

# High-resolution integrated stratigraphy of the Hauterivian in Umbria-Marche (Central Italy)



Sébastien Wouters, Sara Satolli, Mathieu Martinez, Johann Schnyder,  
Frédéric Boulvain, Thomas Goovaerts, Bruno Meyvis & Xavier Devleeschouwer

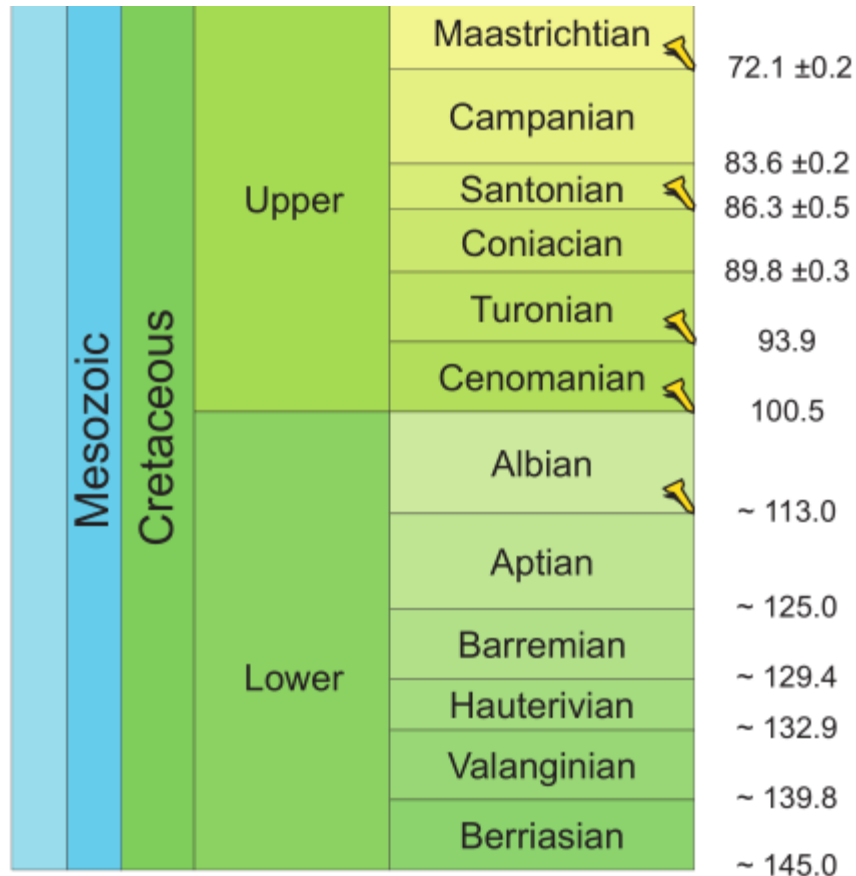
STRATI 2019 2<sup>nd</sup> -5<sup>th</sup> July



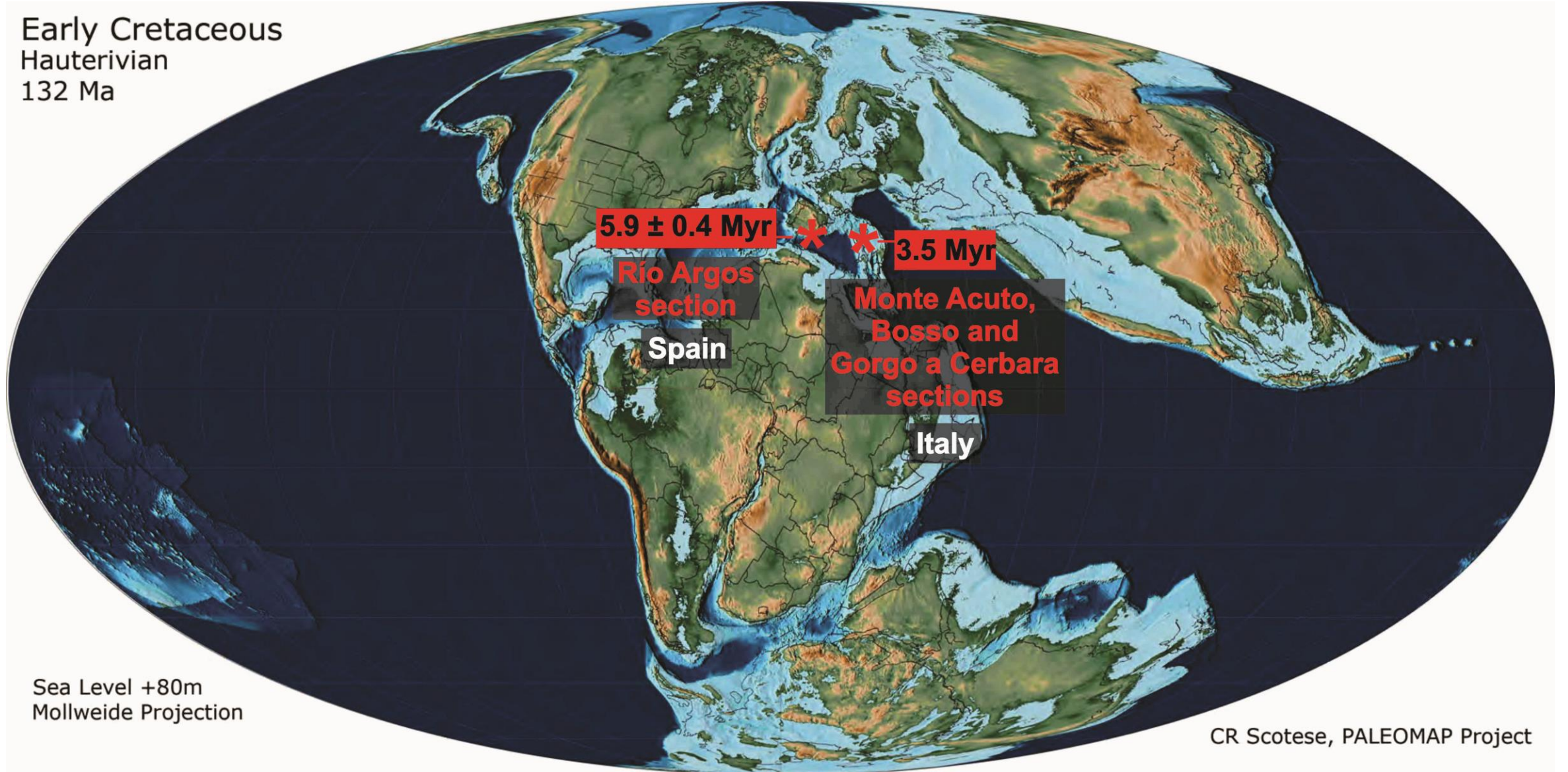
# Introduction

► The **CRASH** project:

Checking the **R**eproducibility of **A**strochronology in the **H**auterivian



Early Cretaceous  
Hauterivian  
132 Ma



Sea Level +80m  
Mollweide Projection

CR Scotese, PALEOMAP Project

# Introduction

► The **CRASH** project:

Checking the **R**eproducibility of **A**strochronology in the **H**auterivian

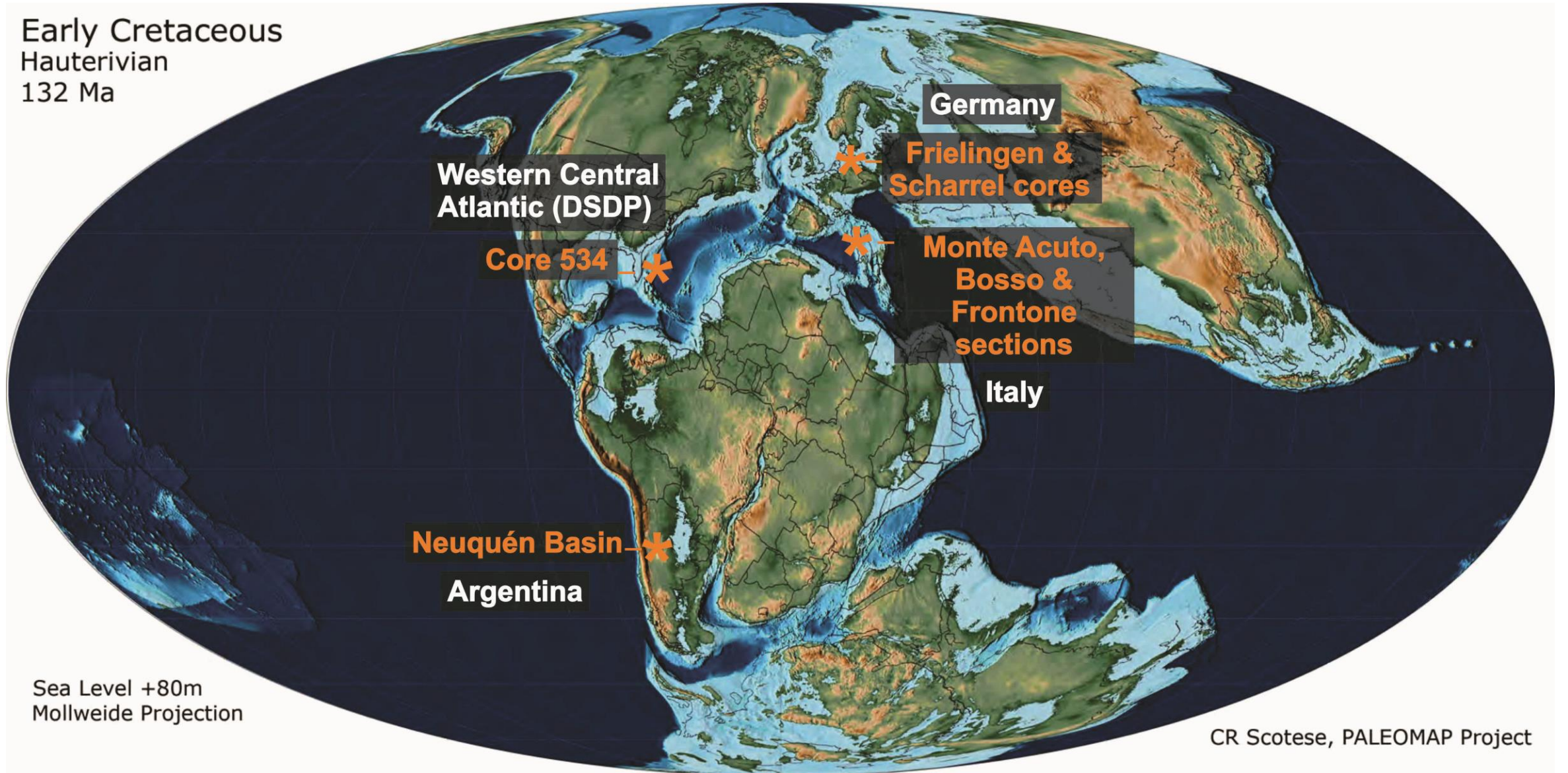
► Discrepancy of astrochronological duration of the Stage:

- **5.9 ± 0.4 Myr** in Río Argos (Spain)

- **3.5 Myr** in Italian sections (Bosso and Monte Acuto)



Early Cretaceous  
Hauterivian  
132 Ma



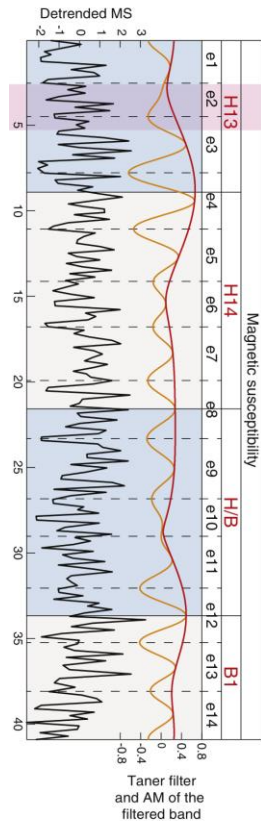
Sea Level +80m  
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# Introduction

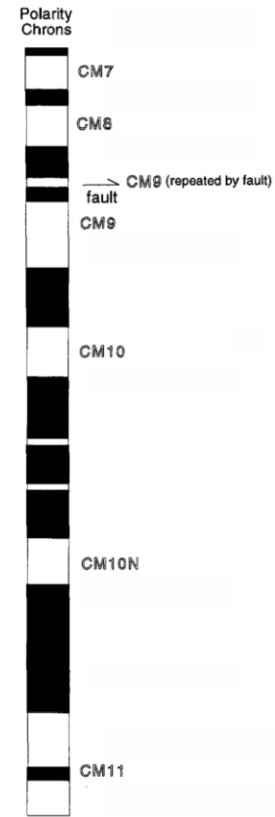
► The **CRASH** project:

Checking the **R**eproducibility of **A**strochronology in the **H**auterivian



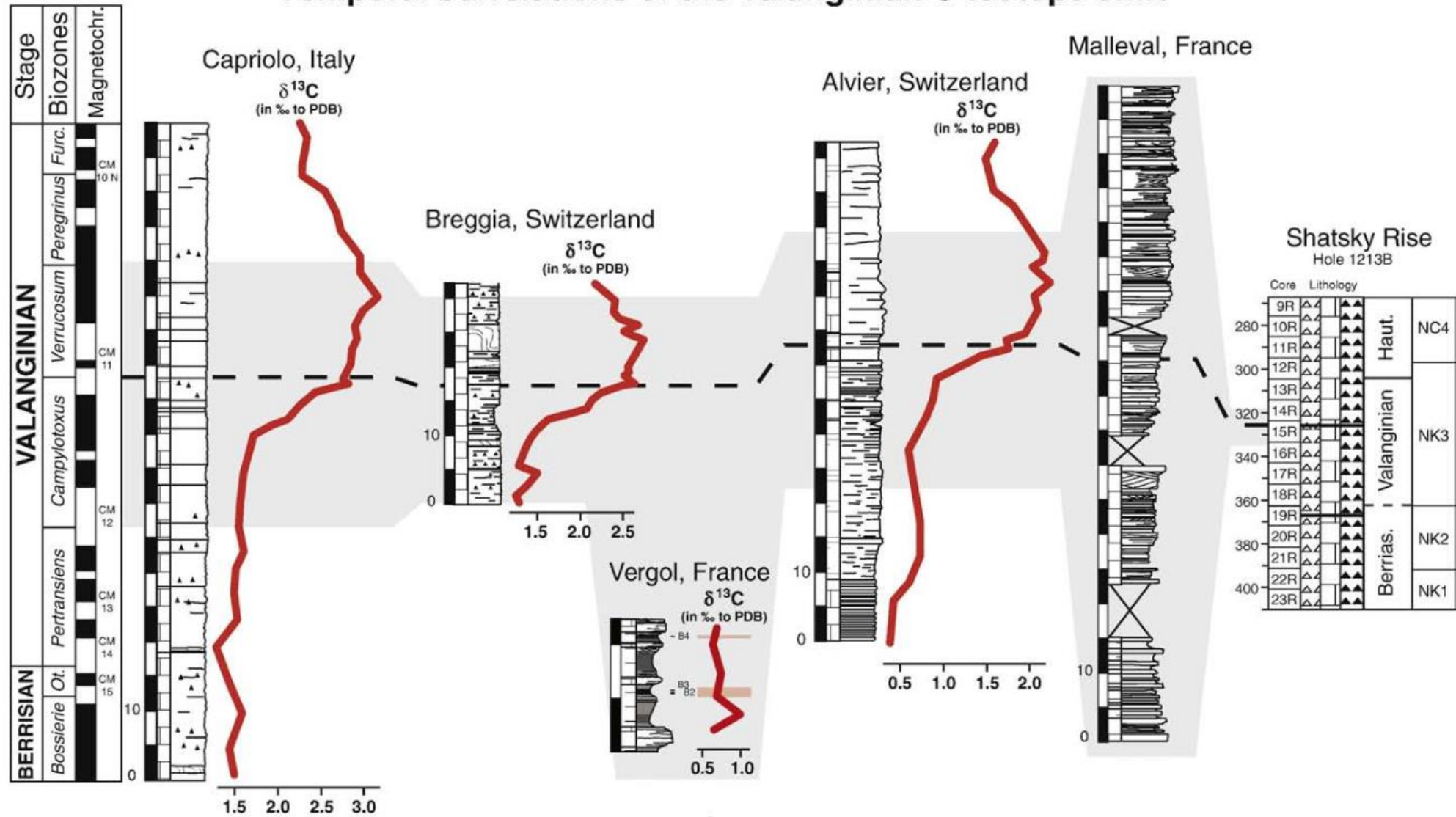
Spain

Examples of cyclo- and magnetostratigraphy in the Hauterivian (Channell et al., 1995, Martinez et al., 2015)



Italy

# Temporal correlations of the Valanginian C-isotope shift



- LEGEND**
- ☐ Limestones
  - ▨ Marly-limestones
  - ▬ Marls
  - ☞ Slump
  - ▲▲▲ Chert
  - ▲▲▲▲ Porcelanite

(Westermann et al., 2010)



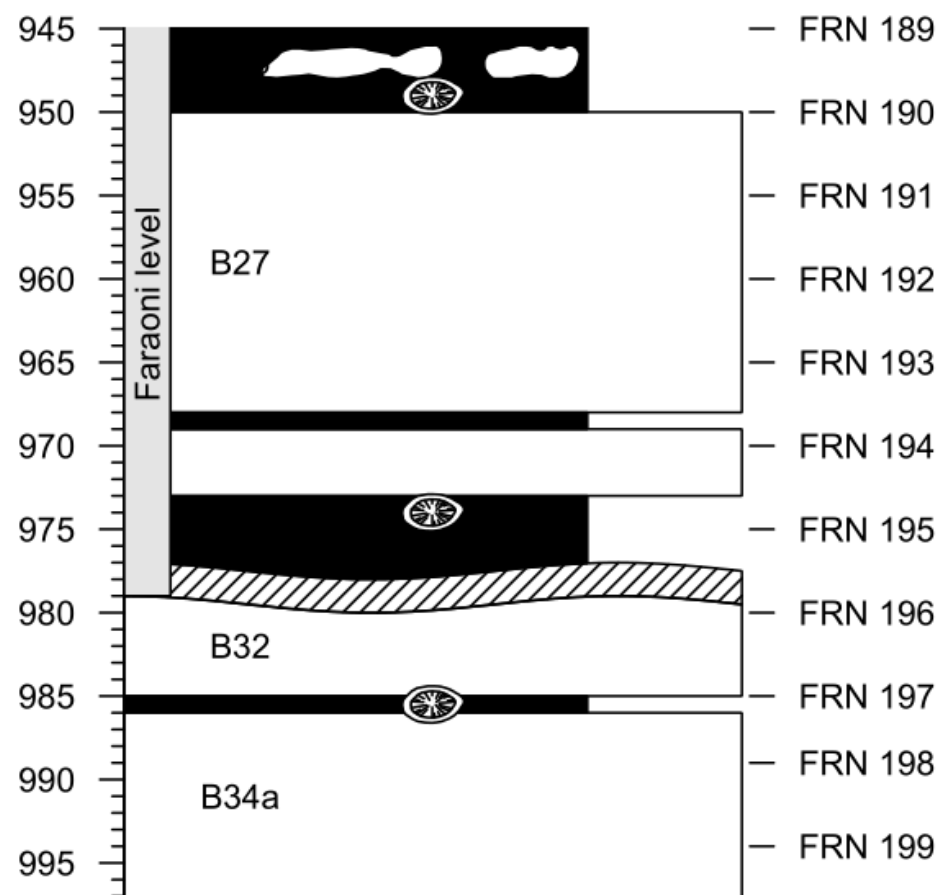
# StratigrapherR

## StratigrapherR: Integrated Stratigraphy

Version: 0.0.6  
Depends: R ( $\geq 3.5.0$ )

<https://CRAN.R-project.org/package=StratigrapherR>

- ▶ R package available on the Comprehensive R Archive Network (**CRAN**)
- ▶ Entirely **open source**
- ▶ Implements R functions for integrated stratigraphy, to be used in **combination of base R functions**





# StratigrapherR

## StratigrapherR: Integrated Stratigraphy

Version: 0.0.6  
Depends: R (≥ 3.5.0)

<https://CRAN.R-project.org/package=StratigrapherR>

# Poster: panel n° 17 on Thursday and Friday ST2.3-12

Stratigrapher (version 0.0.6) is an open-source integrated stratigraphy package. It is available in three software environments: R (<https://CRAN.R-project.org/package=StratigrapherR>), or see QR code below) and is designed to manage the large amount of data needed to perform cyclostratigraphy.

As cyclostratigraphy can be carried out by visual analysis on lithological observations and by time-series analysis, StratigrapherR endeavours to link the two by allowing the semi-automated generation of lithology, the processing of stratigraphical information, and the visualisation of any plot along the lithology in the R environment.



### 1. How to draw a simple, long and monotonous lithology

This applies if you want to draw a simple lithology with beds as rectangles. To avoid drawing them one by one in a manual drawing software you can generate them in R in two commands. This can serve as a base for more complicated lithologies, and the result can be imported by one external drawing software (package: Adobe Illustrator, CorelDraw, ...).

```
1. Create a table of every relevant information for each bed:
```

bedID	Interval (m)	Interval (cm)	Interval (mm)	Color	Lithology	Thickness (cm)
11	1	1	1	Grey	Shale	1
12	2	2	2	Black	Clay	1
13	3	3	3	Black	Clay	1
14	4	4	4	White	Limestone	1
15	5	5	5	Black	Limestone	1
16	6	6	6	Black	Limestone	1
17	7	7	7	Black	Clay	1
18	8	8	8	Black	Clay	1
19	9	9	9	Black	Clay	1
20	10	10	10	Black	Clay	1
21	11	11	11	Black	Clay	1
22	12	12	12	Black	Clay	1
23	13	13	13	Black	Clay	1
24	14	14	14	Black	Clay	1
25	15	15	15	Black	Clay	1
26	16	16	16	Black	Clay	1
27	17	17	17	Black	Clay	1
28	18	18	18	Black	Clay	1
29	19	19	19	Black	Clay	1
30	20	20	20	Black	Clay	1

2. Import the table into R. A large set of R functions exist to import tables in formats such as csv (such as the function read.table and read.csv), xls (read.xls) or xls or xls (see for instance the xlsx package on the CRAN website).

```
# Read a package to import .xlsx files
library(xlsx)
# set the file directory where the data file is, and # where your output will be
# Import the file
table <- read.xlsx("table.xlsx", 1, stringsAsFactors = F)
```

3. Create a data table (what is known as a data frame in the R vocabulary) of the rectangles coordinates for your use using the lithology() function.

```
# This will need to import the Stratigrapher package
library(Stratigrapher)
# create the coordinates for each rectangle
left <- lithology()
right <- lithology()
# create the coordinates for each rectangle
left <- lithology()
right <- lithology()
```

```
# The 1 and 2 arguments in lithology() stand in a general sense for the left and right boundary of intervals. Both can equally deal with upper and lower bed beds.
```

```
# The data frame created by the lithology() function (Fig. 1) provides an id for each polygon (each bed), and their coordinates for functions like arbitrary coordinates identified in x/y versus depth or time (t).
```

4. Make a personalized lithology for each lithology (or any kind of feature characterizing an interval bed).

```
# Import xlsx for table data from excel file
library(xlsx)
# Create a table for each lithology, to be basic # graphical arguments (see help pages table data), # plotting colour, shading density and angle, etc... legend <- data.frame(lithology_code = c("1", "2", "3", "4"), col = c("grey80", "grey90", "white"), density = c(0, 0, 30), angle = c(0, 0, 45), stringsAsFactors = F)
```

```
# Use the bed table with the legend by the lithology() function. It can be used to define the lithology for each bed separately. bed.legend <- data.frame(legend, by = "lithology_code")
```

5. Plot the lithology (Fig. 2), using the multiplot() function designed to plot multiple polygons.

```
# Import Stratigrapher if you # have not done it already
library(Stratigrapher)
# Prepare the plotting environment par(mfrow = c(1, 1, 1, 1)) plot.window(xlim = c(0, 15), ylim = c(-1, 23))
```

```
# set a scale plot.window(xlim = c(0, 15), ylim = c(-1, 23)) # Plot the top with the adequate # symbology for each bed (see Fig. 2) multiplot(left, right, legend, bed.legend, angle = bed.legend$angle)
```

```
# The functions here respectively # import a .img directly and generate # a legend, both for a making a different # appears to be used on bed boundary t1 = frameimg(0, 4, 6, 5), output = F) t2 = strangle(0, 1, 2, 3, 4, 5) # Add them to the top, at the desired # bed boundaries (see Fig. 40) legend = multiplot(left, right, legend, bed.legend, angle = 120) plot.legend()
```

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# The functions here respectively # import a .img directly and generate # a legend, both for a making a different # appears to be used on bed boundary t1 = frameimg(0, 4, 6, 5), output = F) t2 = strangle(0, 1, 2, 3, 4, 5) # Add them to the top, at the desired # bed boundaries (see Fig. 40) legend = multiplot(left, right, legend, bed.legend, angle = 120) plot.legend()
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```

### 2. How to add drawing elements (fossils, minerals, anything really...)

This allows to import in R simple drawings from graphical vectorial software (Inkscape, Adobe Illustrator, CorelDraw, ...). They have to be saved as .img files, a format that the all main graphical software can report and export with.

```
1. Create a simple .img made of lines, polygons, and rectangles only (Fig. 3). These objects are made of simple listed together by single lines. Any other type of object will not be imported, as R graphics are not designed to accommodate them without reformatters.
```

```
2. Import the .img file using the centerimg() function
library(Stratigrapher)
# Import an .img file (File choose) # allow to select your file
img <- getimg("file_choose")
```

```
3. Draw using the centerimg() or frameimg() functions, designed for objects made of polygons and polygons together (Fig. 3).
```

```
# Create a plot:
par(mfrow = c(1, 1), mar = c(1, 1, 1, 1))
plot.window(xlim = c(-1, 1), ylim = c(-1, 23))
img <- centerimg(img)
img <- frameimg(img)
```

```
4. Import the .img file using the centerimg() function
library(Stratigrapher)
# Import an .img file (File choose) # allow to select your file
img <- getimg("file_choose")
```

```
5. Import the .img file using the centerimg() function
library(Stratigrapher)
# Import an .img file (File choose) # allow to select your file
img <- getimg("file_choose")
```

```
6. Import the .img file using the centerimg() function
library(Stratigrapher)
# Import an .img file (File choose) # allow to select your file
img <- getimg("file_choose")
```

```
7. Import the .img file using the centerimg() function
library(Stratigrapher)
# Import an .img file (File choose) # allow to select your file
img <- getimg("file_choose")
```

```
8. Import the .img file using the centerimg() function
library(Stratigrapher)
# Import an .img file (File choose) # allow to select your file
img <- getimg("file_choose")
```

```
9. Import the .img file using the centerimg() function
library(Stratigrapher)
# Import an .img file (File choose) # allow to select your file
img <- getimg("file_choose")
```

```
10. Import the .img file using the centerimg() function
library(Stratigrapher)
# Import an .img file (File choose) # allow to select your file
img <- getimg("file_choose")
```

```
11. Import the .img file using the centerimg() function
library(Stratigrapher)
# Import an .img file (File choose) # allow to select your file
img <- getimg("file_choose")
```

```
12. Import the .img file using the centerimg() function
library(Stratigrapher)
# Import an .img file (File choose) # allow to select your file
img <- getimg("file_choose")
```

```
13. Import the .img file using the centerimg() function
library(Stratigrapher)
# Import an .img file (File choose) # allow to select your file
img <- getimg("file_choose")
```

```
14. Import the .img file using the centerimg() function
library(Stratigrapher)
# Import an .img file (File choose) # allow to select your file
img <- getimg("file_choose")
```

```
15. Import the .img file using the centerimg() function
library(Stratigrapher)
# Import an .img file (File choose) # allow to select your file
img <- getimg("file_choose")
```

```
16. Import the .img file using the centerimg() function
library(Stratigrapher)
# Import an .img file (File choose) # allow to select your file
img <- getimg("file_choose")
```

```
17. Import the .img file using the centerimg() function
library(Stratigrapher)
# Import an .img file (File choose) # allow to select your file
img <- getimg("file_choose")
```

### 4. How to visualise large R plots directly on your default PDF reader

Using the pdfRplot() function, R plots of any size can directly be opened in a PDF reader (Fig. 3). Involvement loading of the content of the file (e.g., pdf, eps, etc.) allows not having to close the reader at each modification. For Windows users, using the Sumatra PDF reader allows to modify a PDF file without closing the reader, removing the need to adapt to the file name at each change.

```
library(Stratigrapher)
# Plot the graphical parts in function form
plot <- function() { plot(1, 1) }
# modify function to stratigrapher
pdfRplot(plot.D,"test")
```

```
library(Stratigrapher)
# Import an .img file (File choose) # allow to select your file
img <- getimg("file_choose")
```

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library(Stratigrapher)
# Import an .img file (File choose) # allow to select your file
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```
library(Stratigrapher)
# Import an .img file (File choose) # allow to select your file
img <- getimg("file_choose")
```

### Additional features

The Stratigrapher package furthermore allows basic visualization (Fig. 4) and processing of oriented data used for magnetostratigraphy:

- Stereographic projections
- Dip-slip plots
- Conversion between data conventions
- Rotation between (sample coordinate, bedding coordinate, rotation)

It also provides a set of functions to deal with selected stratigraphic intervals (for instance in the 3D format): time slice simplification, merging, inversion and visualization of intervals, as well as identifying the samples included in any given interval, and characterizing the relative of the intervals with other nearby neighbouring ones.



Fig. 4: Example of a dip-slip projection and a dip-slip plot of paleomagnetic data.

### Possibilities

- Automating lithology generation
- Plotting logs in parallel with other R figures (profiles, filtering results,...)
- Centralizing all relevant stratigraphical information in R

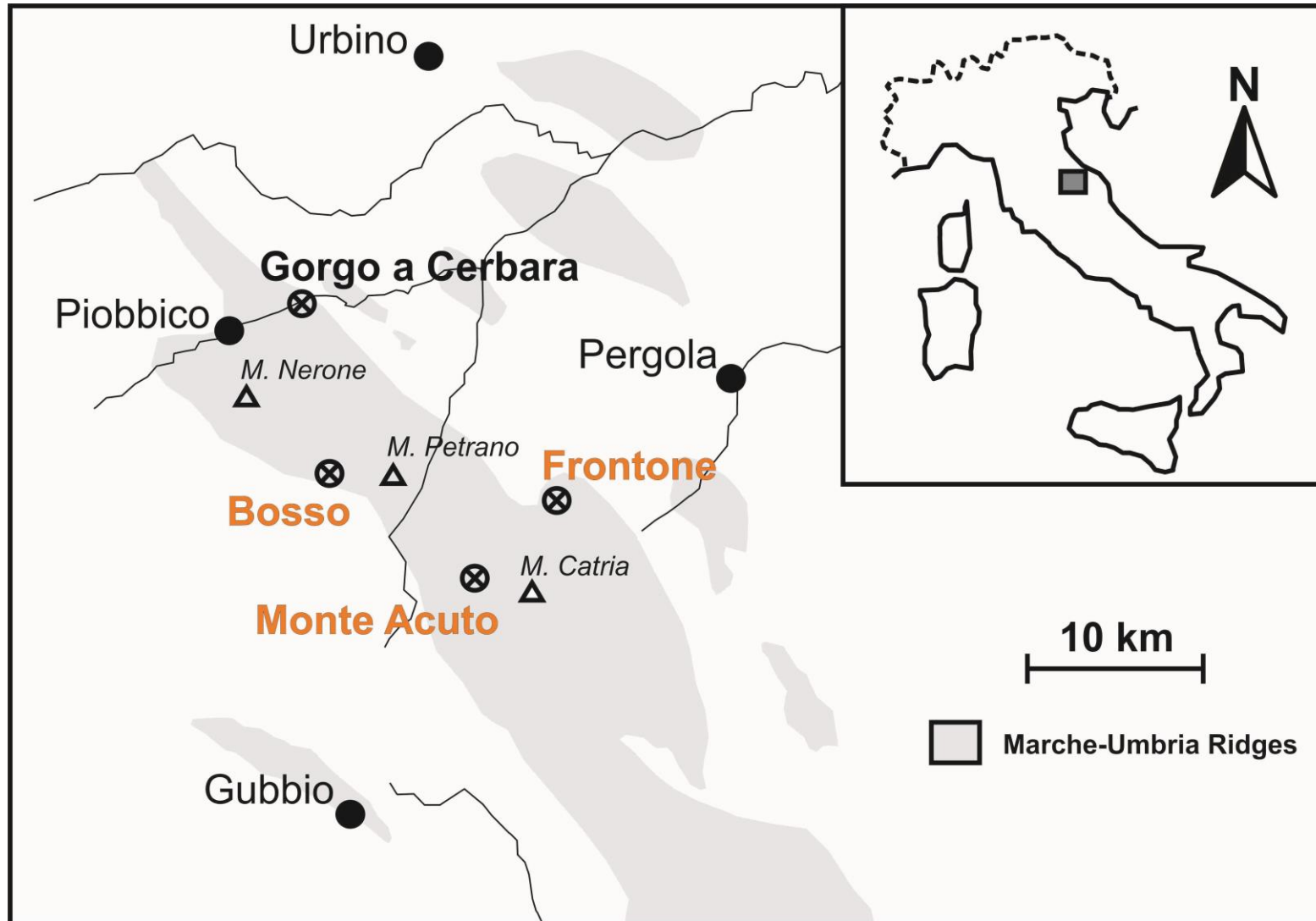
### Prospects for the future

Adapting evolutive time-series analyses (EVA, wavelet,...) already existing as functions in R to be able to visualize their output in parallel with stratigraphical information and lithologies (complete or synthetic).

R can be an ideal environment to deal with all kind of stratigraphic data. Paleomagnetic data of any format (Magic, Utrecht, Rennes, Puffinplot,...) could be imported into a preformated R conversion for paleomagnetic data (in a scheme known as a 53 object). This would allow to automate paleomagnetic functions and data checking in R, and to allow direct translation from one data format to another.

The current R graphic system used for Stratigrapher can be upgraded (from R base graphics to grid graphics) to allow for more features allowing among others better automation.

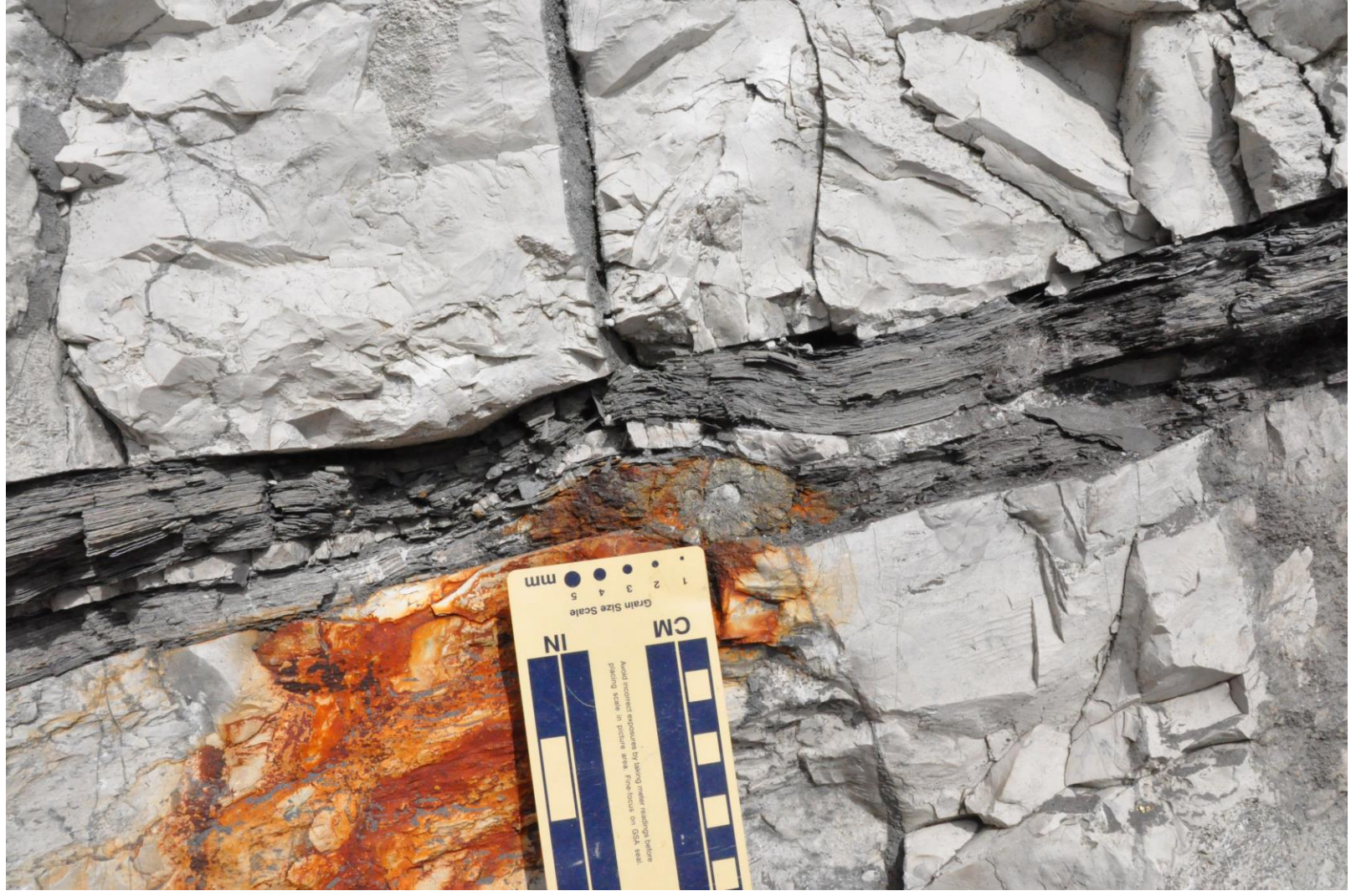
# Geological setting















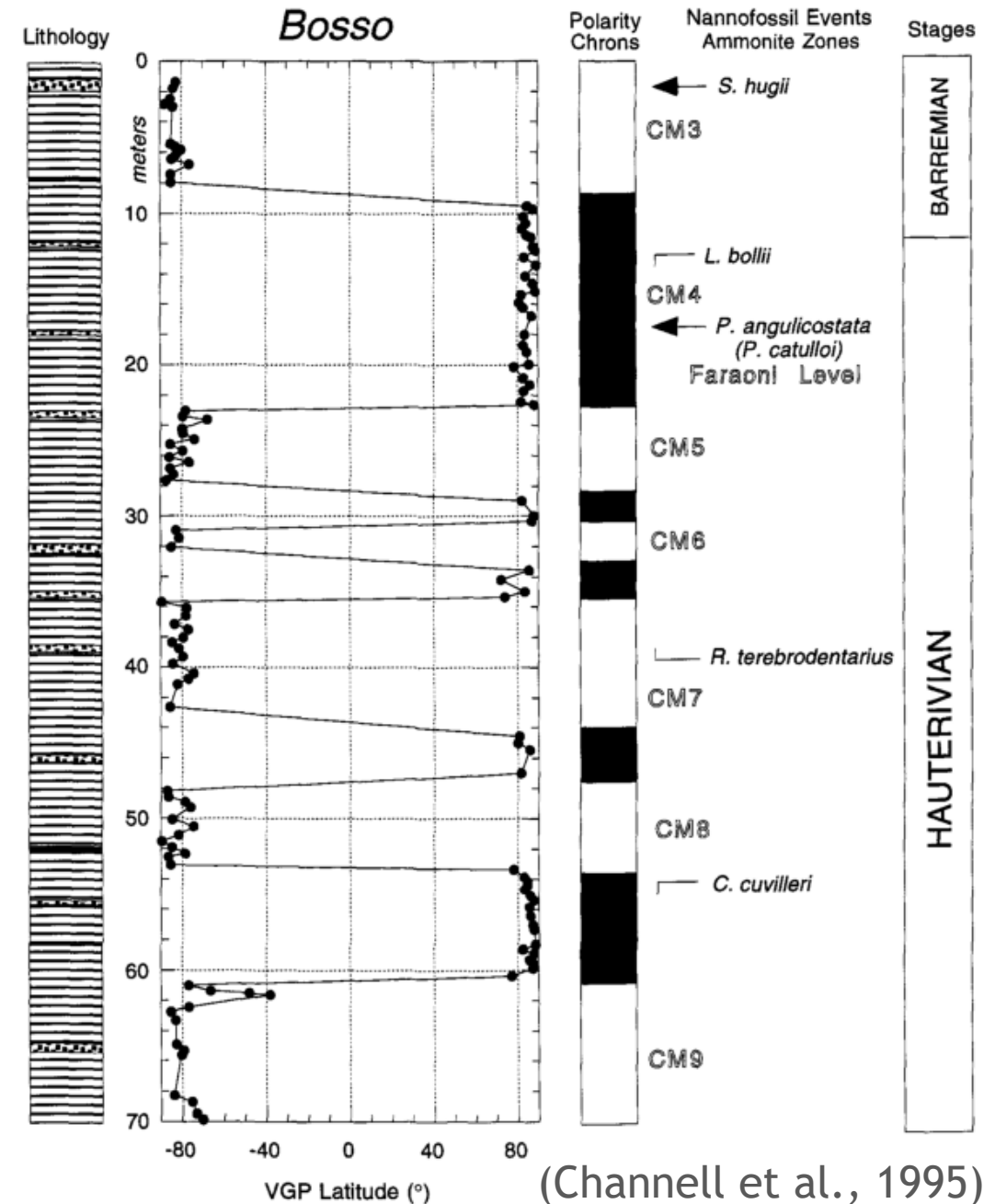


# New magnetostratigraphic framework

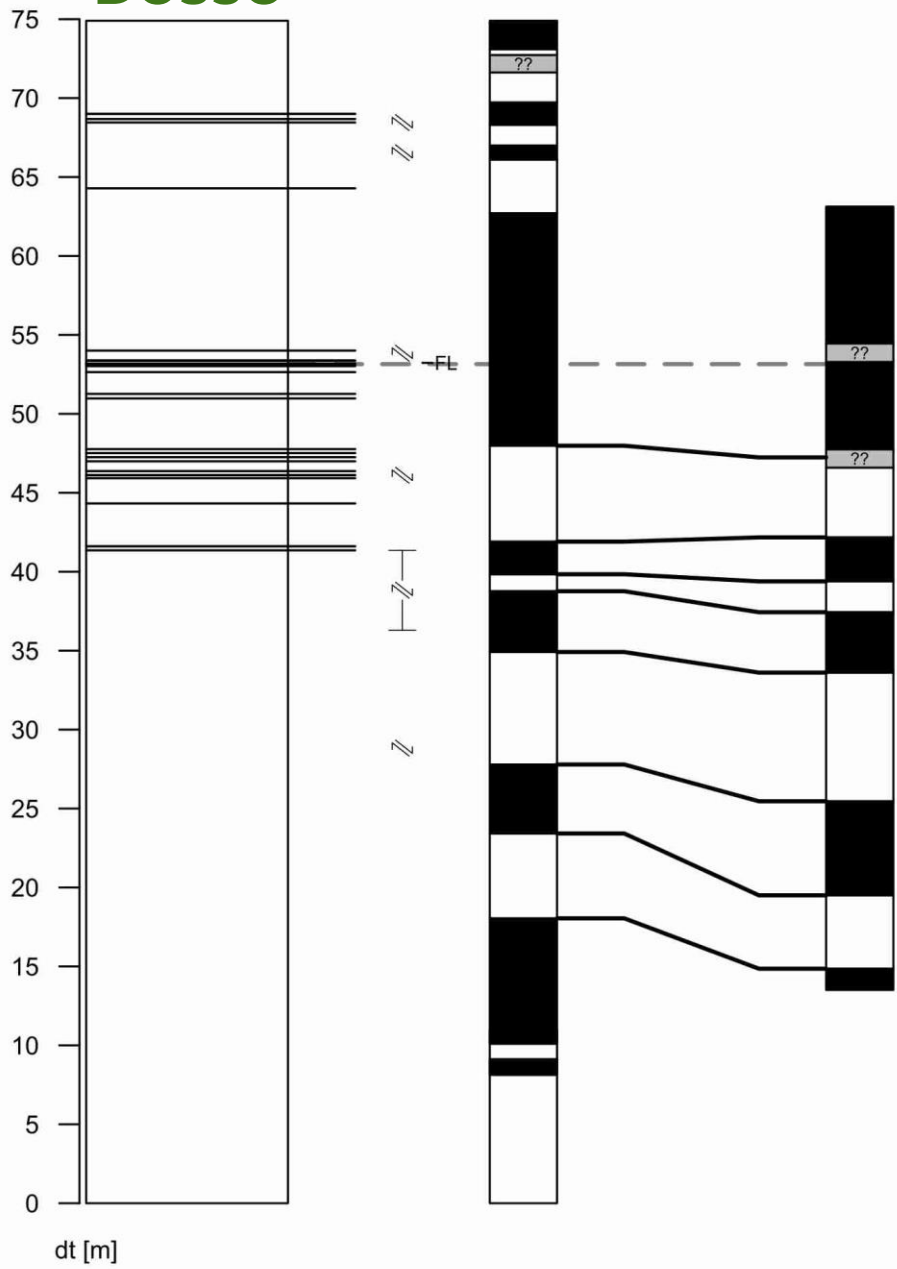
- We refined the magnetostratigraphic framework:

Increased resolution at the magnetic inversions (in progress)

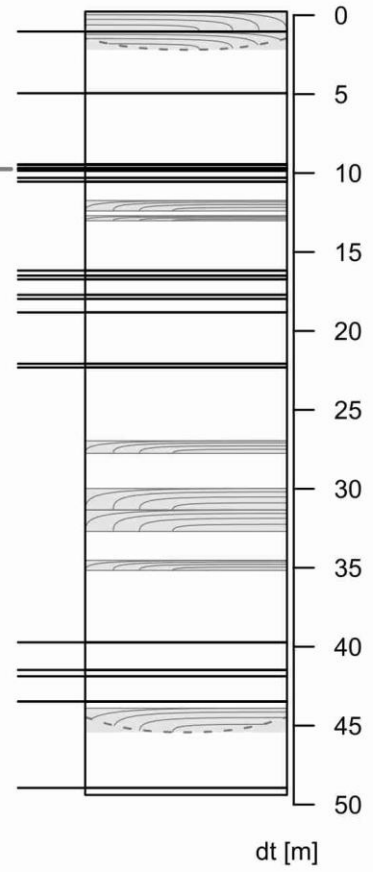
Palaeomagnetic samples well positioned against high resolution litholog and cyclostratigraphic samples




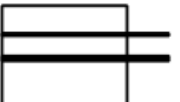




# Bosso



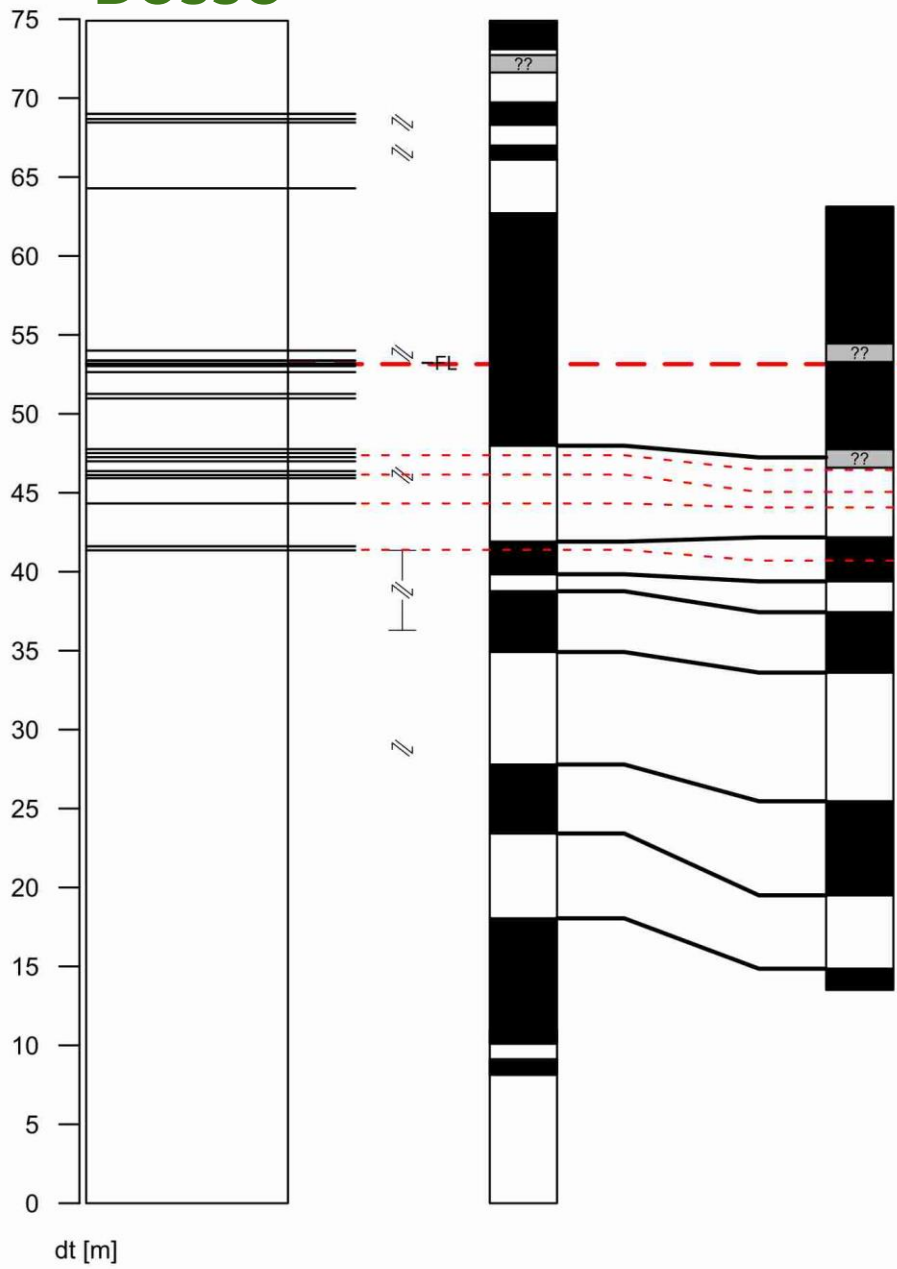
# Frontone



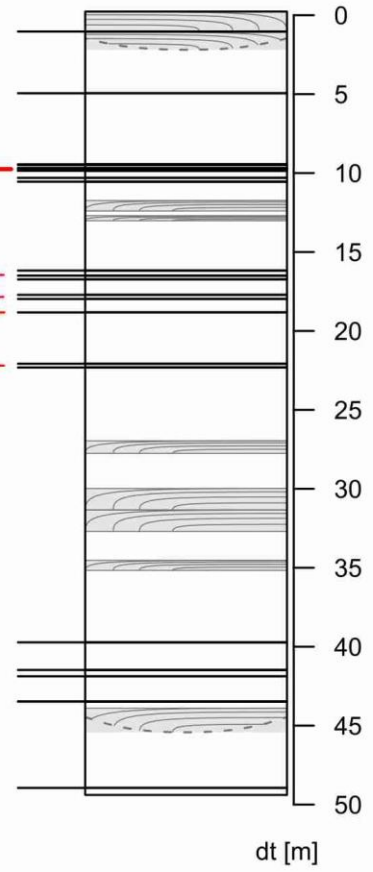
## Synthetic litholog legend

-  Limestones and cherts
-  Black shale levels
-  Fractured zone
-  Slump
-  Slump with basal erosion scar
-  Fault







# Bosso



# Frontone



## Synthetic litholog legend

-  Limestones and cherts
-  Black shale levels
-  Fractured zone
-  Slump
-  Slump with basal erosion scar
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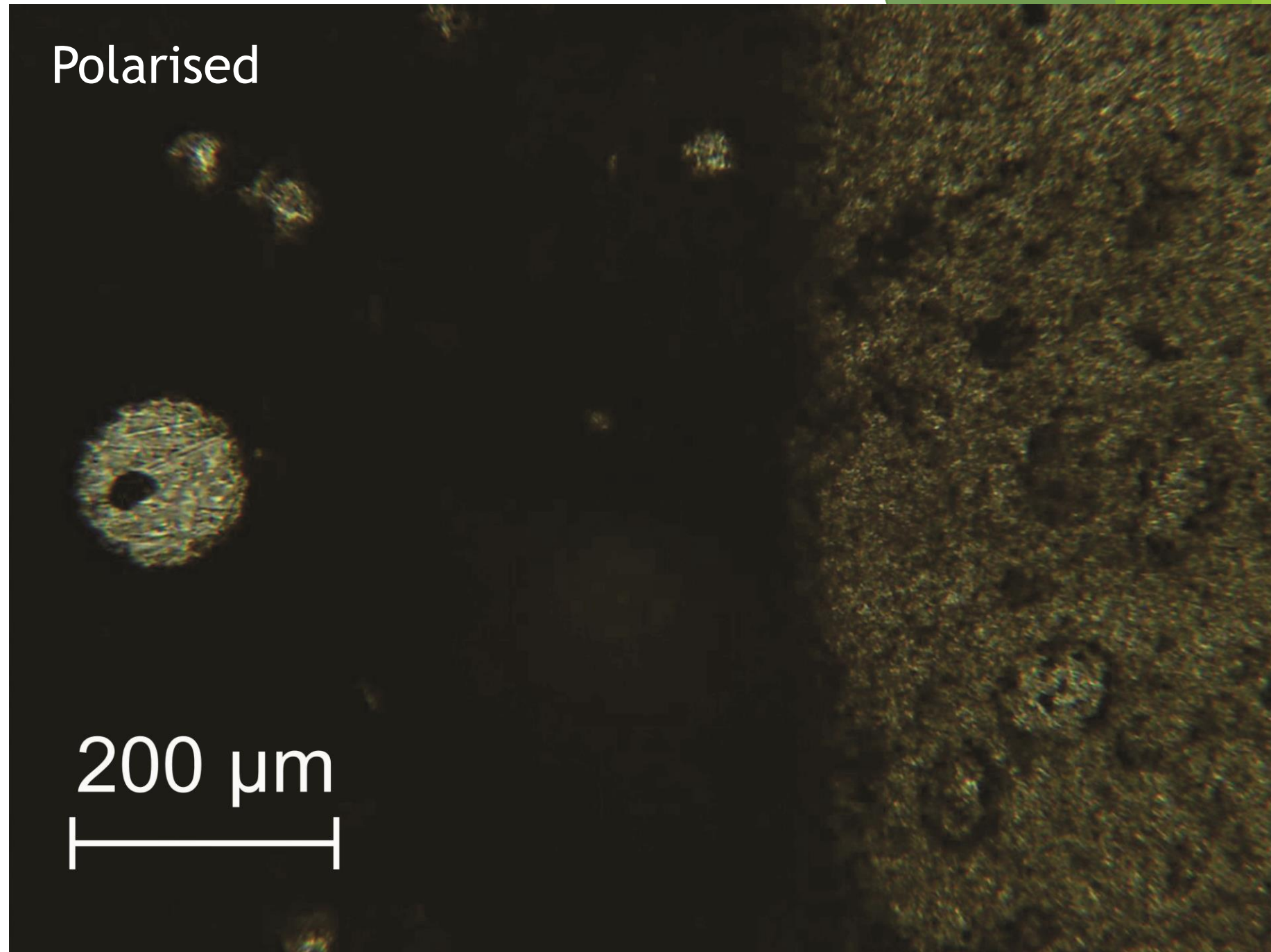


# Chert and limestone in thin sections

Differentiating quartz and calcite

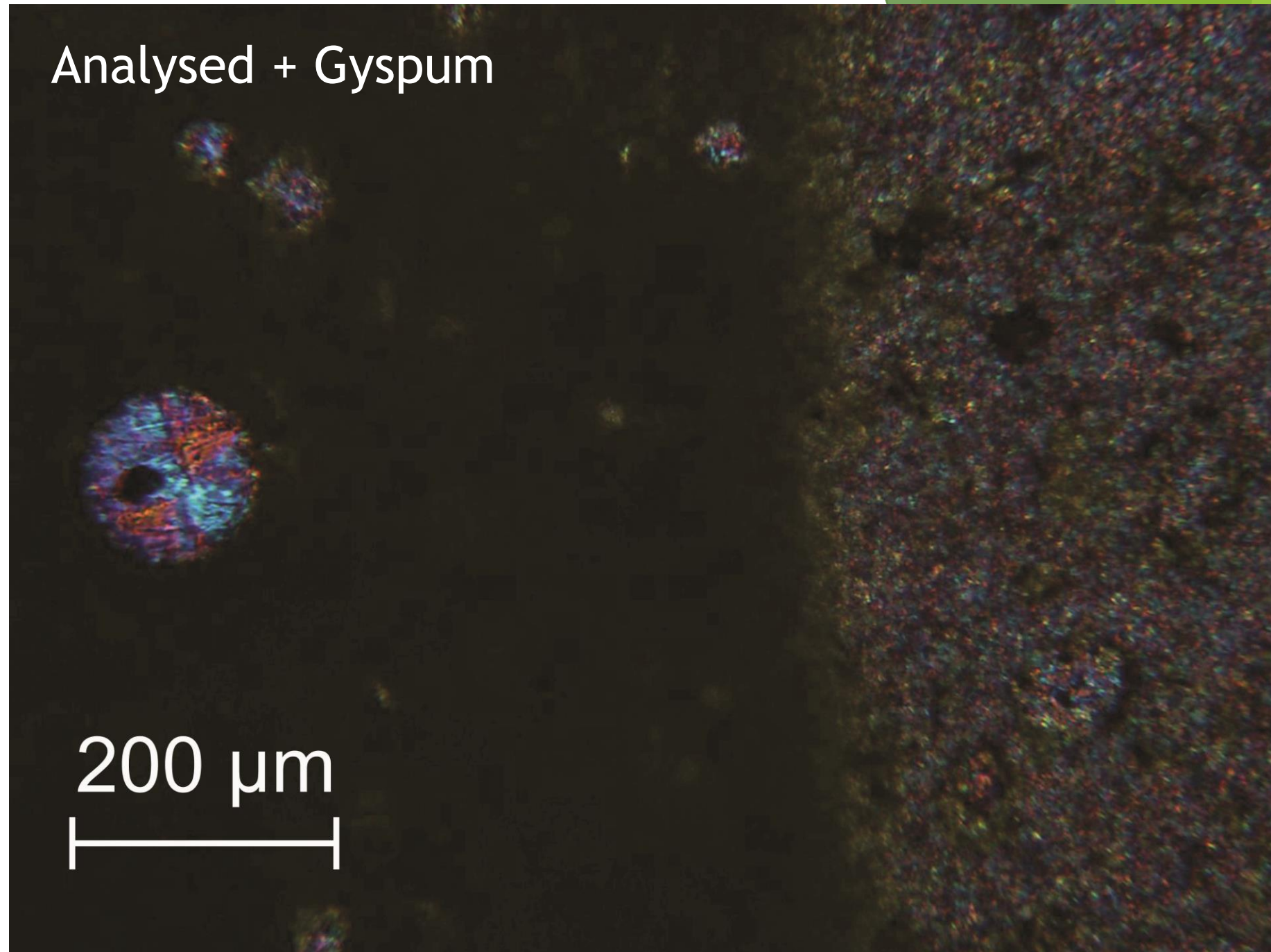
## Polarised

- ▶ Limestone:
  - Fine micrite
- ▶ Cherts:
  - microquartz ( $< 20 \mu\text{m}$ )



## Analysed + Gypsum

- ▶ Limestone:
  - Fine micrite
- ▶ Cherts:
  - microquartz ( $< 20 \mu\text{m}$ )



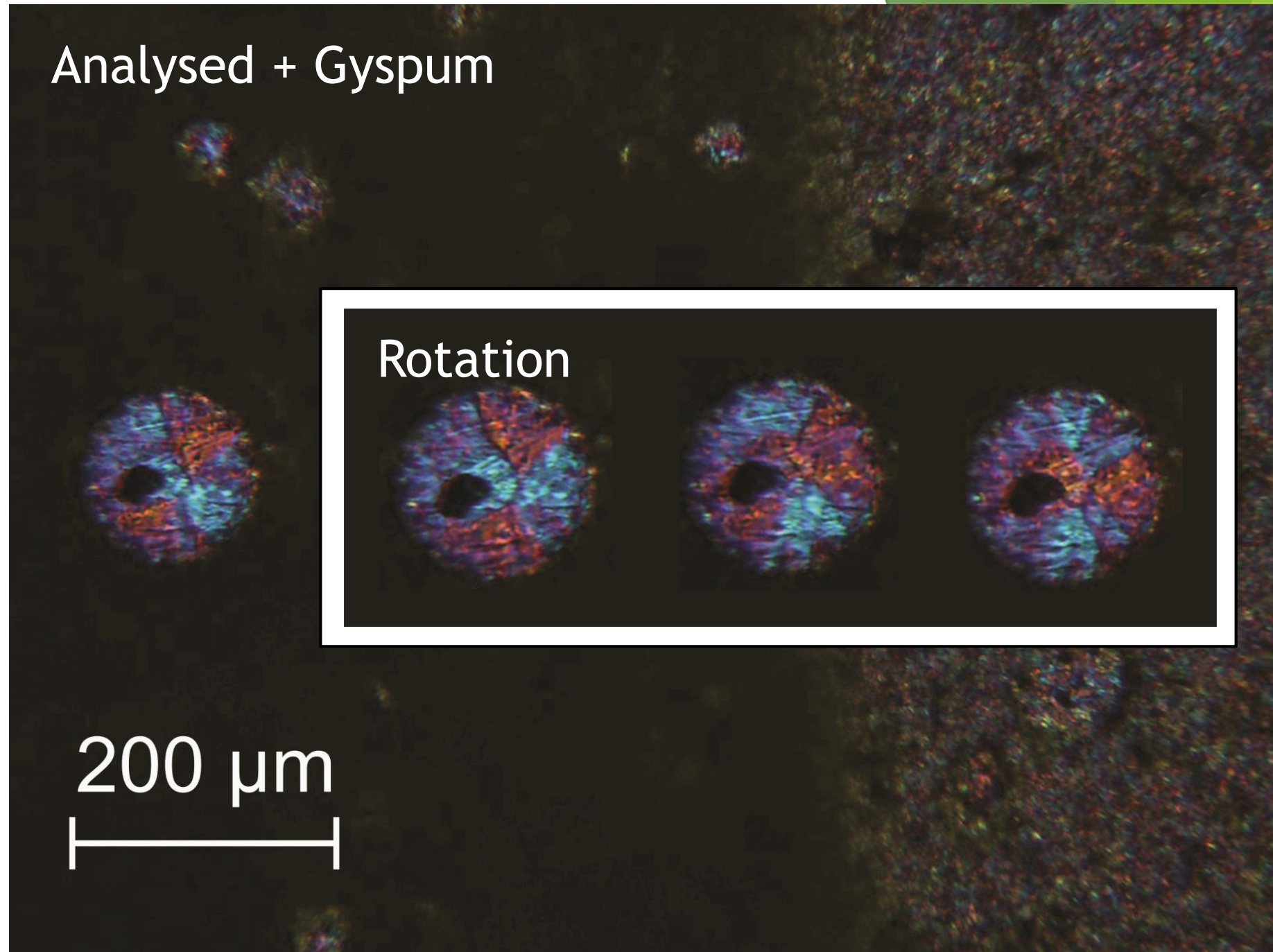


# Analysed + Gypsum

- ▶ Limestone:
  - Fine micrite
- ▶ Cherts:
  - microquartz ( $< 20 \mu\text{m}$ )
- ▶ Radiolaria:
  - Silicified or calcified

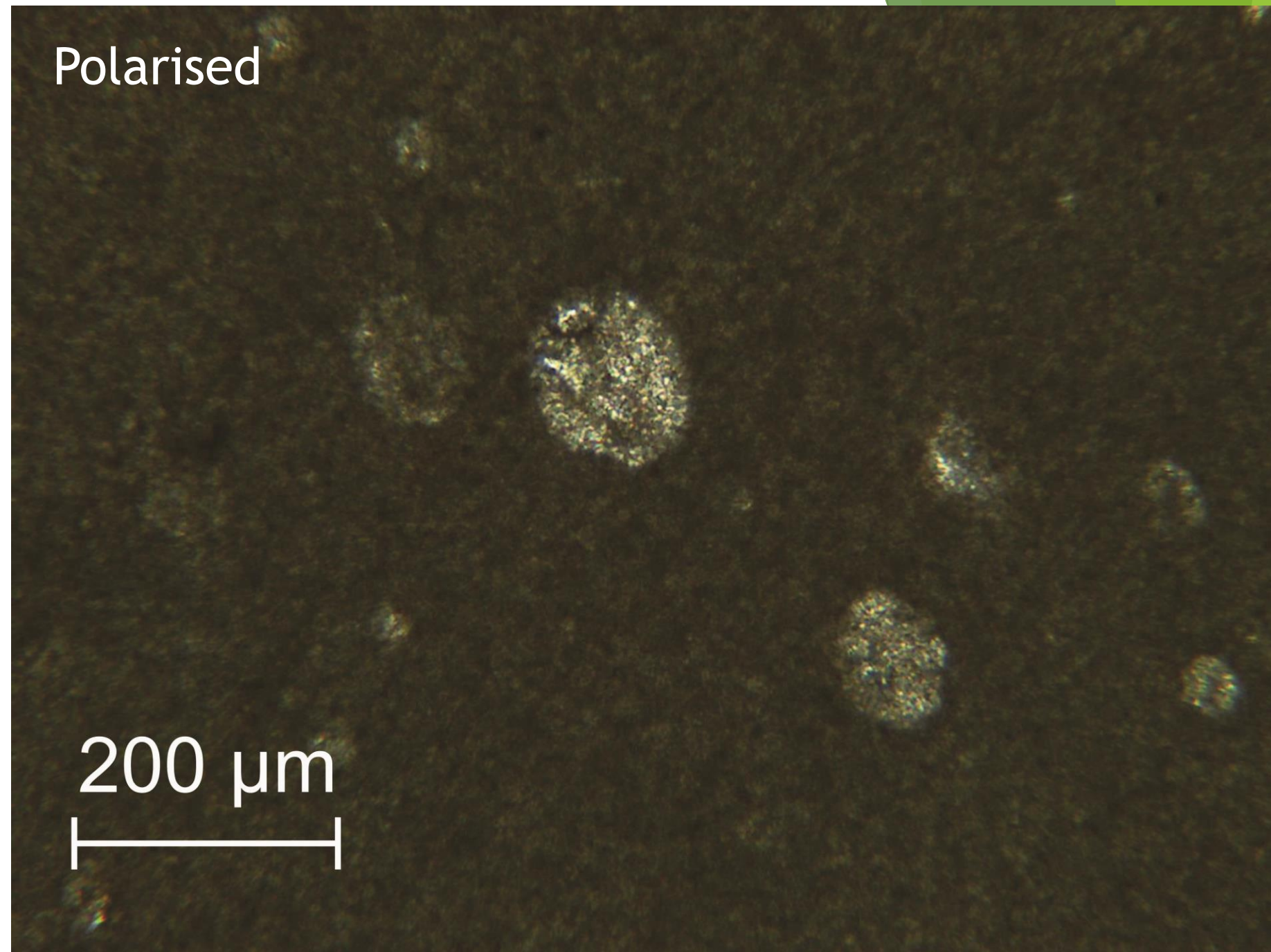
## Rotation

200  $\mu\text{m}$

A white horizontal scale bar with vertical end caps, indicating a length of 200 micrometers.



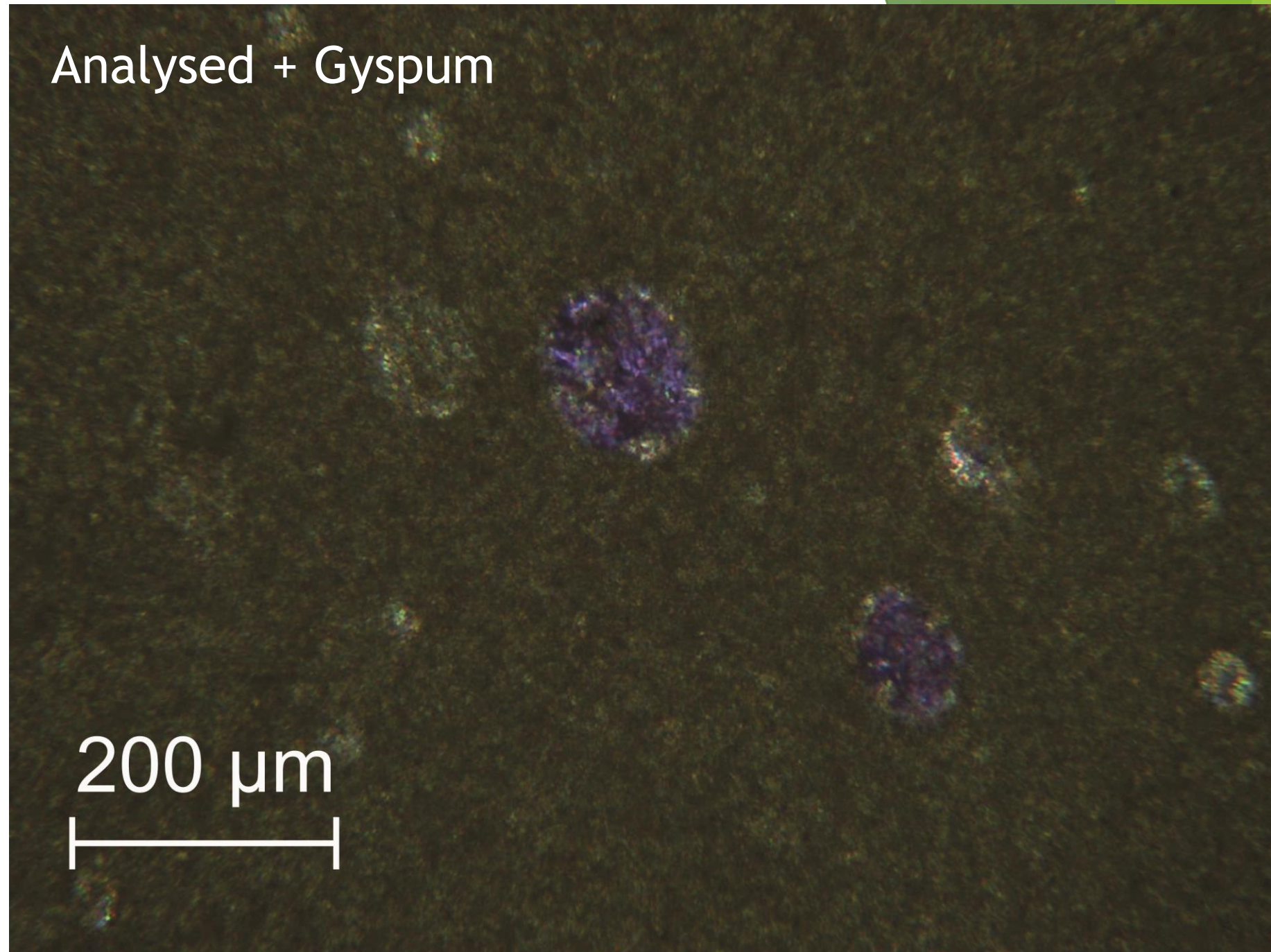
- ▶ Limestone:
  - Fine micrite
- ▶ Cherts:
  - microquartz ( $< 20 \mu\text{m}$ )
- ▶ Radiolaria:
  - Silicified or calcified



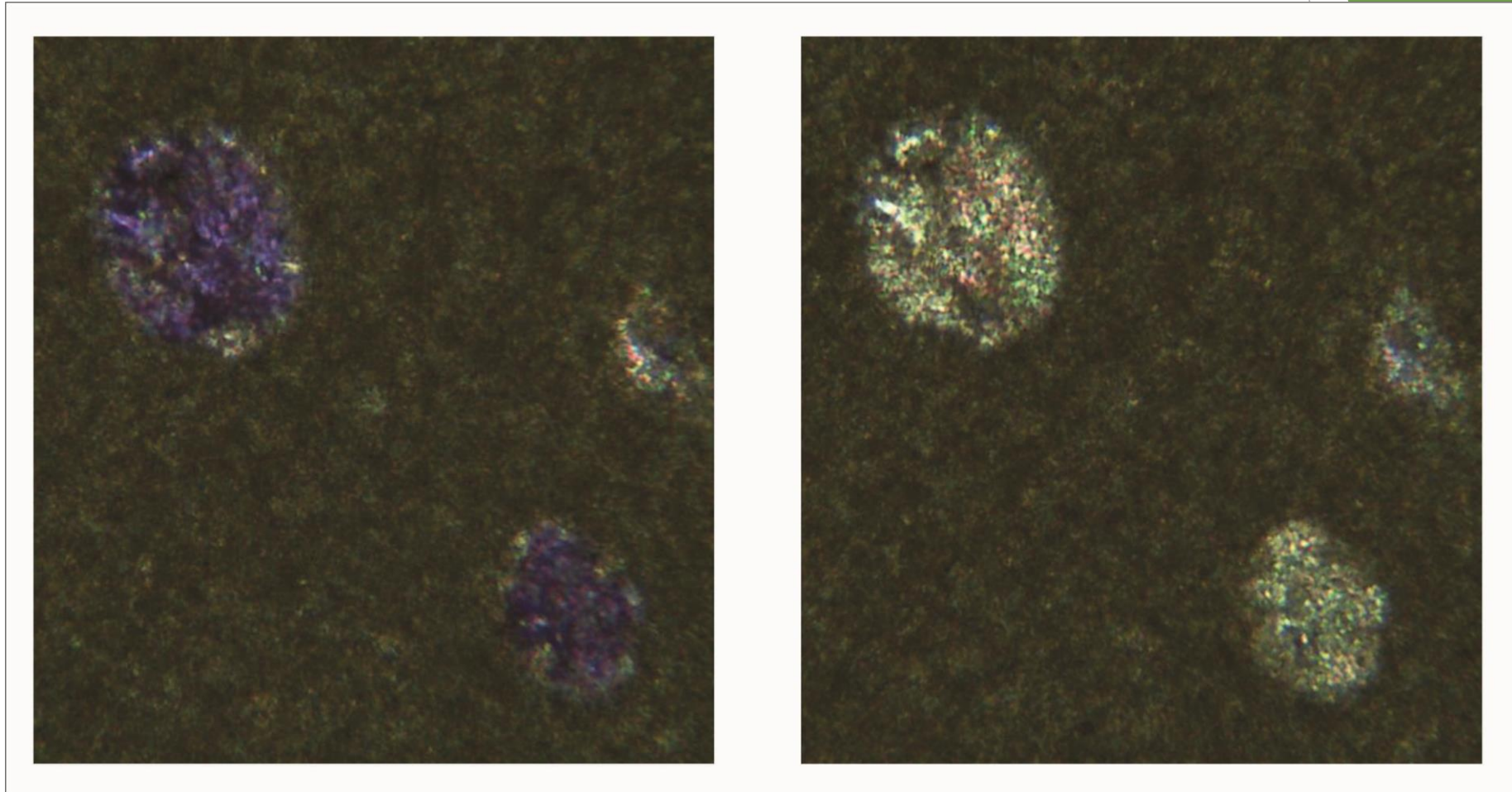


## Analysed + Gypsum

- ▶ Limestone:
  - Fine micrite
- ▶ Cherts:
  - microquartz ( $< 20 \mu\text{m}$ )
- ▶ Radiolaria:
  - Silicified or calcified



# Analysed + Gypsum Rotation



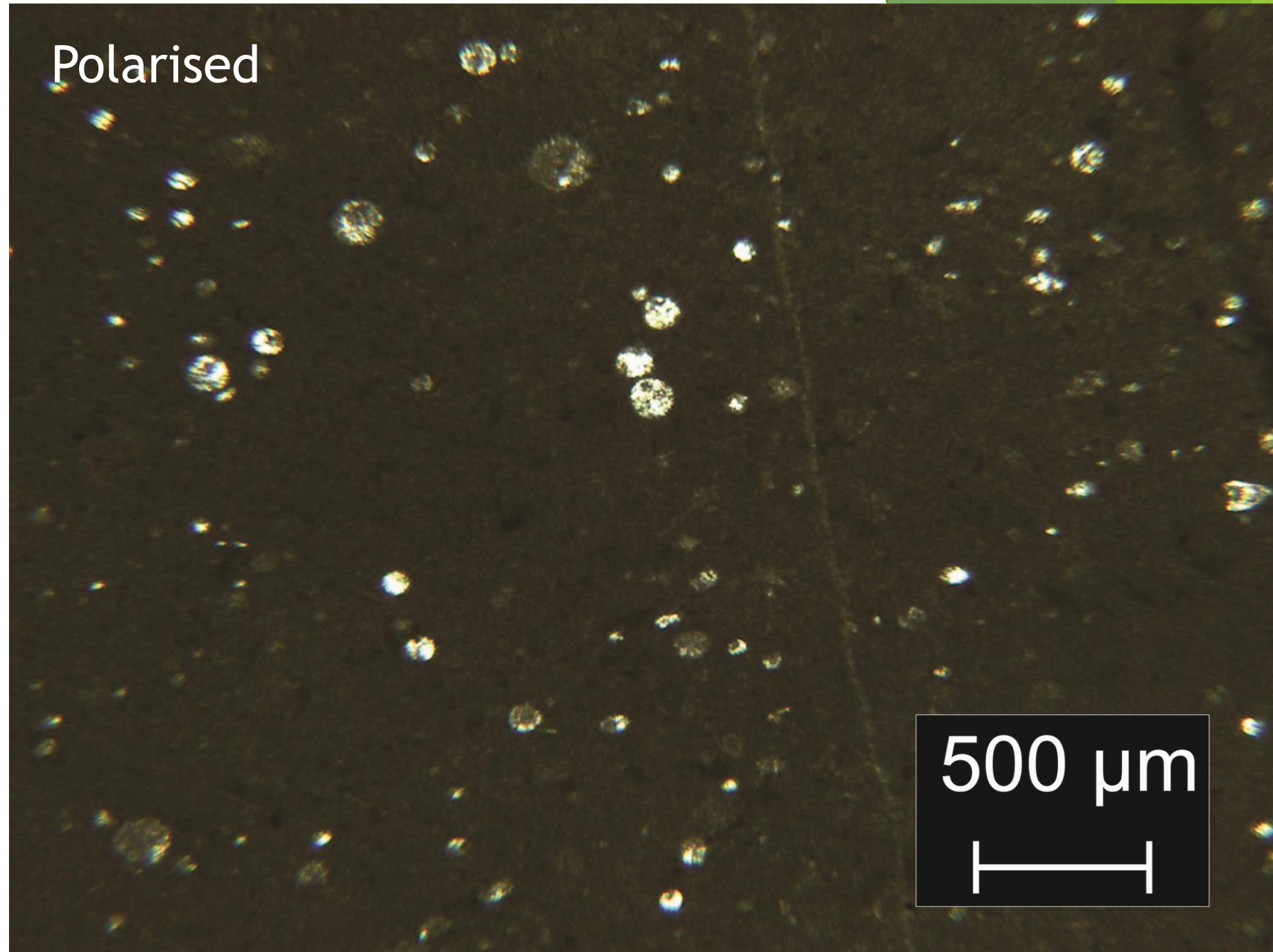


# Chert and limestone in thin sections

Characterization

Polarised

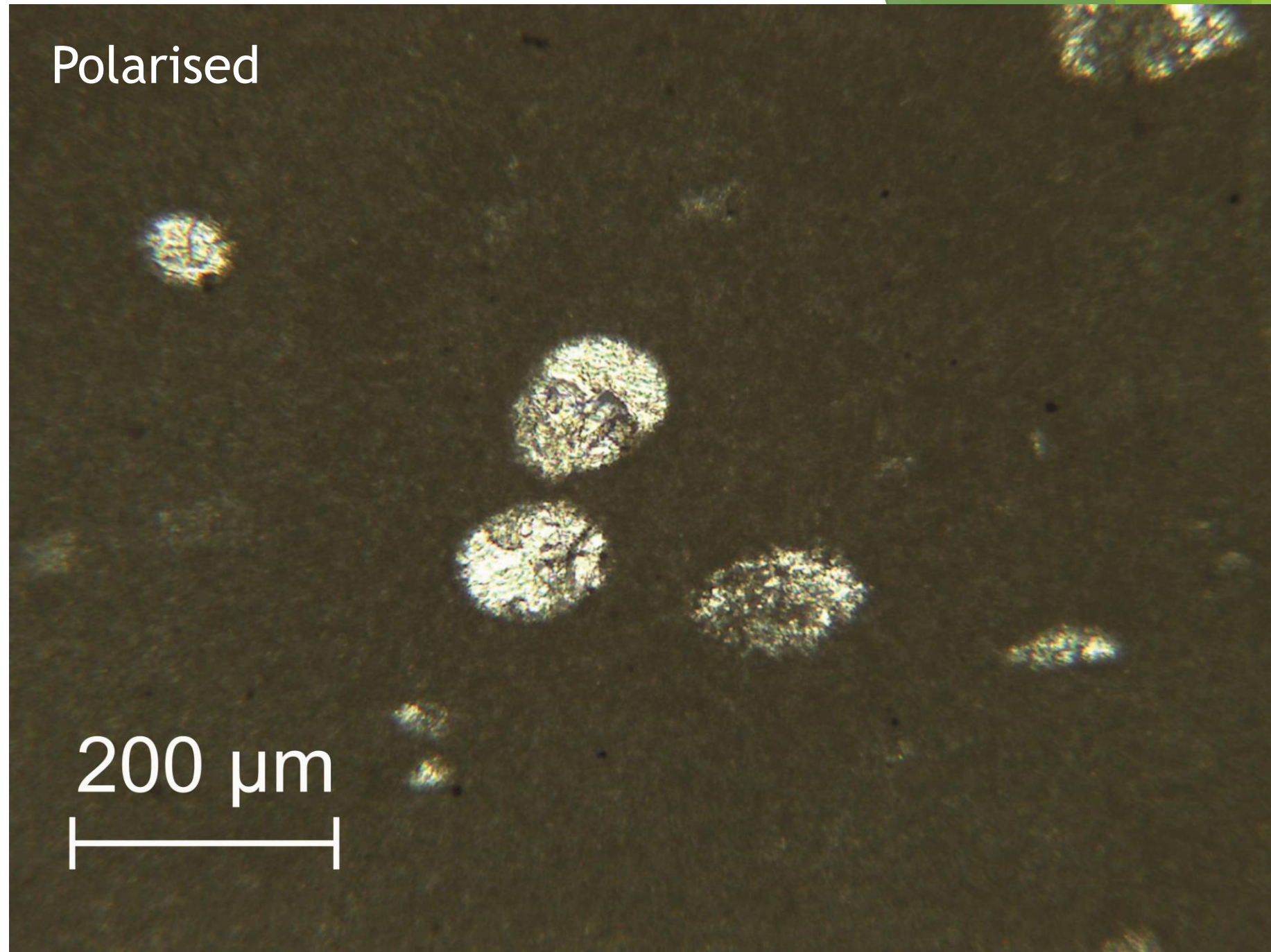
- ▶ Limestone:
  - Fine micrite
  - Calcified radiolaria, badly preserved, visual estimation 5-10%
  - Common stylolites



500  $\mu\text{m}$



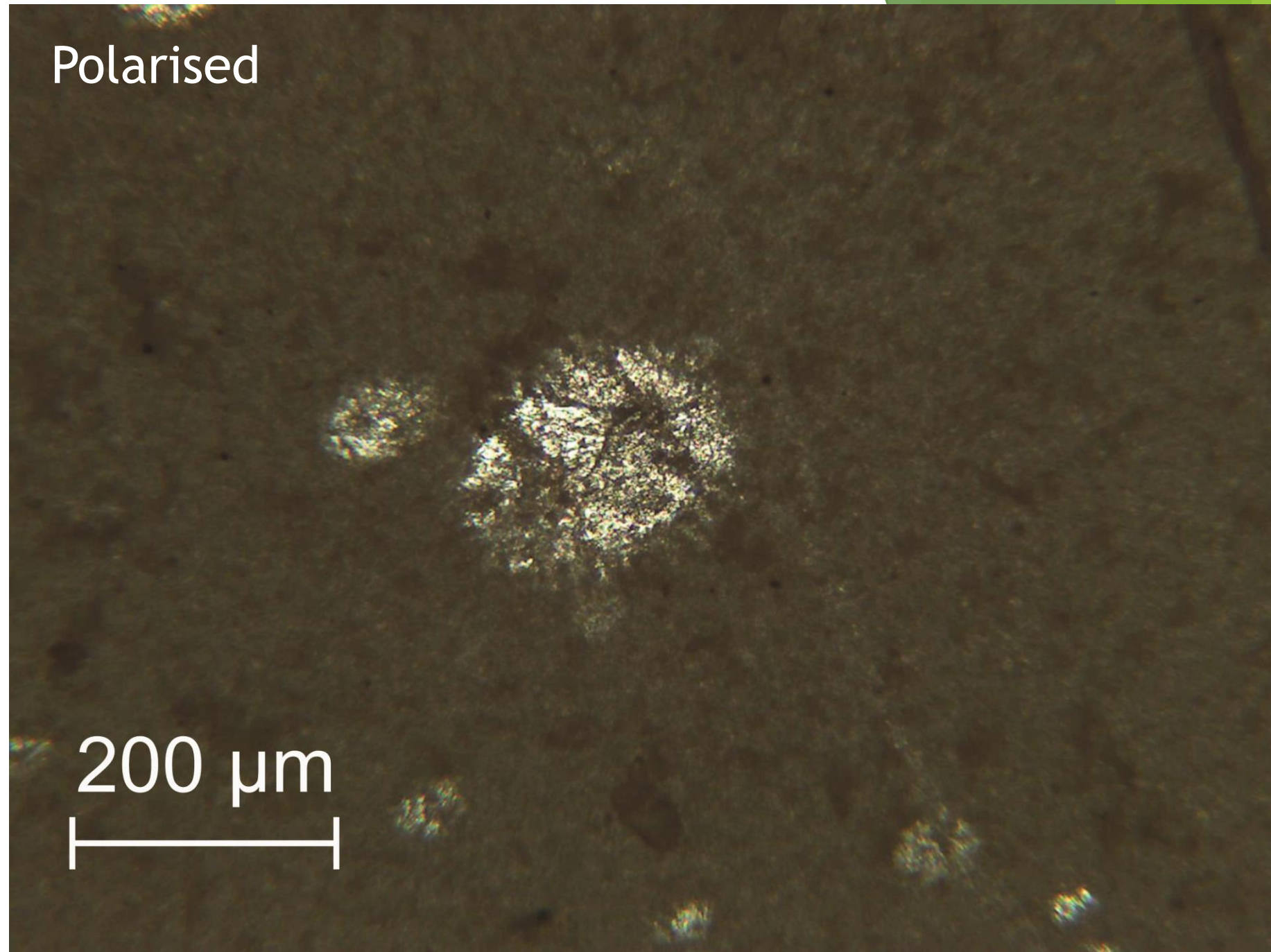
- ▶ Limestone:
  - Fine micrite
  - Calcified radiolaria, badly preserved, visual estimation 5-10%
  - Common stylolites





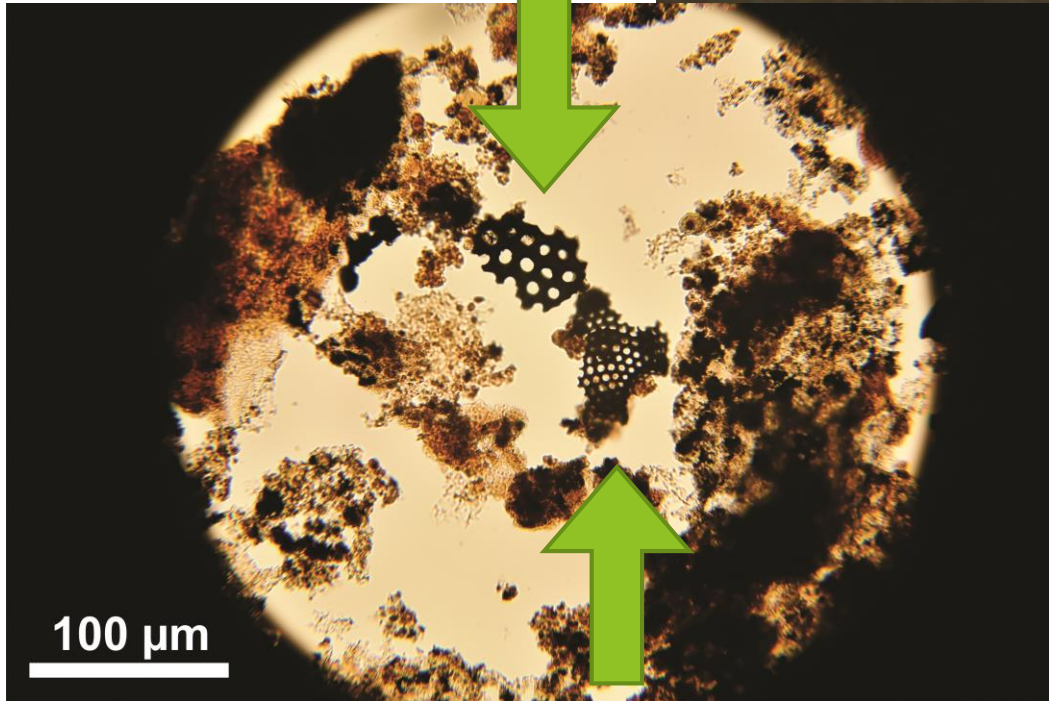
## Polarised

- ▶ Limestone:
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  - Common stylolites

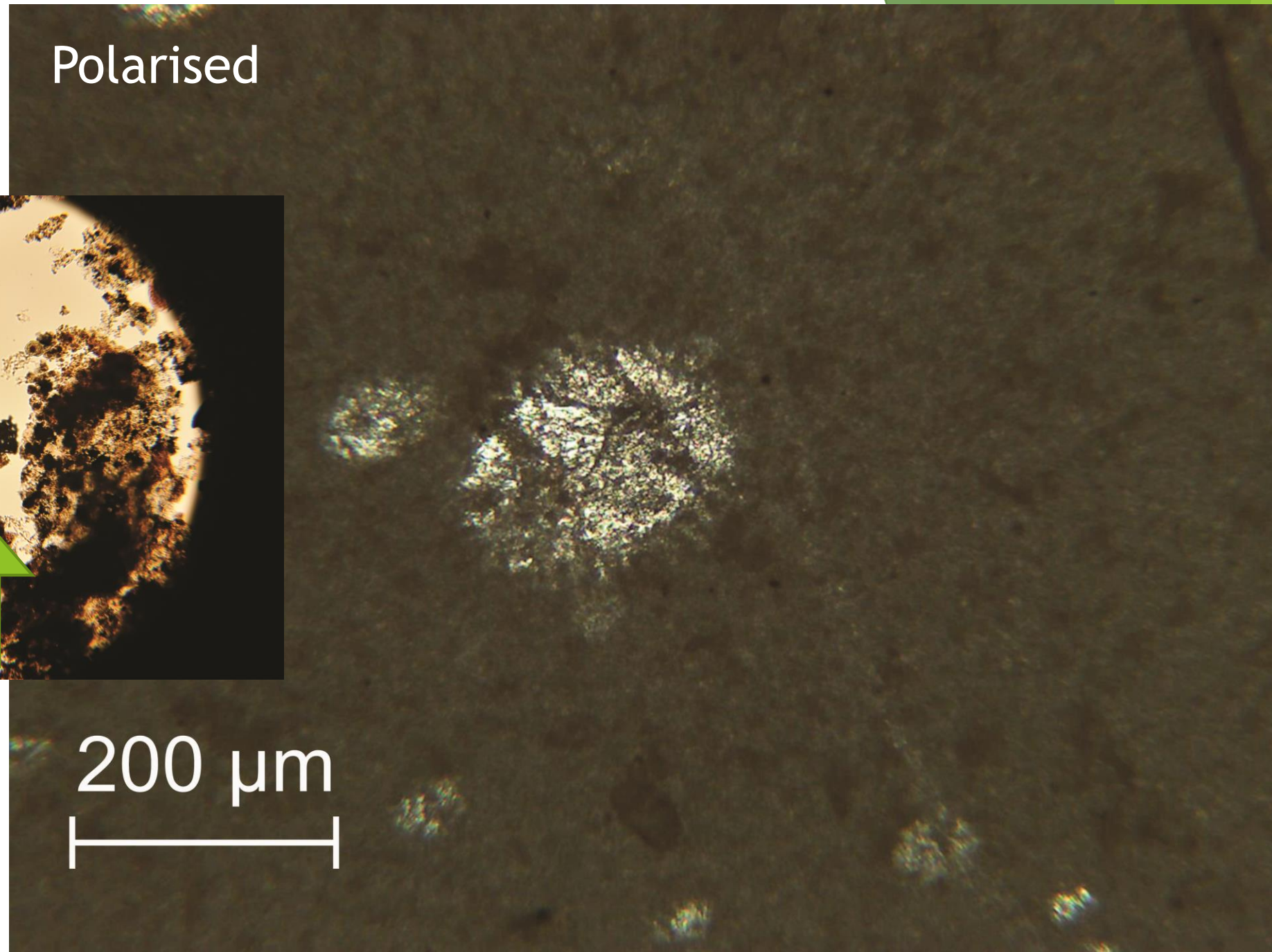




Polarised



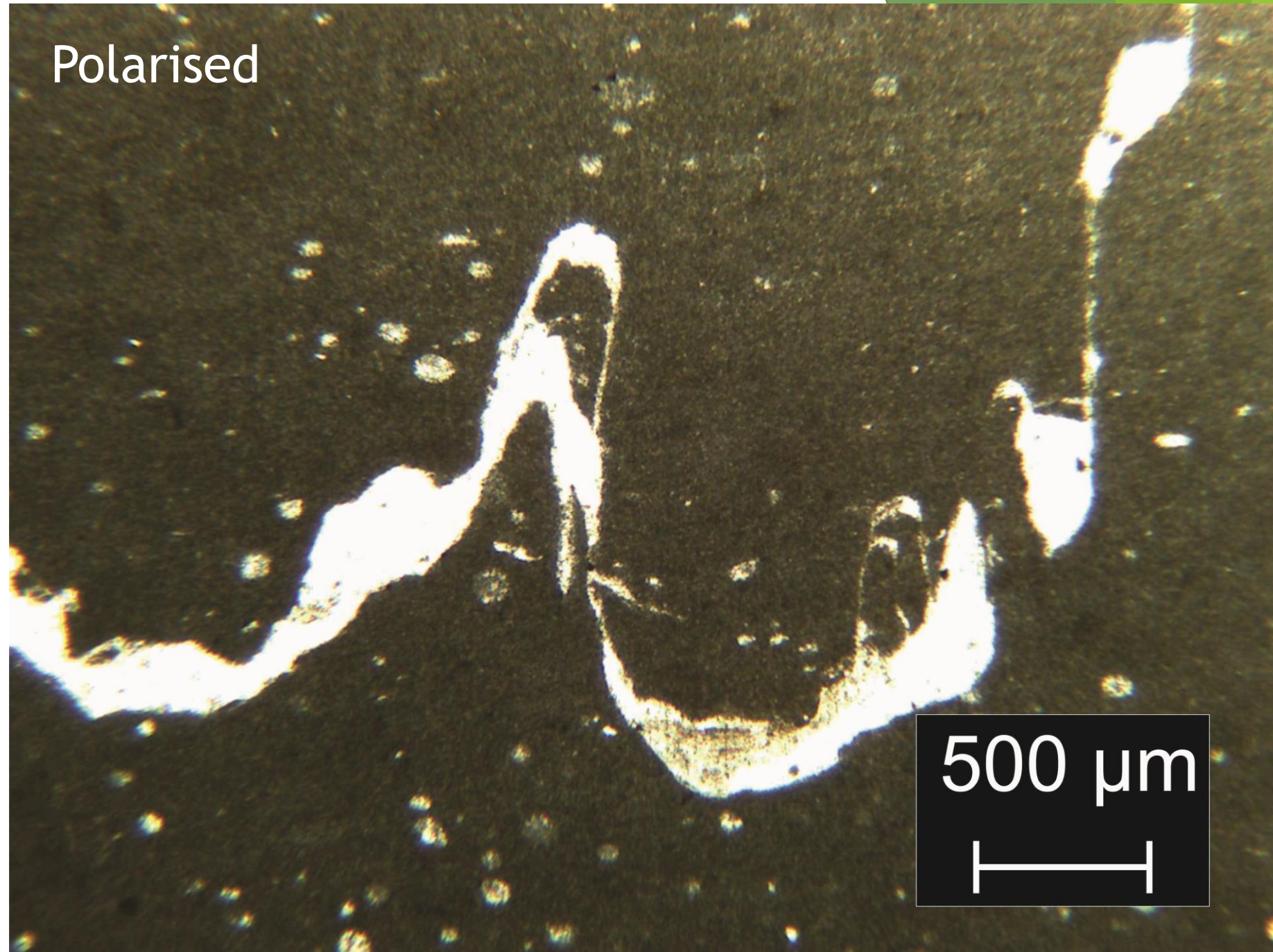
Well preserved (pyritized)  
radiolaria parts in  
palynological thin sections of  
black shale for reference





## Polarised

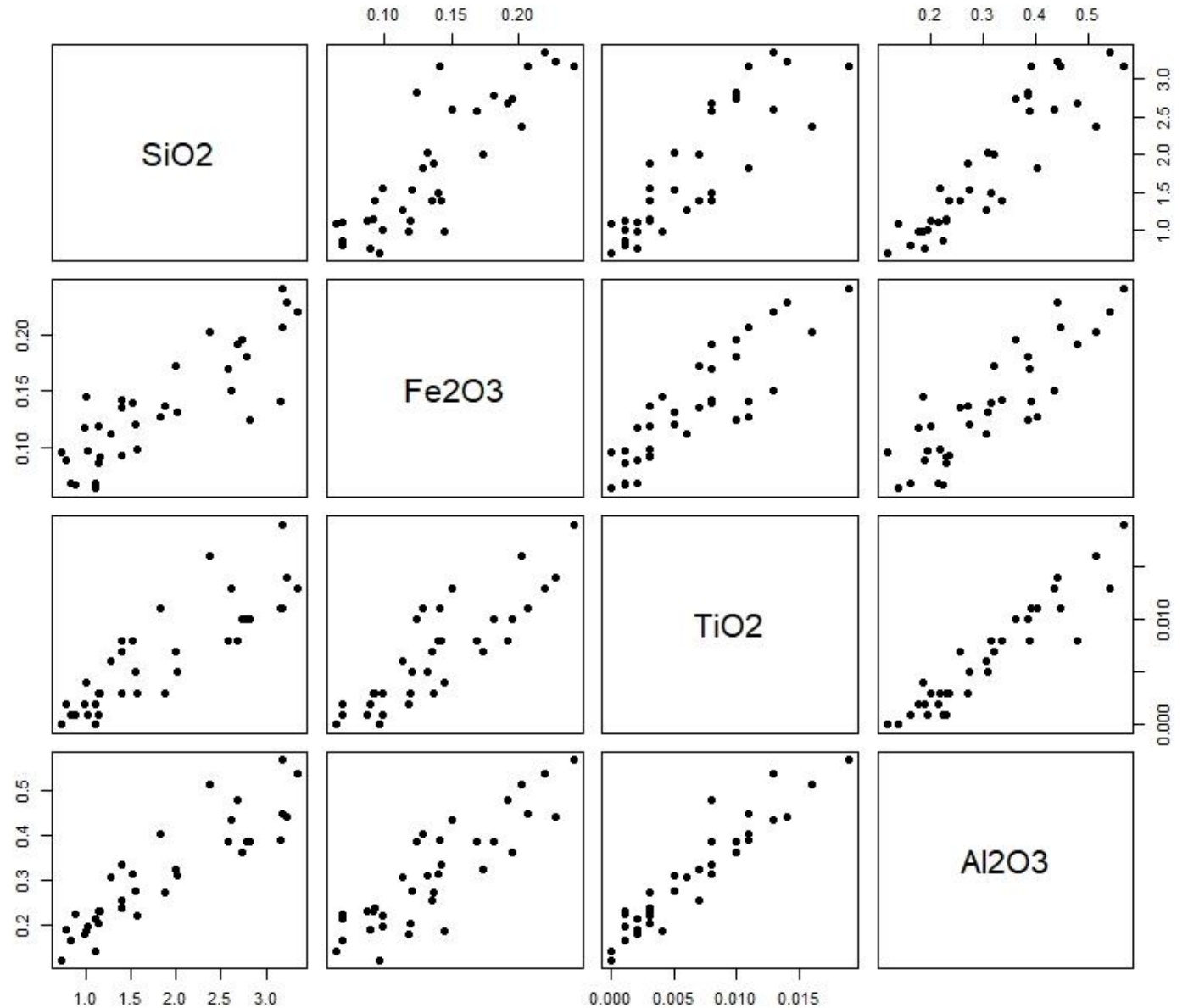
- ▶ Limestone:
  - Fine micrite
  - Calcified radiolaria, badly preserved, visual estimation 5-10%
  - Common stylolites





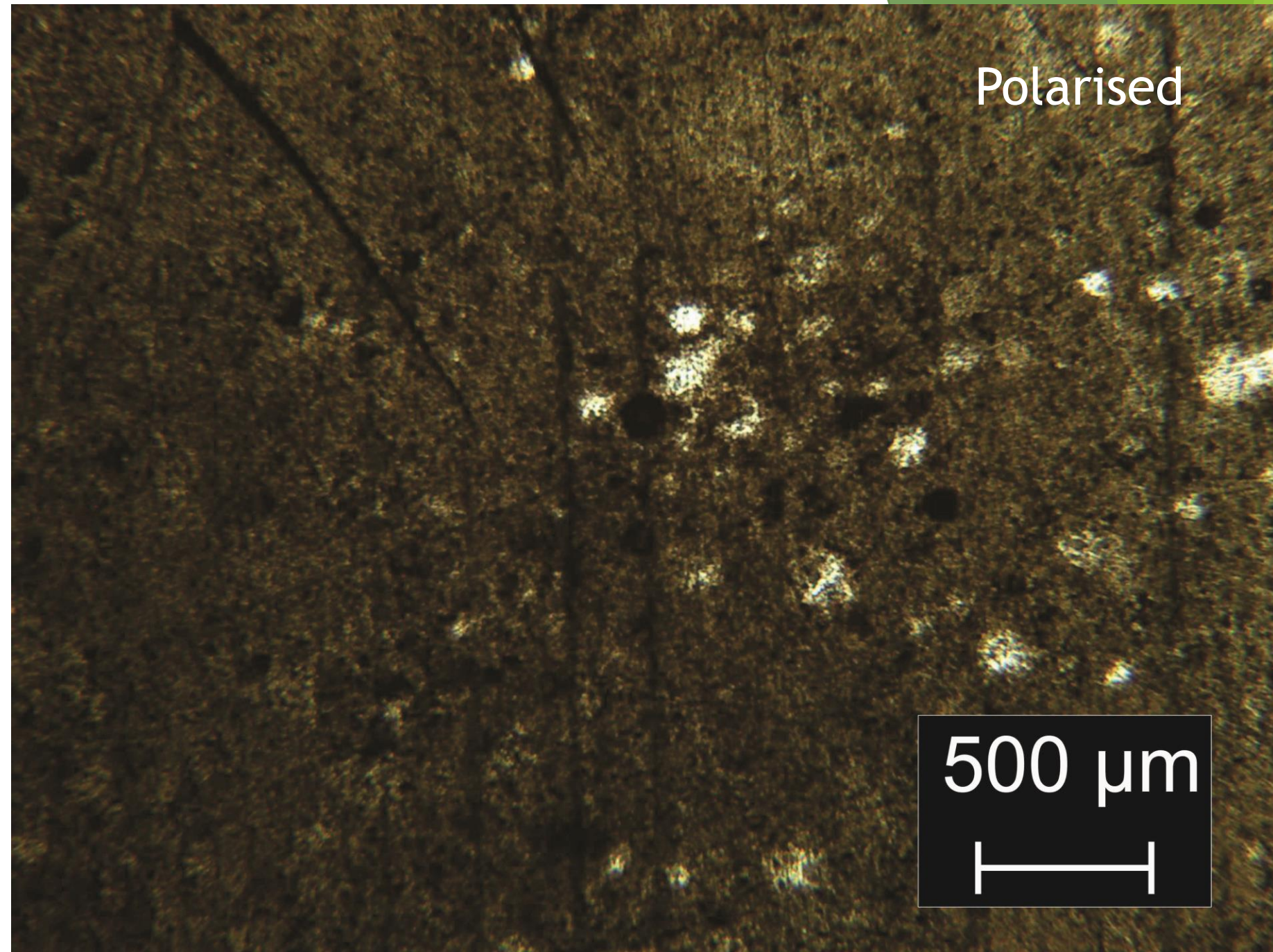
# Limestone

- ▶ Fine micrite
- ▶ Calcified radiolaria, badly preserved, visual estimation 5-10%
- ▶ Common stylolites
  
- ▶ **0.7 to 3.3% SiO<sub>2</sub>**, well correlated to:
  - Fe<sub>2</sub>O<sub>3</sub> (R = 0,84)
  - TiO<sub>2</sub> (R = 0,85)
  - Al<sub>2</sub>O<sub>3</sub> (R = 0,90)



► Cherts:

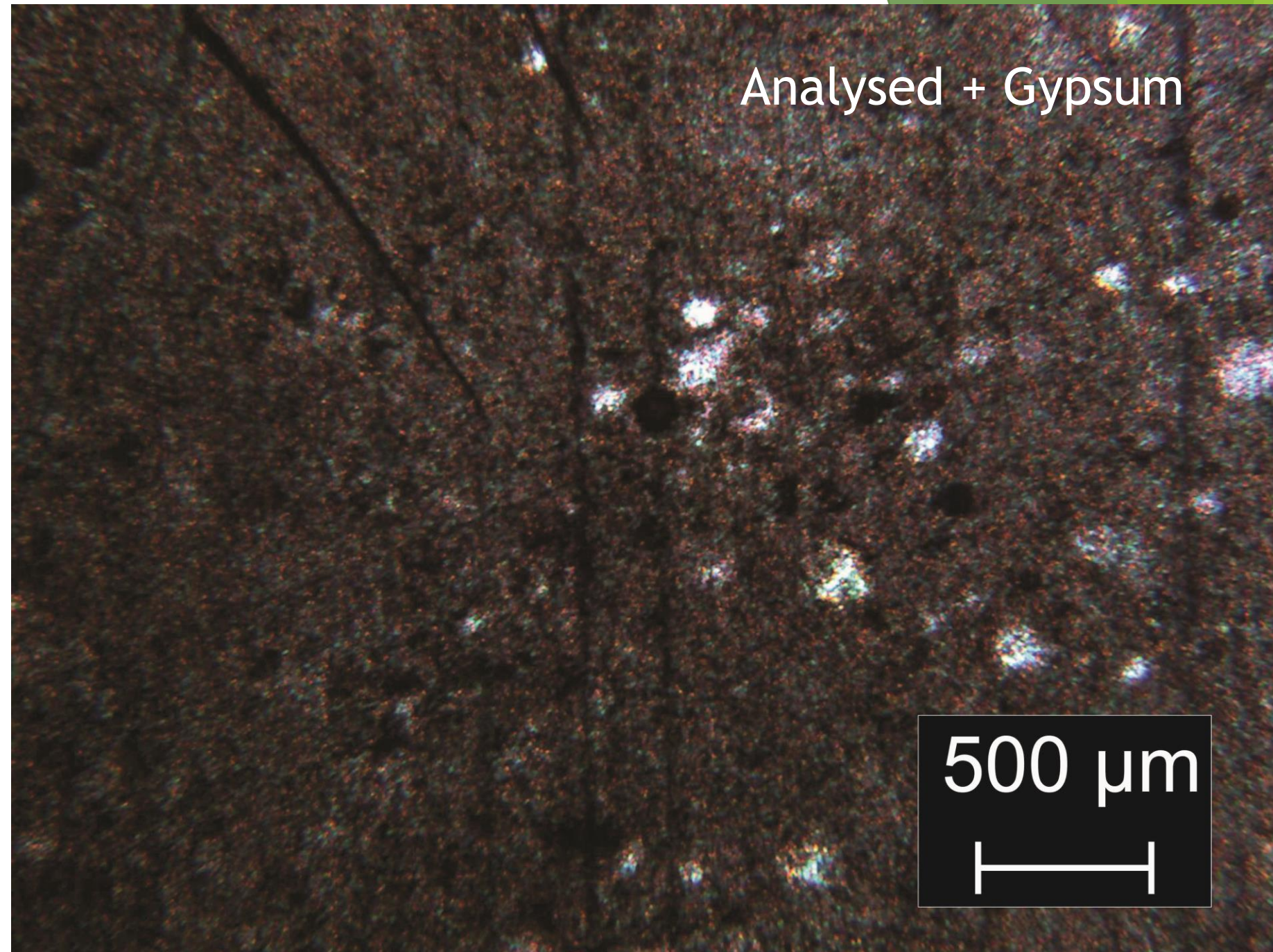
- Microquartz ( $< 20 \mu\text{m}$ )
- Silicified radiolaria in cherts or neighbouring limestones, well preserved, visual estimation 5-10%
- Limestone/chert interface sometimes sharp, sometimes transitional





► Cherts:

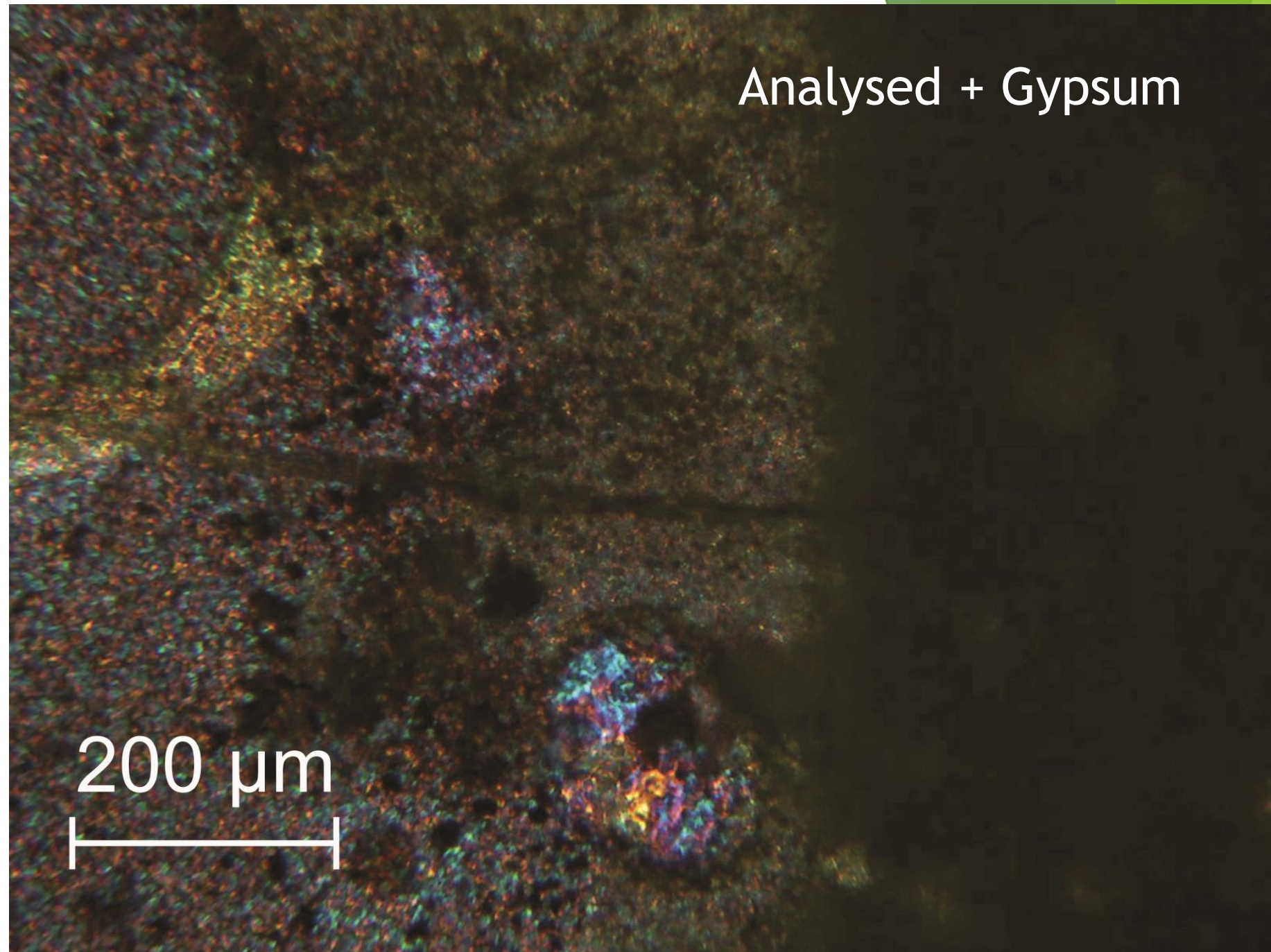
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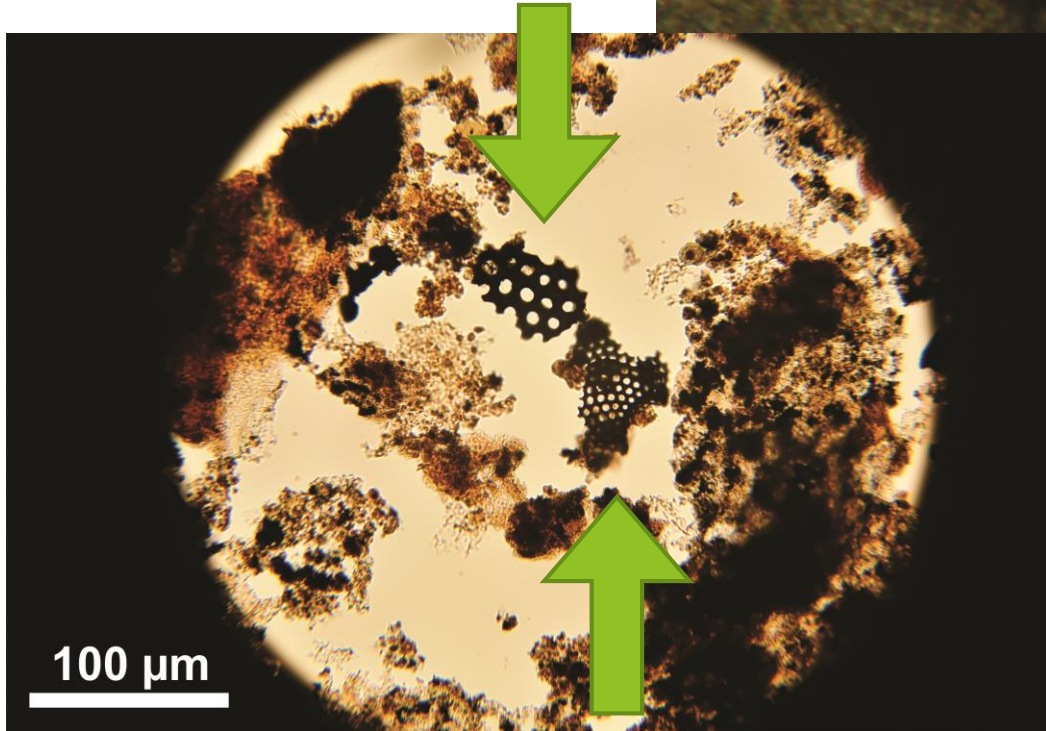
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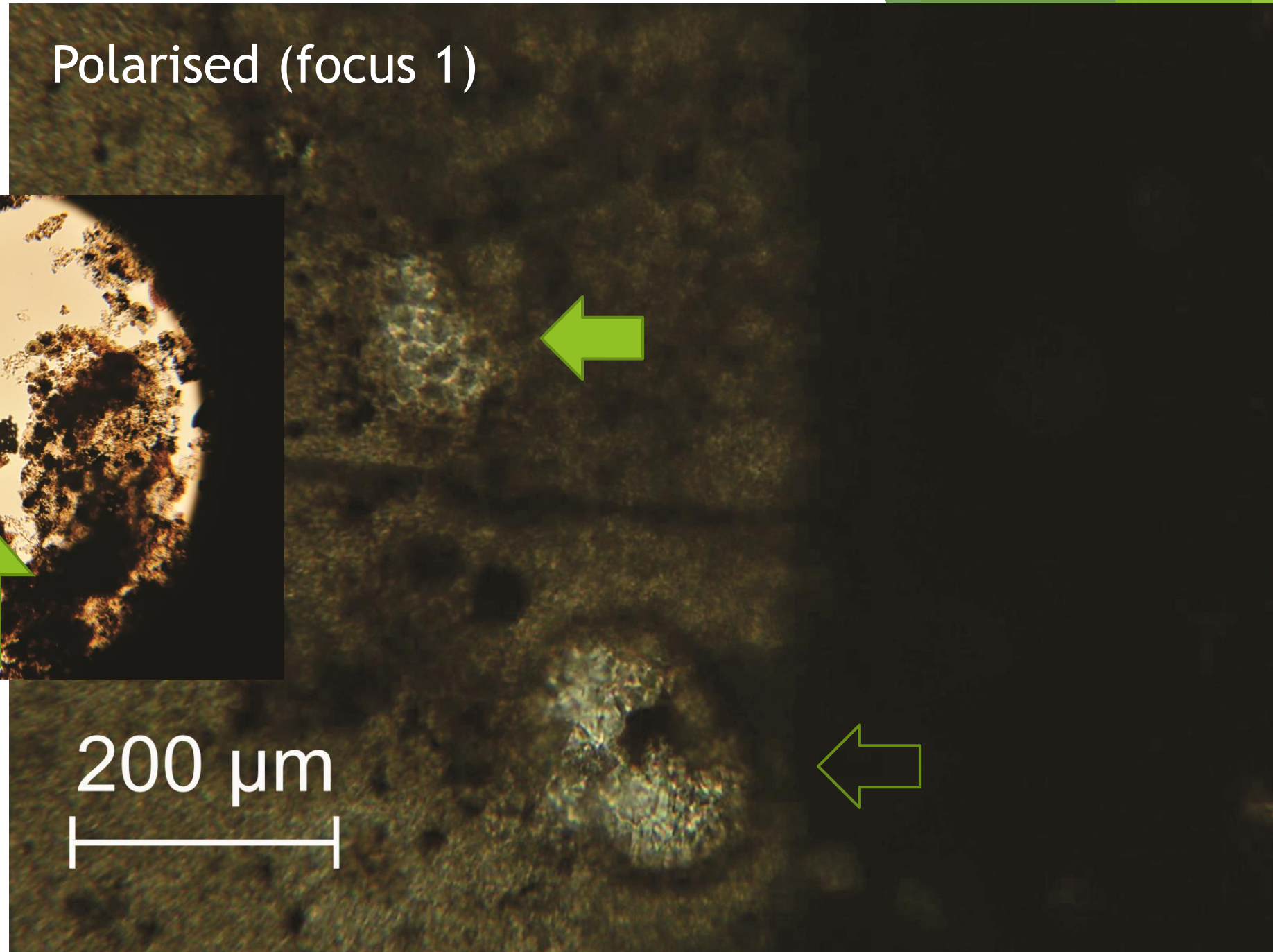




Polarised (focus 1)

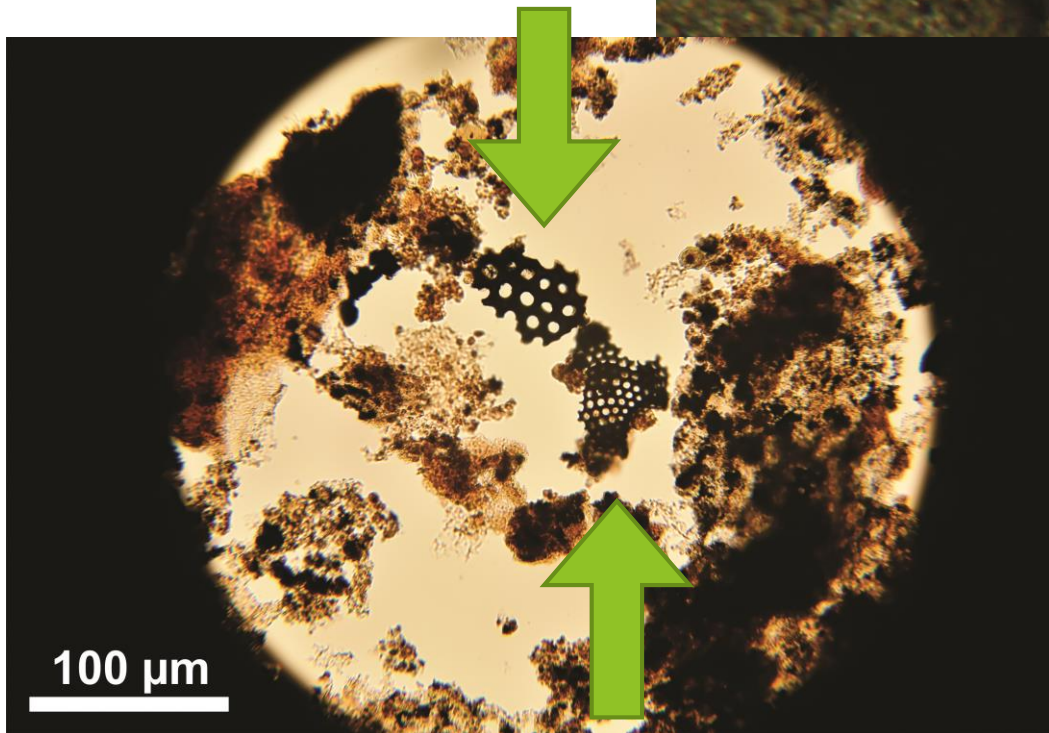


Well preserved (pyritized)  
radiolaria parts in  
palynological thin sections of  
black shale for reference

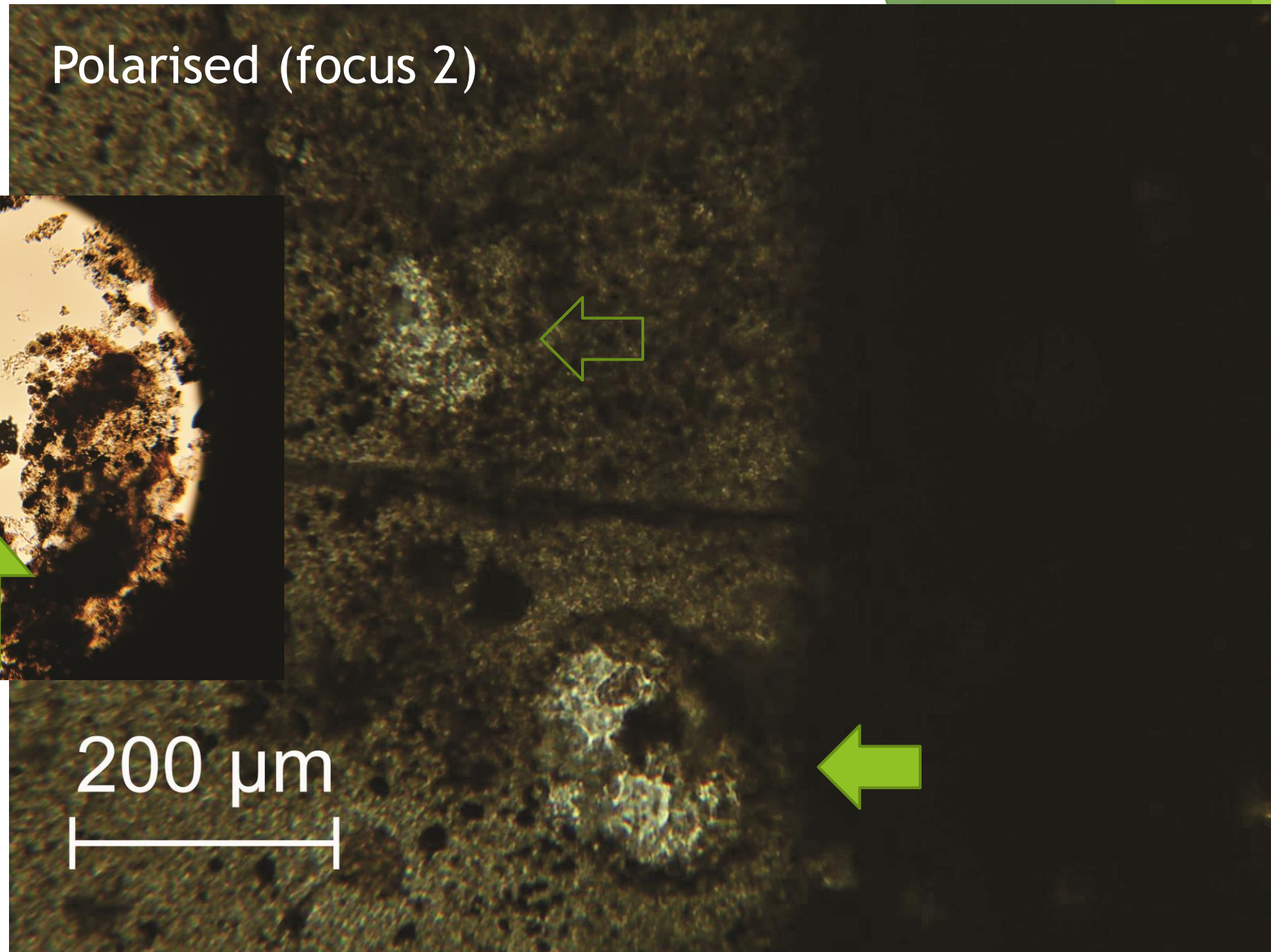




Polarised (focus 2)



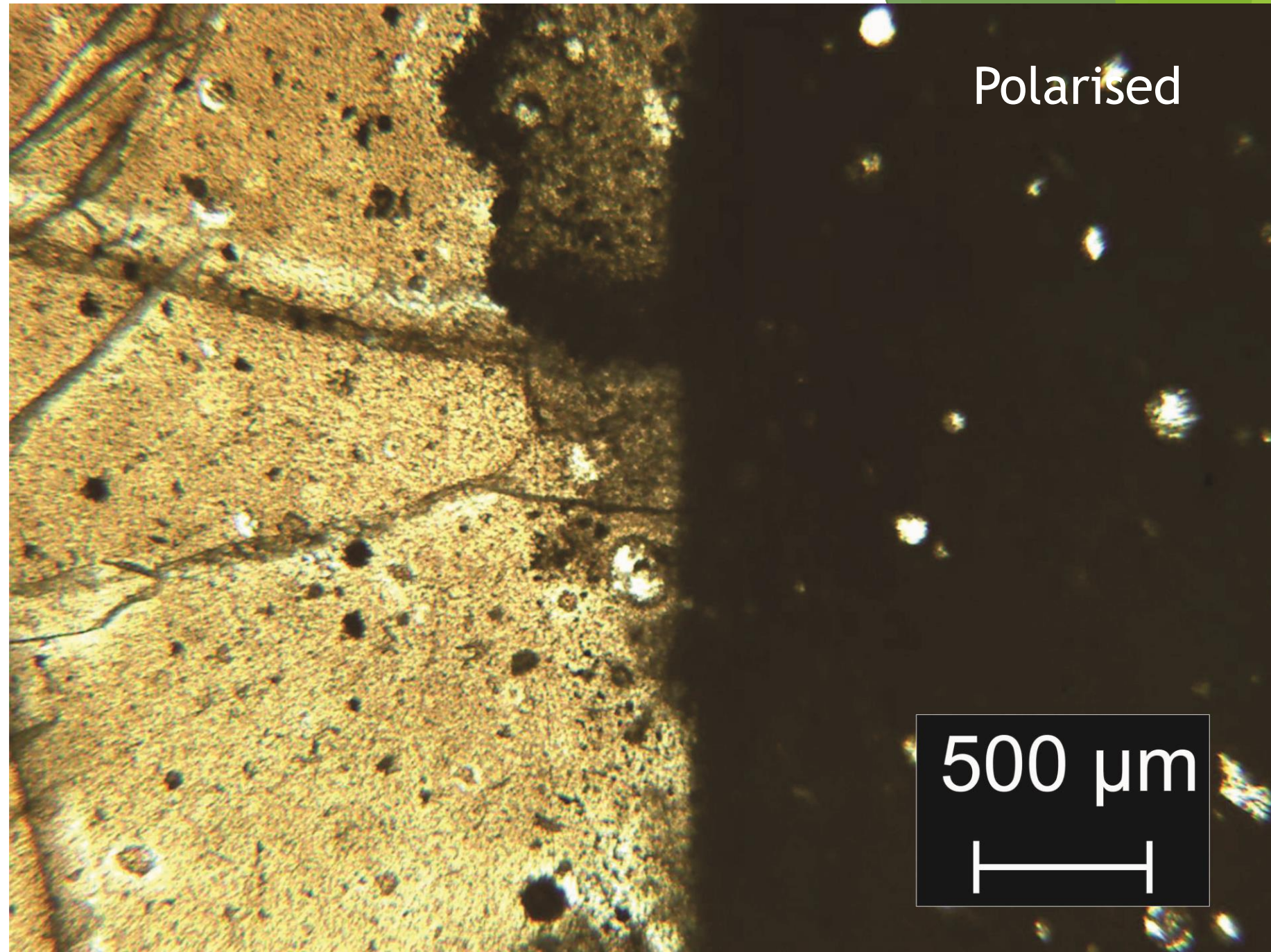
Well preserved (pyritized)  
radiolaria parts in  
palynological thin sections of  
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► Cherts:

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- Silicified radiolaria in cherts or neighbouring limestones, well preserved, visual estimation 5-10%
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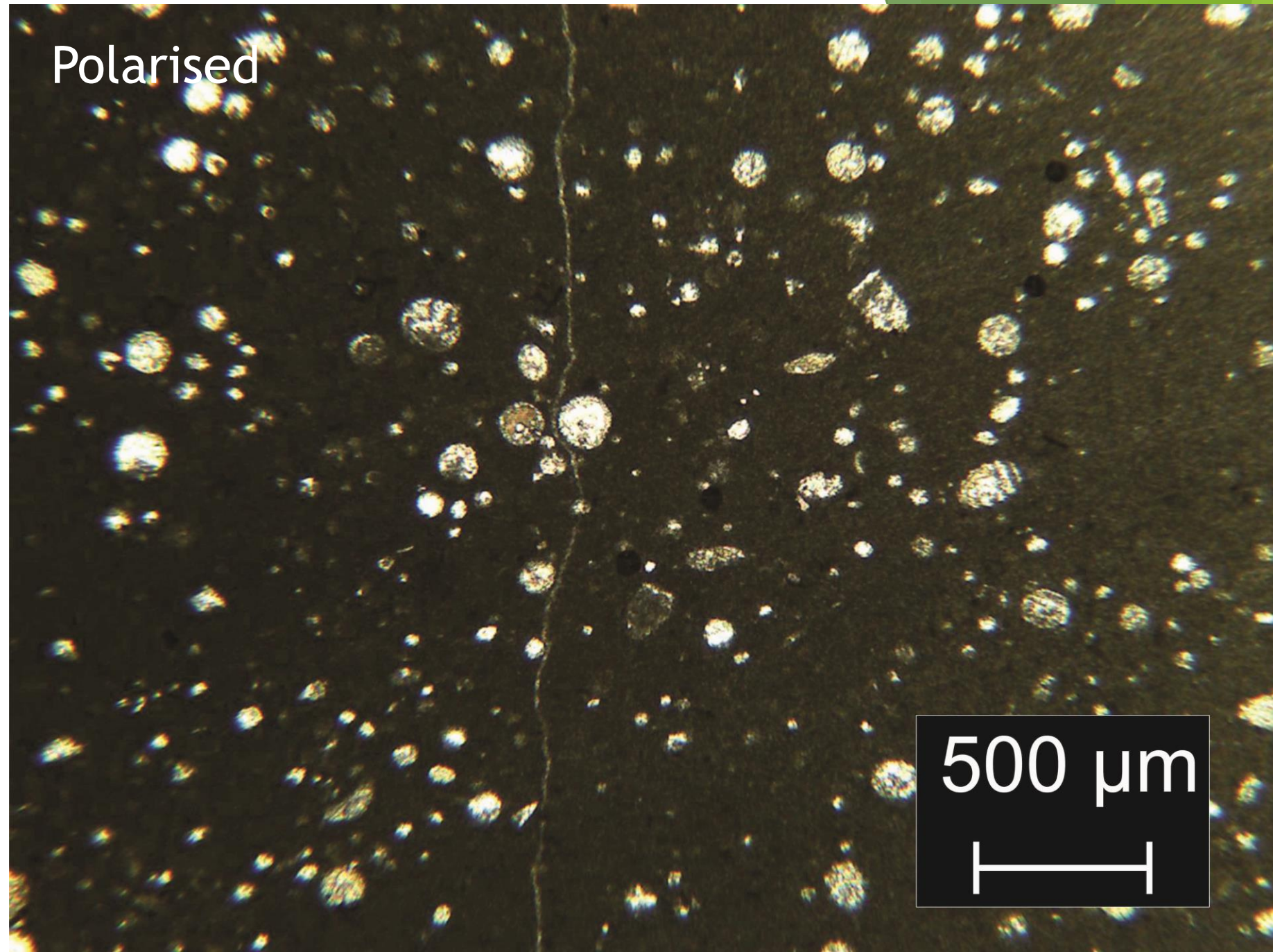


# Chert

- ▶ Microquartz (< 20  $\mu\text{m}$ )
- Silicified radiolaria in cherts or neighbouring limestones, well preserved, visual estimation 5-10%
- ▶ Limestone/chert interface sometimes sharp, sometimes transitional
- ▶ Purest samples:
  - (less than 1% CaO, assumed without contamination, 7 samples on 11)
  - 96 to 98%  $\text{SiO}_2$
  - $\text{TiO}_2$  and  $\text{Al}_2\text{O}_3$  mean values similar to the ones of limestones (but correlations between detrital elements are weak)
  - $\text{Fe}_2\text{O}_3$  mean values 40% of that of the limestones, magnetic susceptibility systematically lower than in limestones

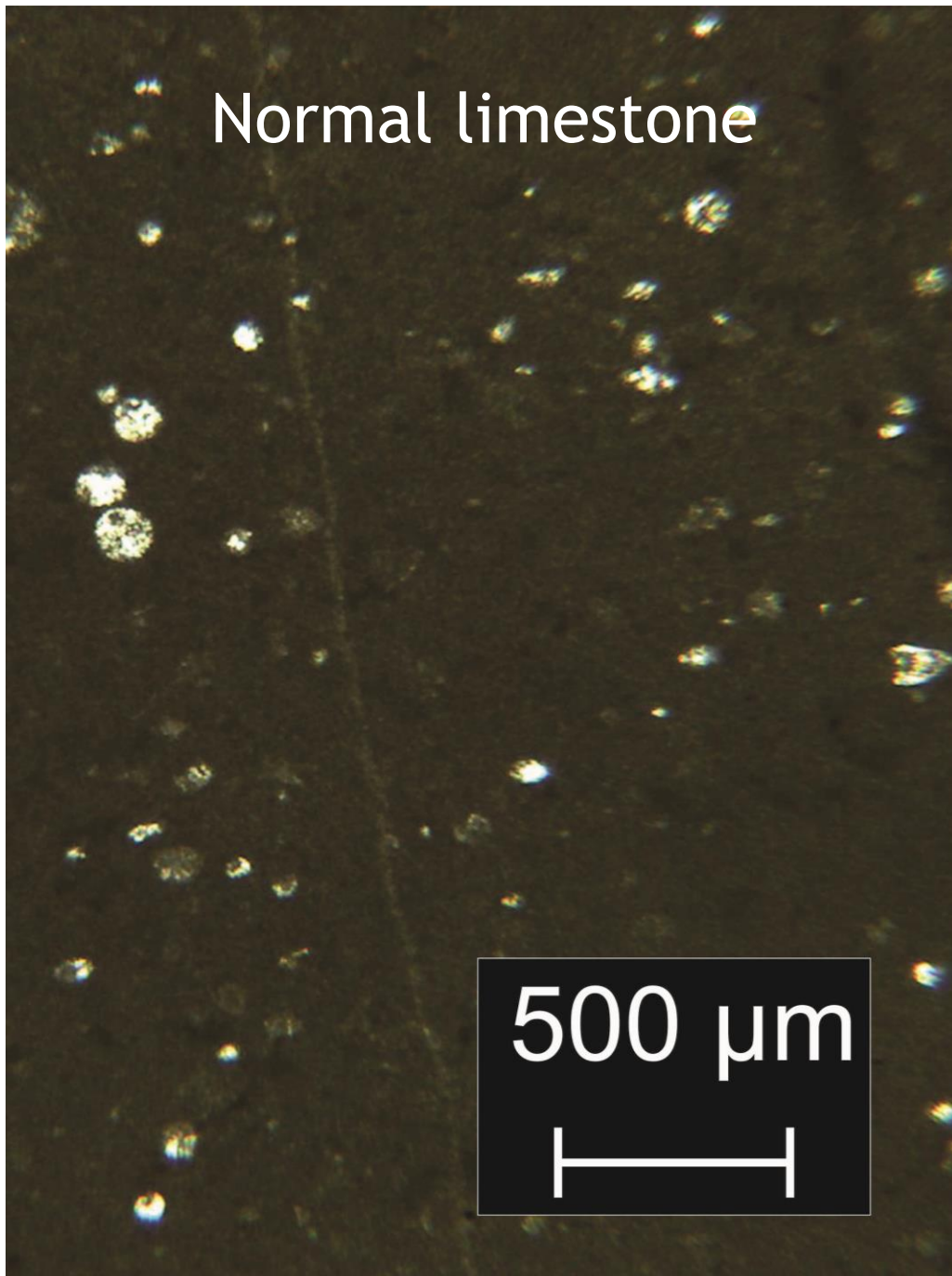
## Polarised

- ▶ Radiolaria rich limestones (3 samples):
  - Higher than average radiolaria density (15-20 %)
  - Associated with cherts nodules
  - Well preserved silicified radiolaria in limestone
  - 15% SiO<sub>2</sub> (1 sample), probably from small nodules, highest Fe content of limestones

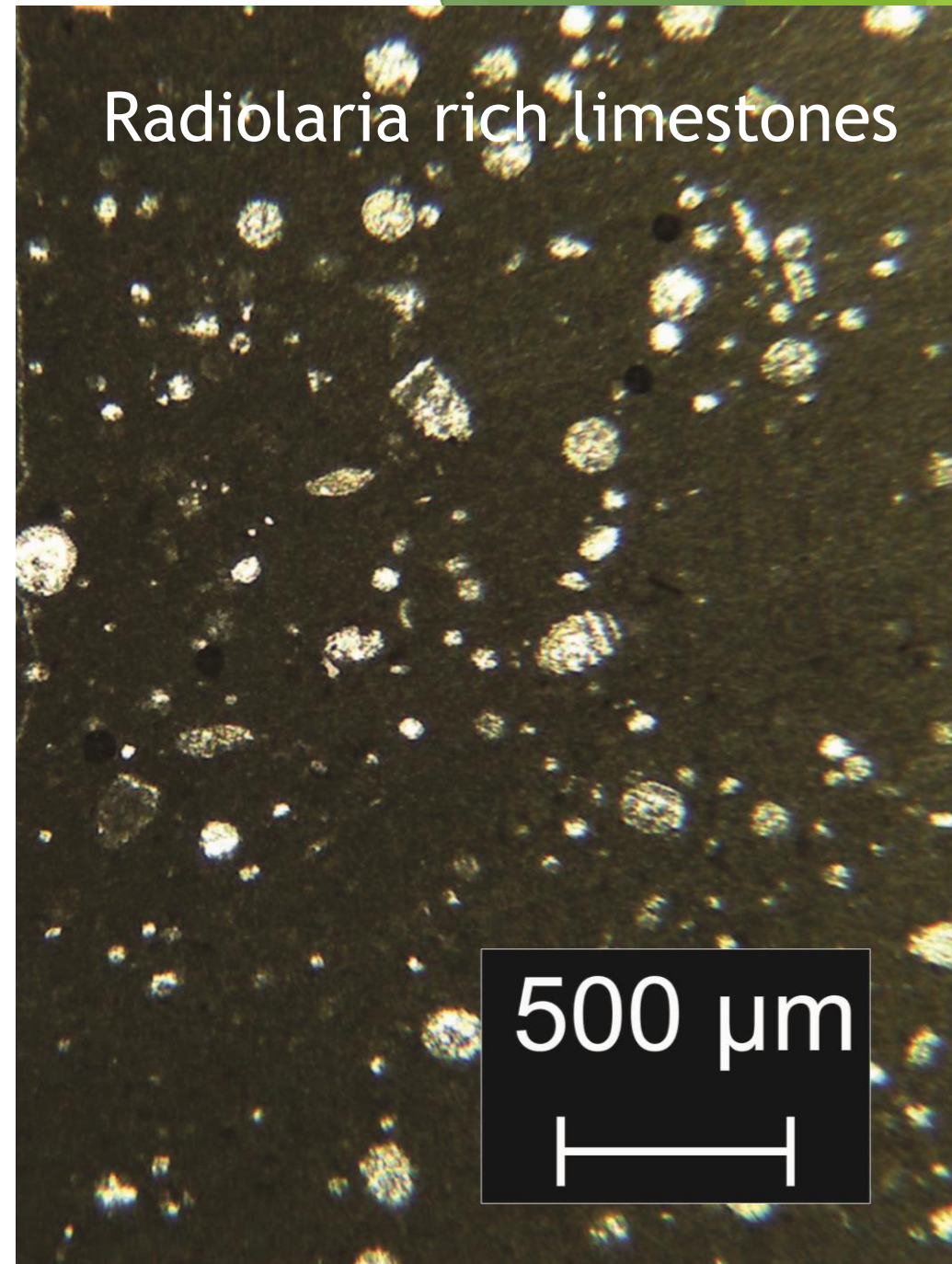




Normal limestone

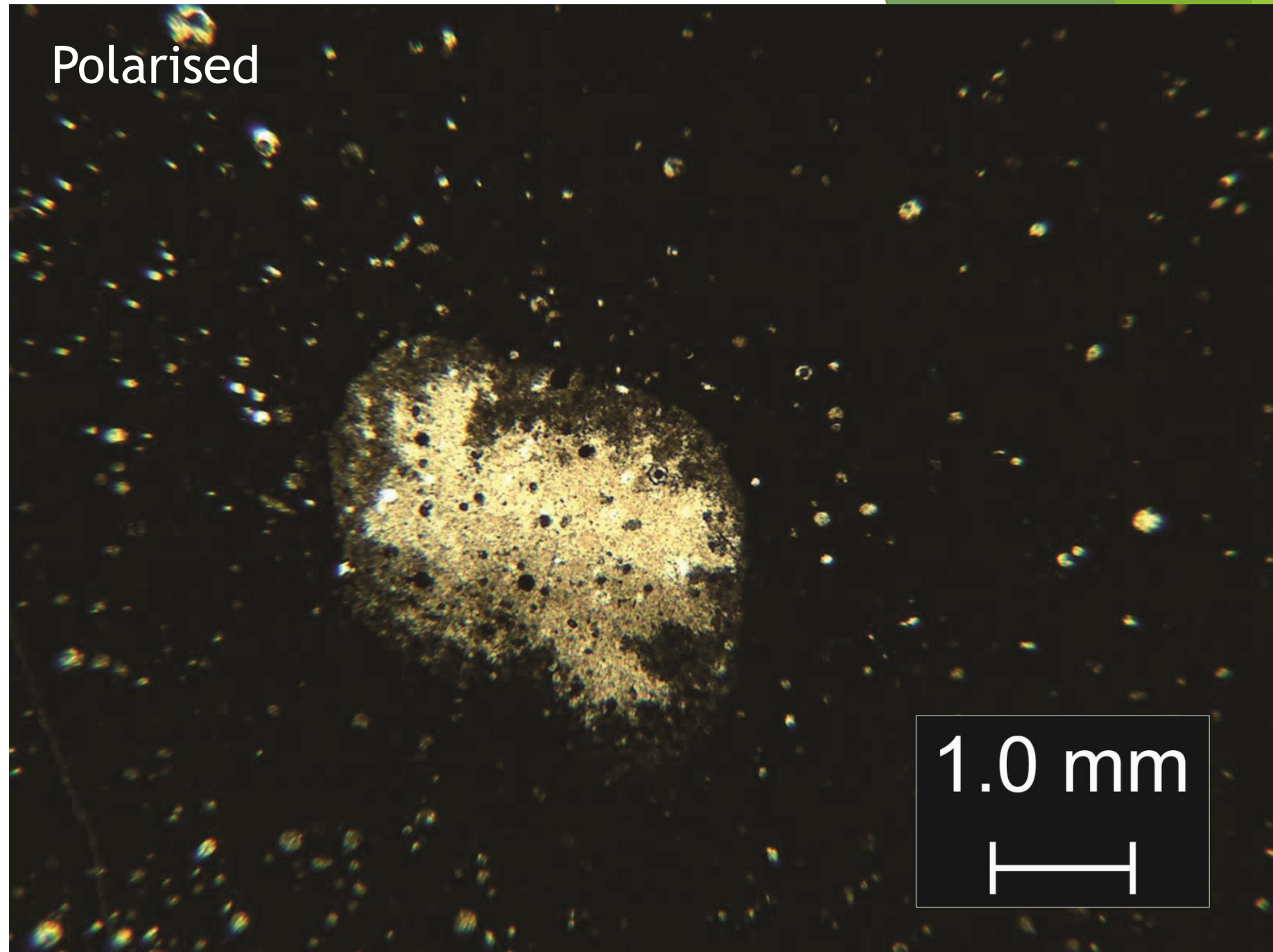


Radiolaria rich limestones



## Polarised

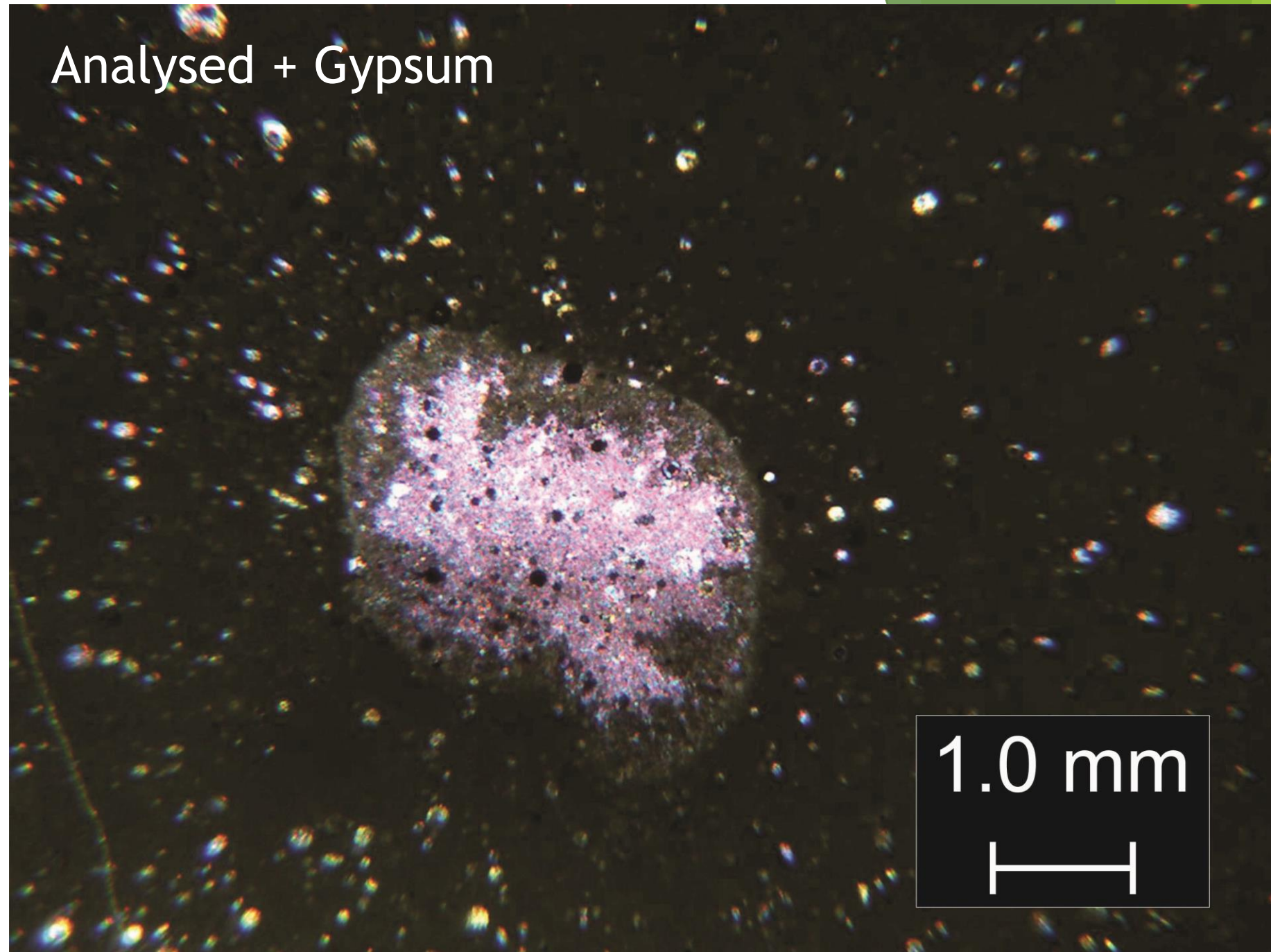
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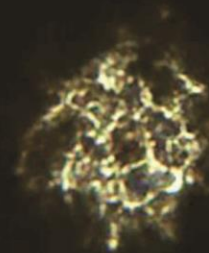
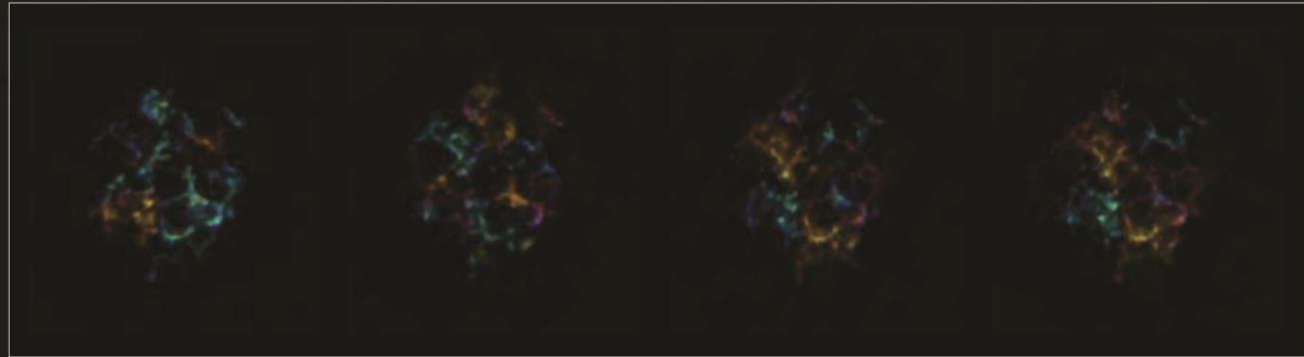
## Analysed + Gypsum

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200 μm





# Diagenetic effect

- ▶ Thorough **segregation** of mobile **Si** and **Ca** between cherts and limestones
- ▶ Similar concentrations of **radiolaria**, **Ti** and **Al** in cherts and limestones
- ▶ The abundance of cherts in the section (estimated from **5 to 12%** based on lithological observation) is coherent with the visual abundance of radiolaria observed in most thin sections (**5 to 10%** cherts and limestones alike)
  
- ▶ Relatively low **Fe** concentrations and low magnetic susceptibility in cherts: iron oxides dissolution ?
  
- ▶ Intermediary samples of limestone with high radiolaria density and chert nodules

# Discussion

- ▶ Is there a primary signal preserved in the limestone/chert alternation ?
- ▶ Is the diagenetic effect reinforcing the alternations or creating them entirely ?

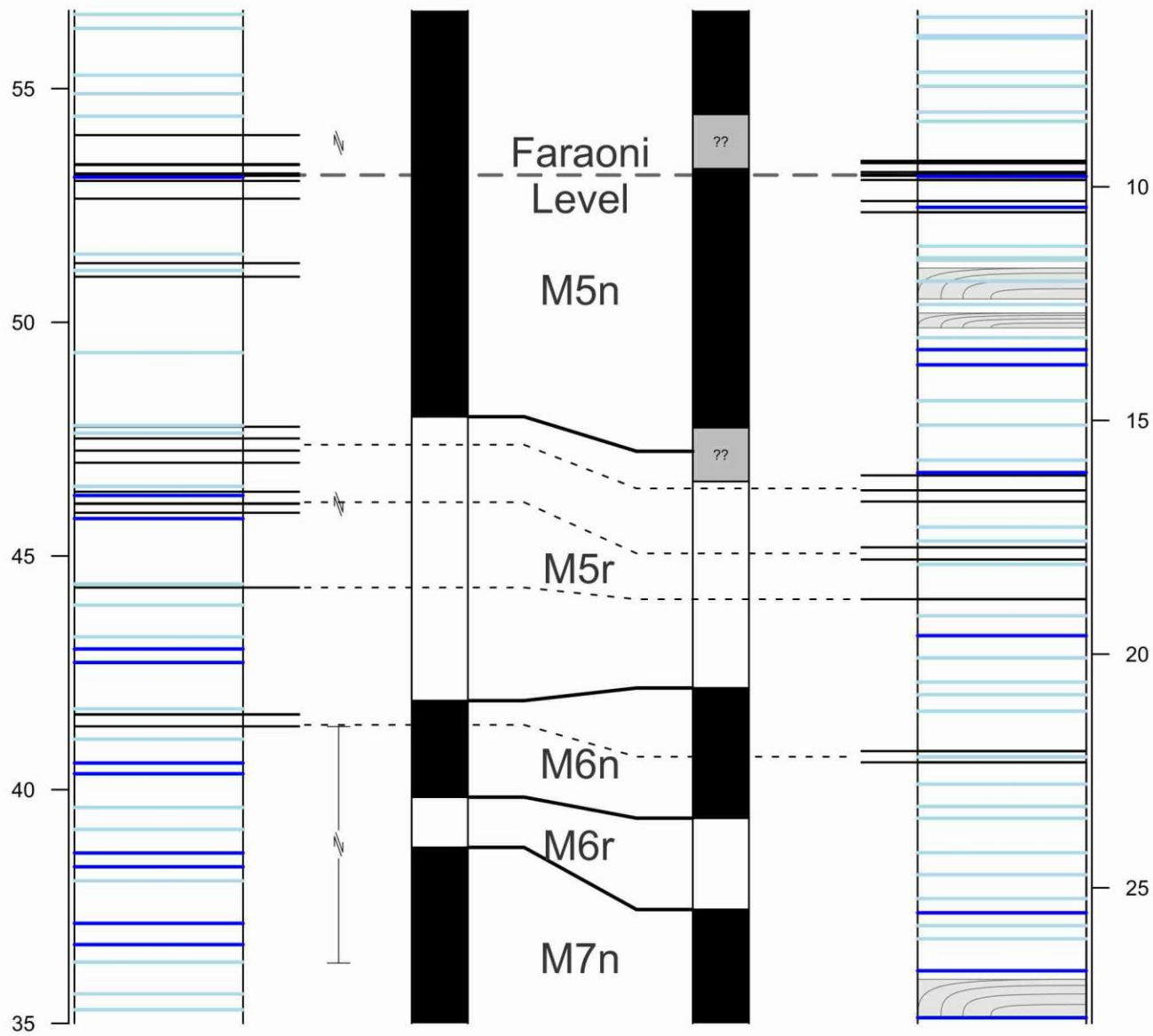
**“...opal-CT nucleation during chertification is largely heterogeneous on pre-existing opal-CT crystals...”** (Maliva and Siever, 1989)

Mechanisms explaining chert formation allow for both possibilities











# Bosso

# Frontone



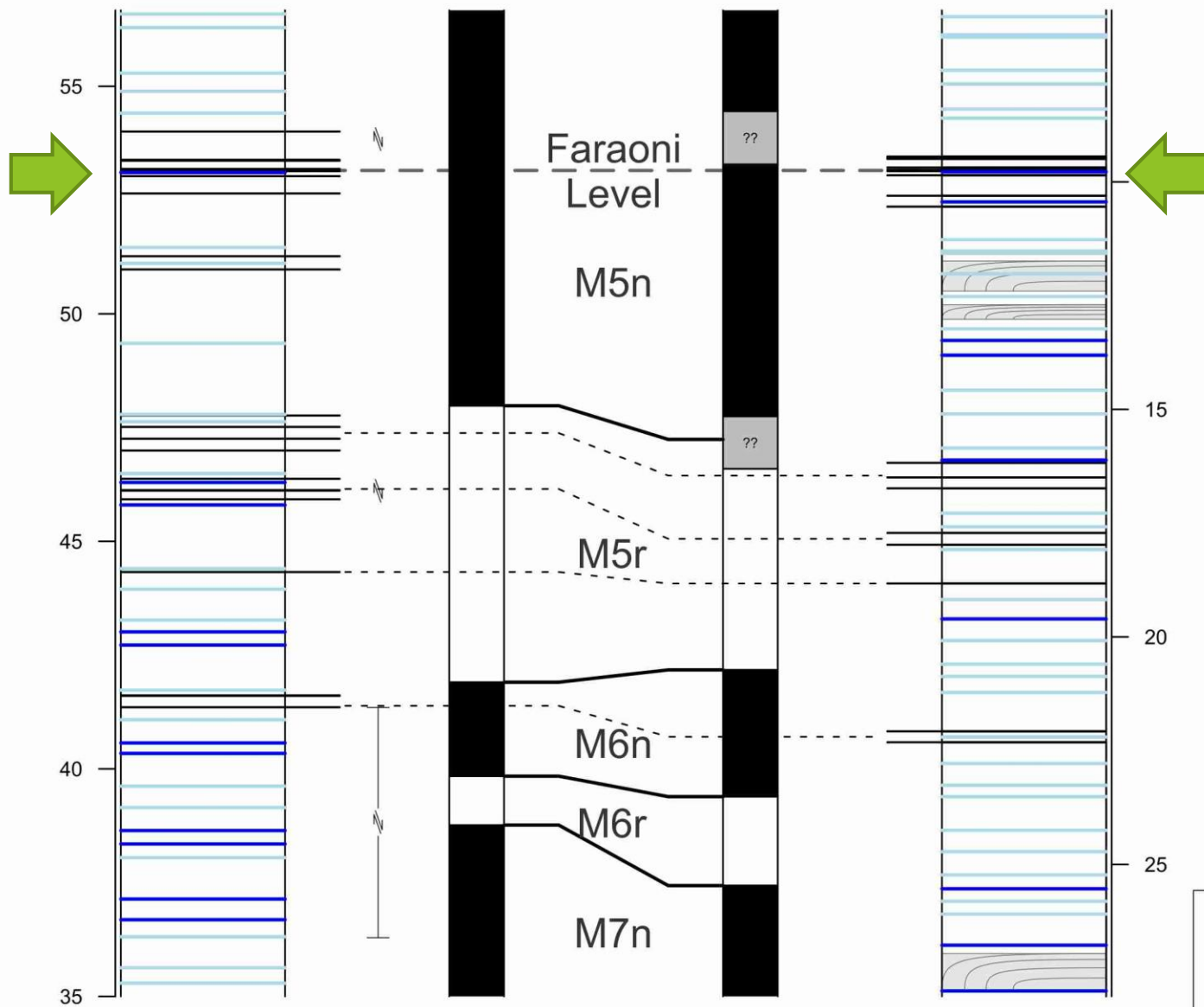
## Synthetic litholog legend

-  Limestones and cherts
-  Black shale levels
-  Fractured zone
-  Slump
-  Slump with basal erosion scar
-  Fault







-  Chert Beds
-  Stratified Chert Nodules



# Bosso

# Frontone



## Synthetic litholog legend

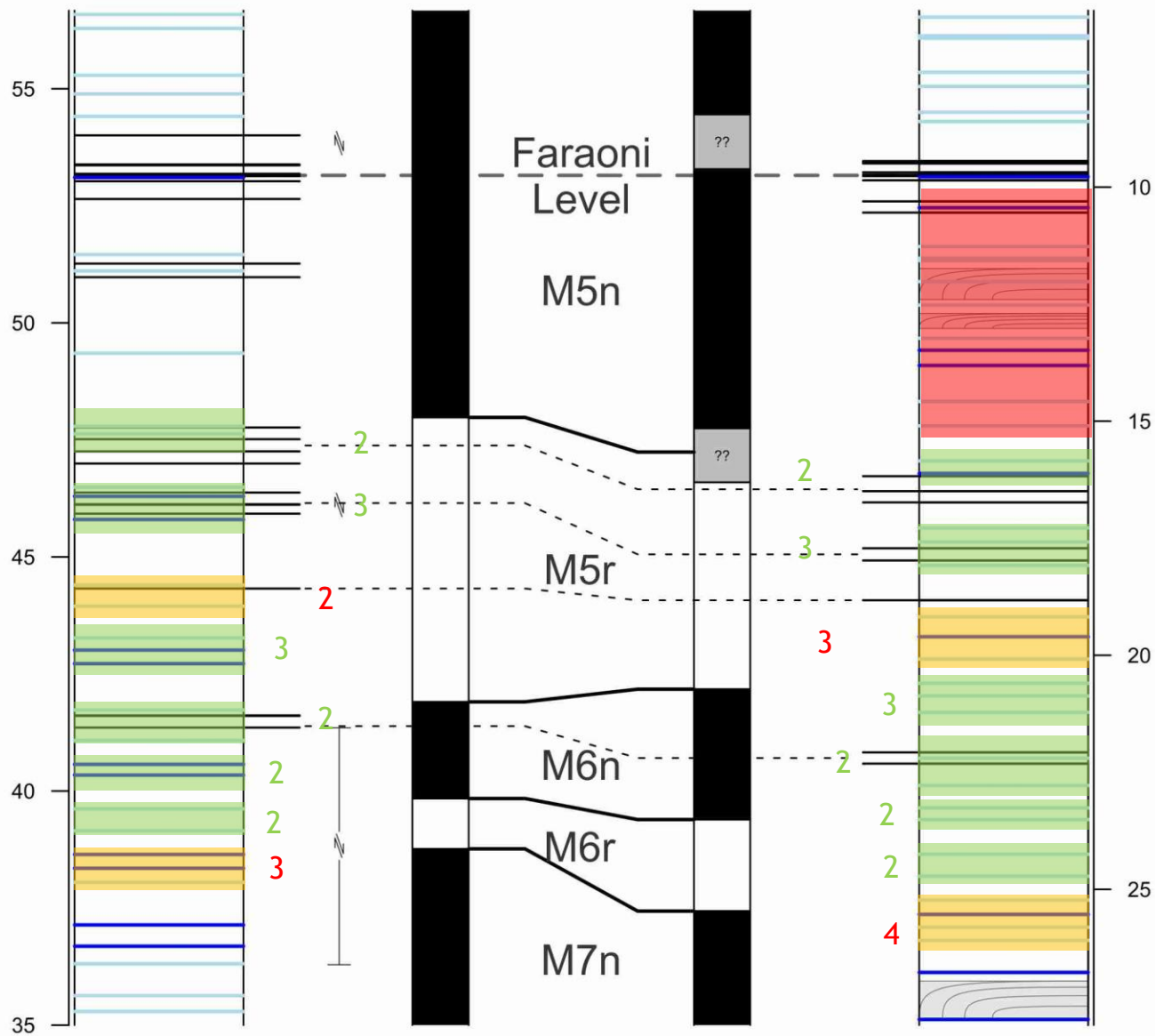
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# Bosso

# Frontone



## Synthetic litholog legend

-  Limestones and cherts
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-  Chert Beds
-  Stratified Chert Nodules

# Using stratigraphy to study diagenesis

- ▶ Chert **beds** and **stratified nodules** can be correlated as bundles in some parts of the sections, with some only small offsets in relation with black shales and a few differences in number of cherts
- ▶ Beds can be correlated to nodules and vice-versa
- ▶ Some parts of the sections are not correlatable (extending beyond the slump-affected parts in Frontone)



# Conclusion

- ▶ Strong **diagenetic segregation** of **Si** and **Ca** at the source of **nearly pure chert and limestones**
- ▶ Chert beds and stratified nodules still record a reproducible pattern at a regional scale
- ▶ **On part strongly inconsistent:**
  - Lack of cherts in Bosso
  - Slumps in Frontone, and abundant chert levels outside neighbouring slump intervals

# Conclusion

- ▶ High-resolution stratigraphy at a regional scale is a powerful tool to study diagenesis
- ▶ **Even with signs of strong diagenesis, diagenetic alternations can still be correlated at a regional scale**
  - => Reinforcement of primary alternations ?
- ▶ **However heterogenous processes seem to be equally capable of creating alternations from nothing**

The ubiquity and regularity of chert layering make it generally difficult to identify any specific pattern without independent high-resolution stratigraphy

**How do we characterise/quantify discrepancies in pattern matching ?**



A photograph of a steep, layered rock face, likely a quarry or a natural rock formation. The rock is light gray and shows distinct horizontal bedding. Several people are visible climbing the face, providing a sense of scale. The foreground is a flat, gravelly area. The sky is blue with some clouds. The text "Thank you for your attention" is overlaid in the center of the image in a white, sans-serif font.

Thank you for your attention



# References

- ▶ Channell, J. E. T., F. Cecca, and E. Erba. 1995. 'Correlations of Hauterivian and Barremian (Early Cretaceous) Stage Boundaries to Polarity Chrons'. *Earth and Planetary Science Letters* 134 (1): 125-40.
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- ▶ Westermann, Stéphane, Karl B. Föllmi, Thierry Adatte, Virginie Matera, Johann Schnyder, Dominik Fleitmann, Nicolas Fiet, Izabela Ploch, and Stéphanie Duchamp-Alphonse. 2010. 'The Valanginian  $\Delta^{13}\text{C}$  Excursion May Not Be an Expression of a Global Oceanic Anoxic Event'. *Earth and Planetary Science Letters* 290 (1-2): 118-31.
- ▶ Westphal, Hildegard, Jonathan Lavi, and Axel Munnecke. 2015. Diagenesis Makes the Impossible Come True: Intersecting Beds in Calcareous Turbidites. *Facies* 61 (2): 3.