X-ray synchrotron imaging: a revolution for paleontology

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When looking at a fossil, paleontologists want to study both external morphology and internal anatomy

But studying the internal anatomy leads to a serious problem, how to have access to it ?

The simplest and fastest way consists in breaking the fossil with a hammer

Unfortunately, it generally leads to quite disappointing results

A better way consists in sawing the fossil in order to precisely control the sample preparation

This technique takes some more time, …

but the results are
generally better !

It is different with rare and important specimens.

In this case using a hammer is too hazardous

Then the paleontologist faces the previous problem : how to have access to the internal anatomy

Some fossils are extremely rare and precious, they represent the only trace of life history on our planet.

It is as important to study them as to preserve them, since they are an inestimable heritage that has to be respected.

Nowadays, paleotologists can be reassured.

It exists another way to look inside fossils without destroying them

This way constists to use a third generation synchrotron like the ESRF in order to look inside the fossils without destroying them.

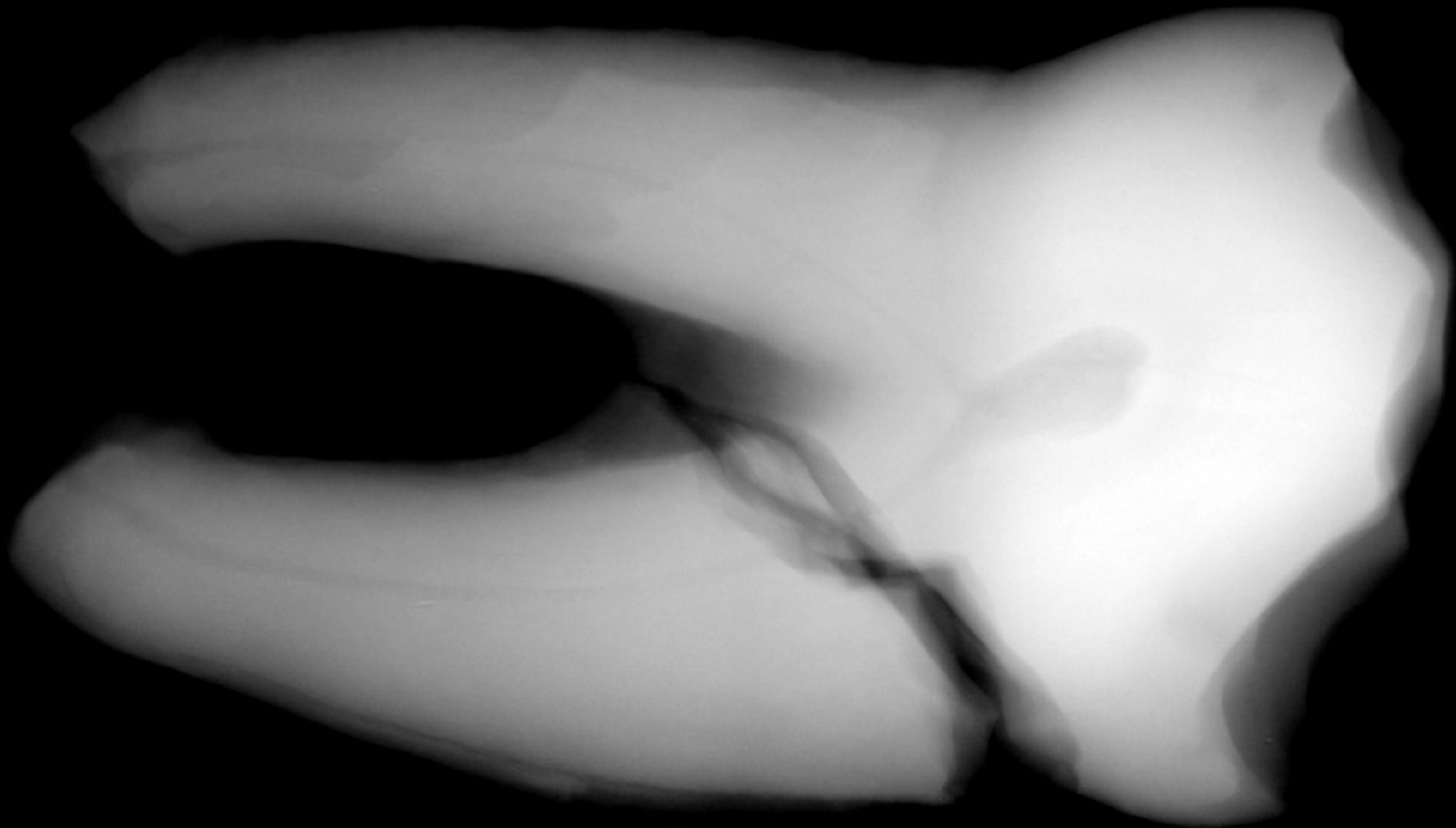
Some basics about synchrotron imaging techniques used for paleontology

X-ray tomography is based on radiographies: the imaged if directly obtained through the recording of the direct beam going through a sample.

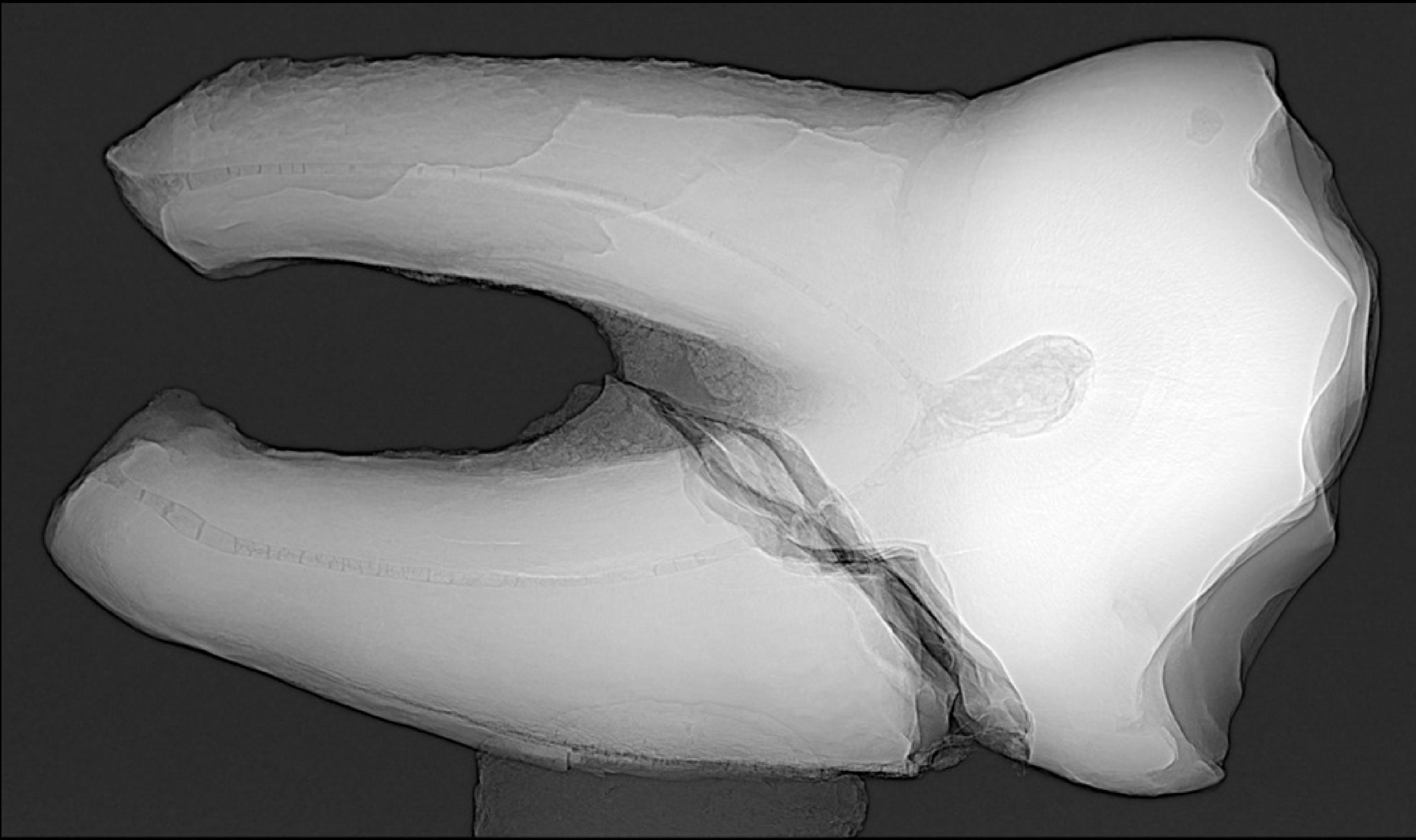
With a synchrotron, thanks to tunable spectrum, high flux, parallel geometry and spatial coherence, several radiographic techniques are available, some of them being used to image fossils :

- Absorption (classical radiography)
- Propagation phase contrast (edge detection)
- Phase retrieval (quantitative phase imaging)

Absorption mode (classical radiograph)



Propagation phase contrast mode

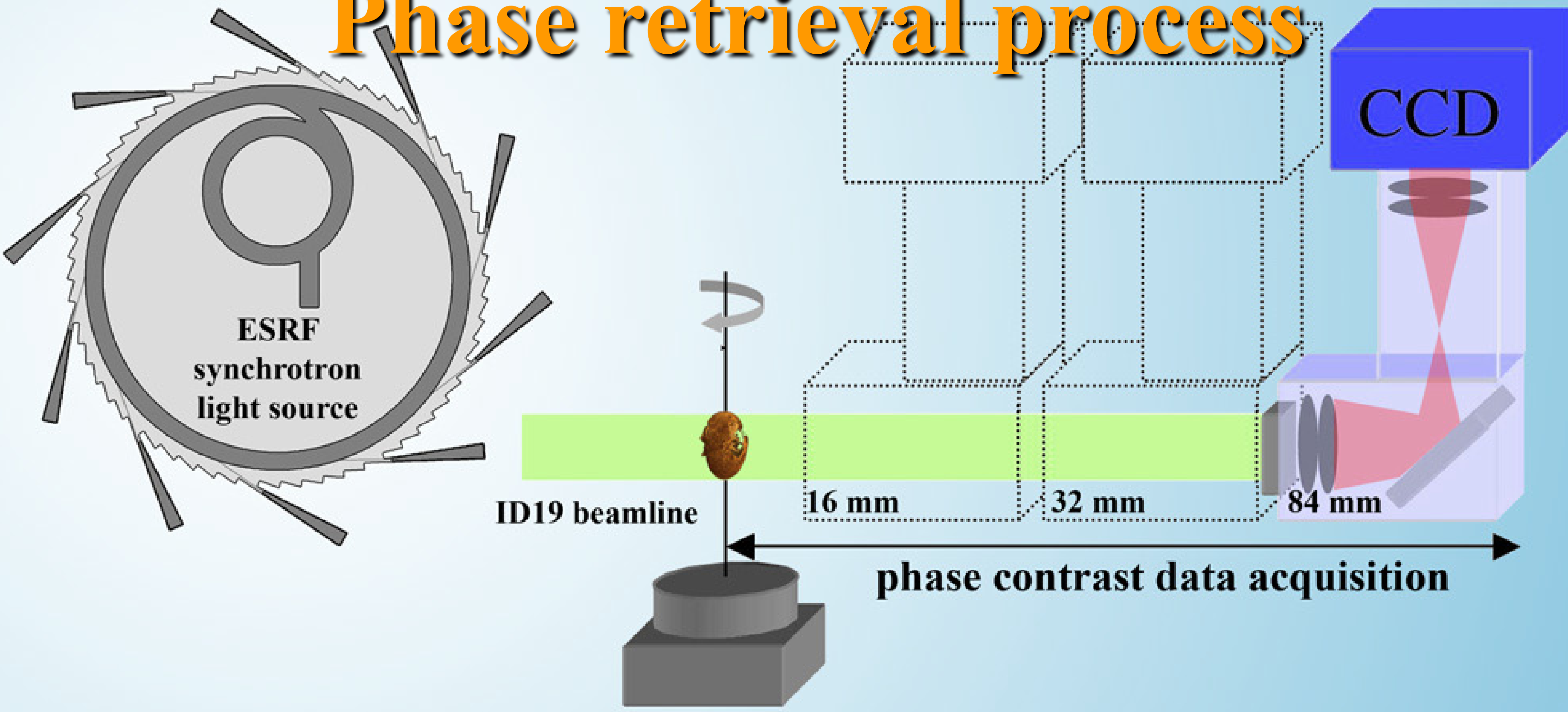


Enhanced edges visibility

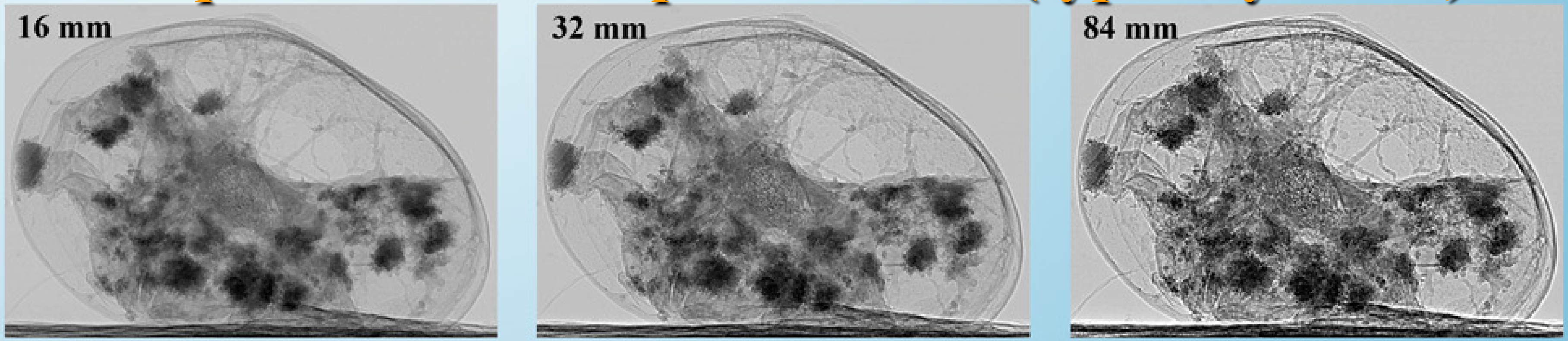
Absorption on opaque amber

Propagation phase contrast

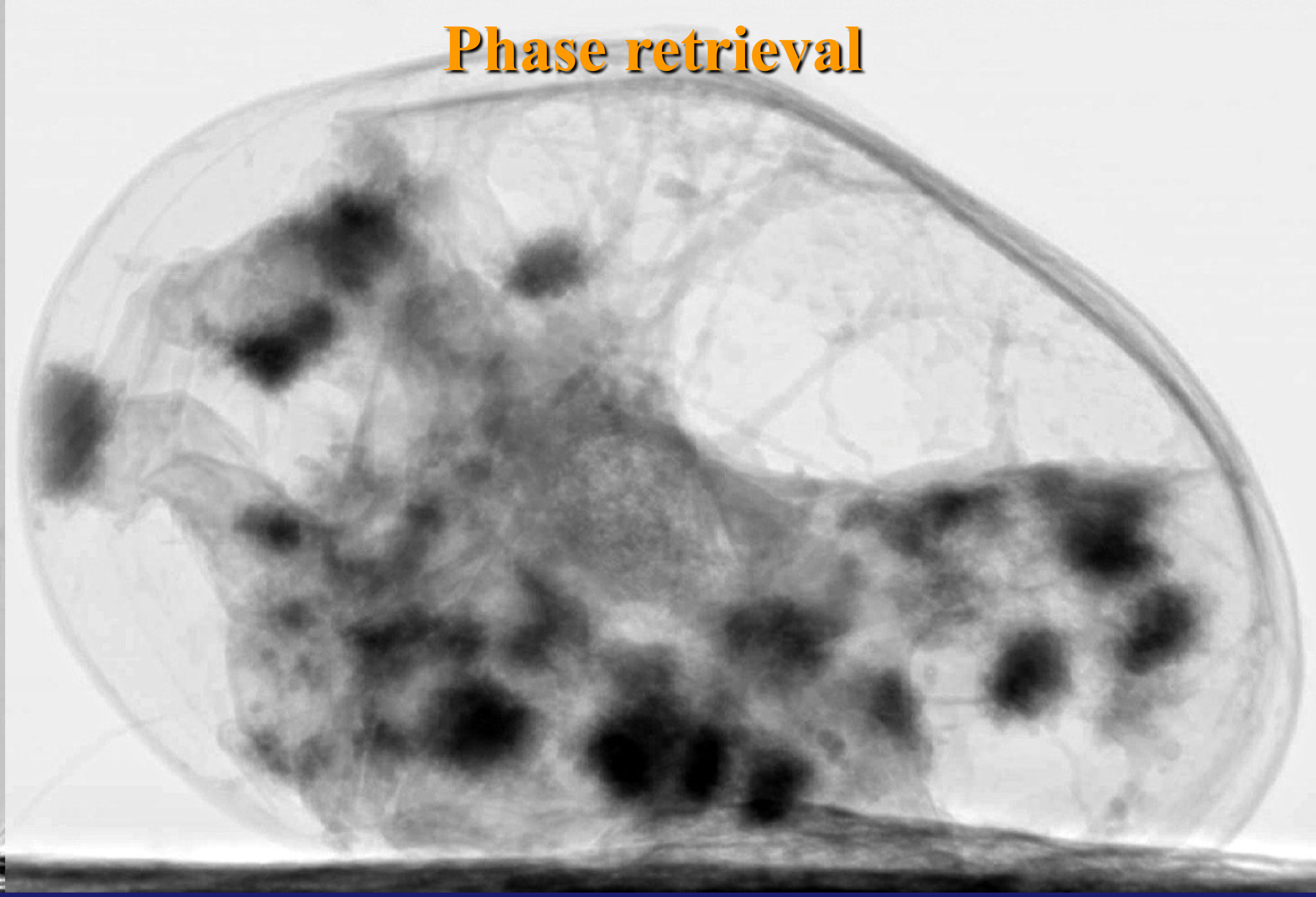
Phase retrieval process



Acquisition of multiple distances (typically 3 or 4)



Phase retrieval



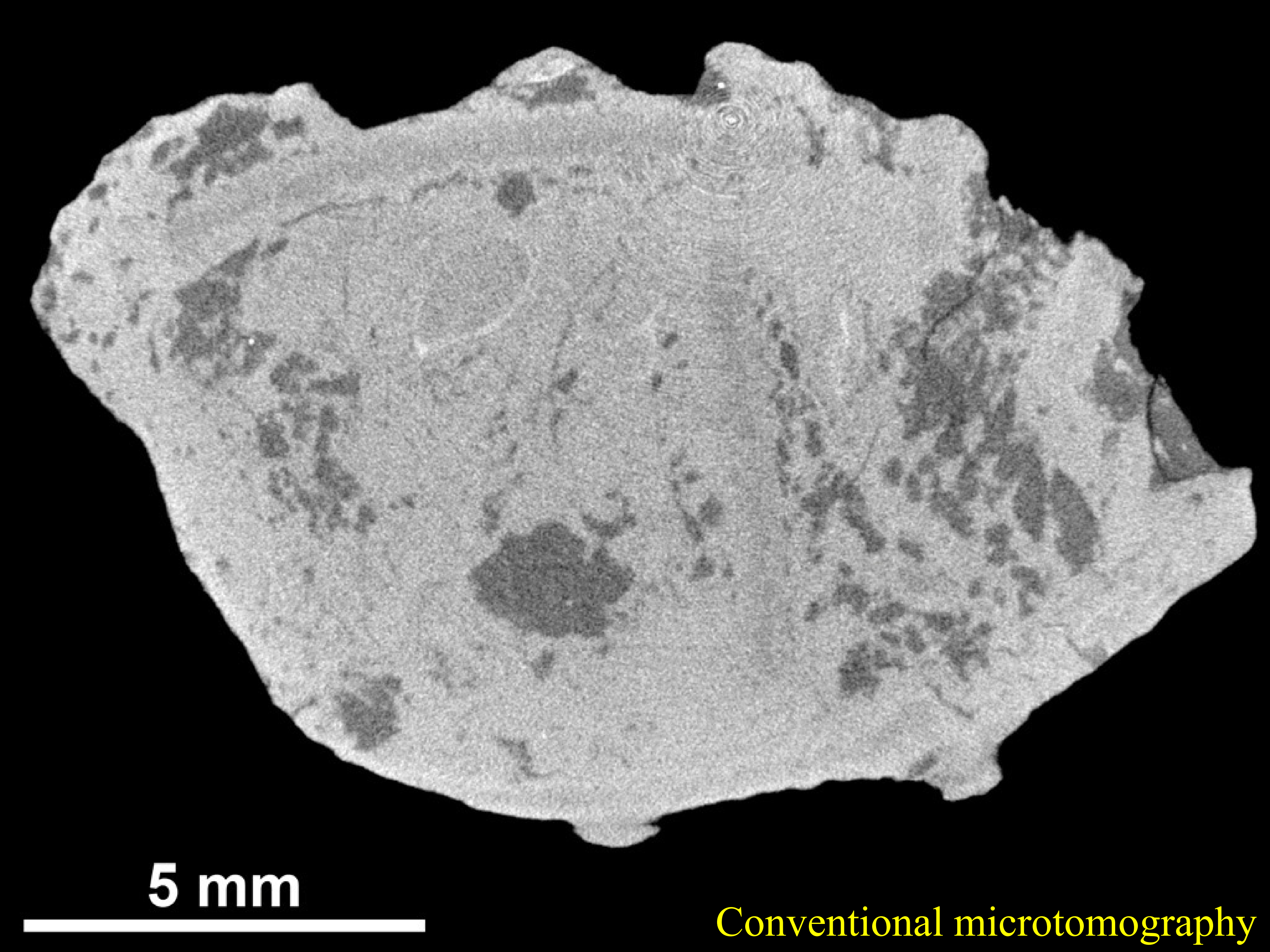
it looks like absorption but is far more sensitive

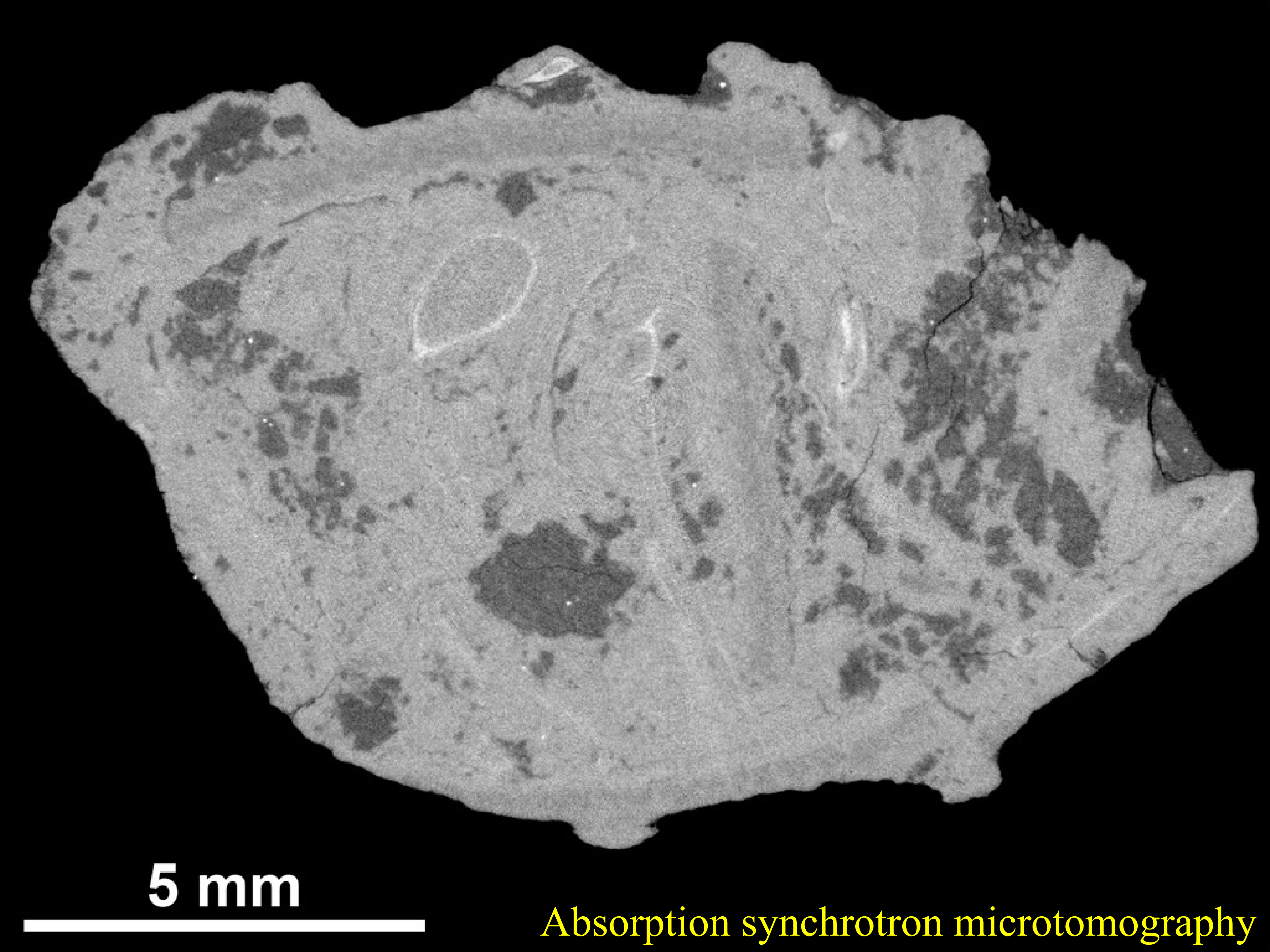
Some applications of Synchrotron imaging in paleontology

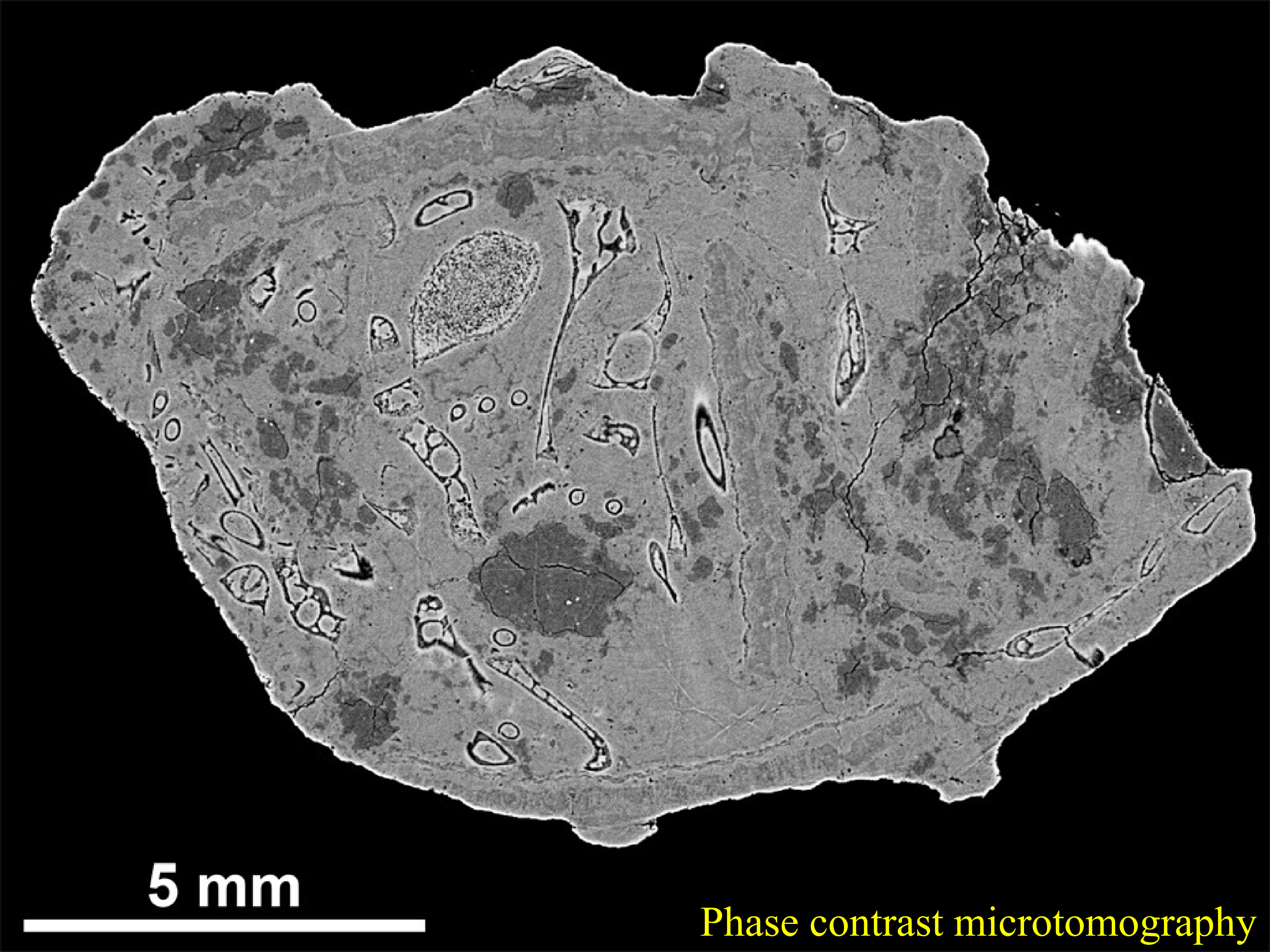
Imaging of fossil embryos in ovo
Small eggs from Cretaceous of Thailand thought, based on the shell structure, to belong either to a small theropod dinosaur or to a bird

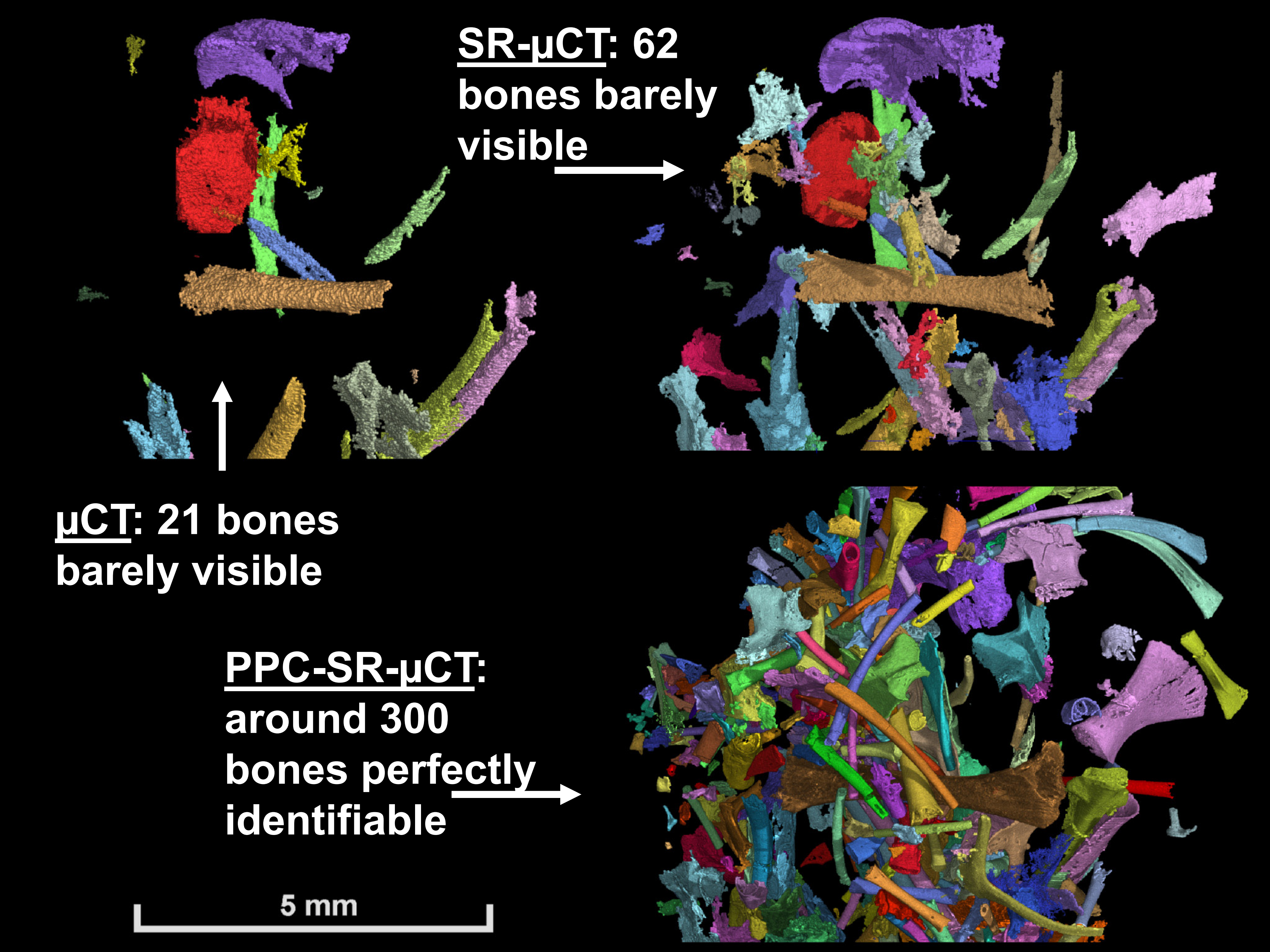
PhD thesis of Vincent Fernandez,

with E. Buffetaut, V. Suteethorn, M. Kundrat, E. Maire, J. Adrien and P. Tafforeau


5 mm
Conventional microtomography


5 mm
Absorption synchrotron microtomography

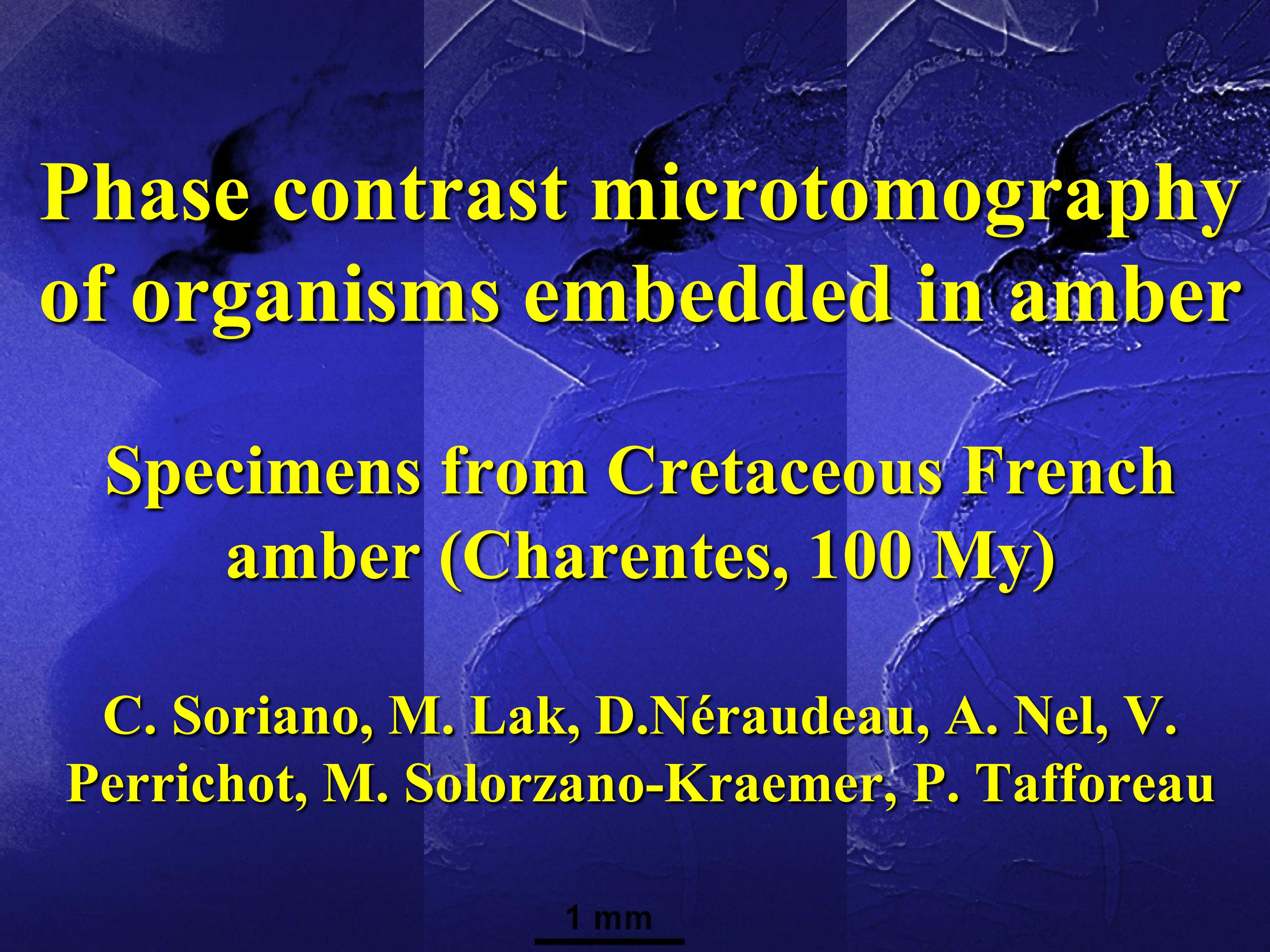

5 mm
Phase contrast microtomography

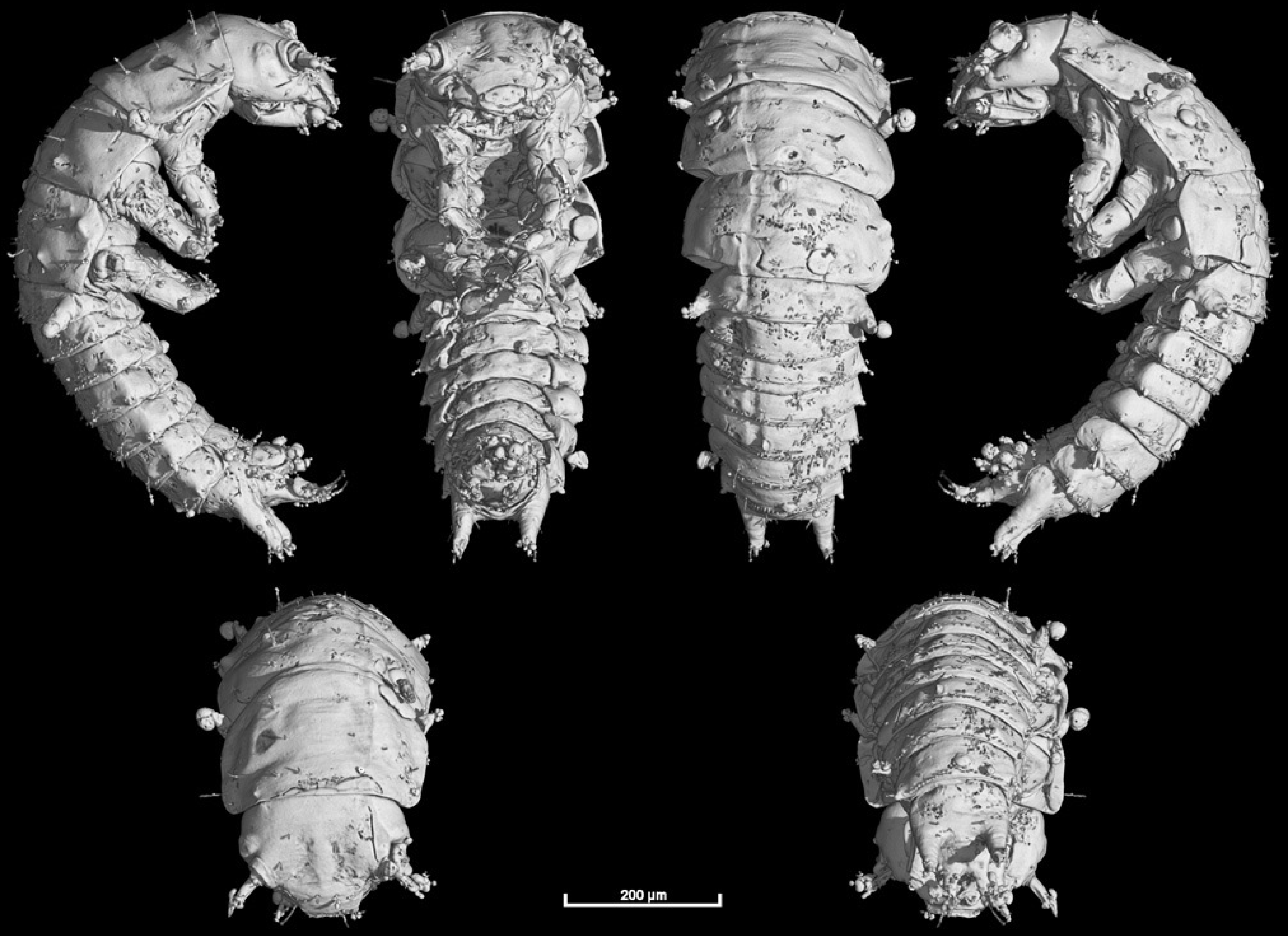

SR-µCT: 62 bones barely visible
µCT: 21 bones barely visible
PPC-SR-µCT: around 300 bones perfectly identifiable
5 mm

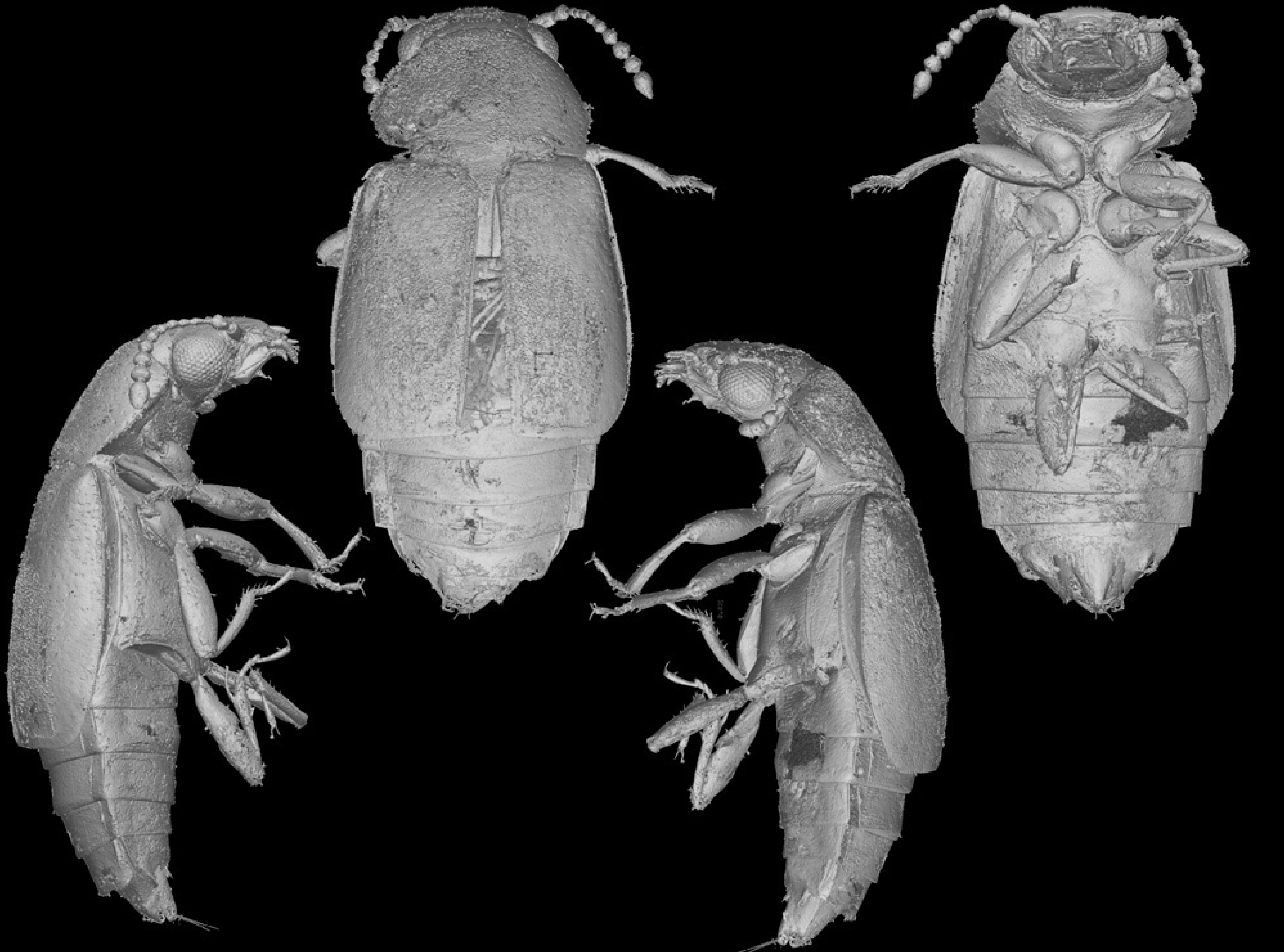
Phase contrast microtomography of organisms embedded in amber

Specimens from Cretaceous French amber (Charentes, 100 My)

C. Soriano, M. Lak, D.Néraudeau, A. Nel, V. Perrichot, M. Solorzano-Kraemer, P. Tafforeau

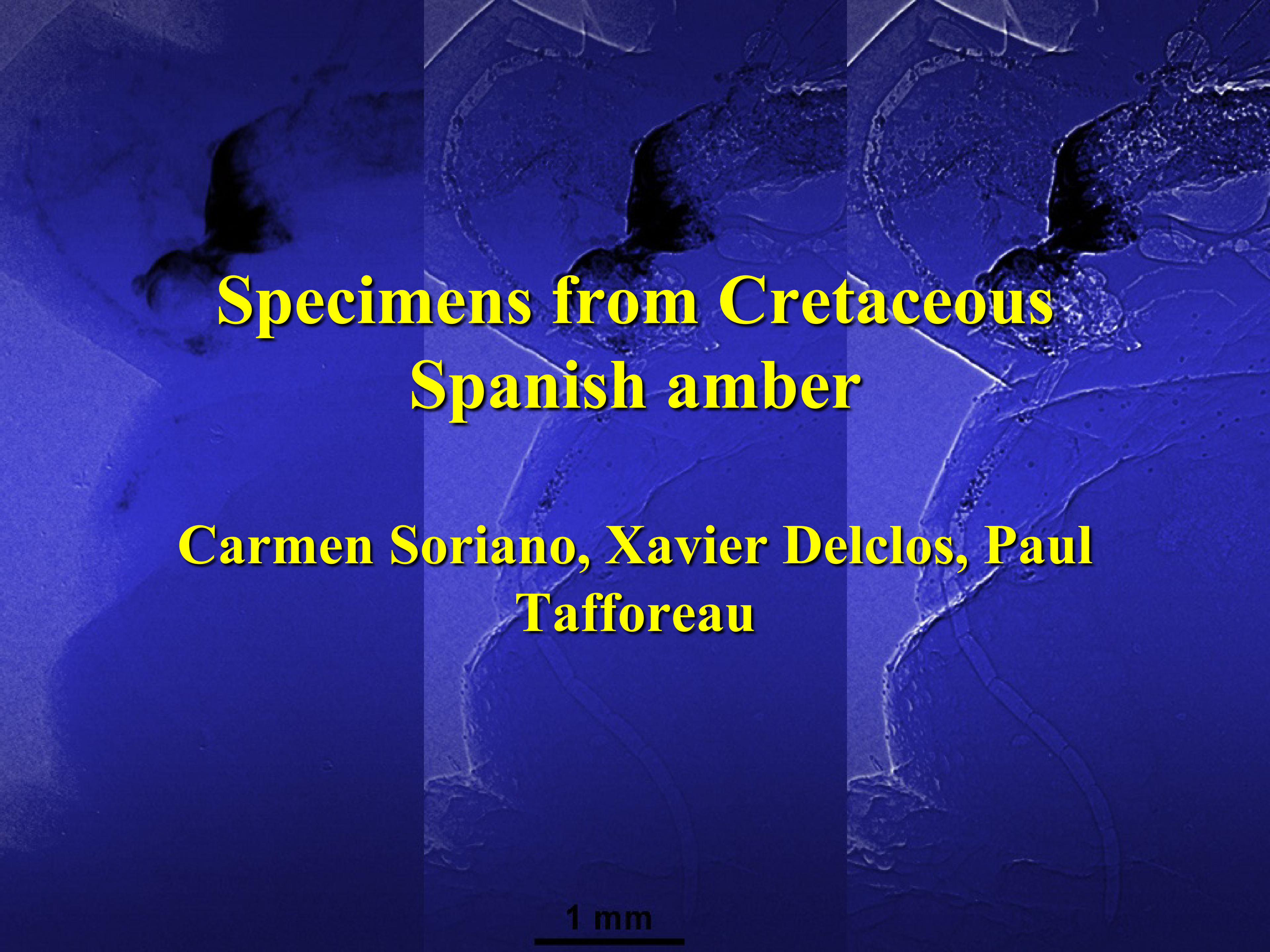


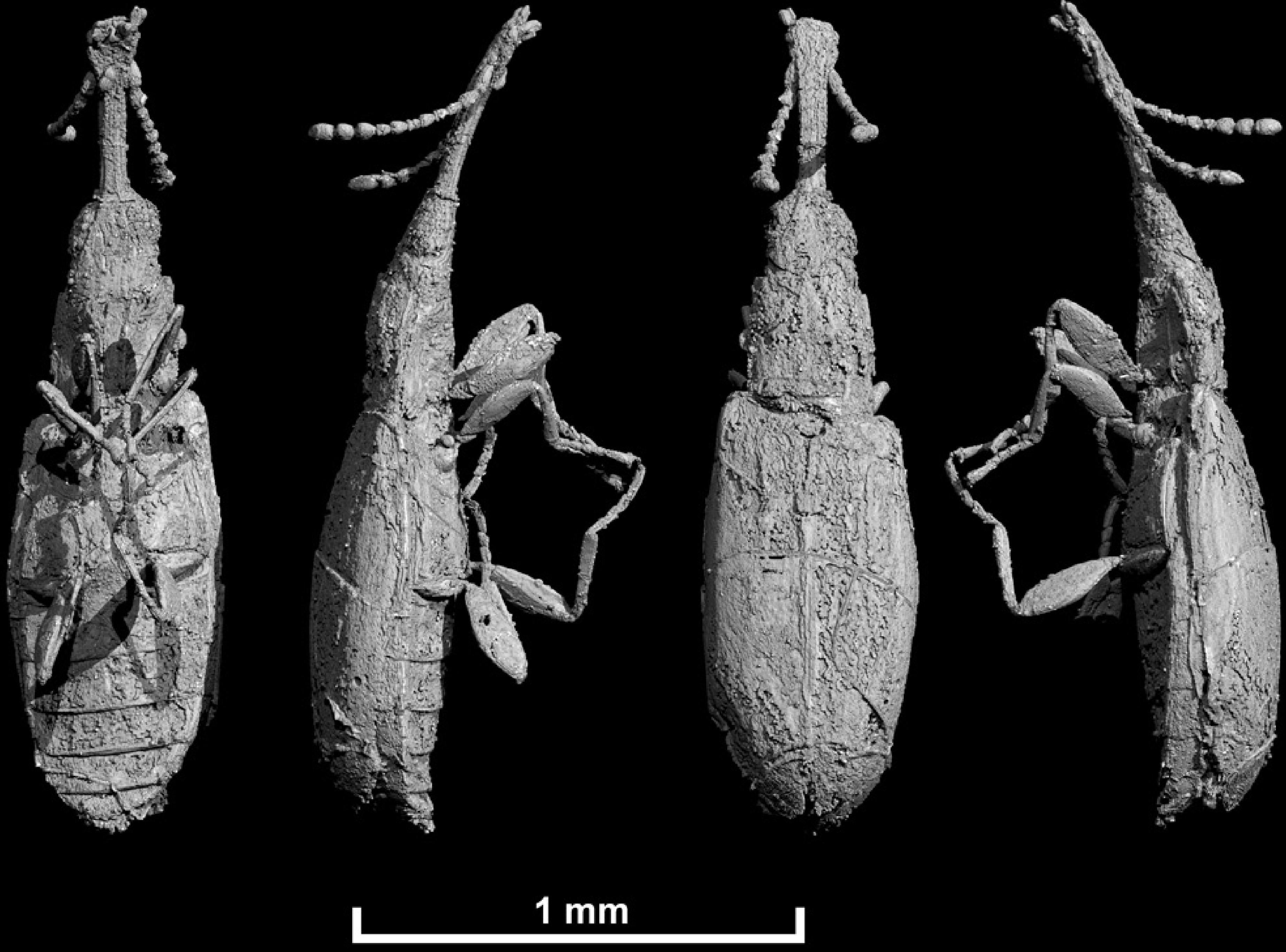

200 µm

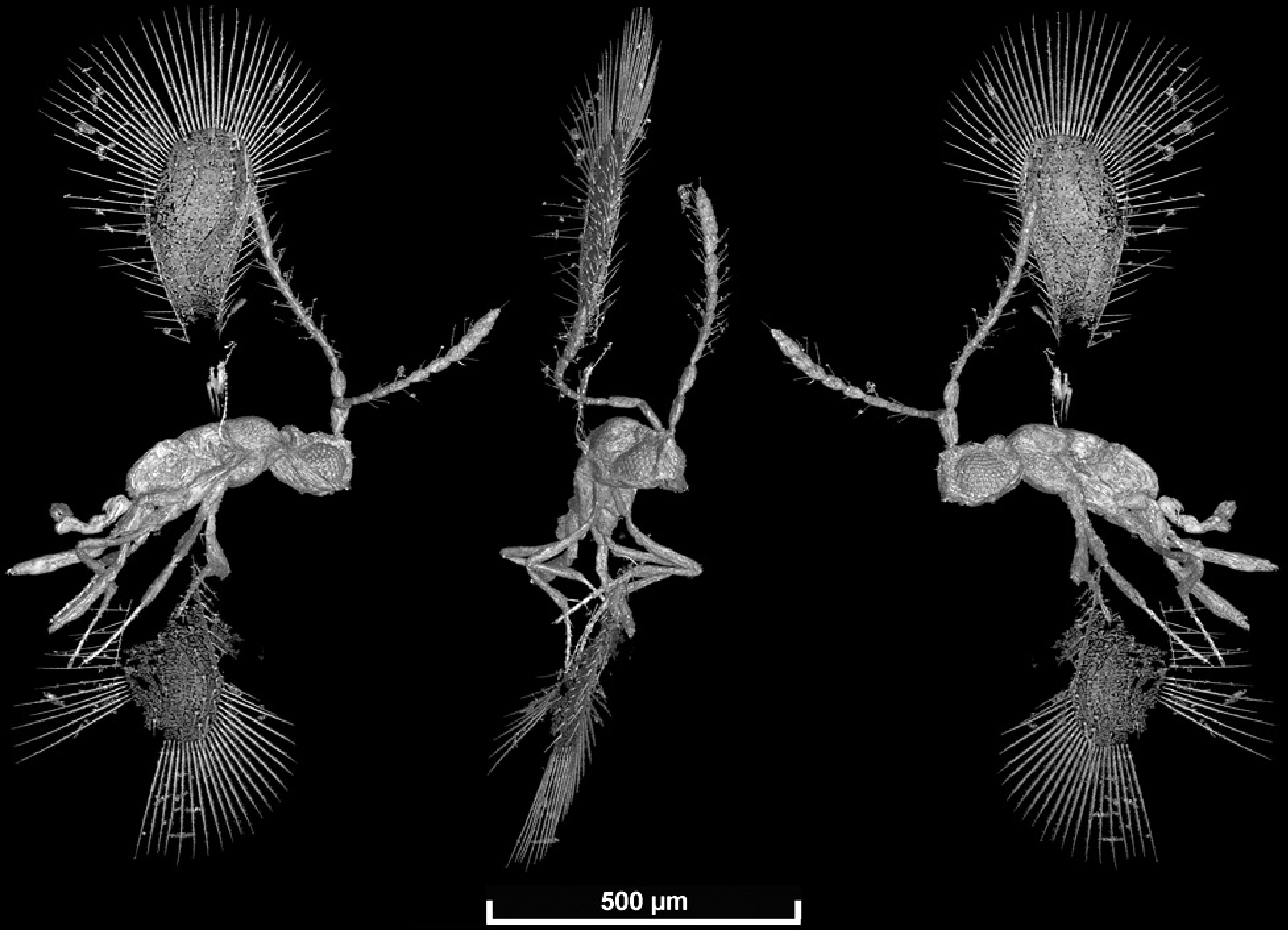


Specimens from Cretaceous Spanish amber

Carmen Soriano, Xavier Delclos, Paul Tafforeau

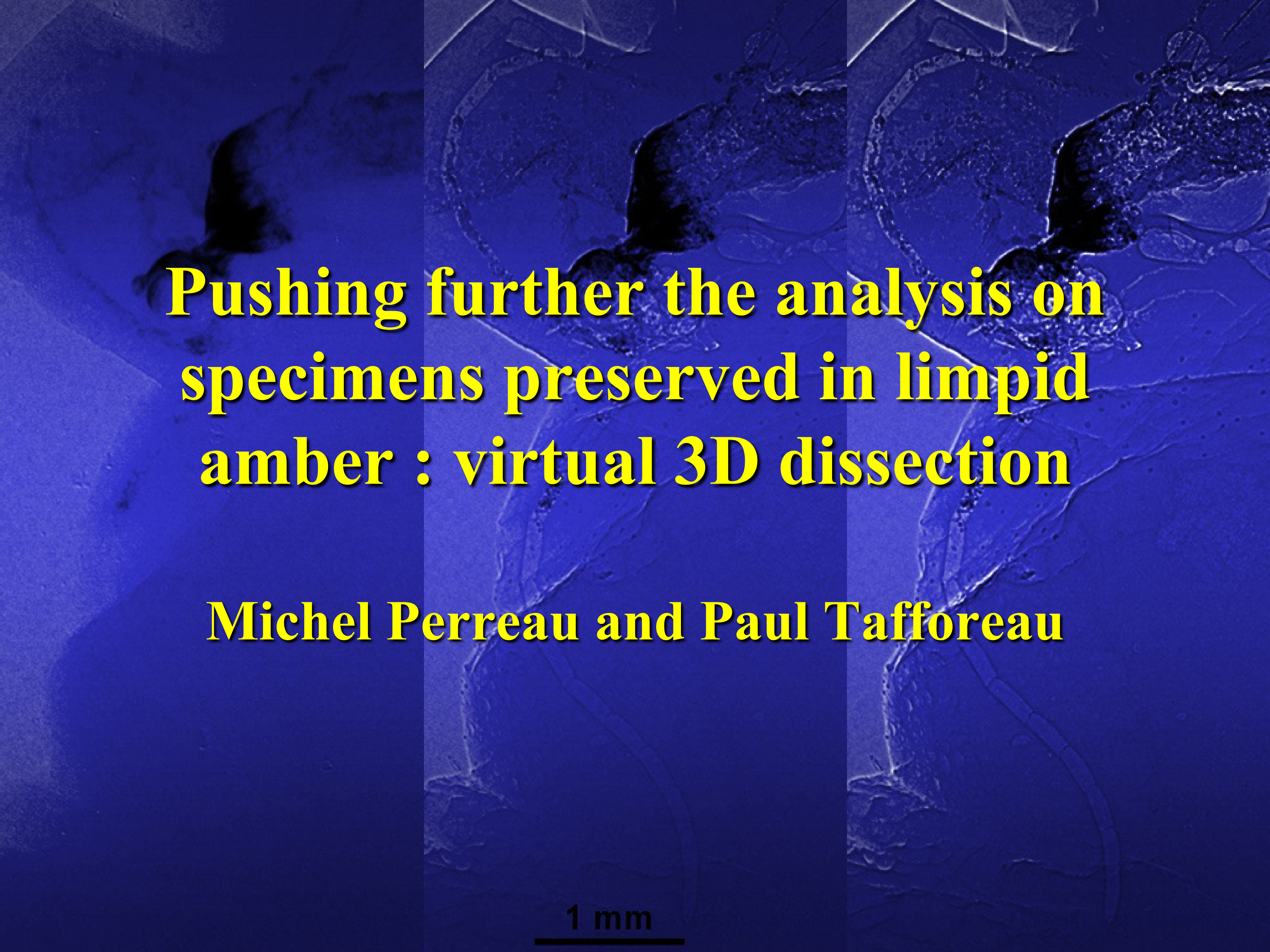



1 mm


500 µm

Pushing further the analysis on specimens preserved in limpid amber : virtual 3D dissection

Michel Perreau and Paul Tafforeau



Nemadus beetle from Baltic amber

Perreau Michel and Tafforeau Paul

Nemadus beetle from Baltic amber

Perreau Michel and Tafforeau Paul

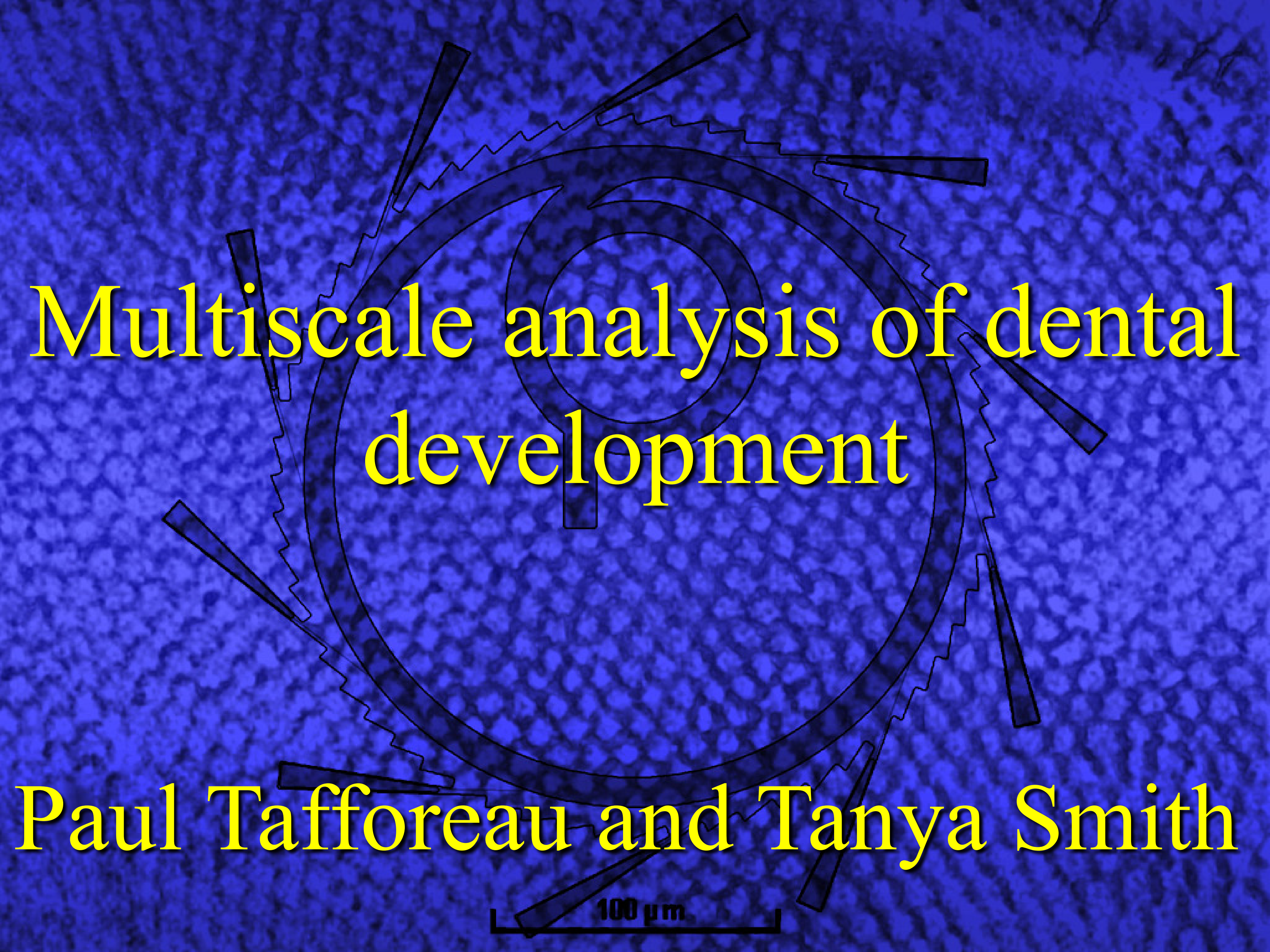
Click on image to see video

Palaeoanthropological applications

- One of the major research topic in palaeontology at the ESRF
- Based on multiscale phase-contrast based analysis
- Two main aspects: teeth studies for developmental approach and very high quality scans of large specimens

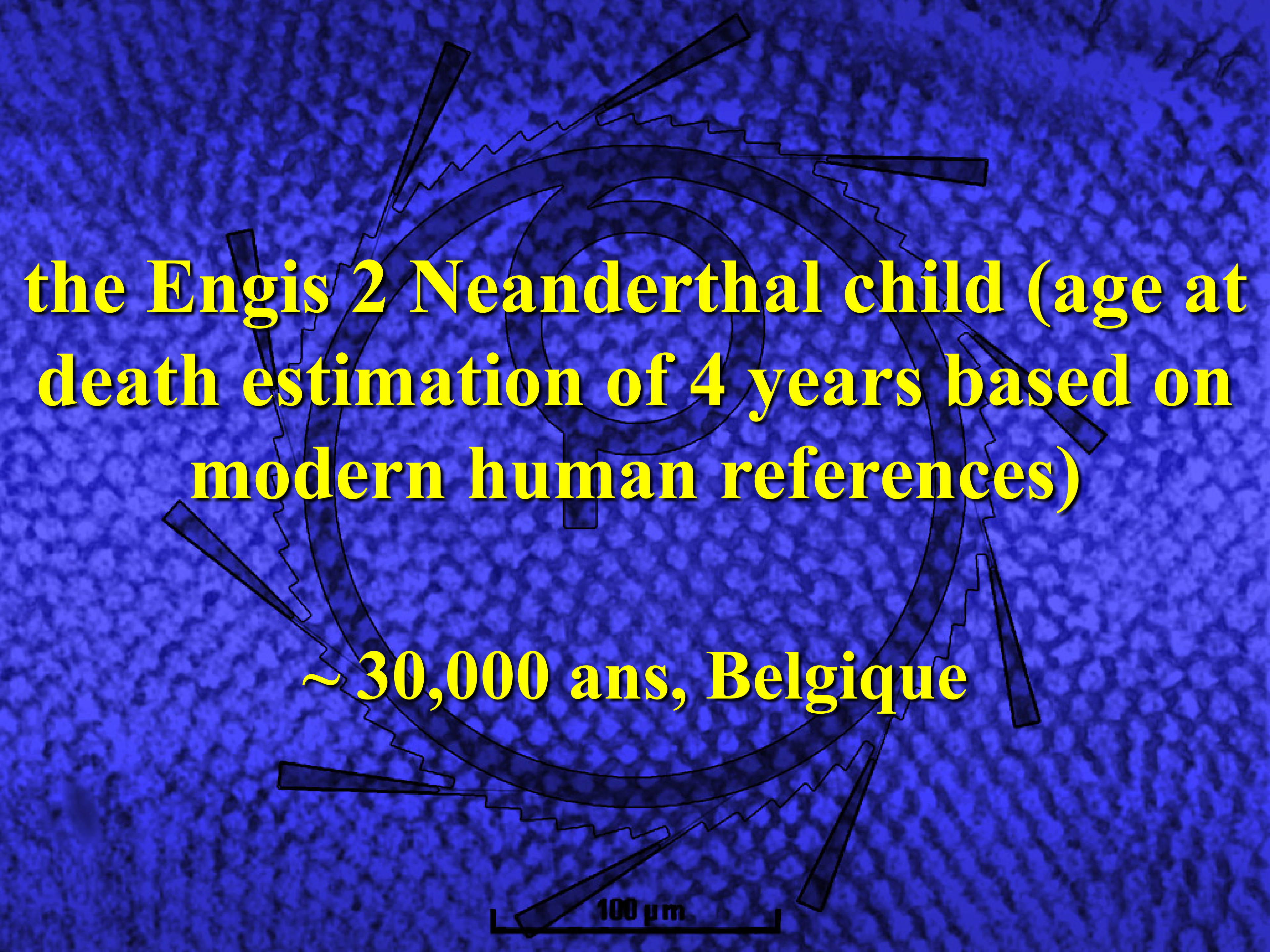
Multiscale analysis of dental development

Paul Tafforeau and Tanya Smith

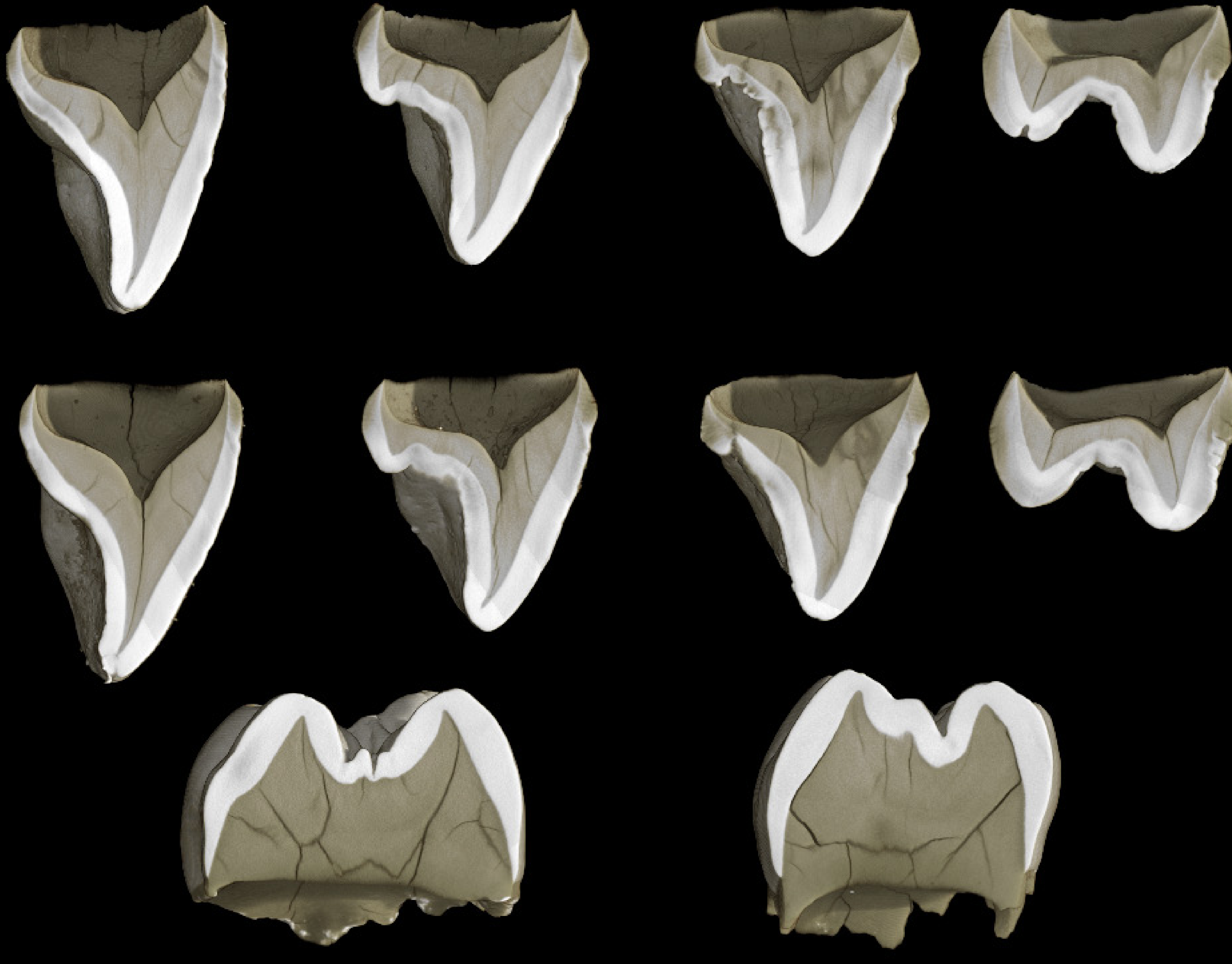


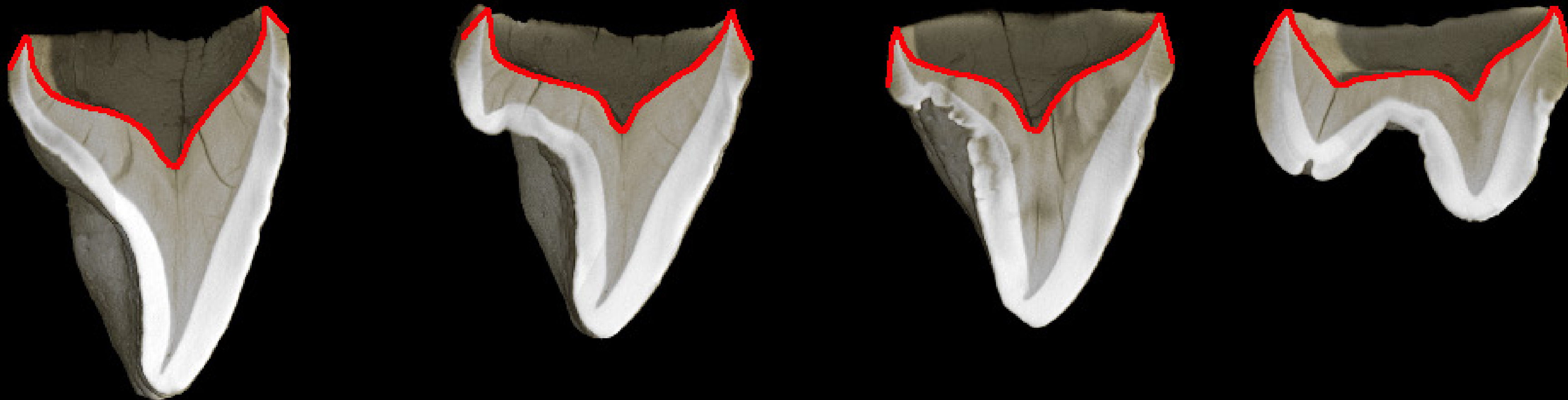
the Engis 2 Neanderthal child (age at death estimation of 4 years based on modern human references)

~ 30,000 ans, Belgique

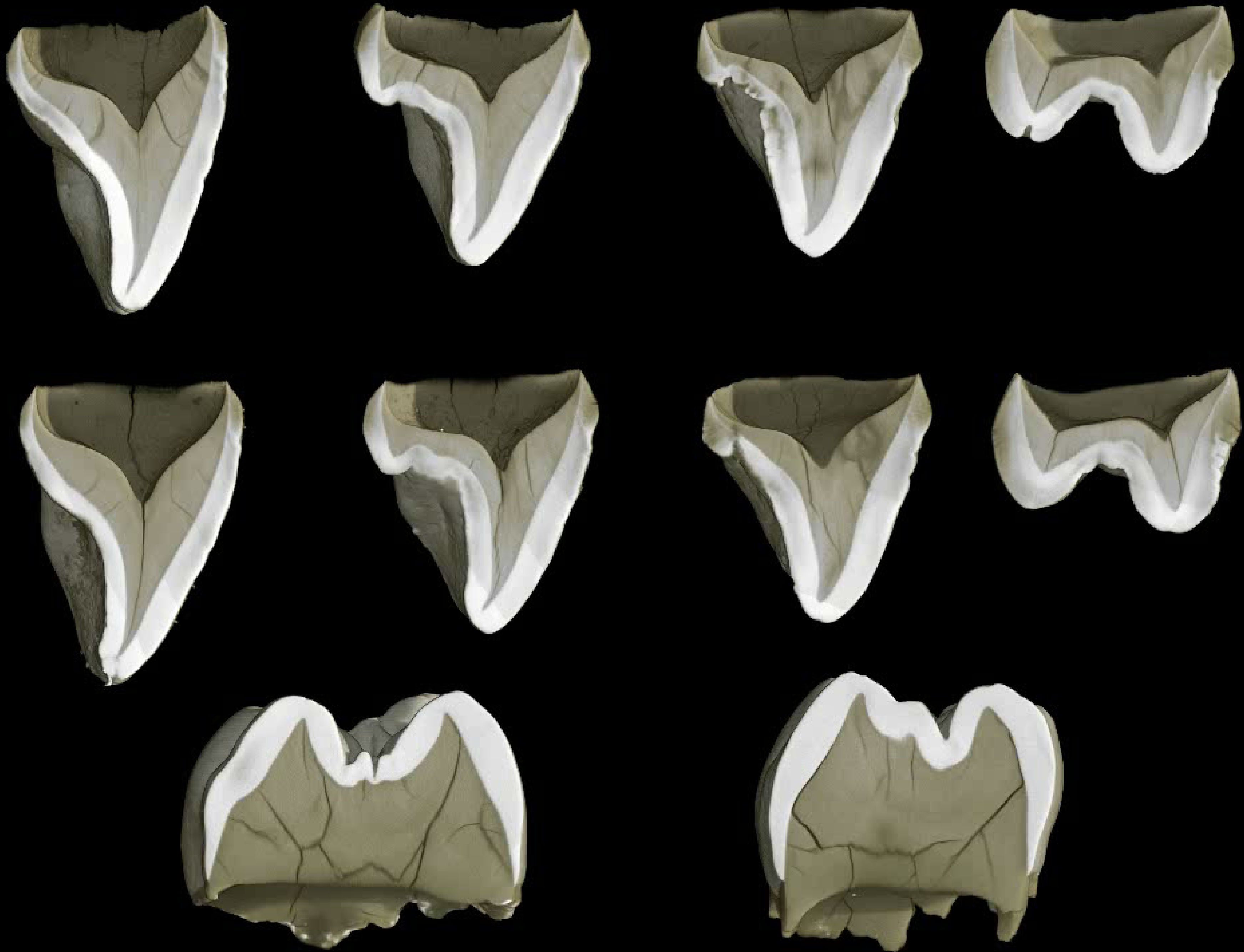


Click on image to see video

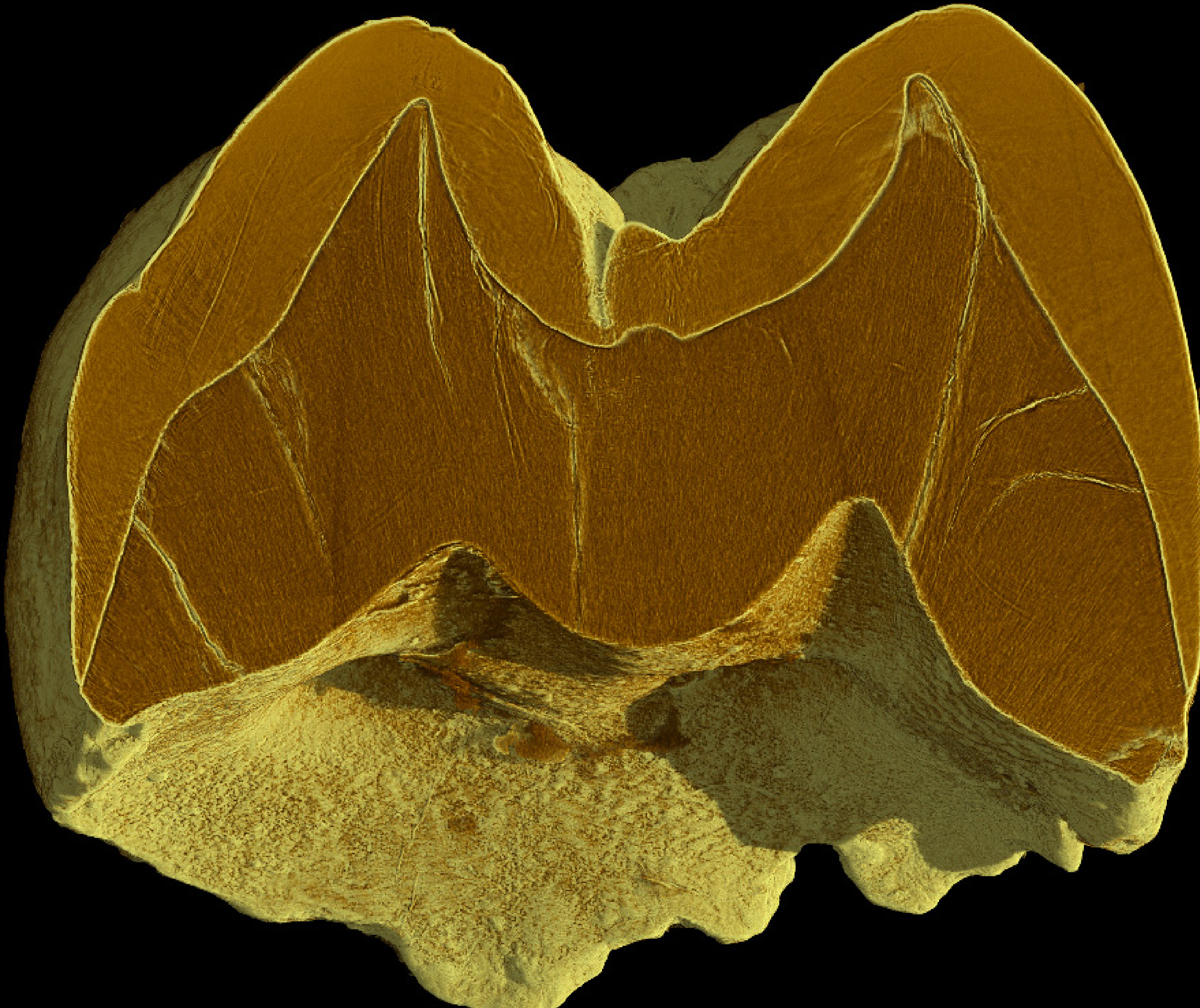


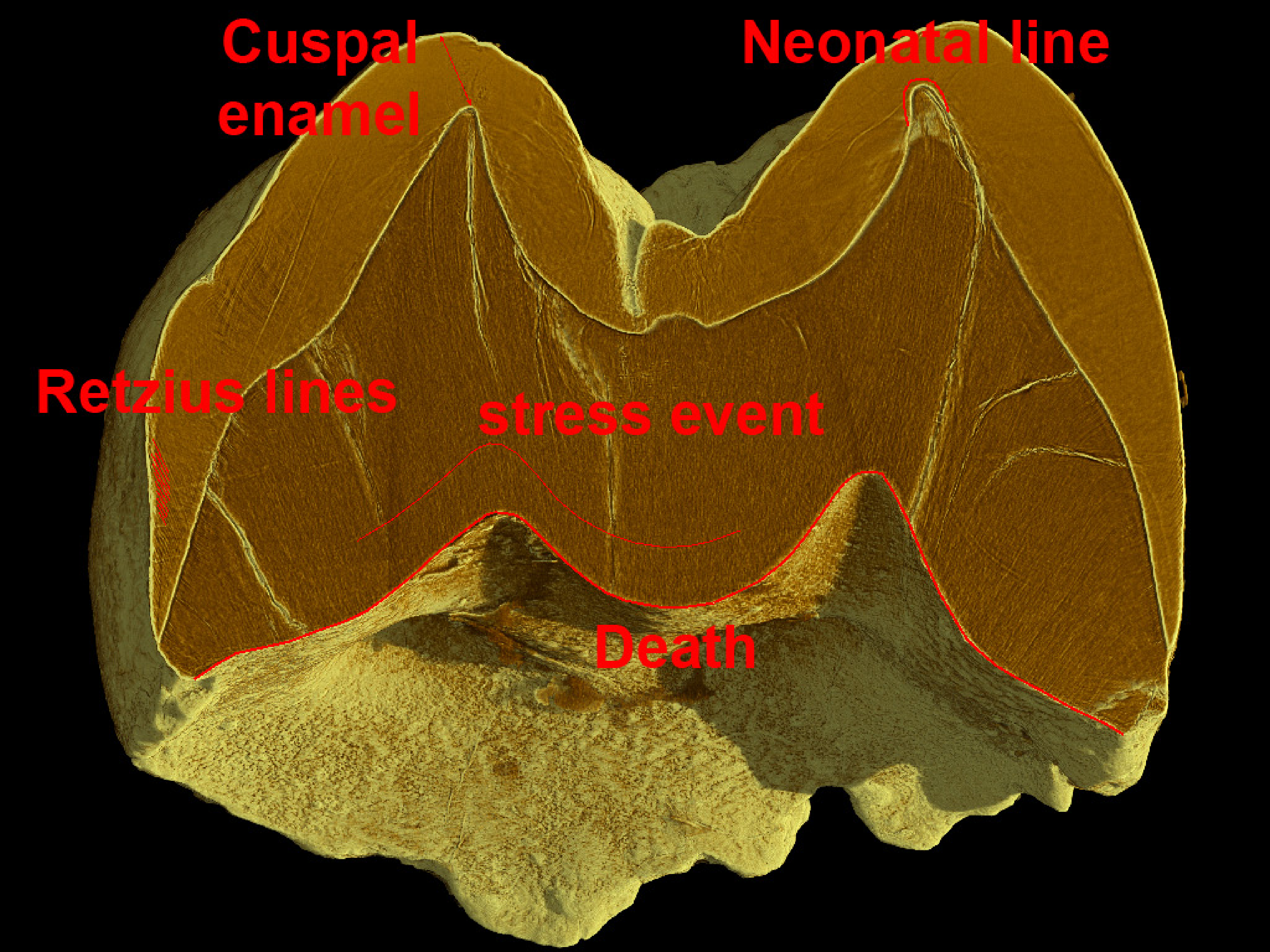


Death is recorded in all the permanent teeth

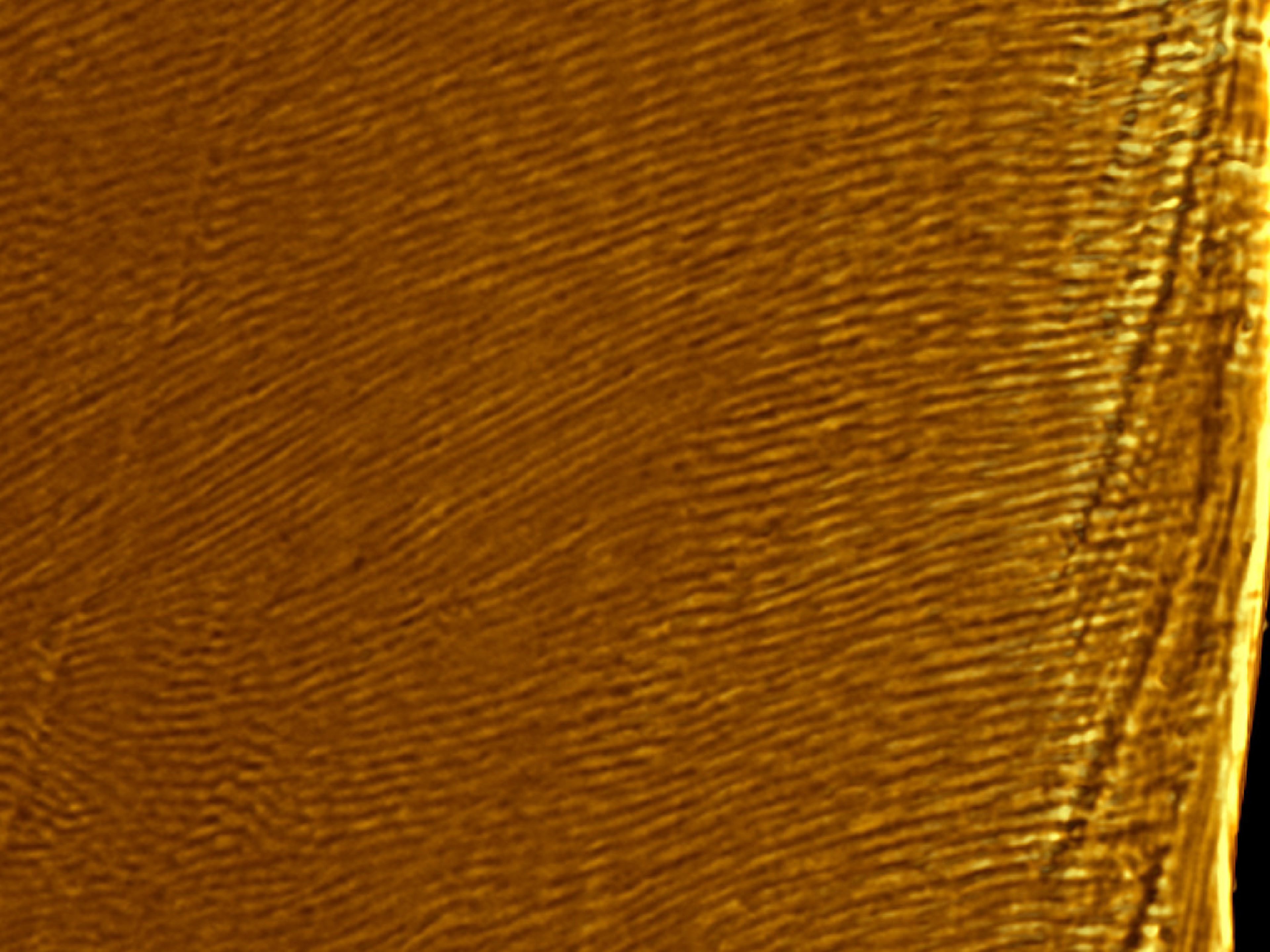


Click on image to see video




Cuspal enamel
Neonatal line
Retzius lines
stress event
Death

Click on image to see video




8 days periodicity between two
consecutive Retzius lines

Age at death calculation

Measured age at death

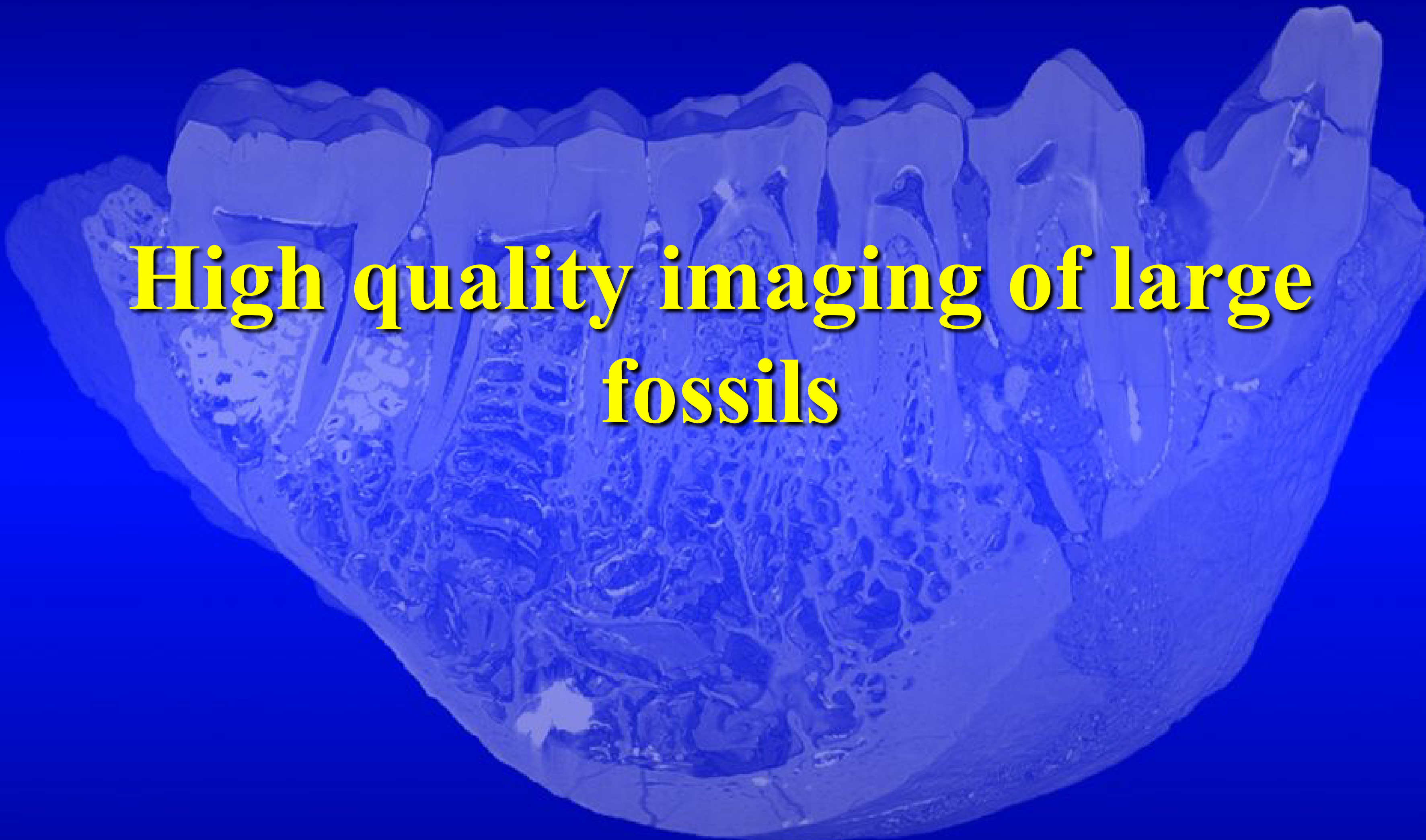
||

(number of long period lines) * periodicity

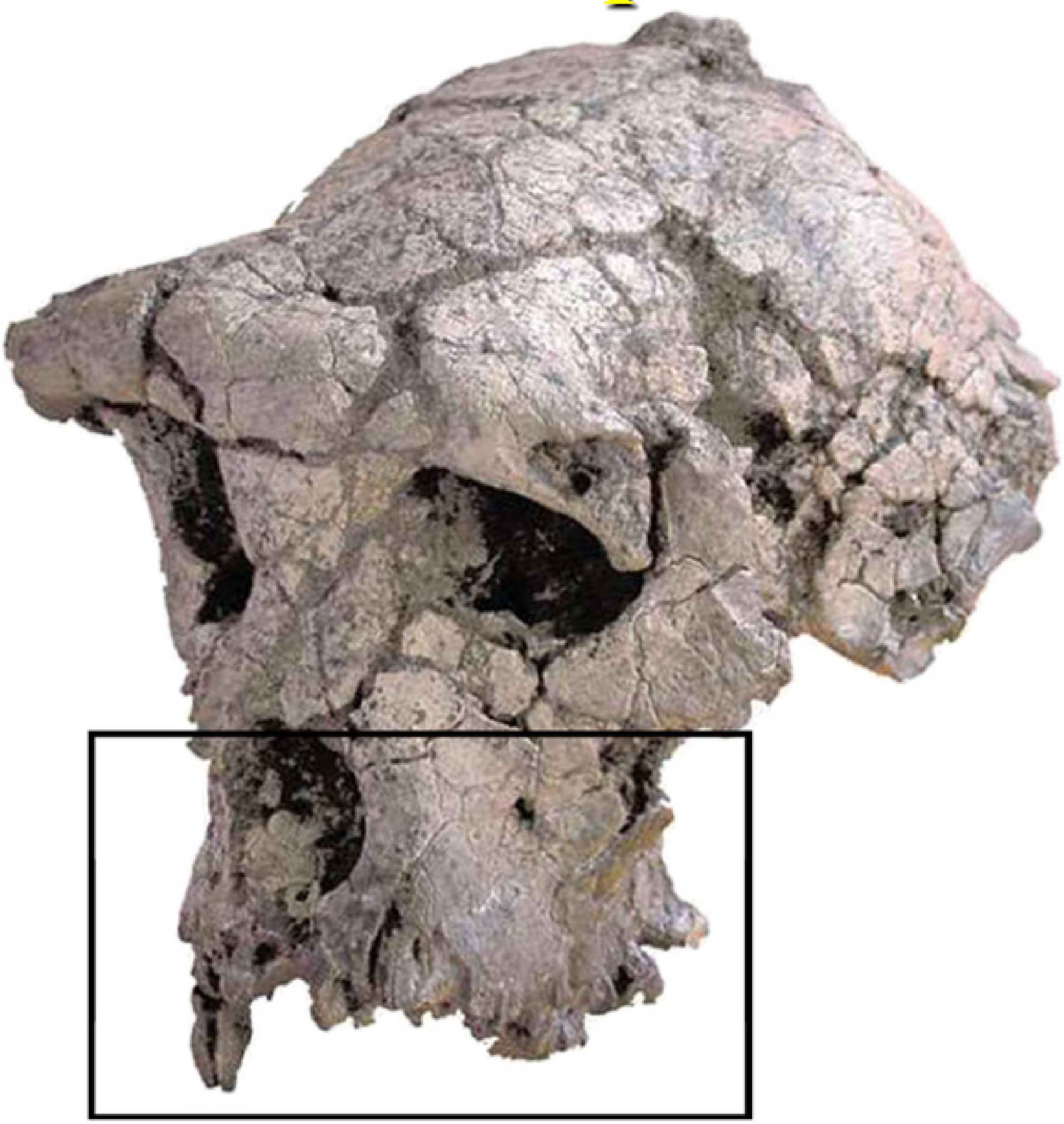
(137) * 8 = 1096 days

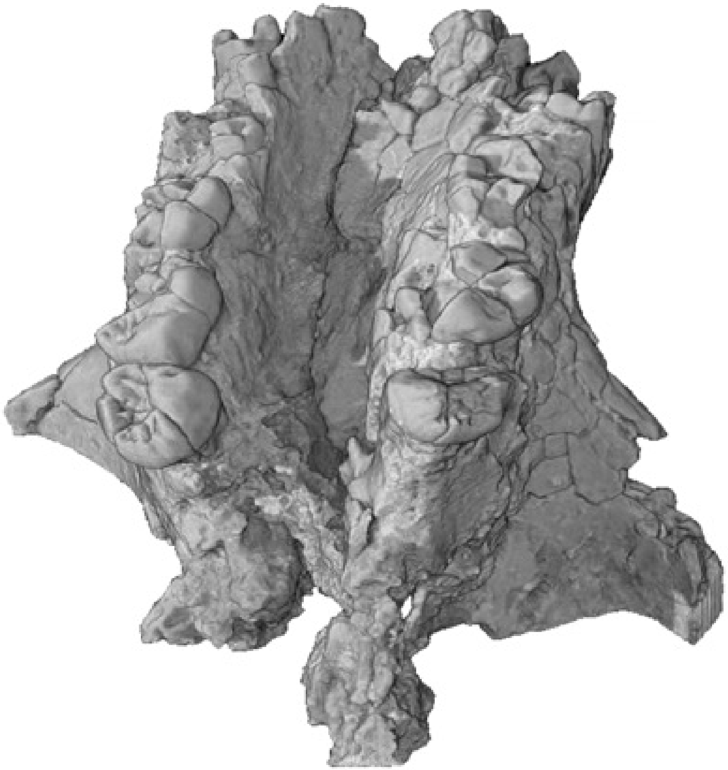
Engis 2 child was 3 years old when it died, not 4. In average Neanderthals were developing faster than *Homo sapiens*

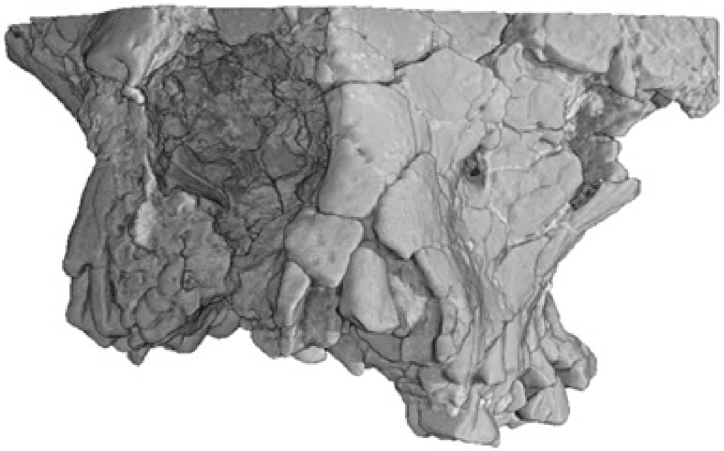
High quality imaging of large fossils



Sahelanthropus tchadensis : Toumaï

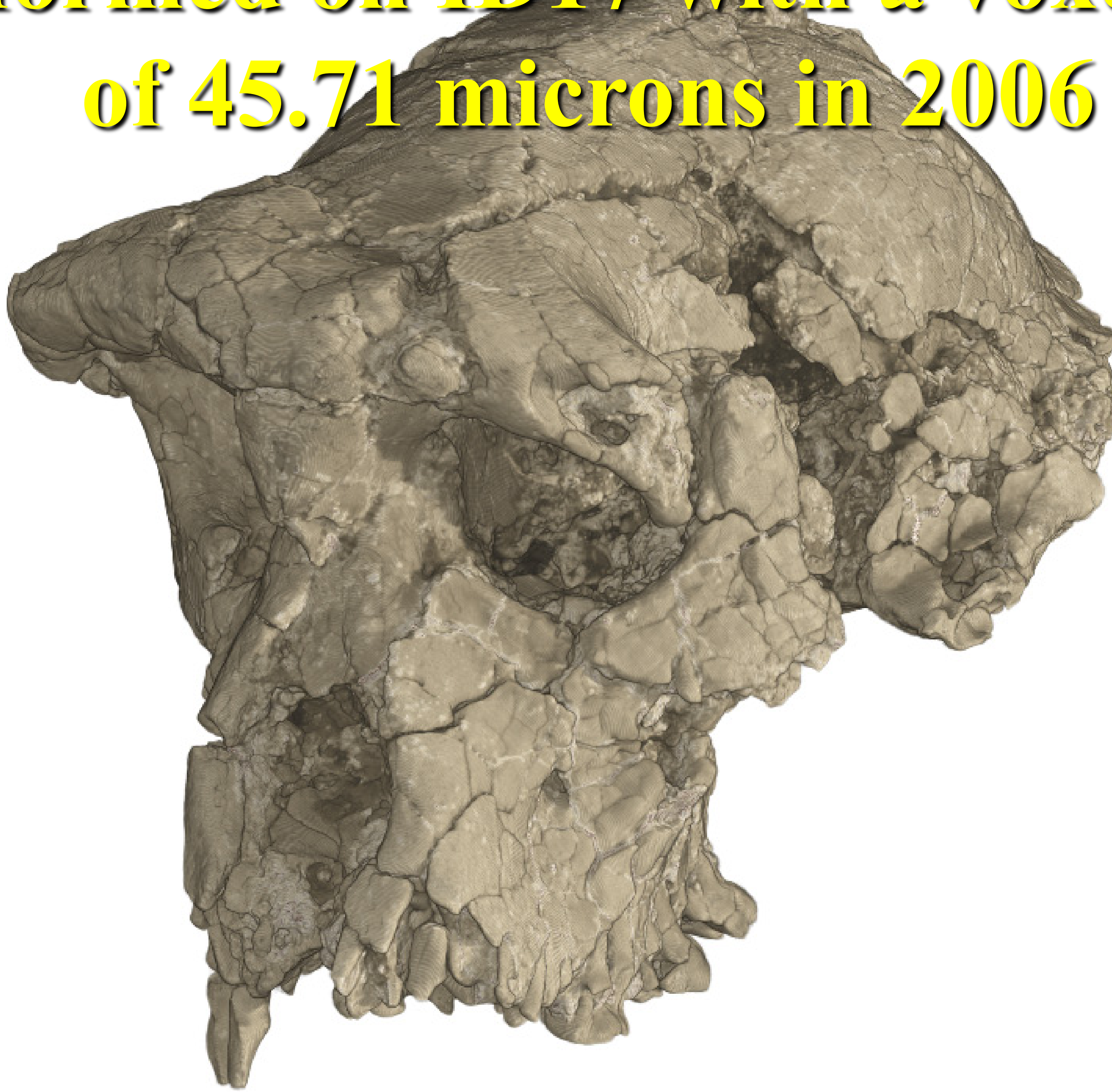






Brunet Michel, Guy Franck, Tafforeau paul *et al.*

Performed on ID17 with a voxel size of 45.71 microns in 2006



Australopithecus sediba : the Malapa hominid (South Africa) ID17, 2010

Berger Lee, Carlson Kris, Tafforeau Paul et al.

Click on image to see video

Conclusion

- After the first scan of a fossil performed in 2000 at the ESRF on ID19, paleontology is living a small revolution. Synchrotron imaging of fossils illustrates in a way the paleontology of the 21st century.

- Third generation synchrotrons are currently the most powerful machines for non-destructive investigations of fossils. Imaging possibilities are already impressive, but the ongoing upgrade projects at the ESRF will push far further the possibilities.

5 mm


Thank you for
your attention