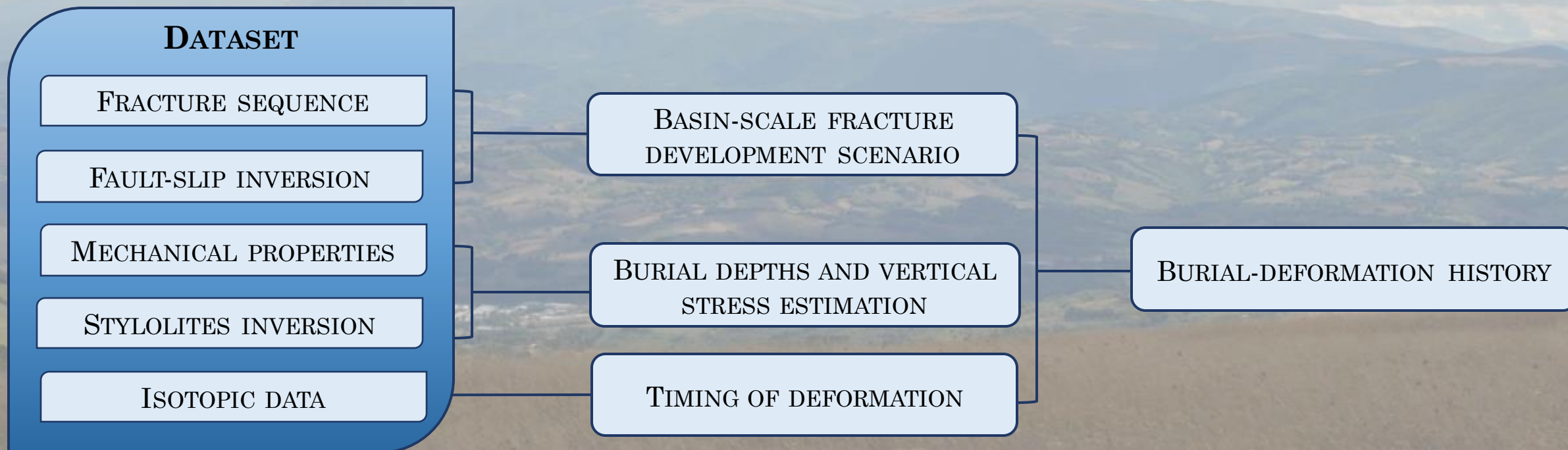


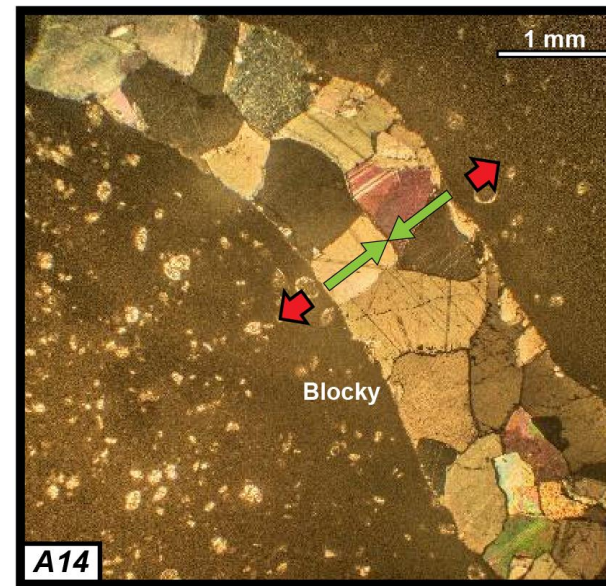
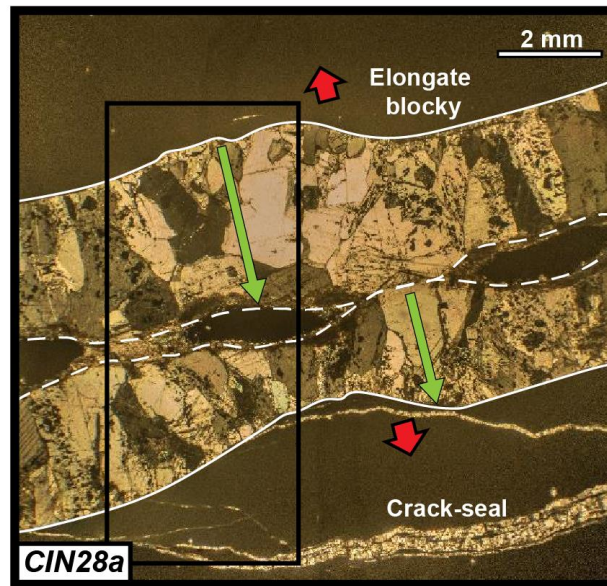
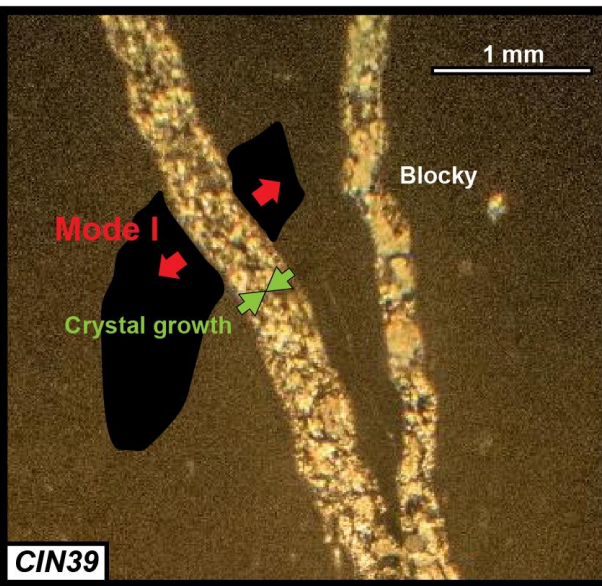
BURIAL-DEFORMATION HISTORY OF AN ARCUATE FOLD UNRAVELED BY FRACTURE ANALYSIS, STYLOLITE PALEOPIEZOMETRY AND VEIN CEMENT GEOCHEMISTRY: A CASE STUDY IN THE CINGOLI ANTICLINE (UMBRIA-MARCHES, NORTHERN APENNINES)

Aurélie Labeur¹, Nicolas E. Beaudoin¹, Olivier Lacombe², Guilhem Hoareau¹, Lorenzo Petraccini³, Laurent Emmanuel², Mathieu Daëron⁴, Jean-Paul Callot¹

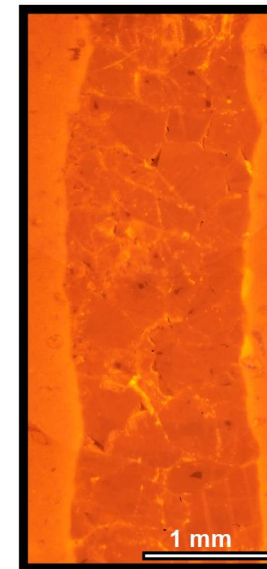
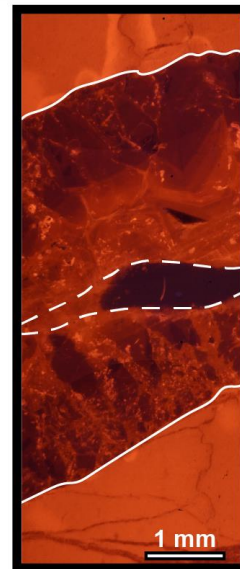
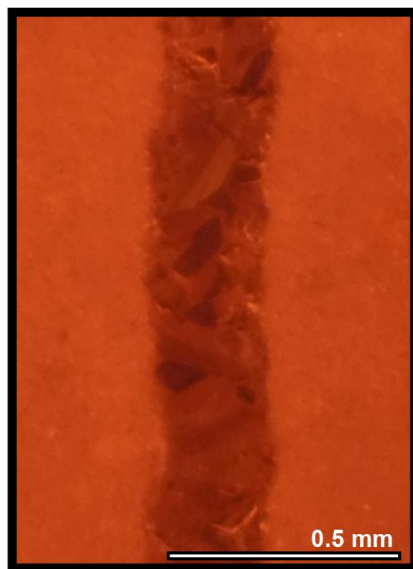
Unravelling the burial-deformation history of sedimentary rocks is prerequisite information to understand the regional tectonic, sedimentary, thermal, and fluid-flow evolution of foreland basins. Nevertheless, the timing and duration of fold-related deformation - including layer-parallel shortening (LPS) - related to fold growth, are difficult to estimate because of a lack of data in most natural cases. This contribution presents an original combination of microstructural analysis, stylolites paleopiezometry, and paleofluid geochemistry, using the case of study of the Cingoli Anticline, to access the timing of deformation in fold-and-thrust belt and foreland basin. In particular, the burial depths were calculated using the sedimentary Stylolite Roughness Inversion Technique (SRIT), then associated stress magnitudes were deduced from the principles of hydrostatic. In addition, the timing of deformation was constrained by coupling these data with the results of clumped isotopes analyses, to reconstruct the burial-deformation history of the Meso-Cenozoic carbonate sequence of this area.



CHARACTERISATION OF FRACTURE-STYLOLITE NETWORK



Labeur *et al.*, 2021



THIN-SECTION

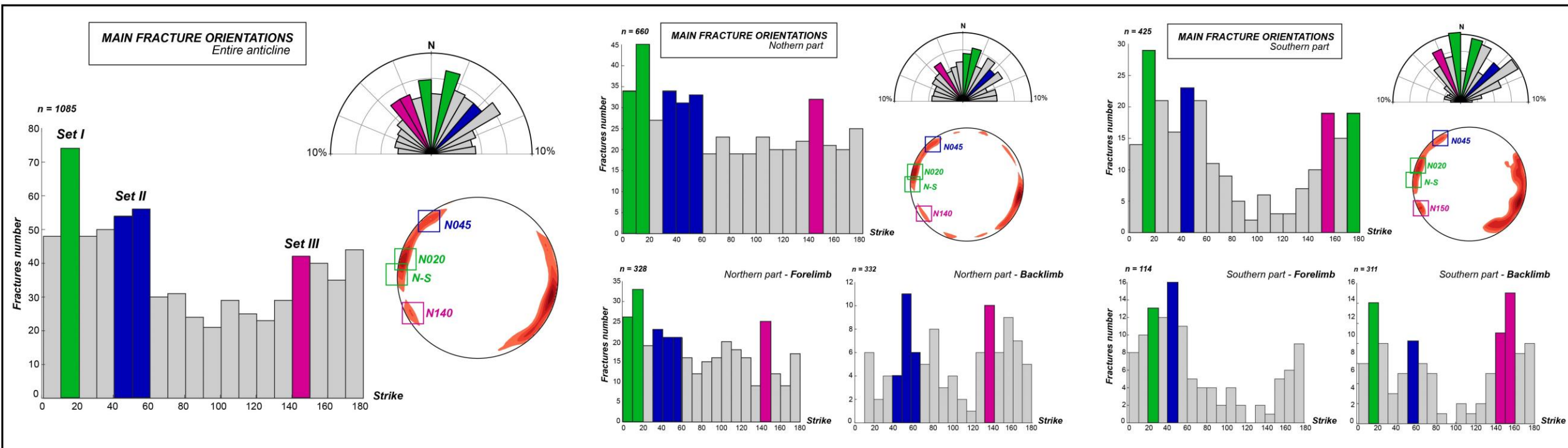
↓
Texture and object shift in the matrix

↓
Mode of deformation (both)
Primary cement (texture)

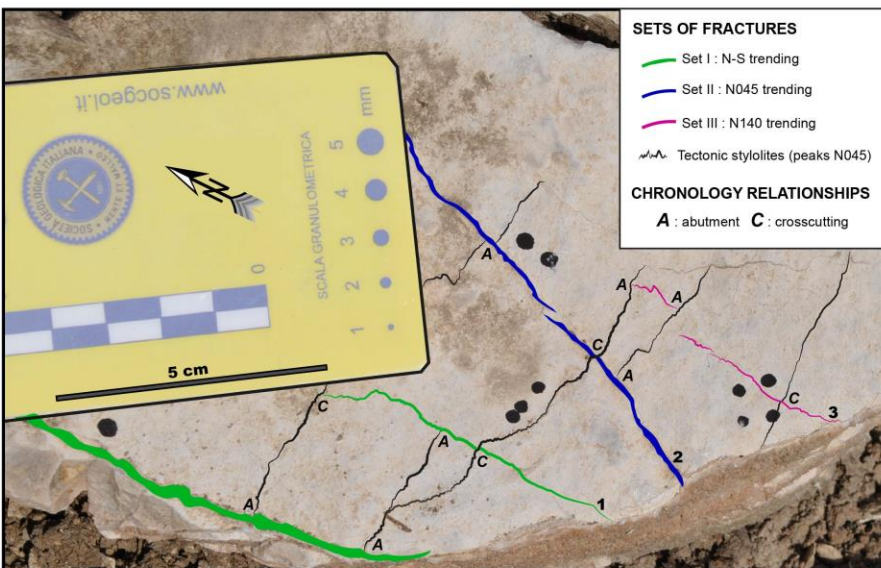
↓
Key point to ensure that the isotopic values reflect the conditions at the time of fracture

Back

CHARACTERISATION OF FRACTURE-STYLOLITE NETWORK



Labeur *et al.*, 2021



FIELDWORK & DATA PROCESSING

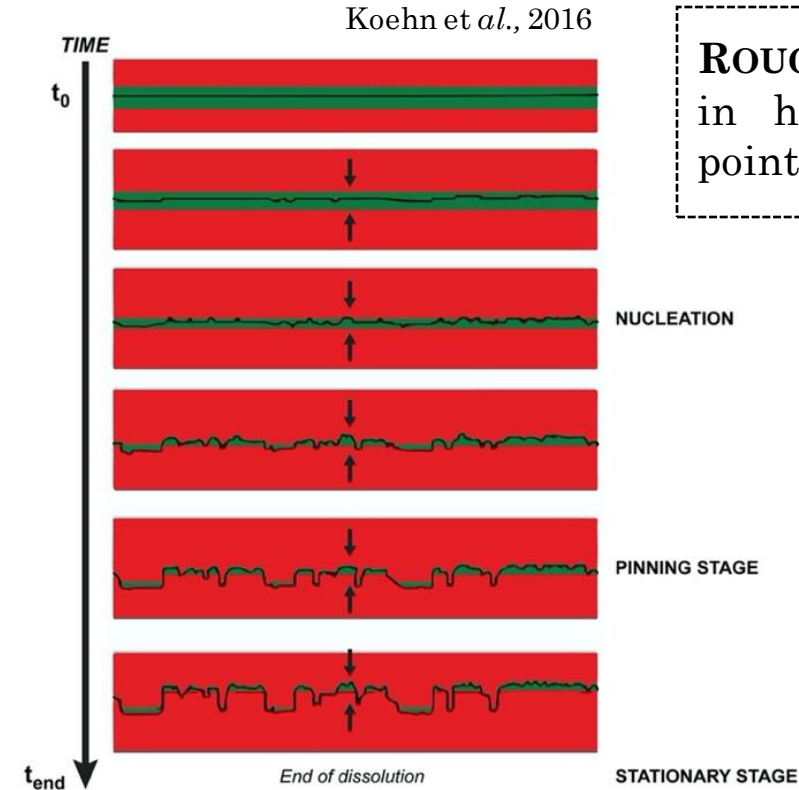
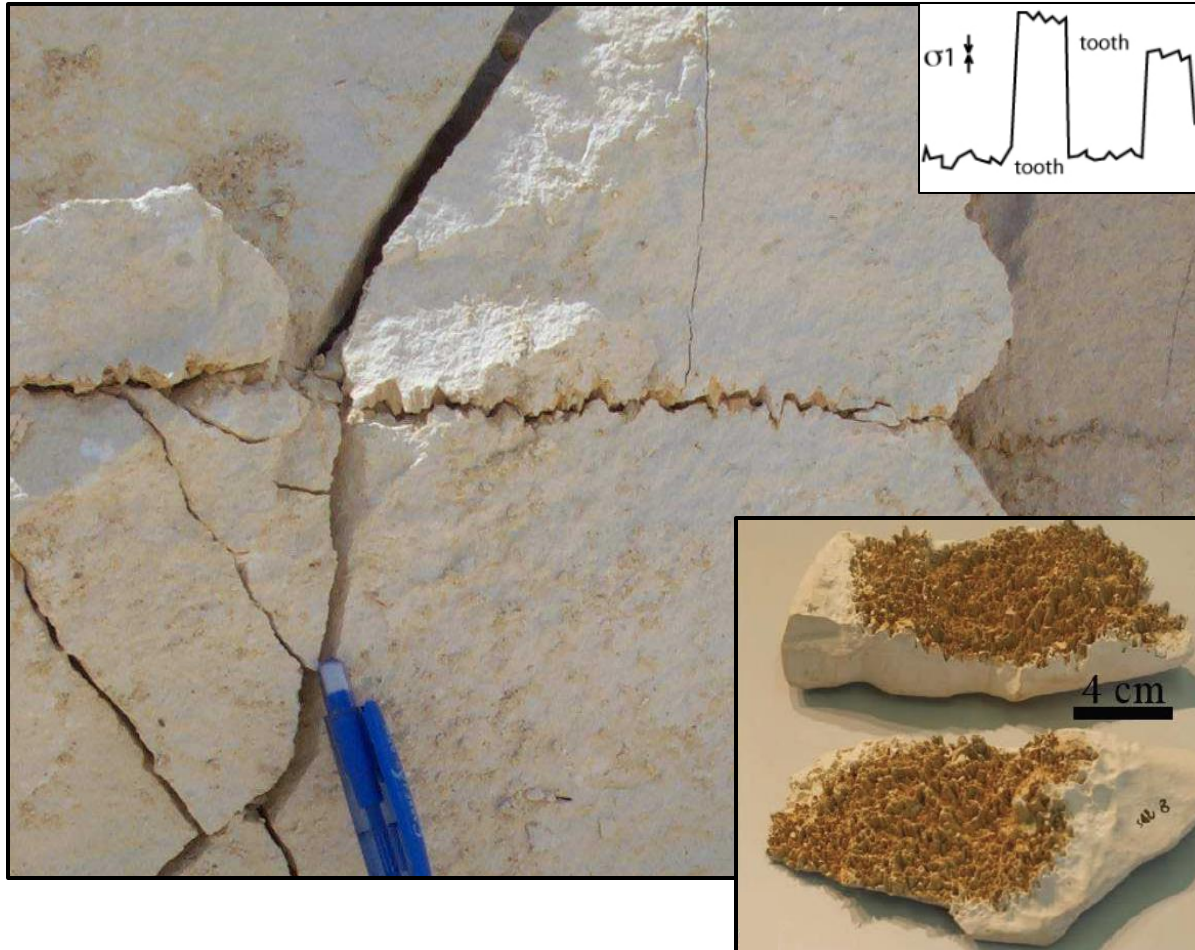
Chronological relationships. Main orientations of fractures and stylolites

- 1- Set I N-S trending
- 2- Set II N045 trending
- 3- Set III N140 trending

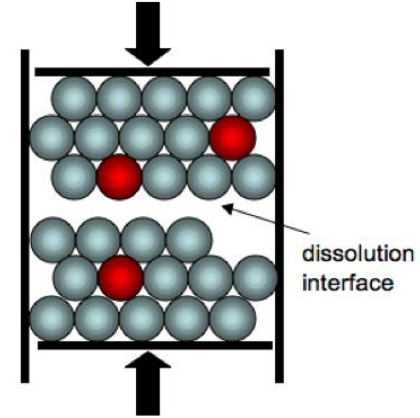
Back

SEDIMENTARY STYLOLITES ROUGHNESS INVERSION

Pressure-solution surfaces frequently observed in carbonates rocks, and usually developed parallel to bedding in sub-horizontal strata during burial, *i.e.*, when σ_1 vertical



ROUGHNESS: difference in height between two points along the track



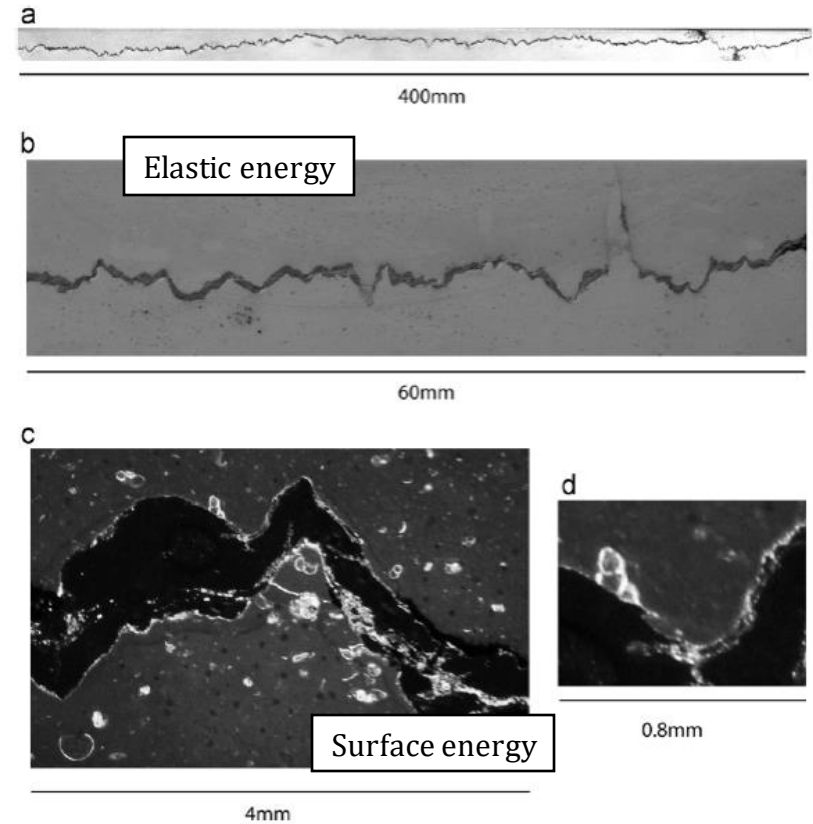
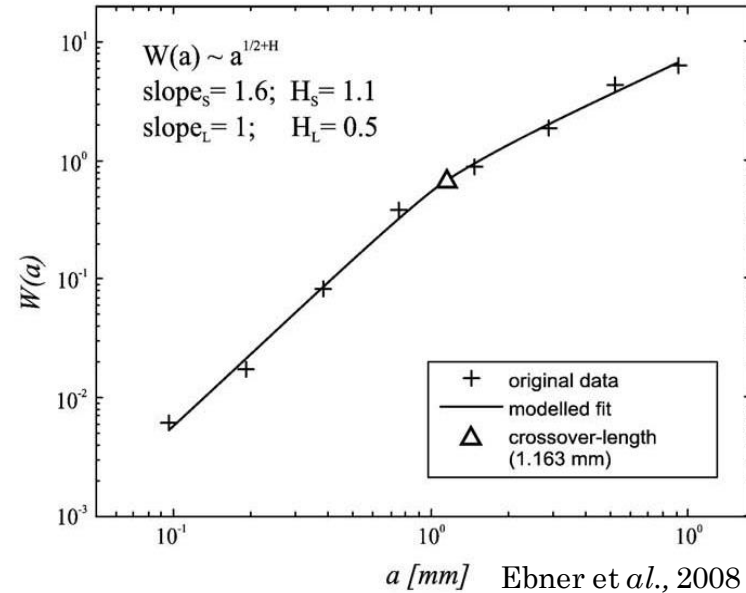
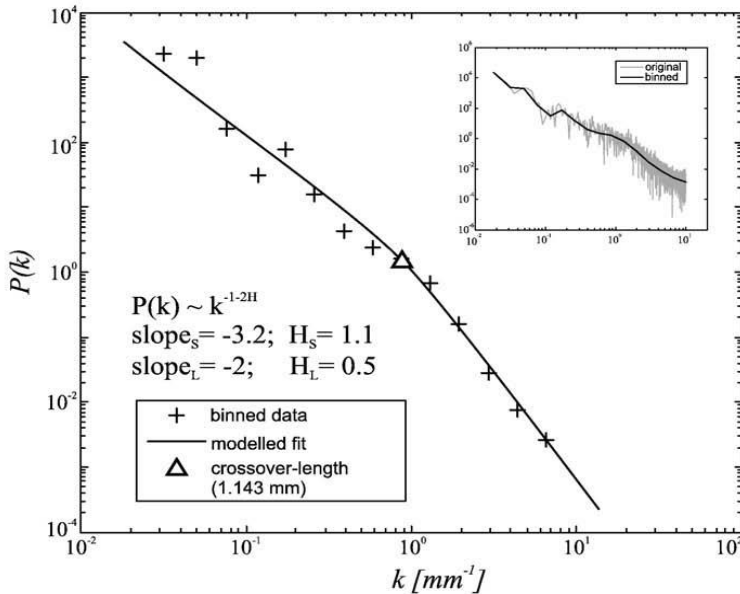
$$D = kV \left(1 - e^{-\frac{(\Delta\psi + \Delta\sigma_n V)}{RT}} \right)$$

Back



SEDIMENTARY STYLOLITES ROUGHNESS INVERSION

SCALING METHODS → Fourier Transform (FT) and Average Wavelet Coefficient (AWC) methods



→ **PREREQUISITE:** 1D signal of the numerical stylolite obeys a self-affine scaling invariance

$$P(k) = k^{D-2h}$$

→ **2 SCALING REGIMES:**

- depending on the predominant energy and the associated Hurst/roughness exponent
- change in roughness exponent is associated with a crossover length (L_c), estimated by the signal processing approach

$$\begin{cases} H_{\text{surface energy}} \approx 1.1 \\ H_{\text{elastic energy}} \approx 0.5 \end{cases}$$

$$L_c = \frac{\gamma E}{\beta \sigma_m \sigma_d}$$

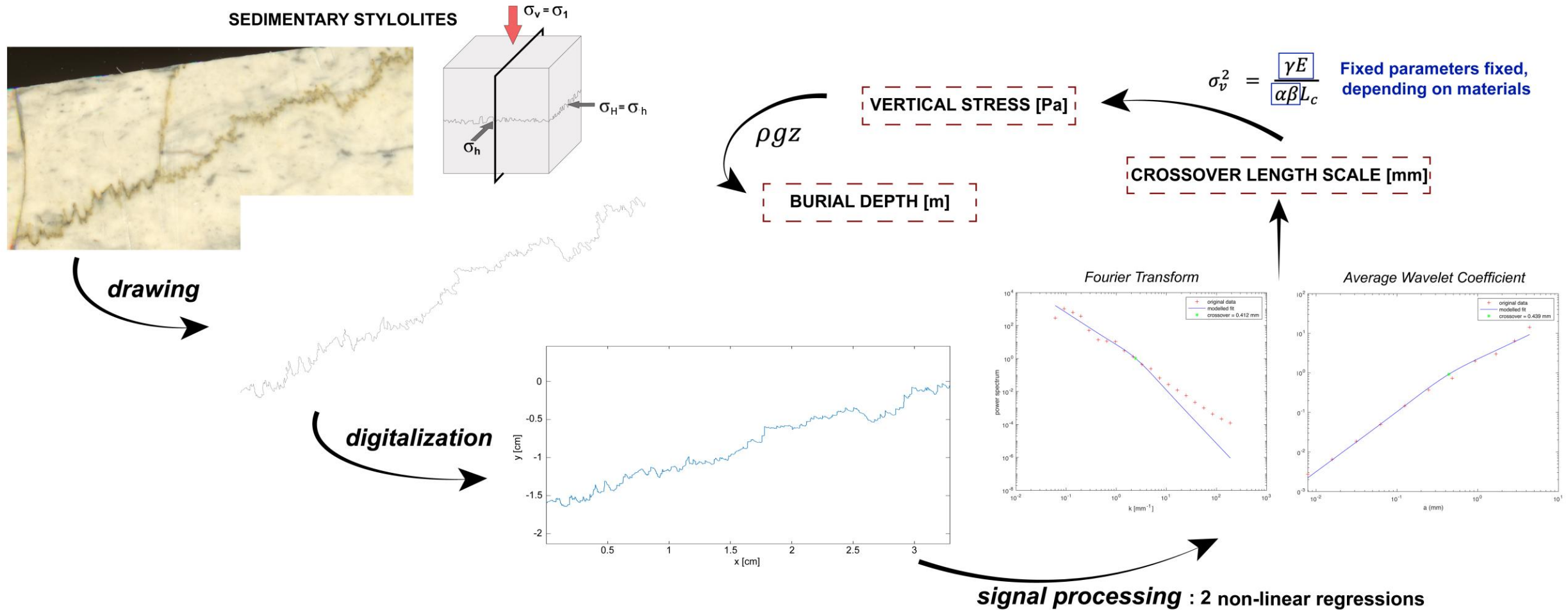
Chemical component
 Mechanical component

β : constant
 E : Young modulus
 γ : surface tension
 σ_m : mean stress
 σ_d : differential stress

Back

SEDIMENTARY STYLOLITES ROUGHNESS INVERSION TECHNIQUE (SRIT)

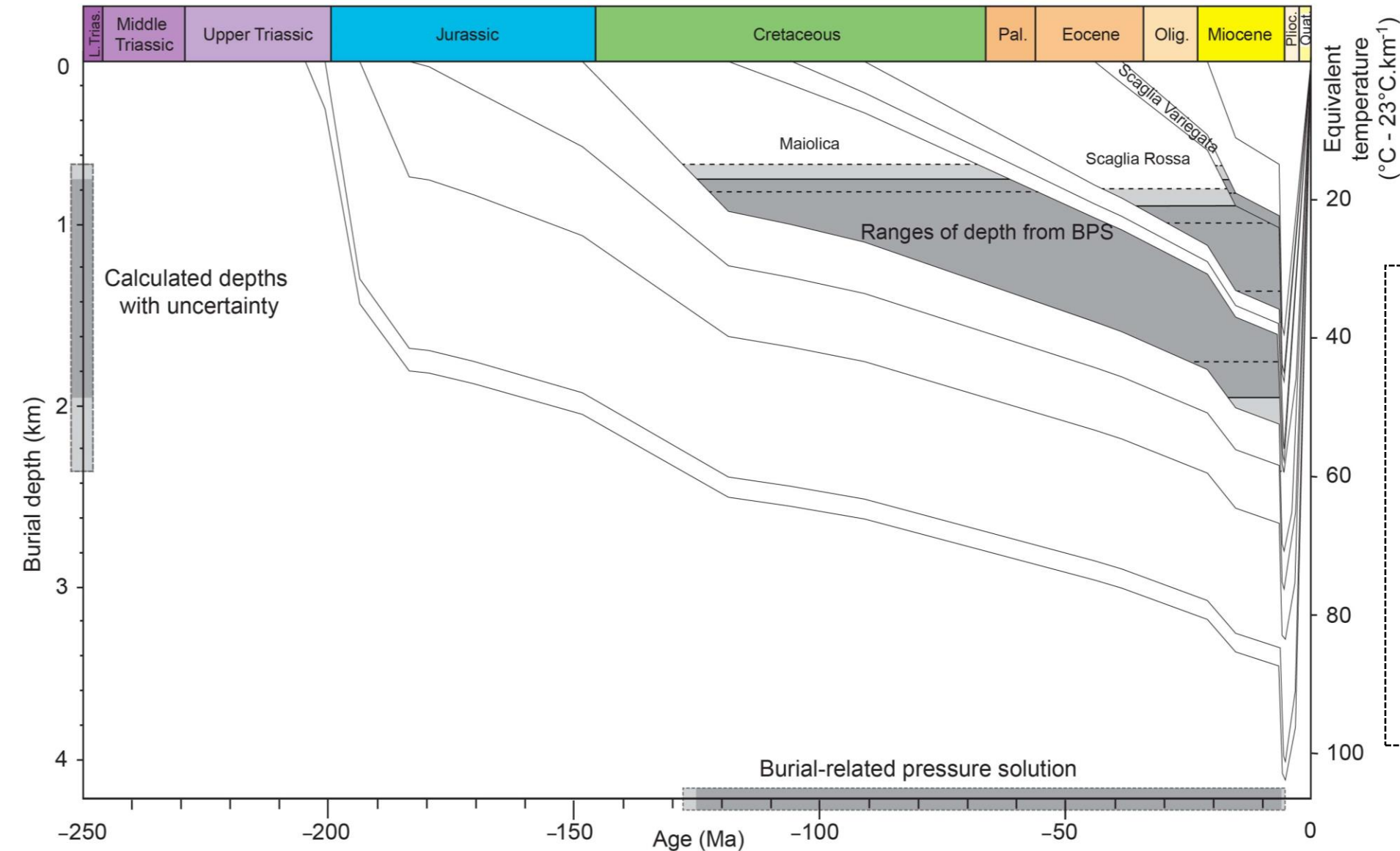
SIGNAL PROCESSING METHOD



Back

BURIAL DEPTHS ESTIMATION

Labeur *et al.*, 2021



Burial curves construction, considering thickness from stratigraphic and well data, and corrected for chemical and physical compaction

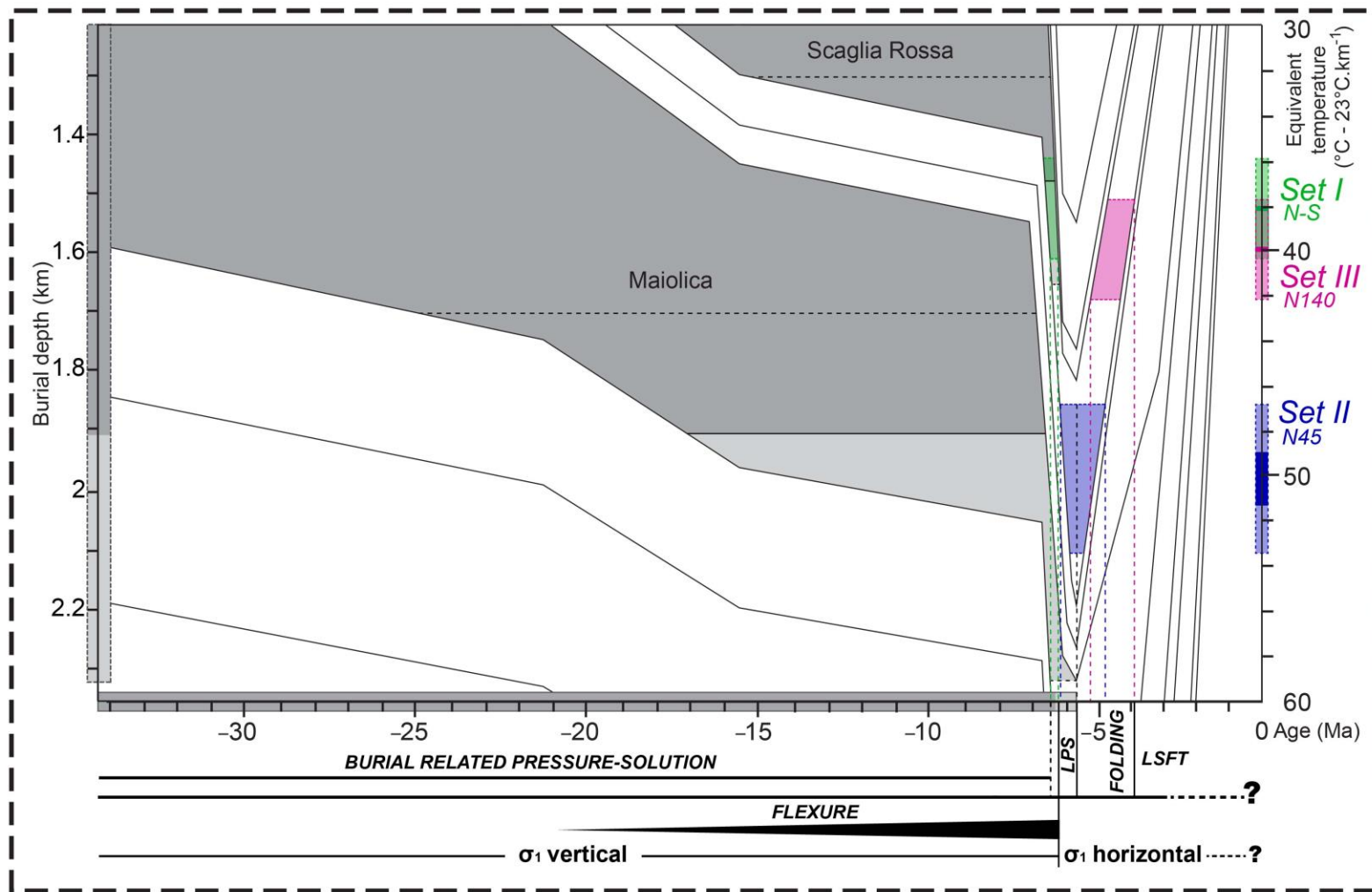
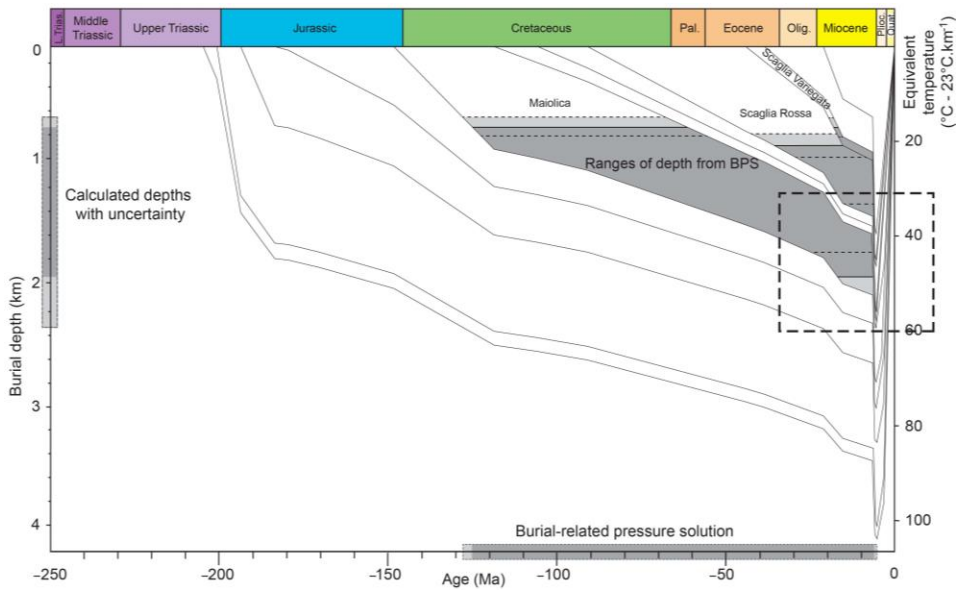
(Backstrip software)



Reconstruction of **burial history of strata** with high resolution using roughness inversion applied to sedimentary stylolites

Back

TIMING OF DEFORMATION



SURFACE TEMPERATURE: 0°C
GEOTHERMAL GRADIENT : 23°C/km

Timing of deformation is constrained by temperatures derived from isotopic data (¹⁸O, ¹³C and clumped isotopes)

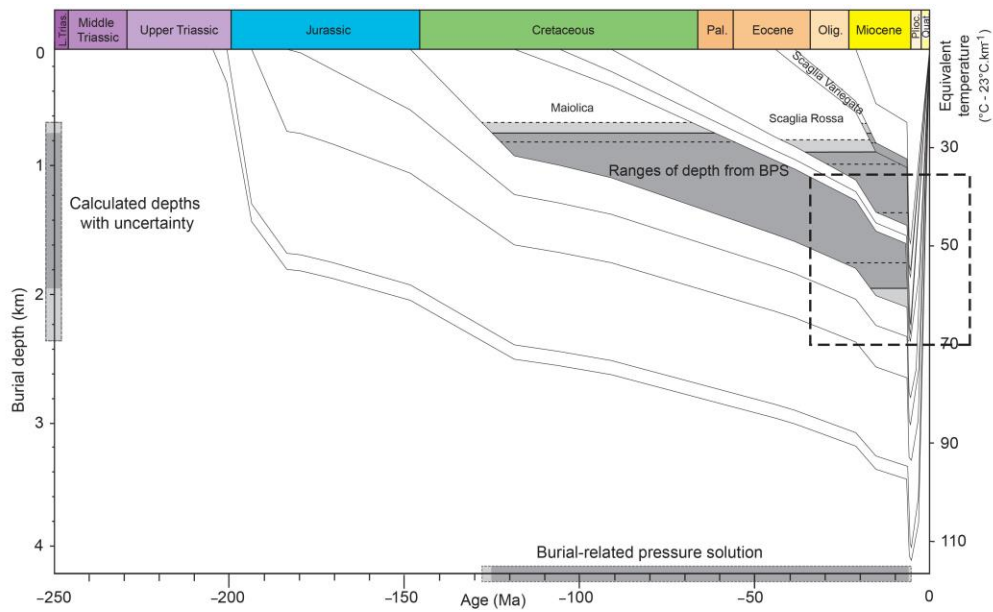
Labeur *et al.*, 2021

Back

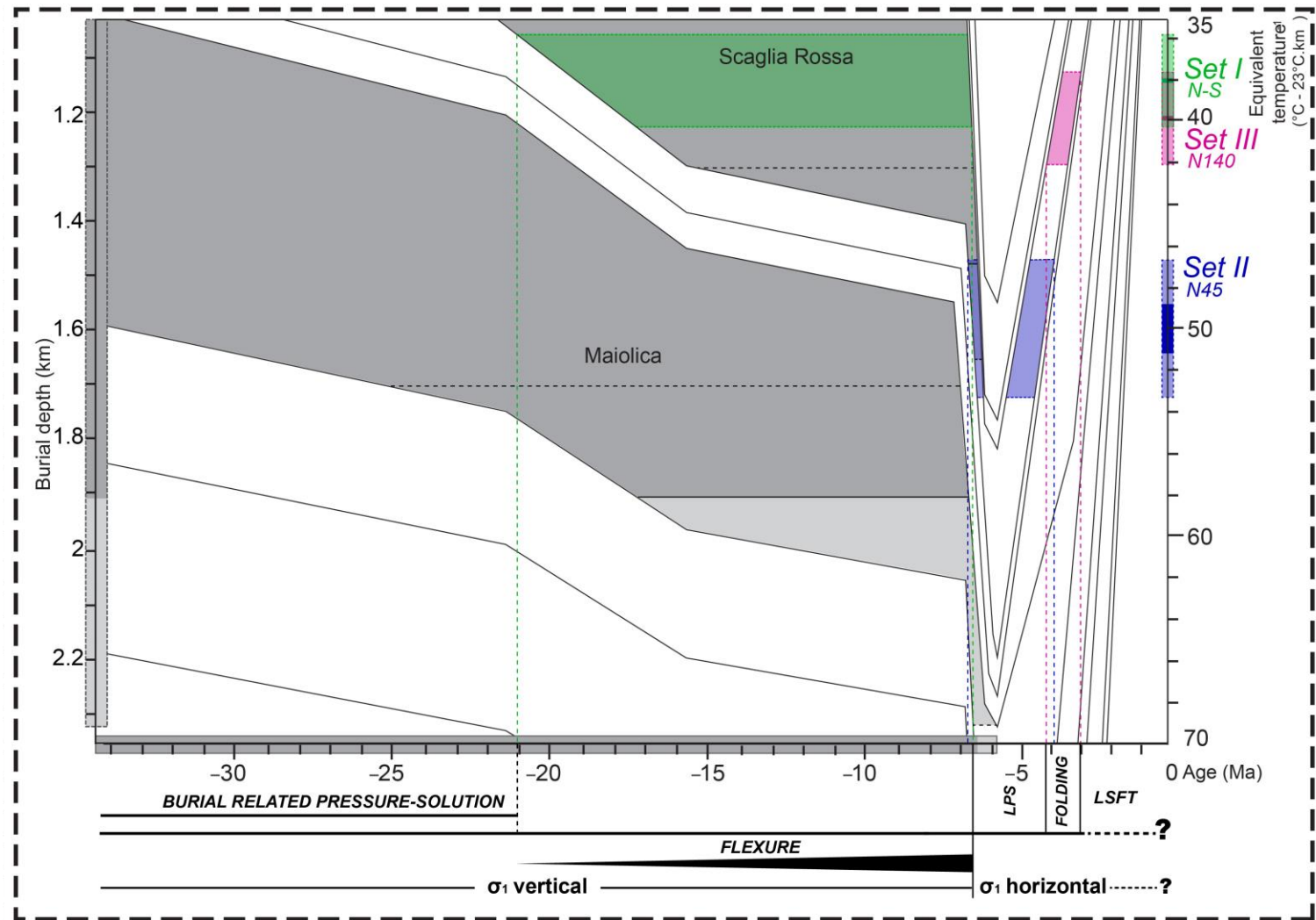


TIMING OF DEFORMATION

GEOTHERMAL GRADIENT IMPACT



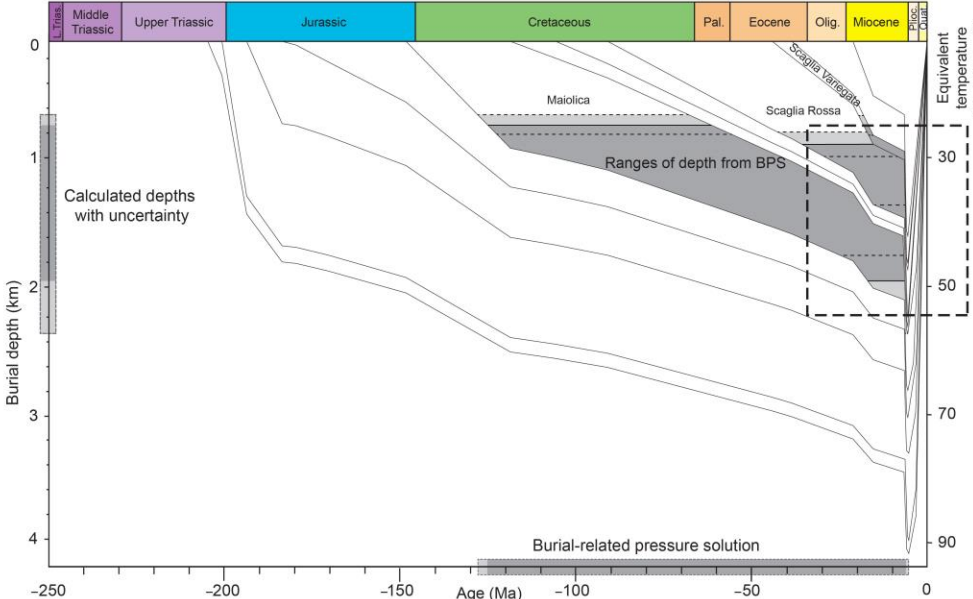
SURFACE TEMPERATURE: 10°C
GEOTHERMAL GRADIENT : 23°C/km



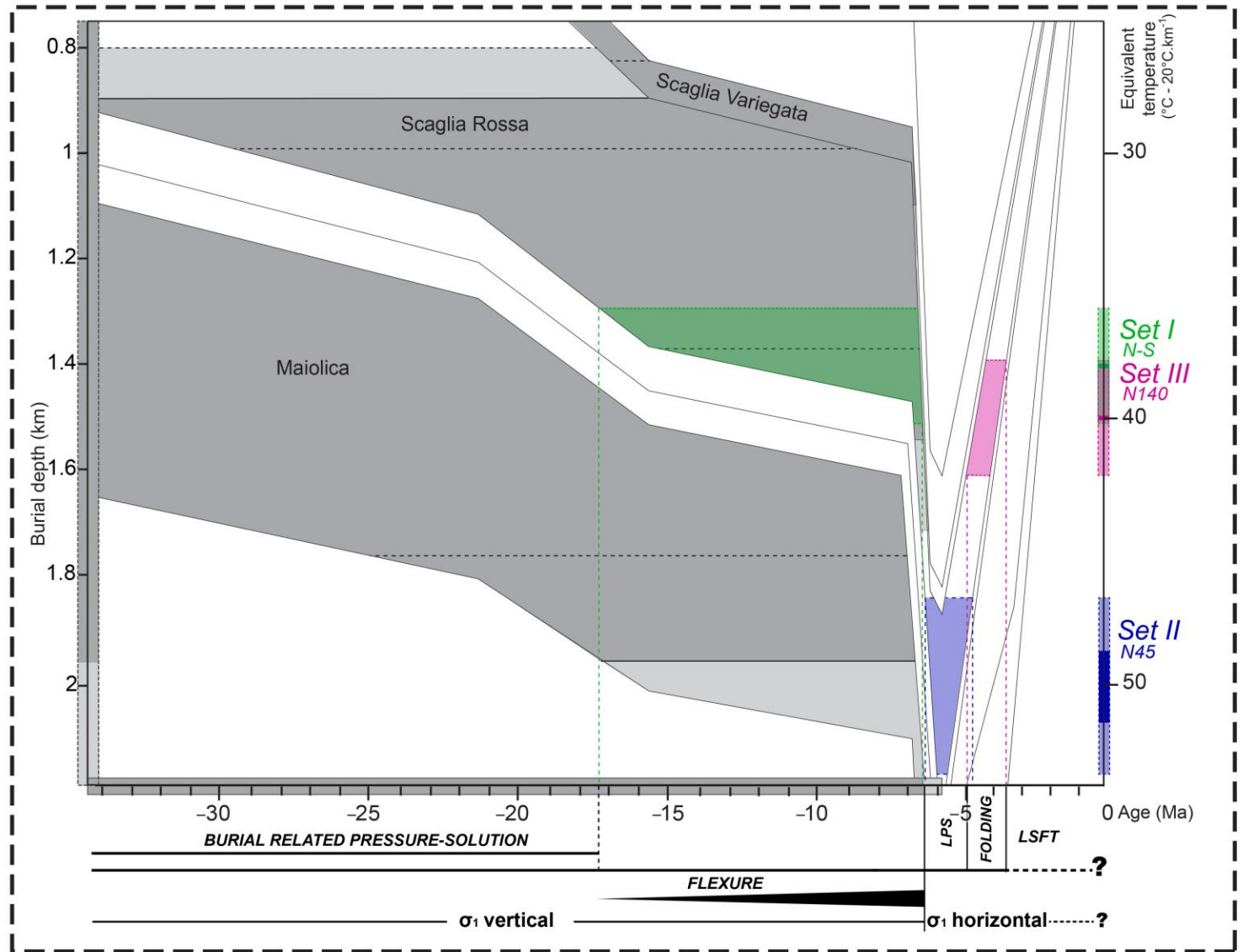
Back

TIMING OF DEFORMATION

GEOTHERMAL GRADIENT IMPACT



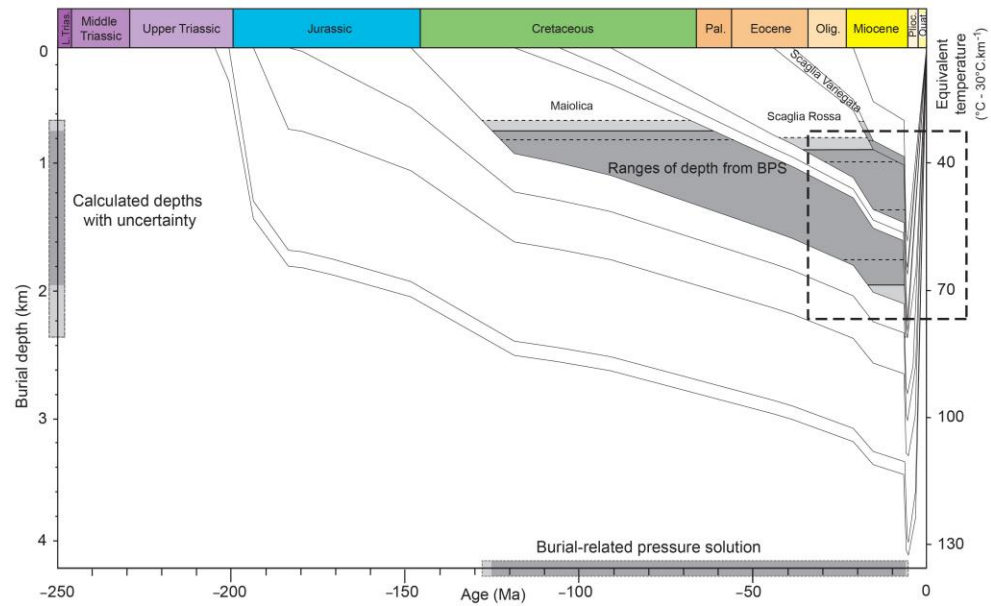
SURFACE TEMPERATURE: 10°C
GEOTHERMAL GRADIENT : 20°C/km



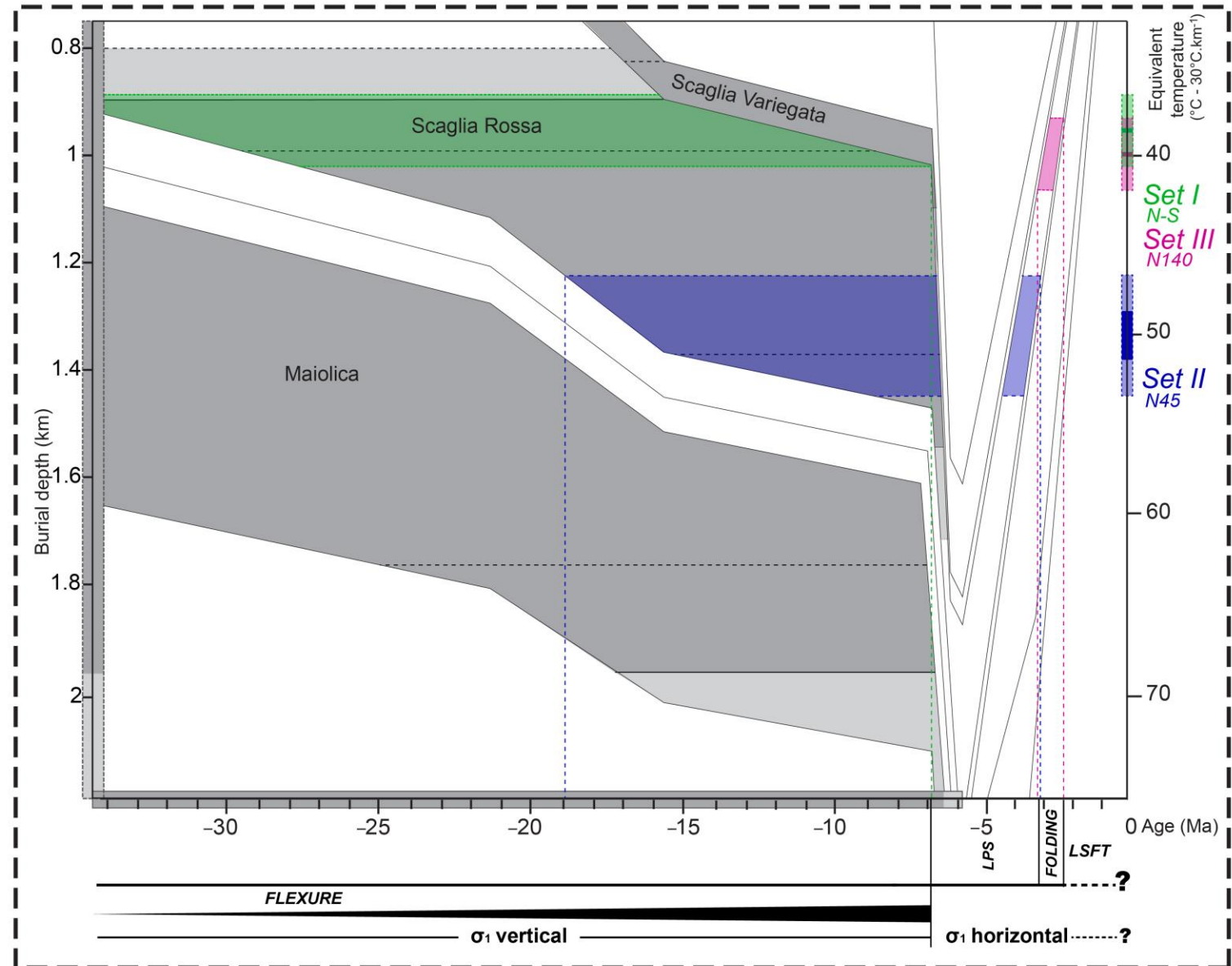
Back

TIMING OF DEFORMATION

GEO THERMAL GRADIENT IMPACT



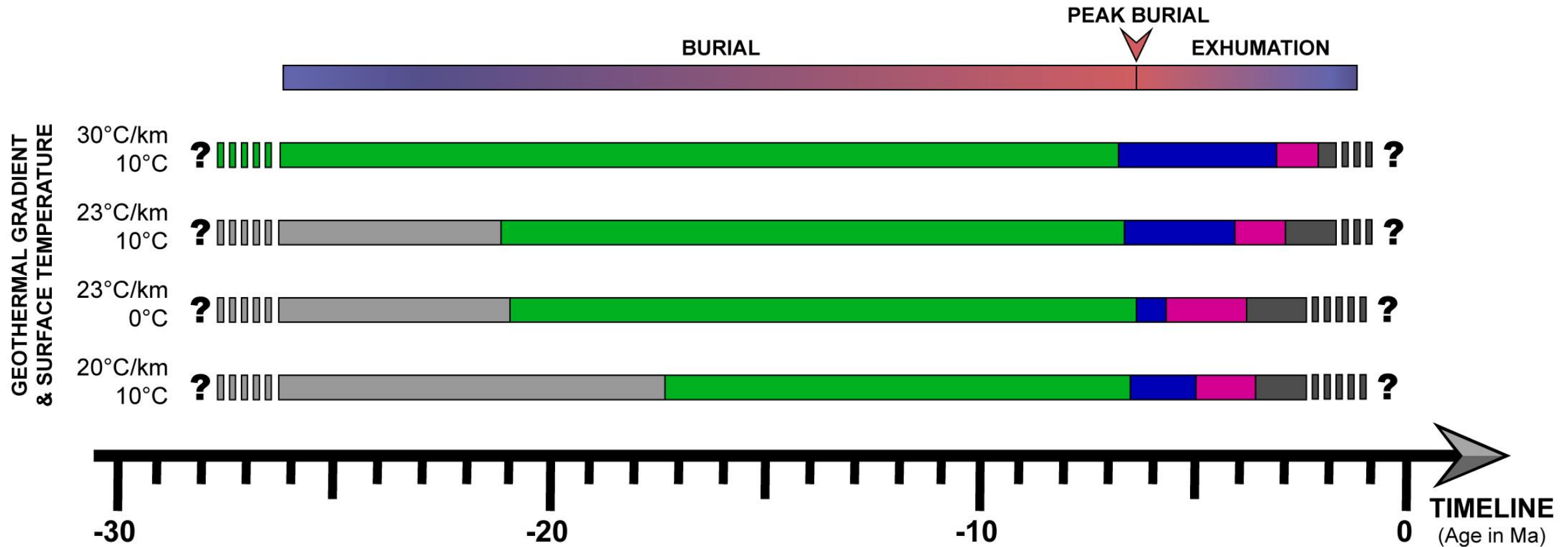
SURFACE TEMPERATURE: 10°C
GEO THERMAL GRADIENT : 30°C/km



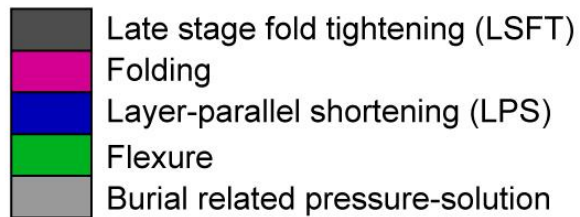
Back

TIMING OF DEFORMATION

GEOHERMAL GRADIENT IMPACT



SEQUENCE OF DEFORMATION



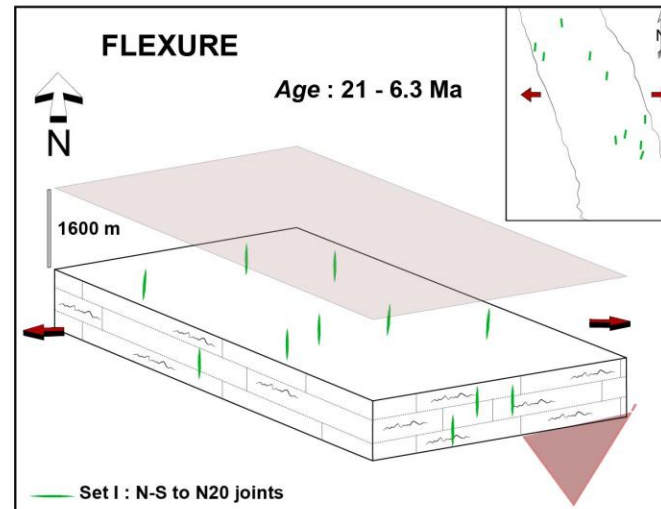
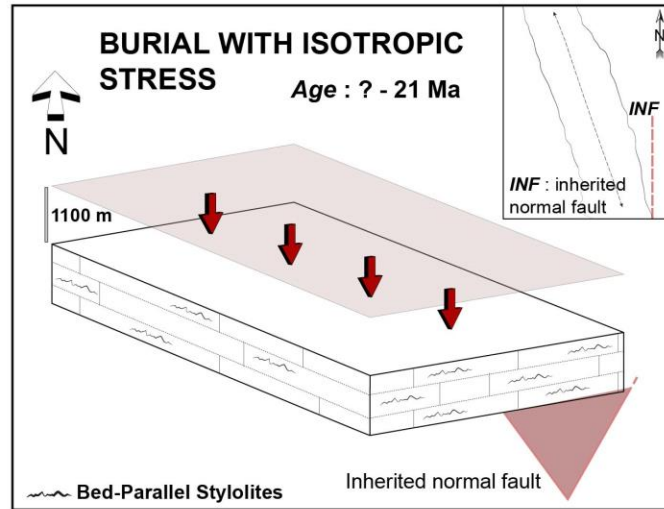
→ Sequence of deformation preserved

→ Timing shifts according to the gradient considered, but remains consistent (overlap of time domains)



BURIAL-DEFORMATION HISTORY

PRE-CONTRACTONAL STAGE : $\sigma_1 = \sigma_v$

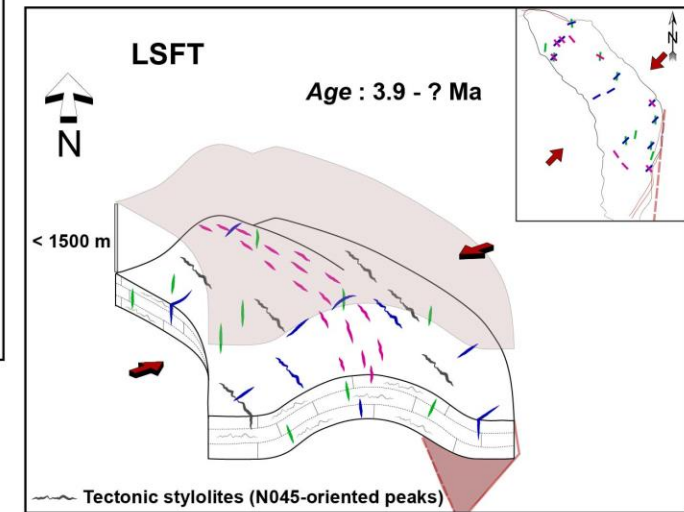
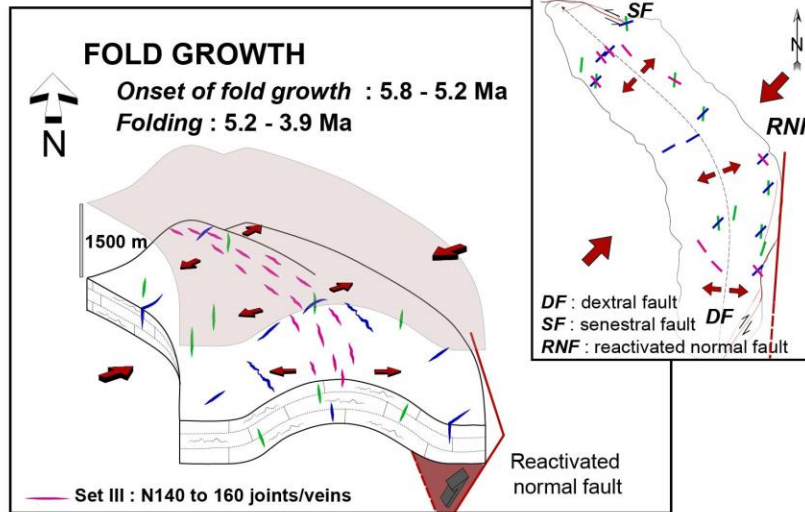
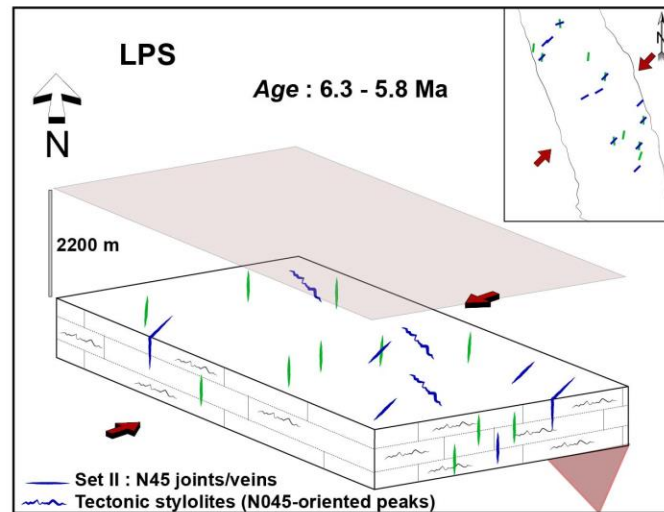


Interpretative model of the history of deformation

↓

This contribution shows how the burial deformation history of folded rocks can be unraveled using an original combination of ubiquitous features of carbonate rocks: fracture analysis, sedimentary stylolites paleopiezometry and vein cement geochemistry

CONTRACTONAL STAGE : $\sigma_1 = \sigma_H$



Labeur *et al.*, 2021

Back