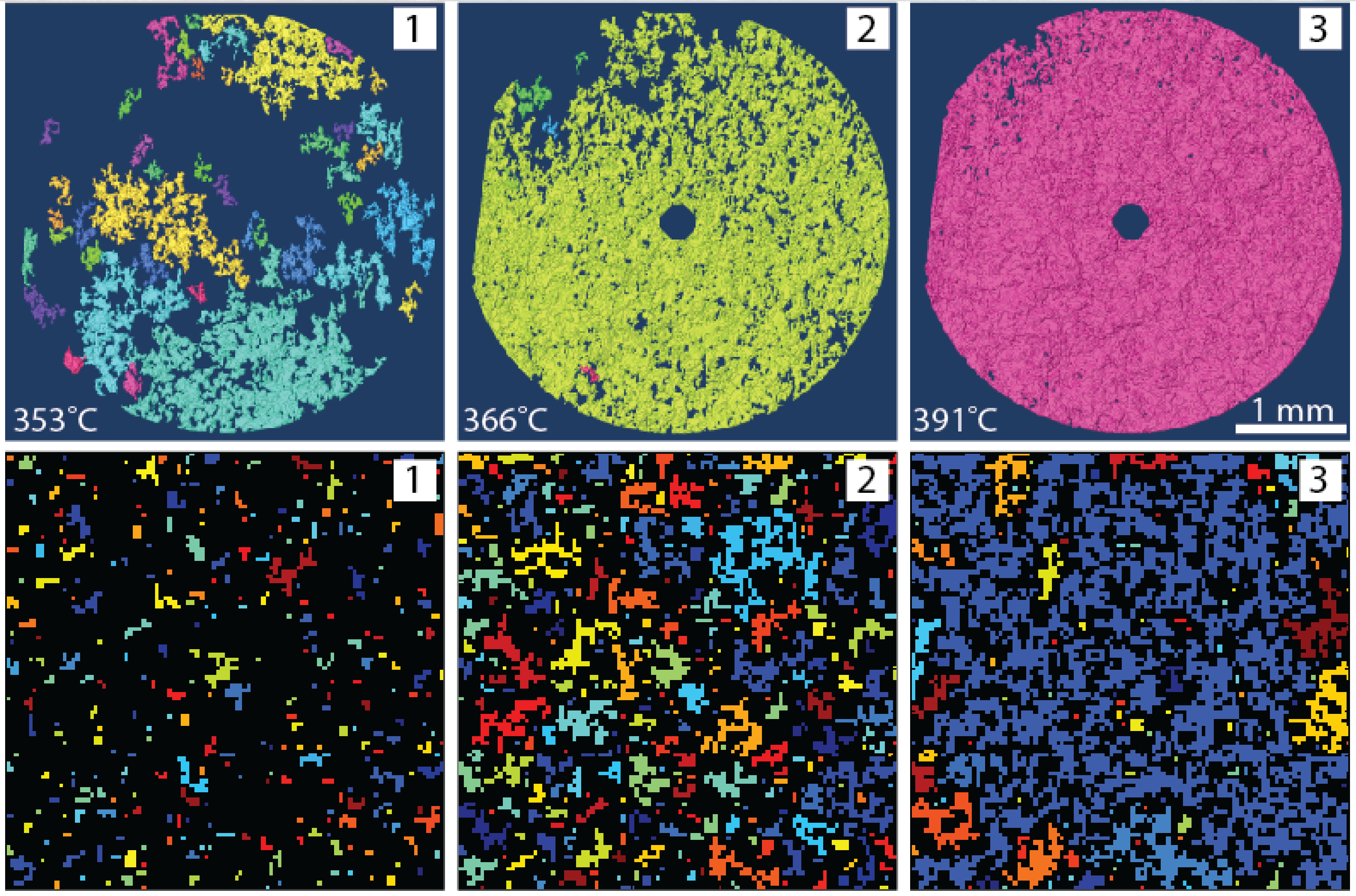
One fracturing shale layer is modelled by 2D lattice



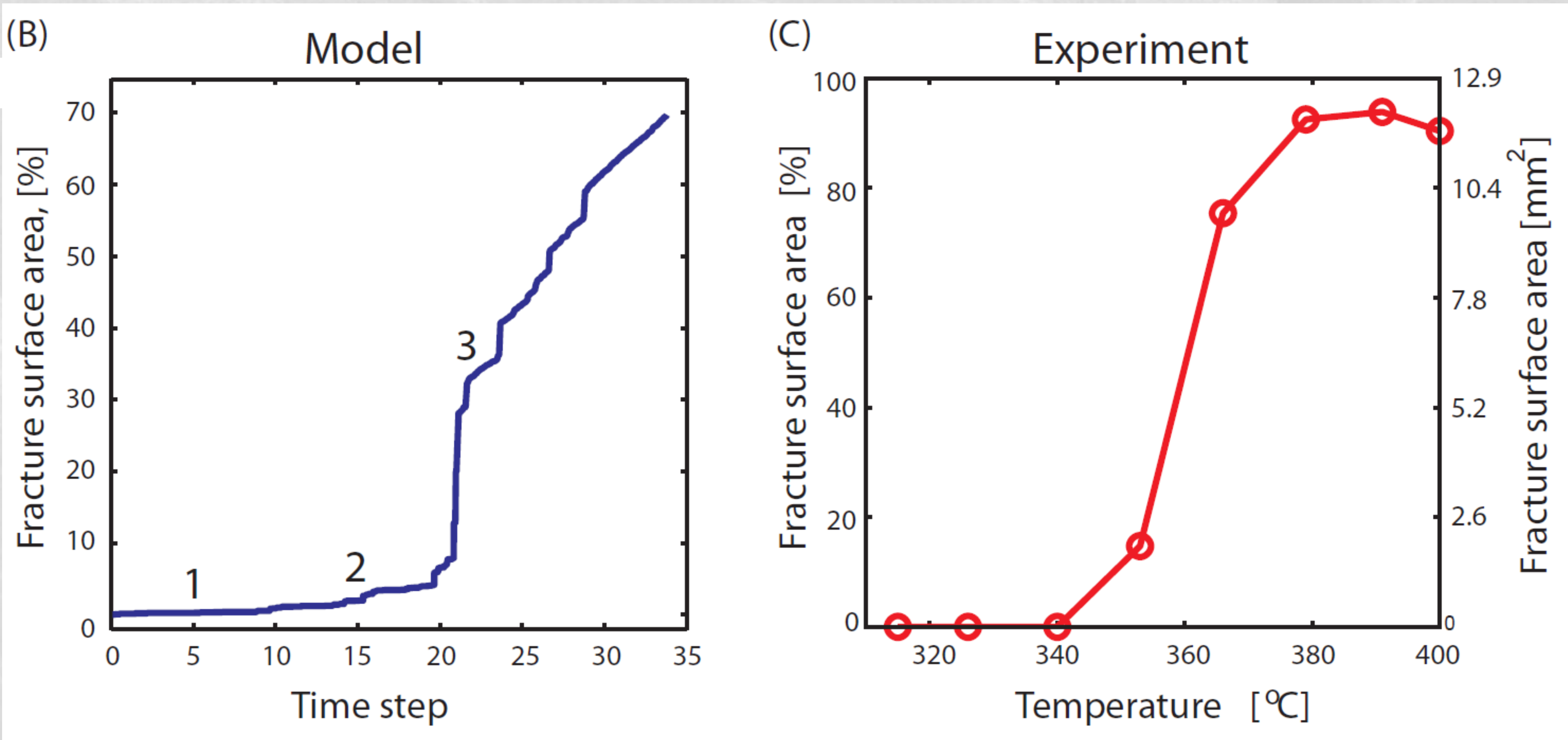


- Linear increase of pressure
- Random distribution of breaking thresholds
- Short range interactions – neighbor weakening

Nucleation, growth and coalescence of cracks



Fracture area vs time/temperature



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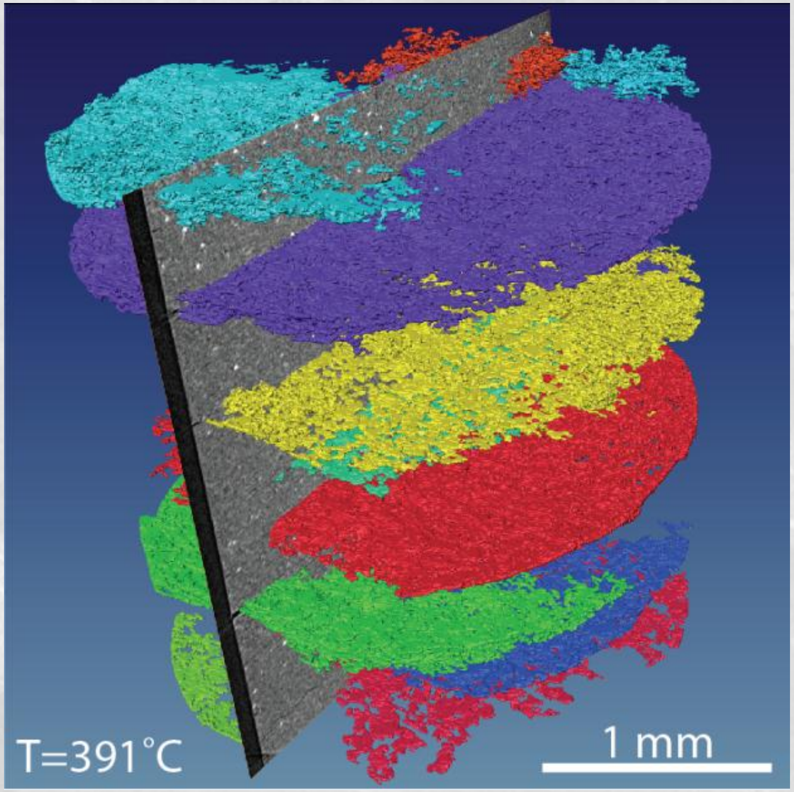
- Organics starts to decompose at ≈300ºC
- Gas production →pressure build
- Fracturing at ≈350⁰C
- Cracks nucleate, grow and coalesce
- Fracture network provide pathways for outcoming fluids



Kobchenko, M. et al,
4D imaging of fracturing in organic-rich shales during heating, *J. Geophys. Res.*, doi:10.1029/2011JB008565.

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