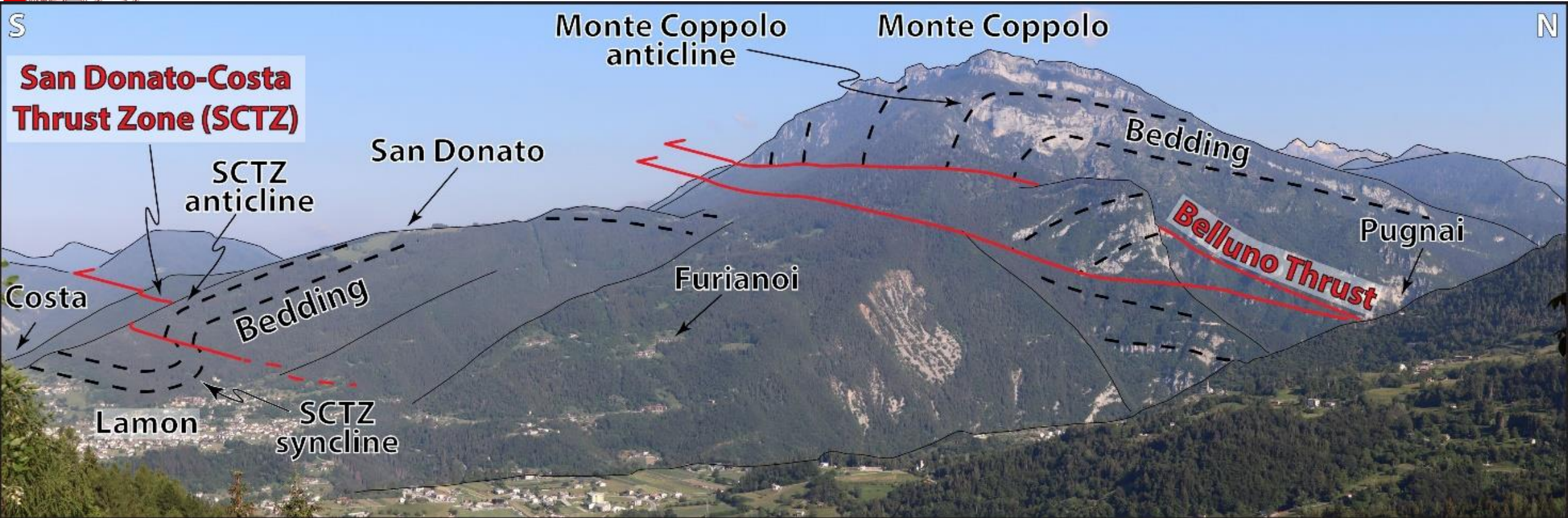


# What steers deformation within fold-and-thrust belts: insights from the carbonate multilayer footwall of the Belluno Thrust, Italian eastern Southern Alps



Zuccari Costantino<sup>1\*</sup>, Viola Giulio<sup>1</sup>, Vignaroli Gianluca<sup>1</sup> and Aldega Luca<sup>2</sup>

<sup>1</sup>Alma Mater Studiorum - University of Bologna

<sup>2</sup>Sapienza - University of Rome

\*costantino.zuccari2@unibo.it

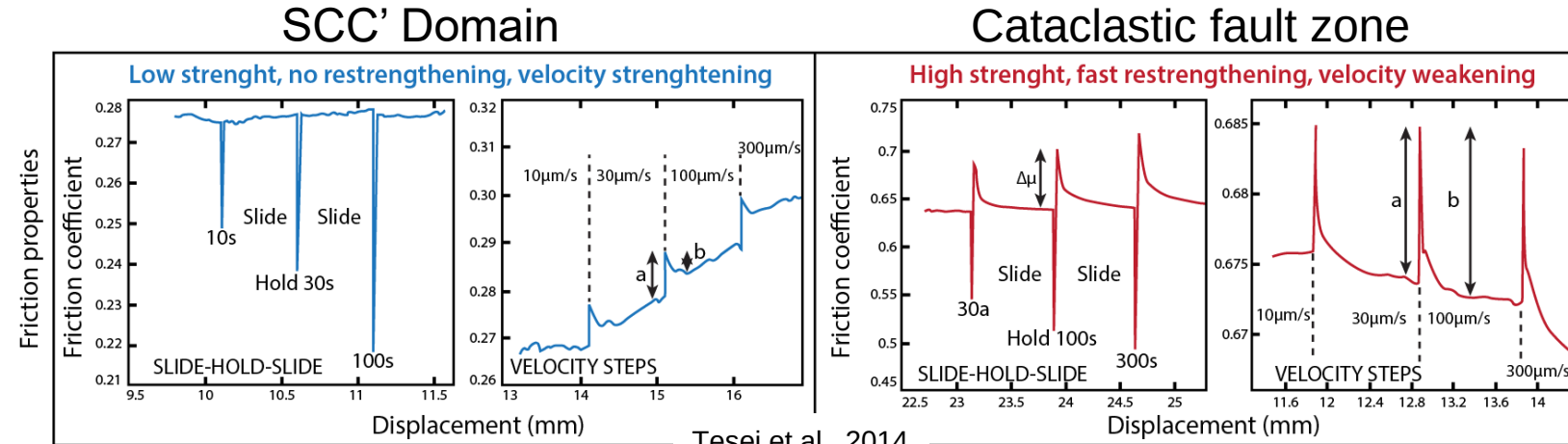
# Deformation in carbonate rocks

Conditions governing deformation of carbonate rocks

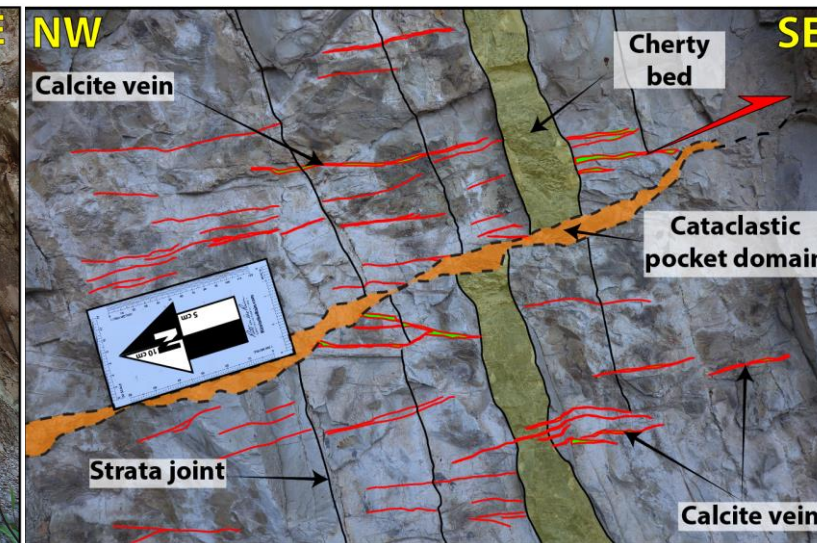
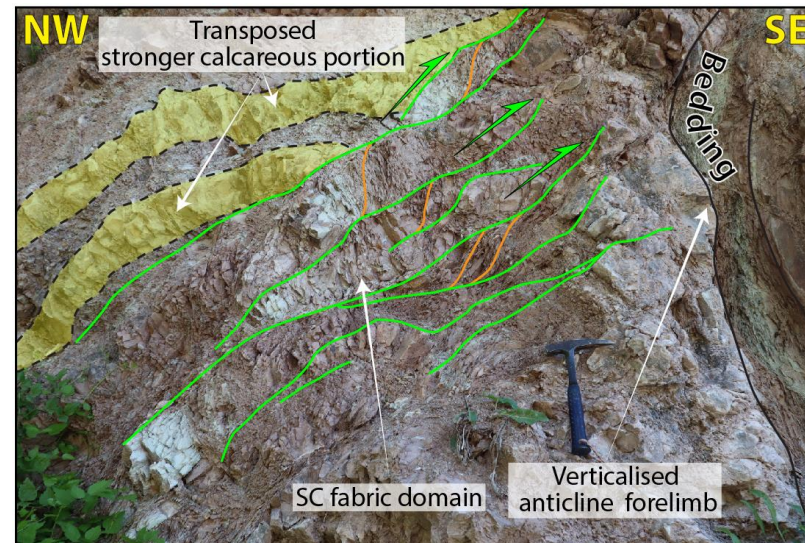
1. Pressure/temperature
2. Stress field
3. Geodynamic setting
4. Lithology
5. Fluid circulation

(e.g. Delle Piane et al., 2017)

**Different behaviour of carbonate rocks during deformation due to their lithological variability**

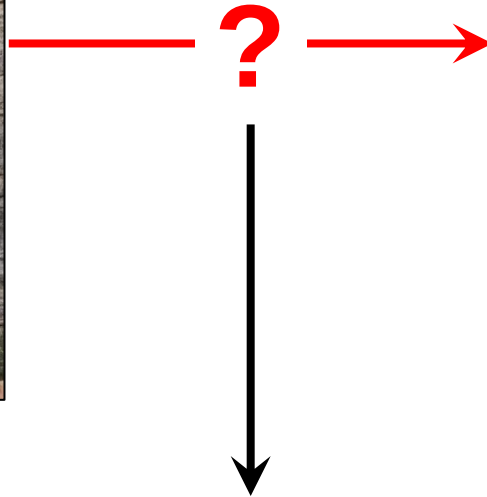


## Aseismic creep vs Coseismic rupturing



# Deformation in carbonate rocks

*What steers the strain localisation?*

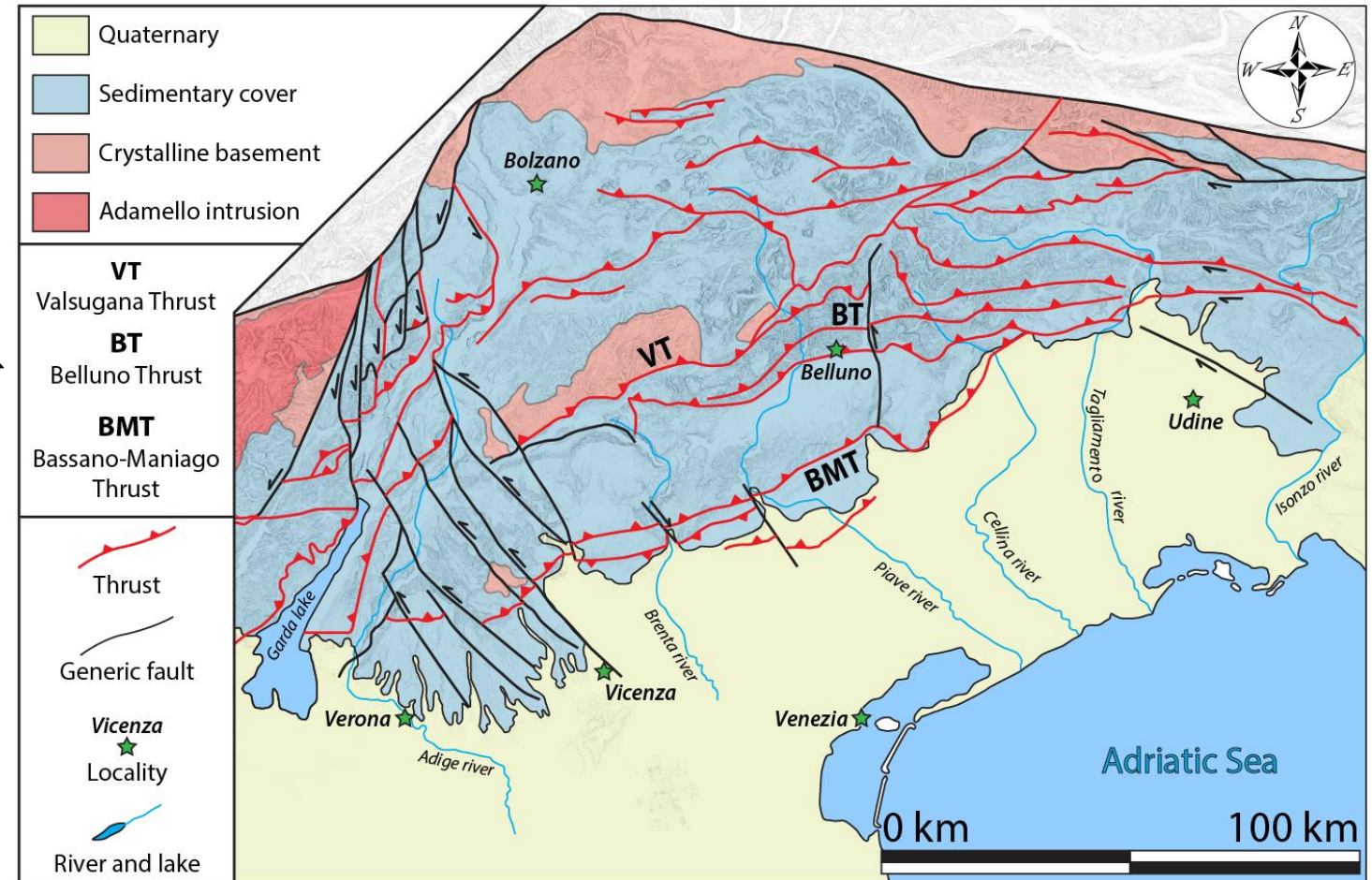


**New insights from the footwall succession of the Belluno Thrust**

# Geological Setting

eastern Southern Alps (ESA)

South verging retro-belt of the eastern sectors of the Alpine Chain

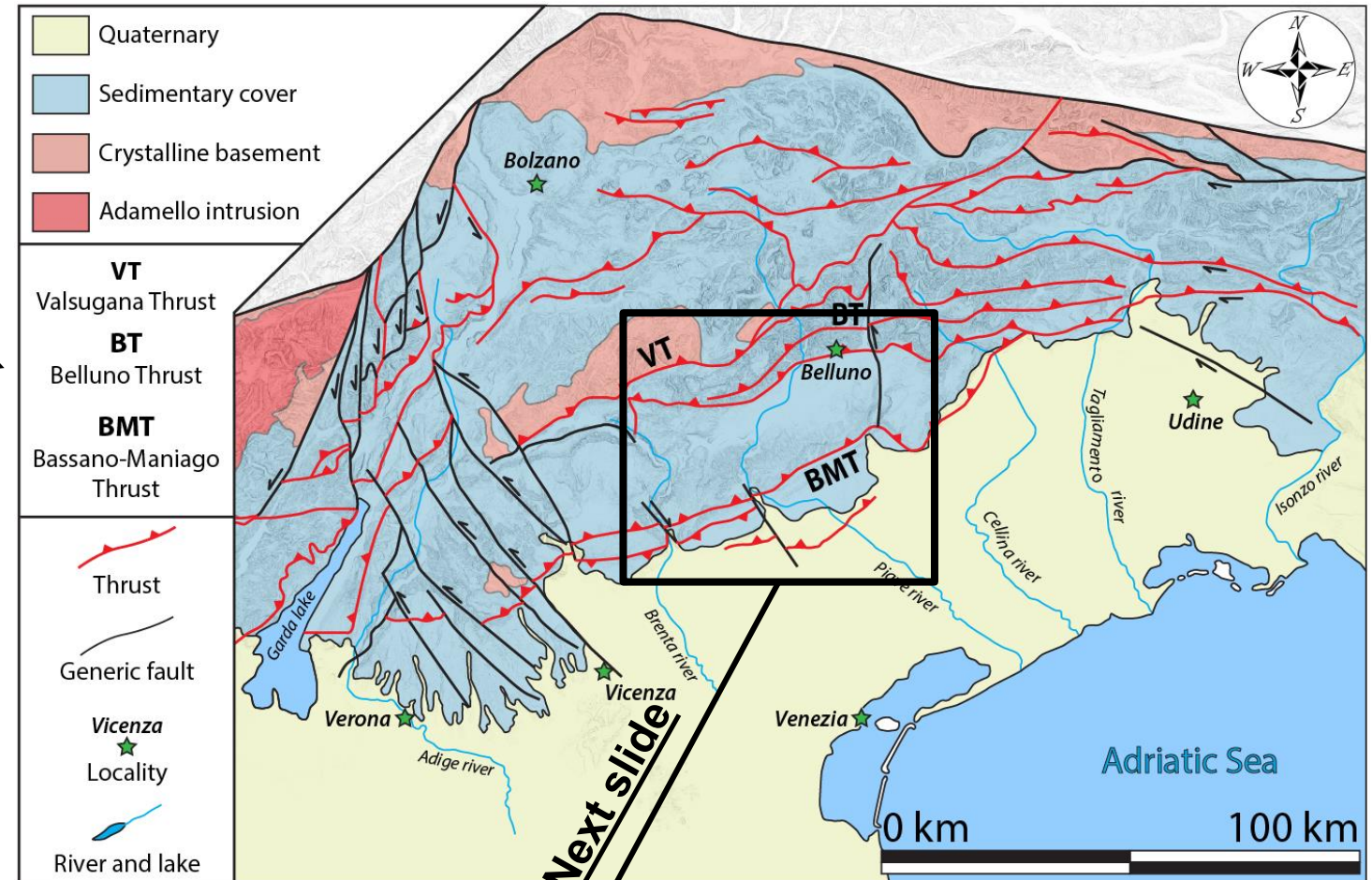


After Castellarin & Cantelli (2000)

# Geological Setting

eastern Southern Alps (ESA)

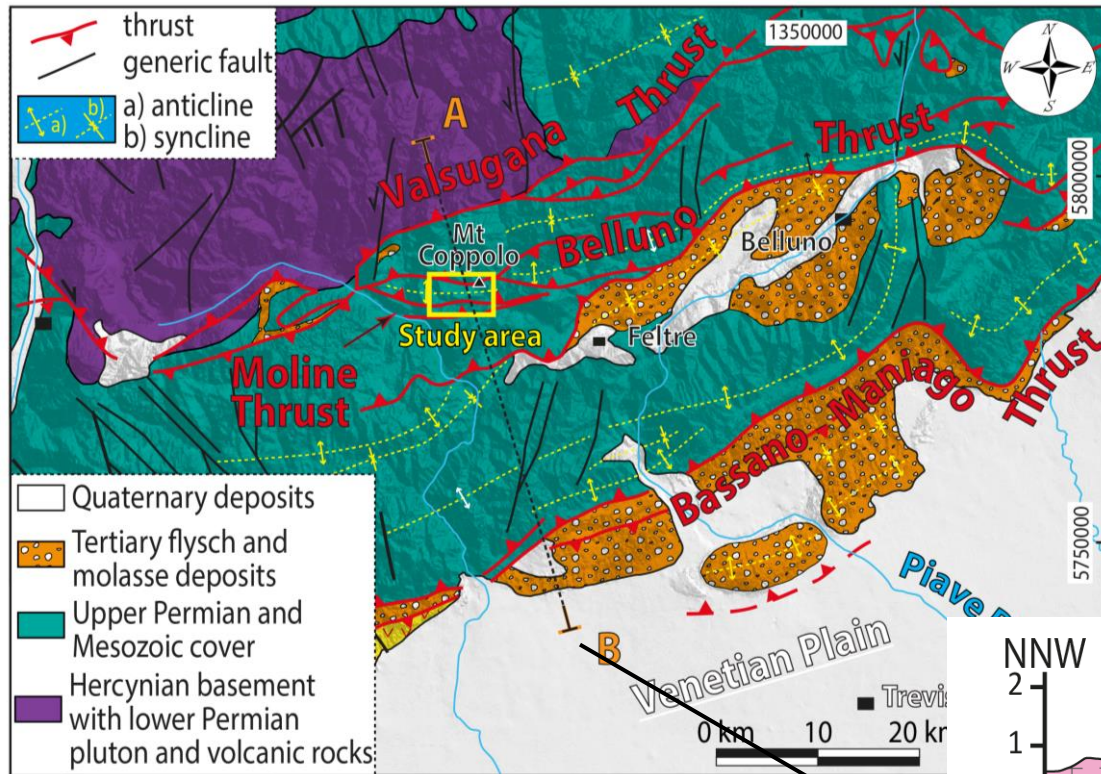
South verging retro-belt of the eastern sectors of the Alpine Chain



Next slide

After Castellarin & Cantelli (2000)

# Geological Setting

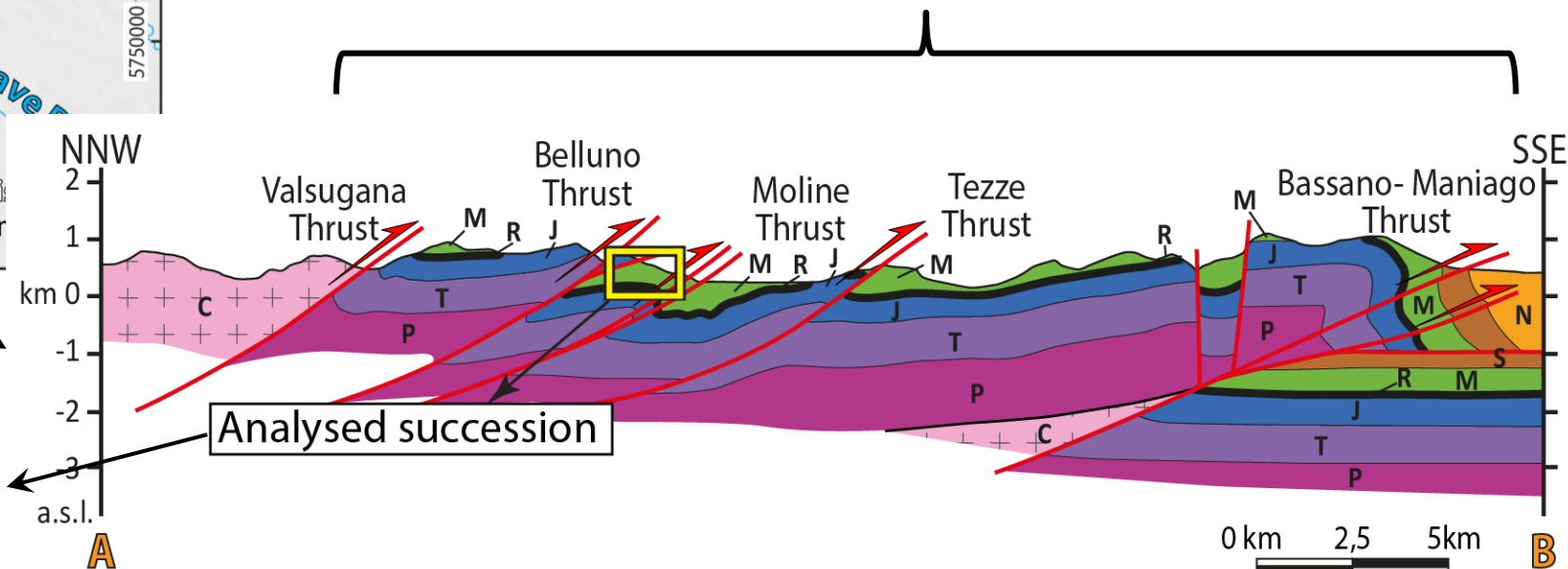


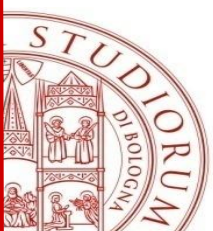
After Doglioni, 1990 and Vignaroli et al., 2020

**The analysed succession belongs to the footwall domain of the Belluno Thrust**

## Venetian Pre-Alps

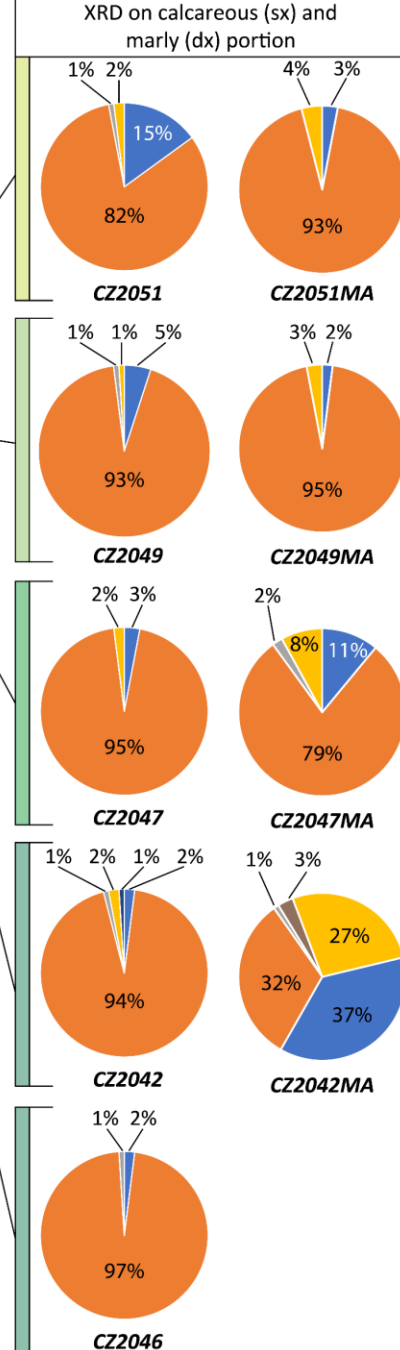
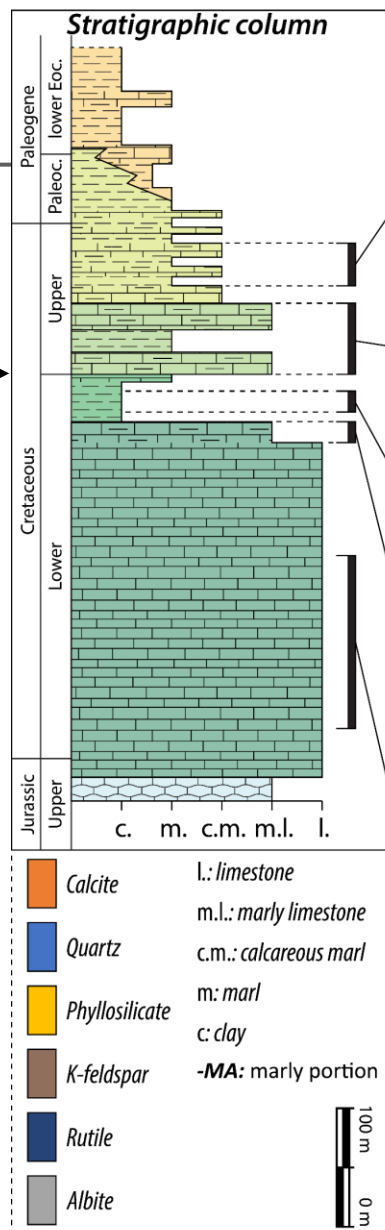
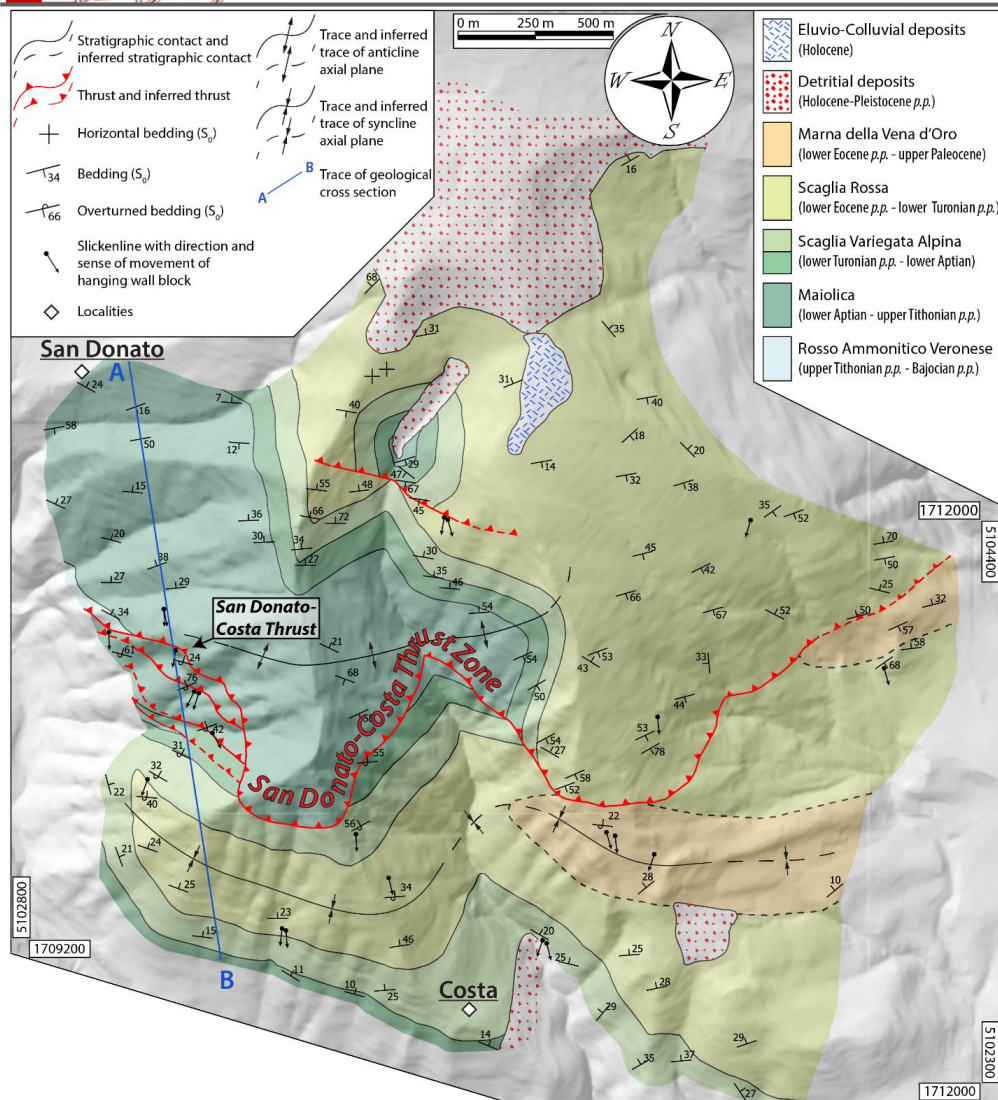
Southernmost portion of the Eastern Southern Alps, bordered by the Valsugana Thrust to the north and by the Venetian plain the south





# Geological map and stratigraphy

## Geological map of the Belluno Thrust footwall unit

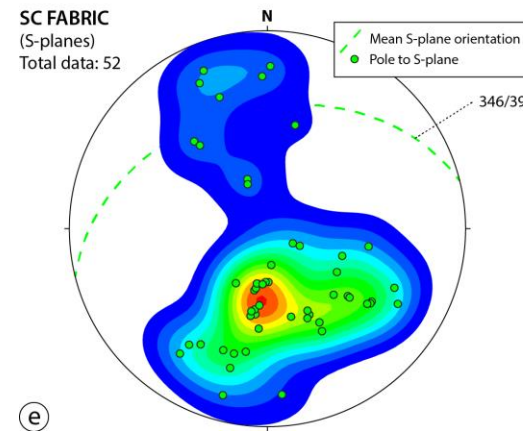
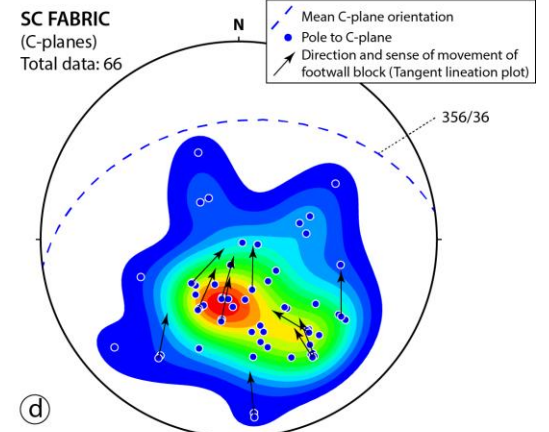
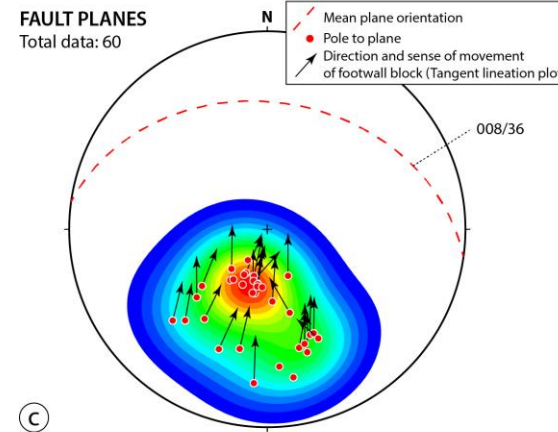
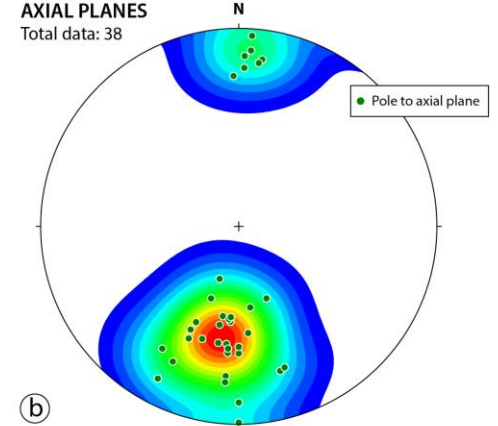
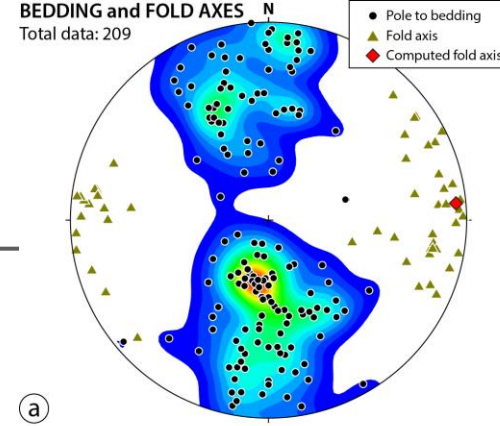
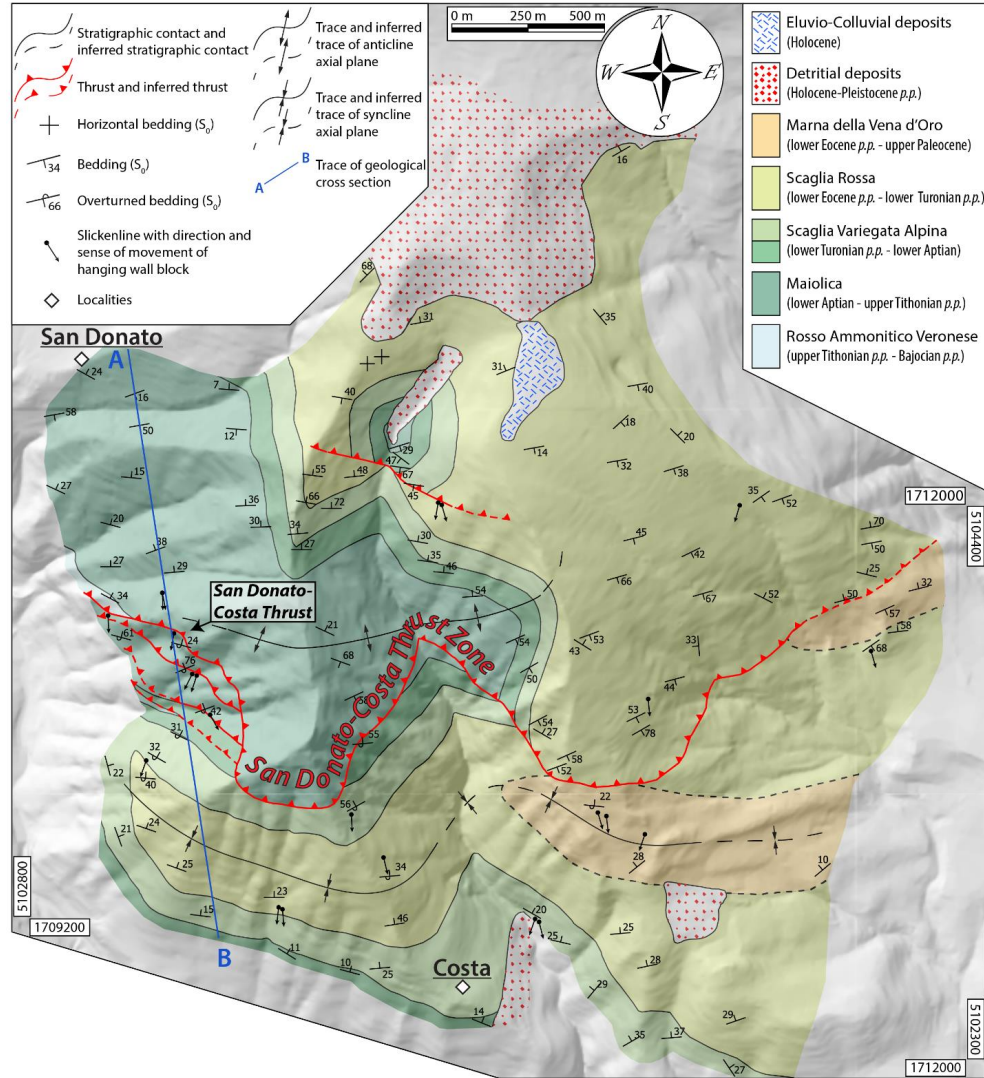


## Jurassic - Paleogene multilayer succession

- General increase of the amount of marly beds toward the top of the succession

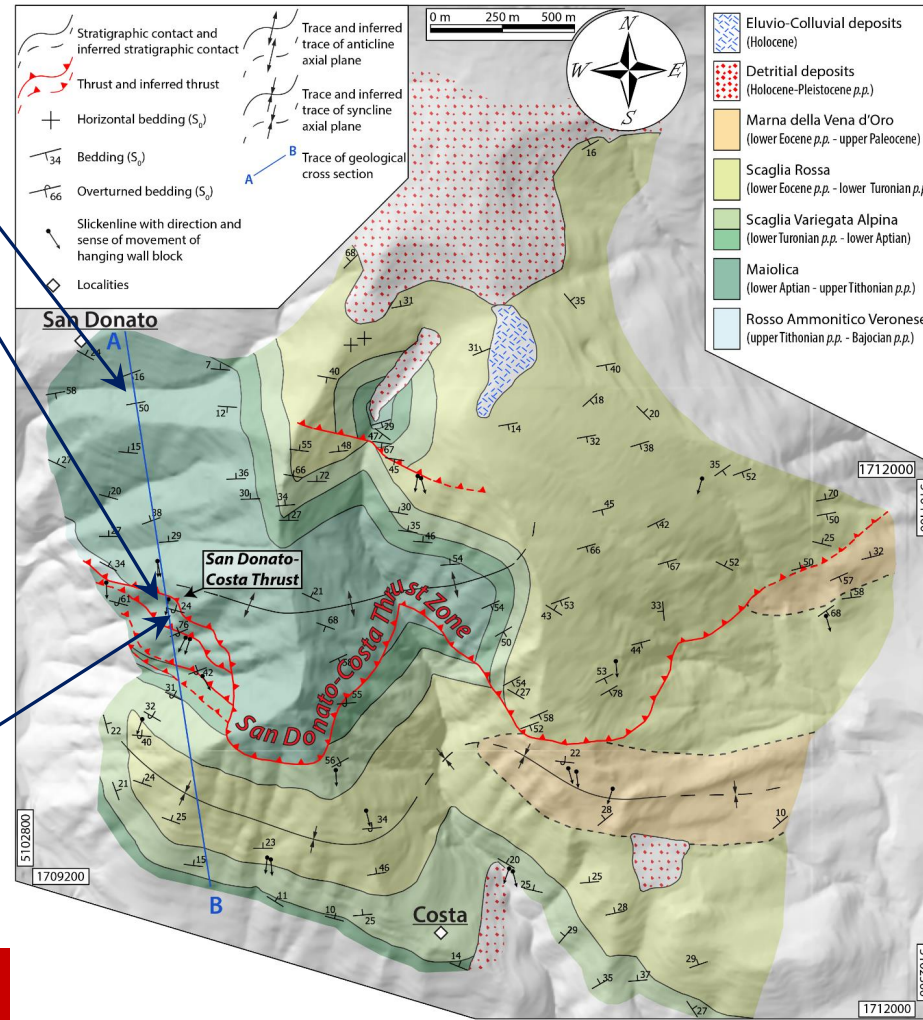
- No evidence of strong mineralogical differences between different units

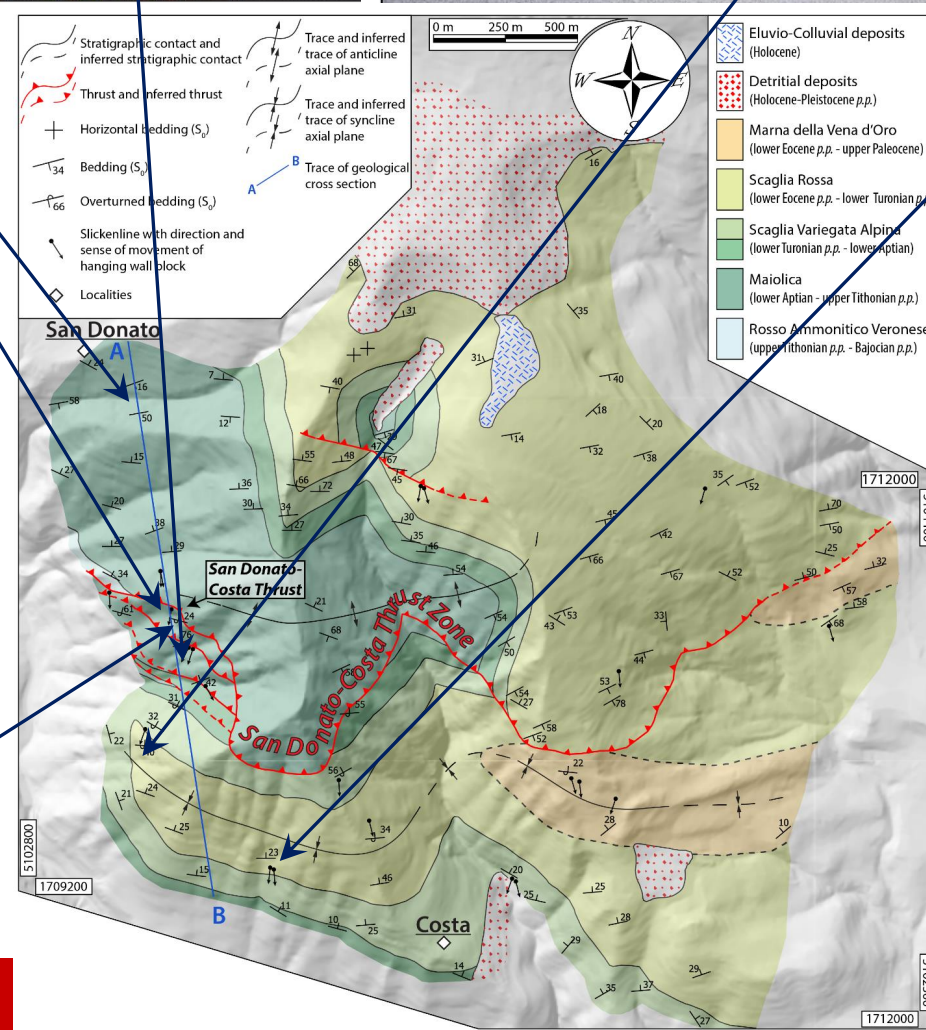
# Structural framework of the study area

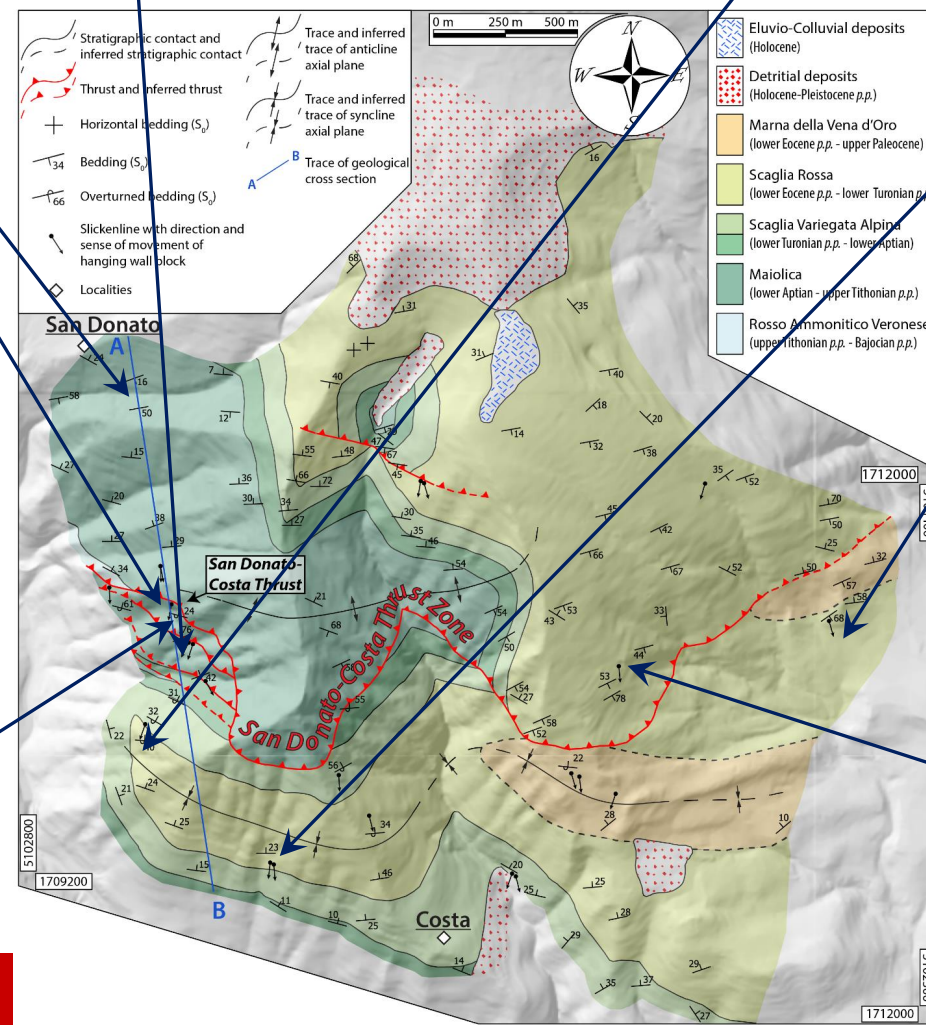


a) contour of poles to bedding, fold axes and computed fold axis (“Bingham Analysis” on pole to bedding); b) contour of poles to axial planes (green circles); c) contour of poles to fault planes; d) contour of poles to C-planes; e) contour of poles to detected S-surfaces . “Hoepfner transformation” for the tangent lineation plot was applied to plot the direction and the sense of movement of the footwall block in plots (c) and (d).

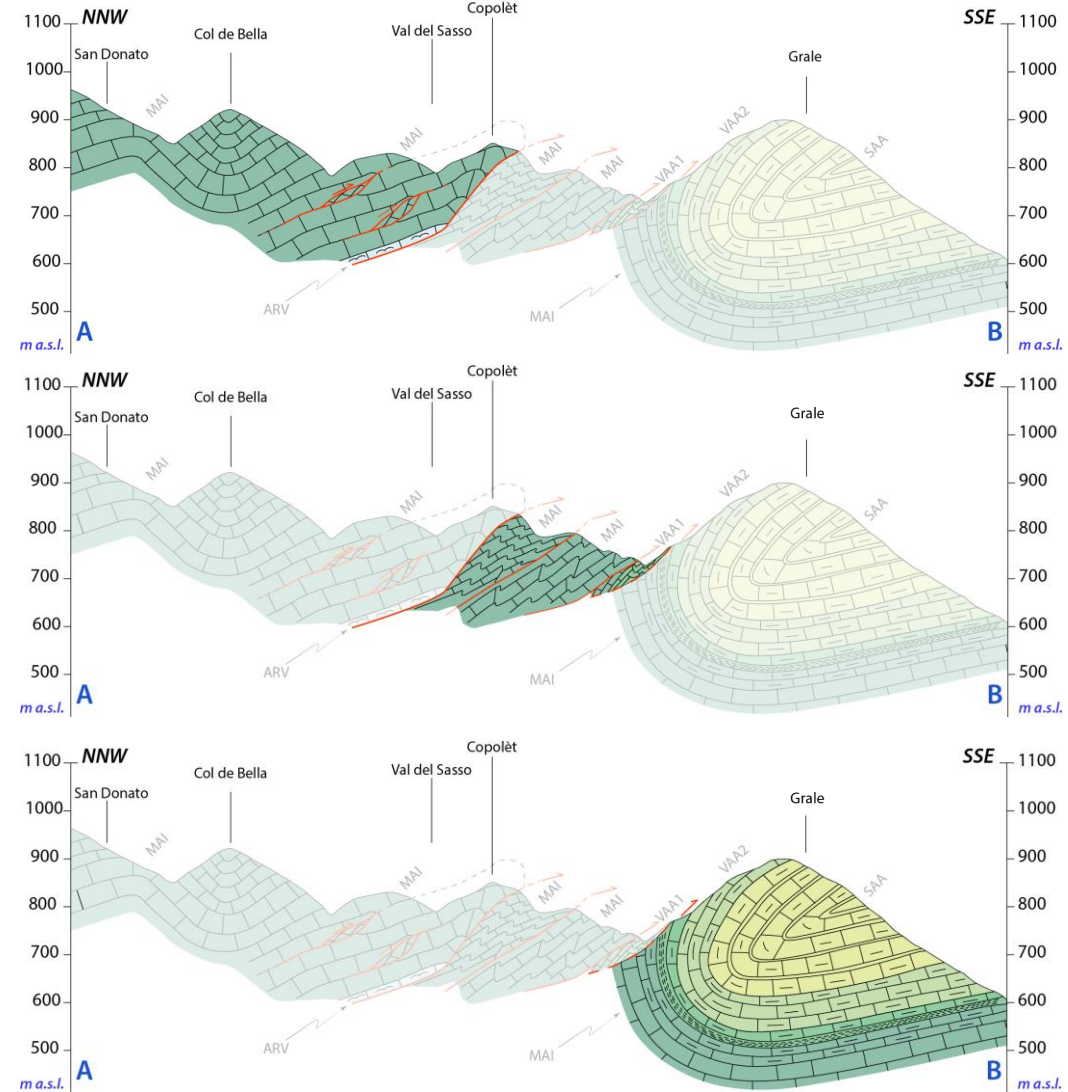
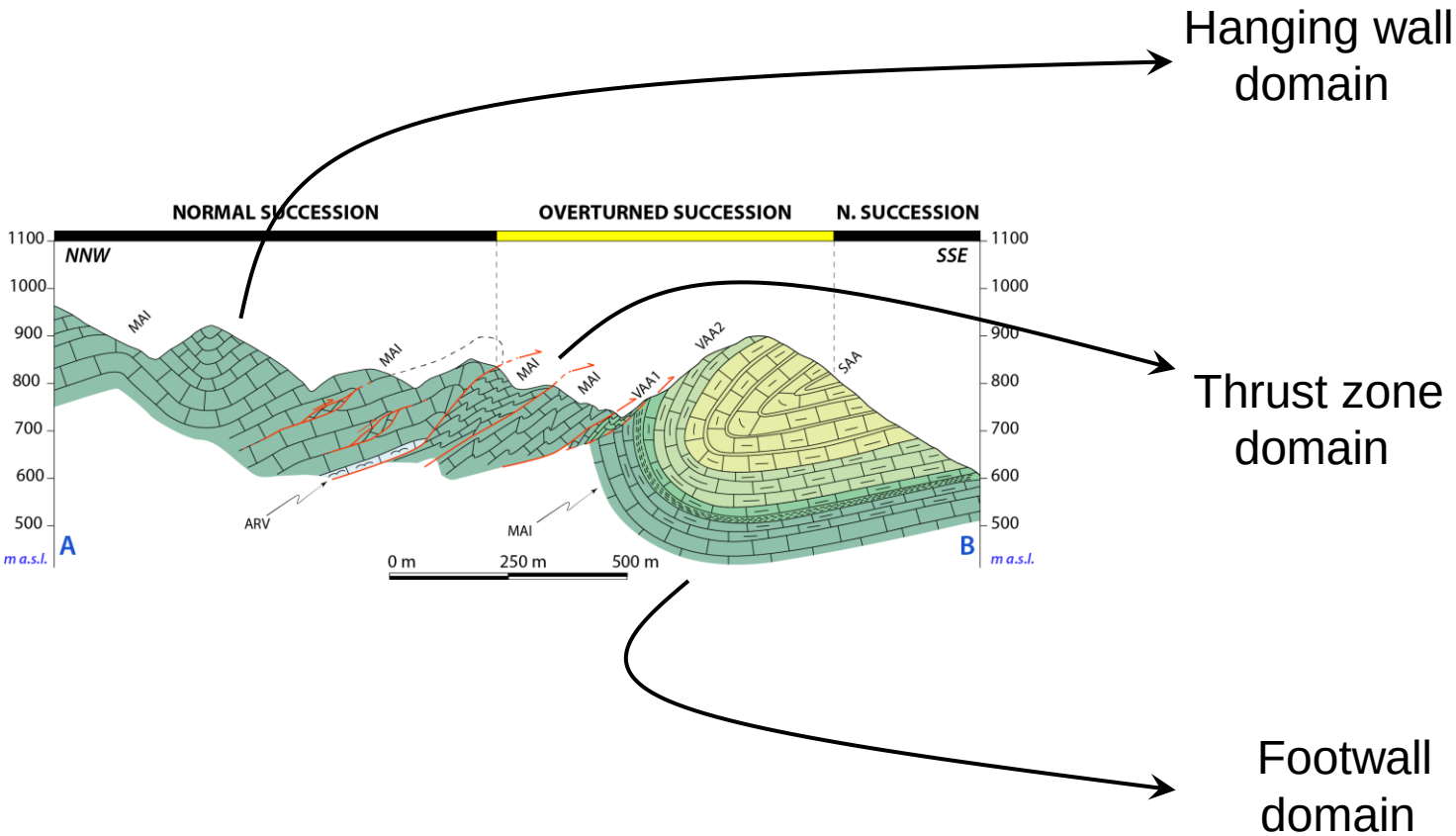
# Variability of deformation processes

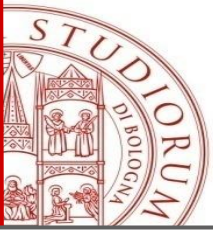




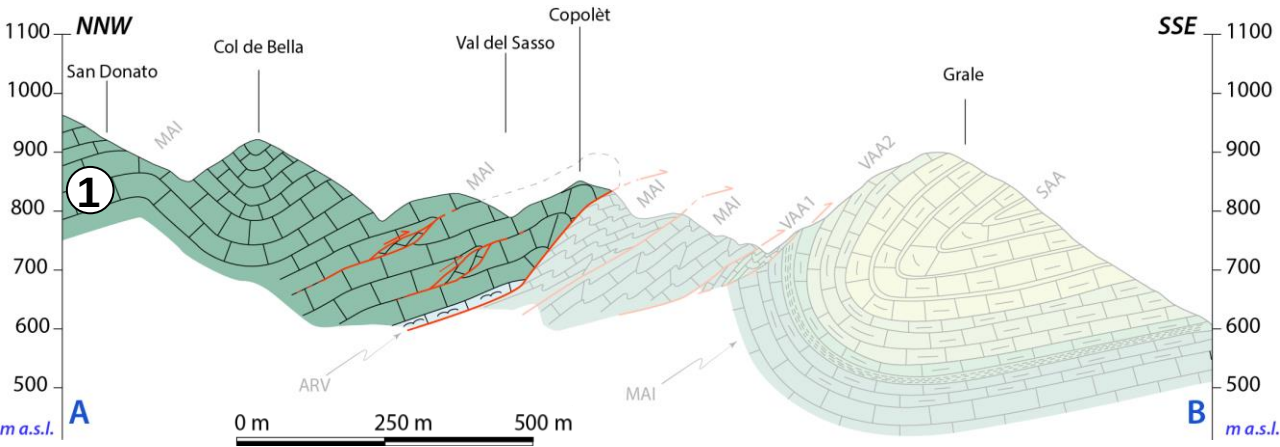


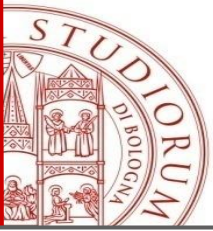
# STRUCTURAL DOMAINS of the San Donato-Costa Thrust zone (SCTZ)



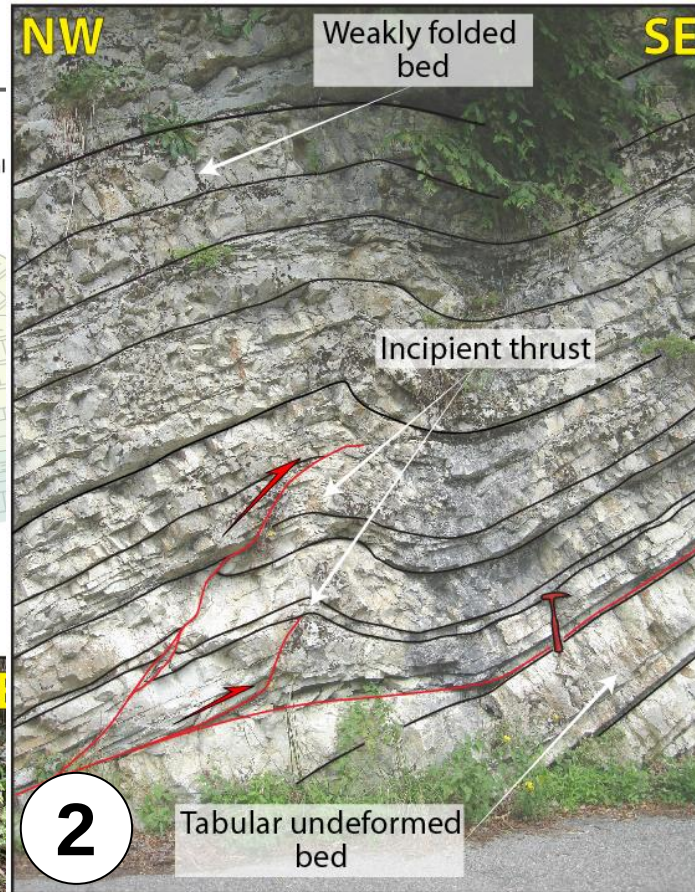
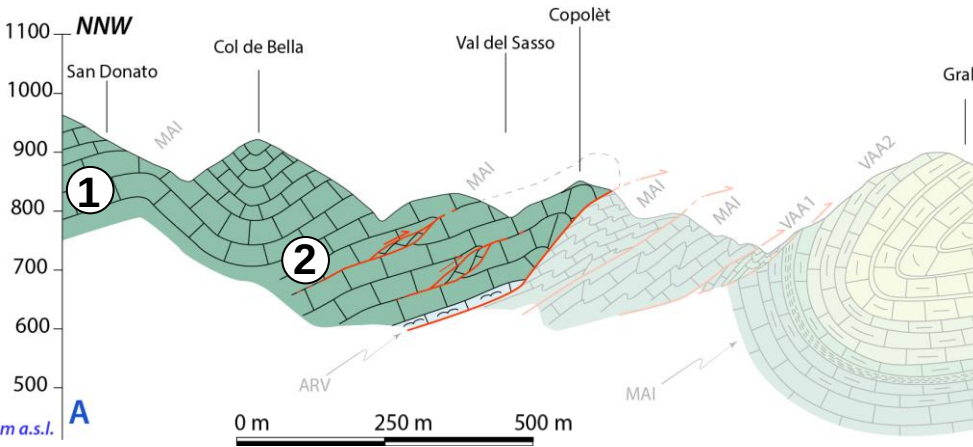


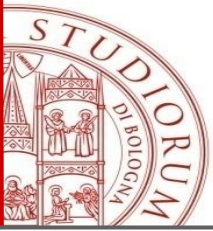
# Hanging wall domain (normal succession)



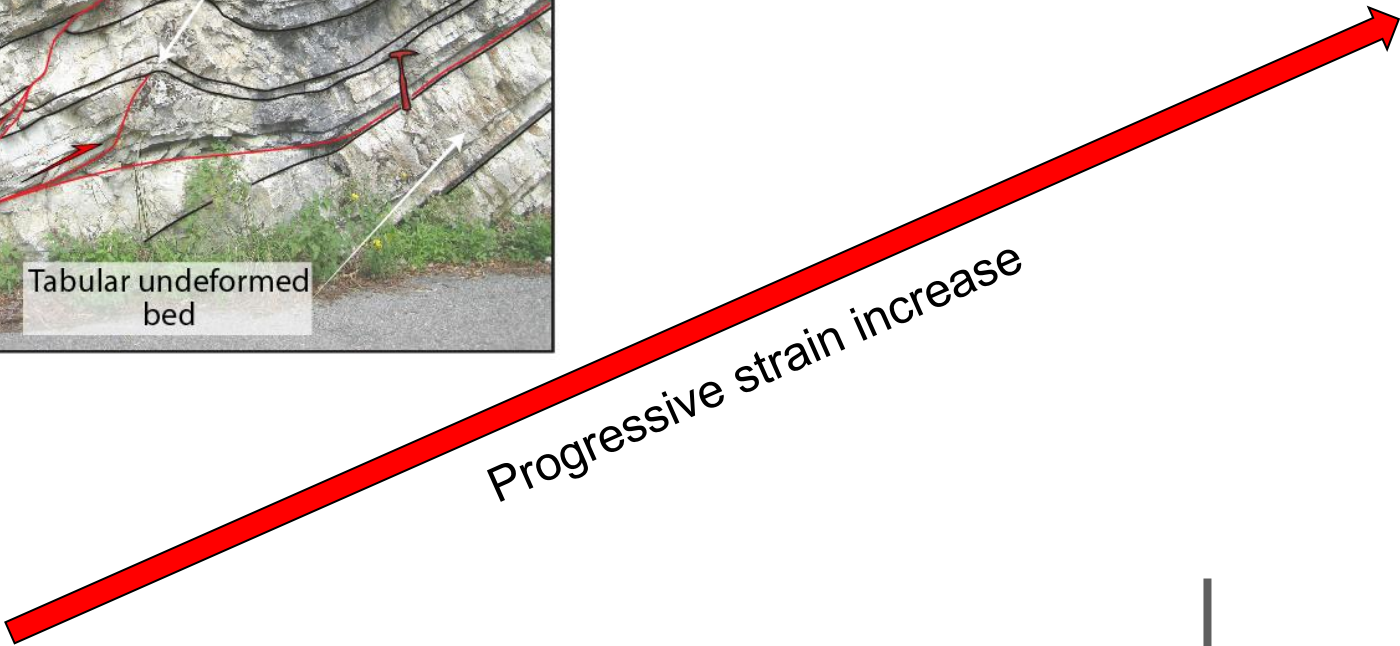
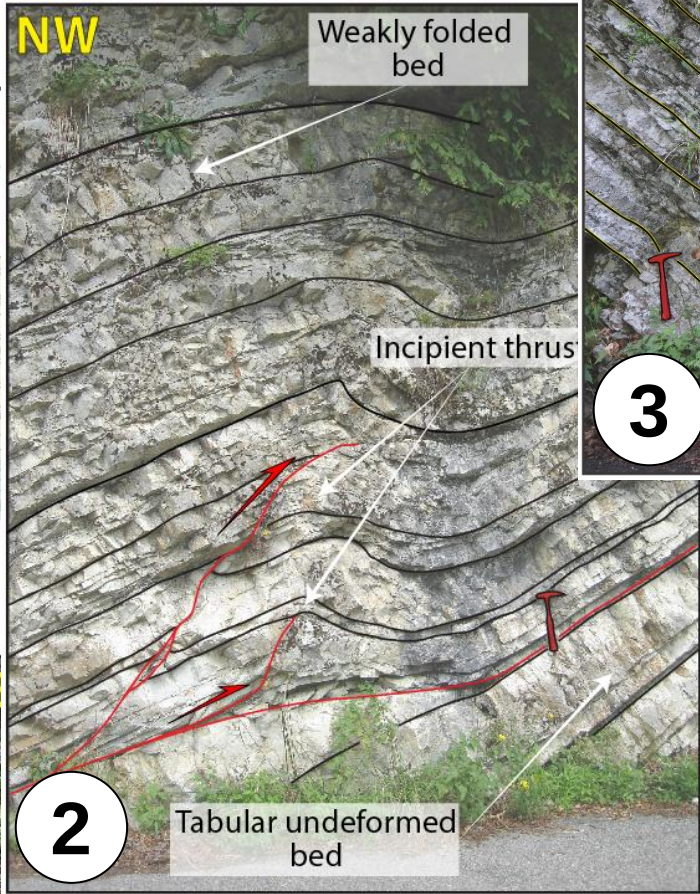
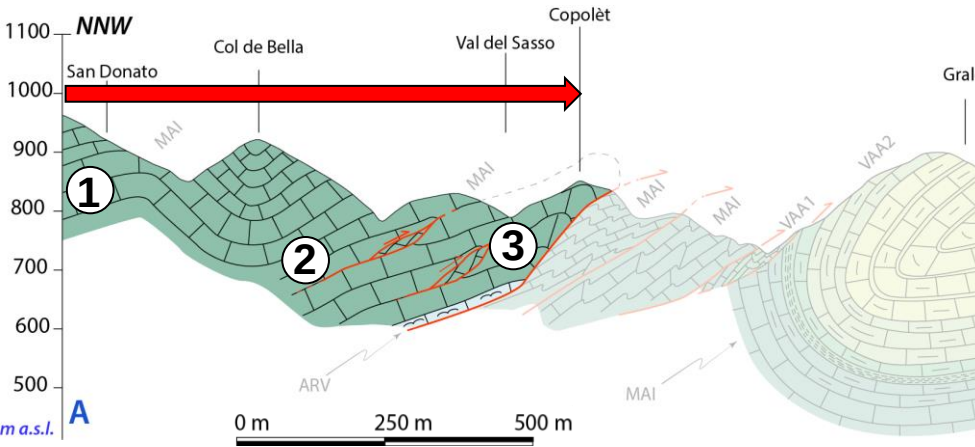


# Hanging wall domain (normal succession)

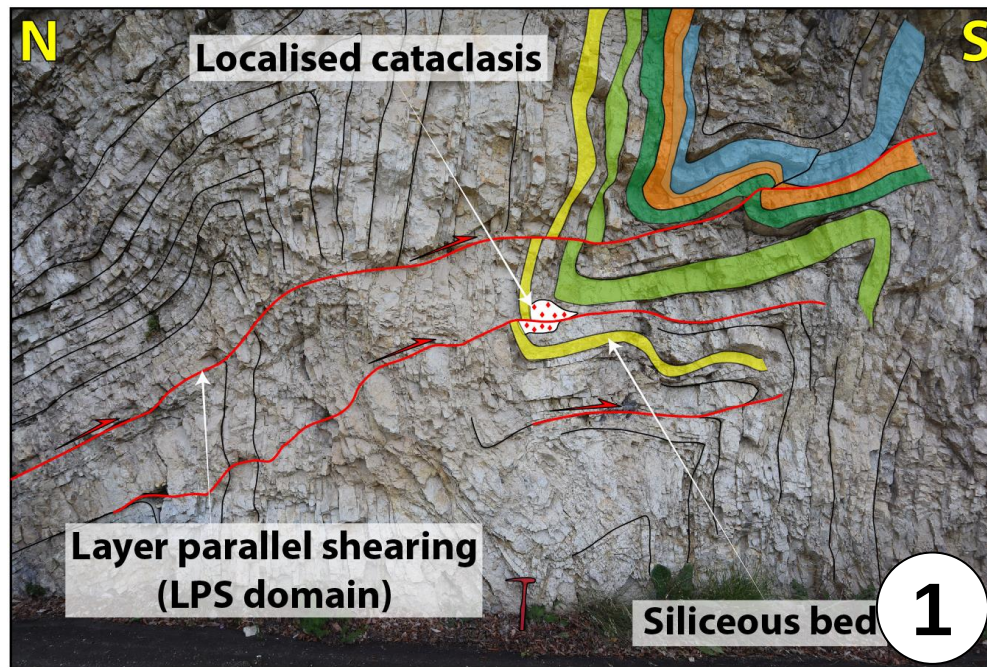
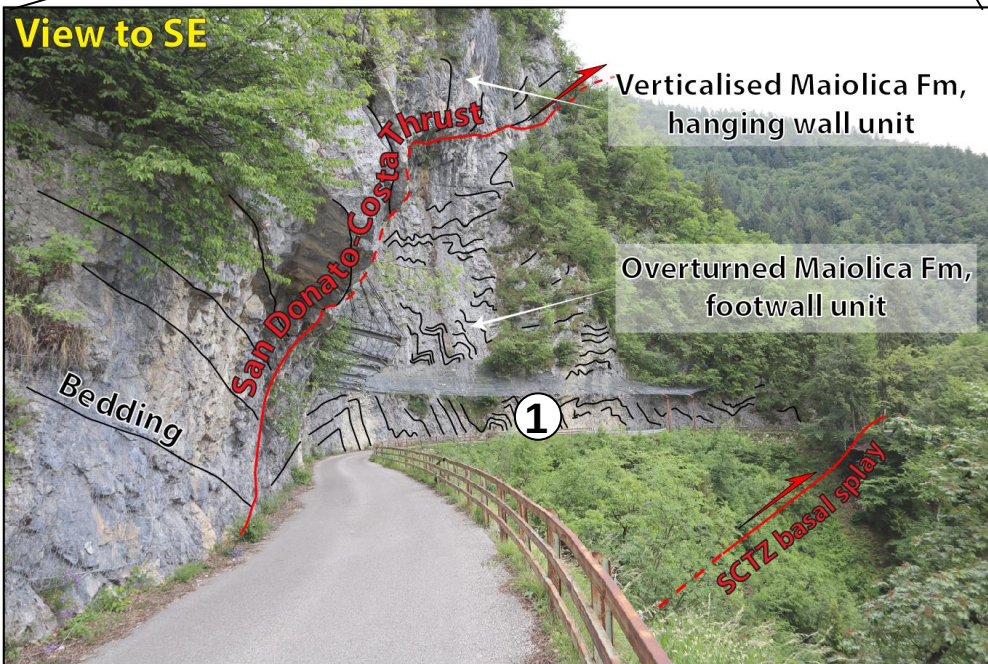
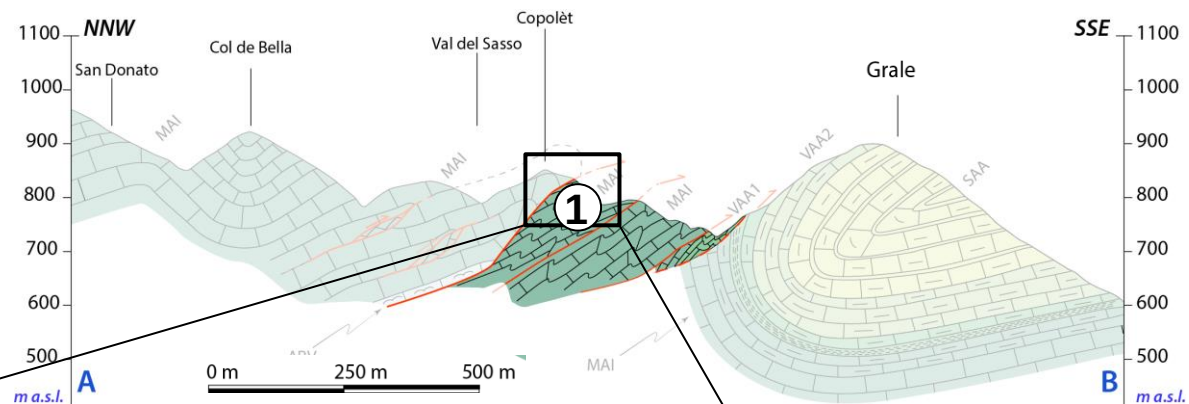




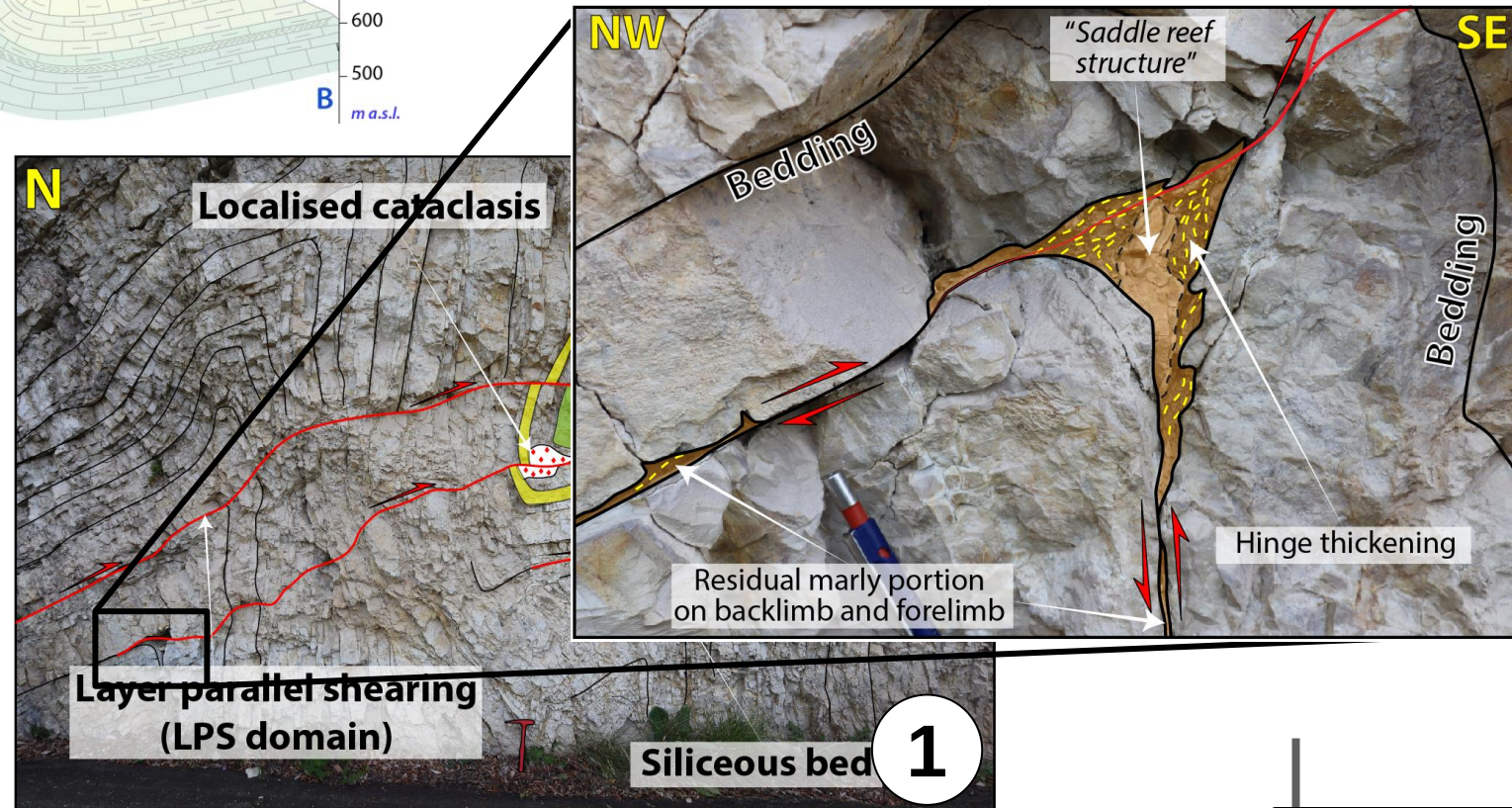
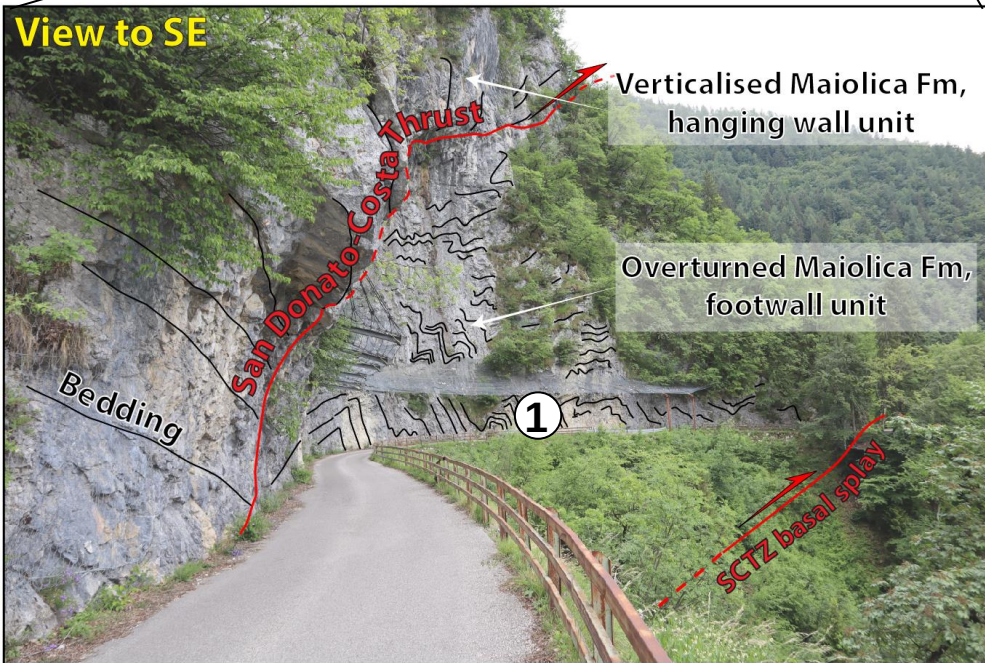
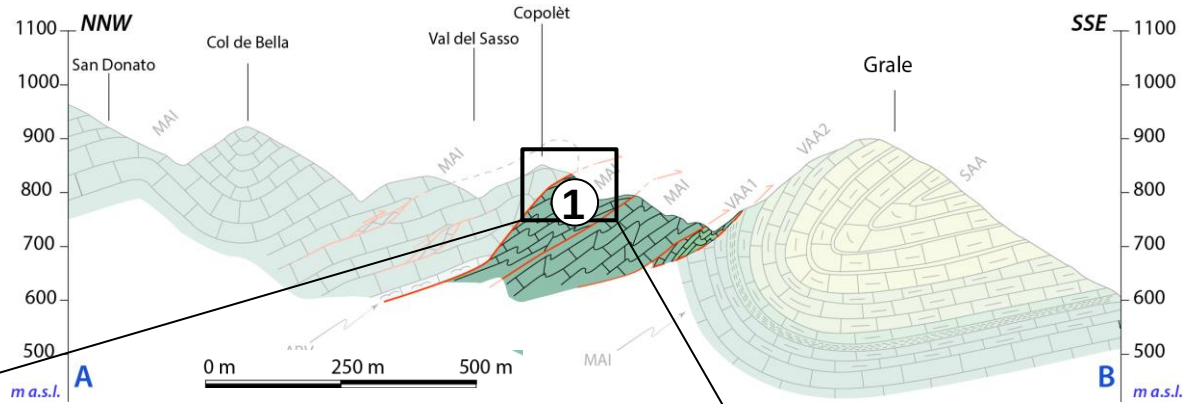
# Hanging wall domain (normal succession)



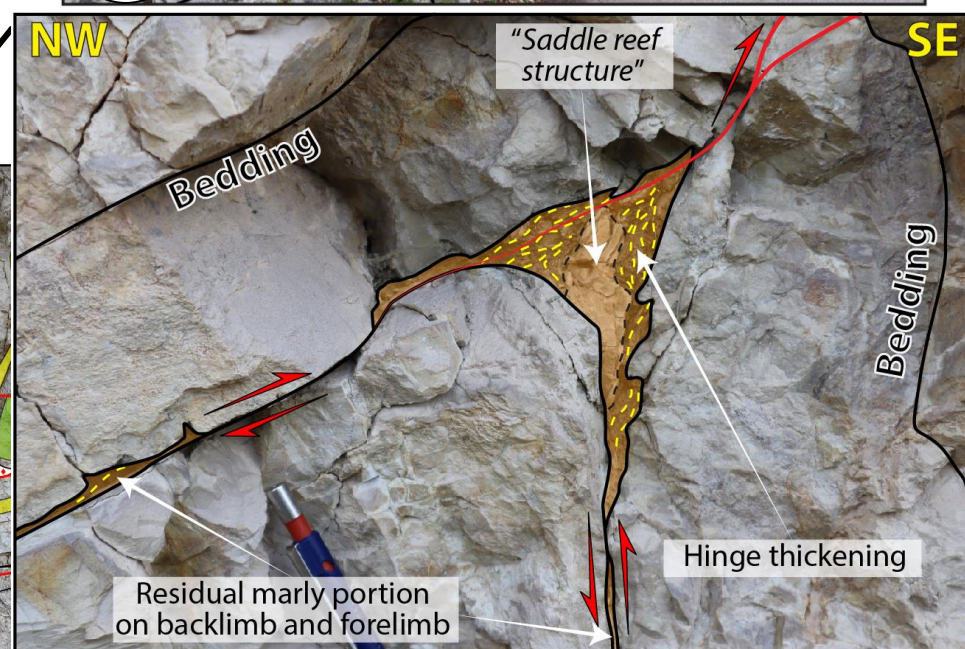
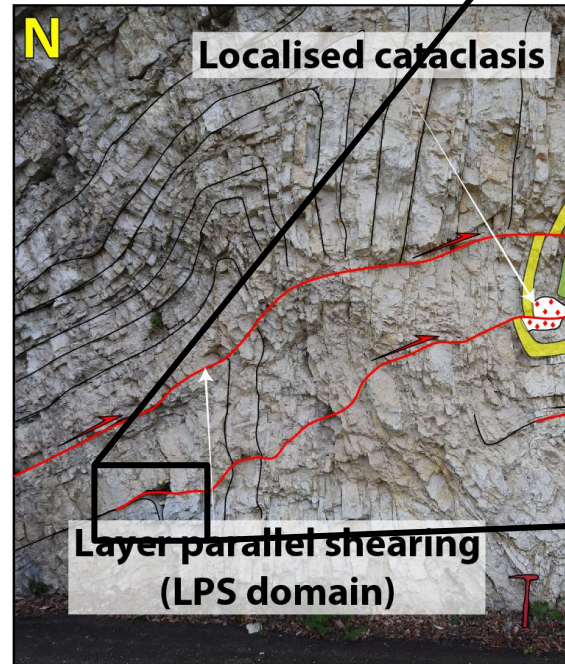
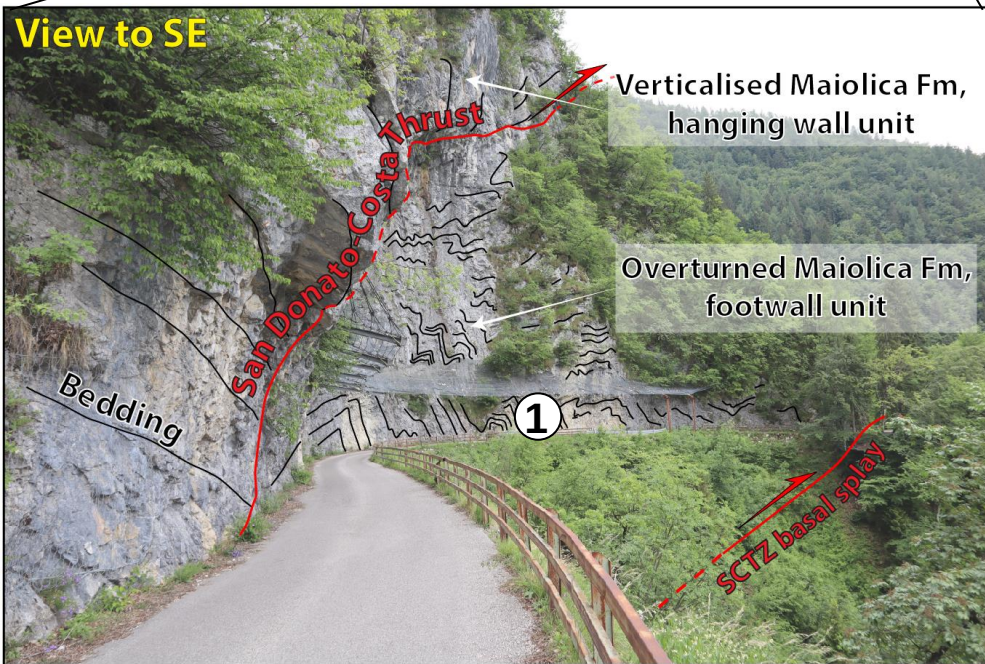
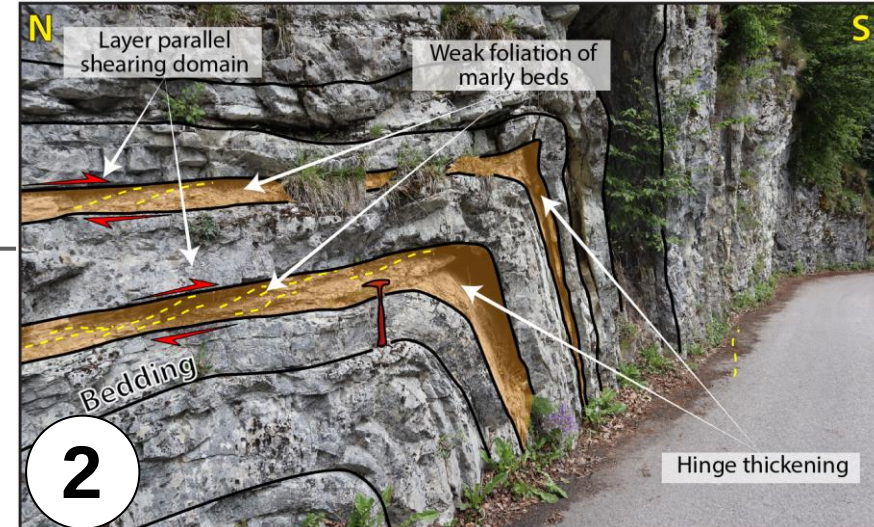
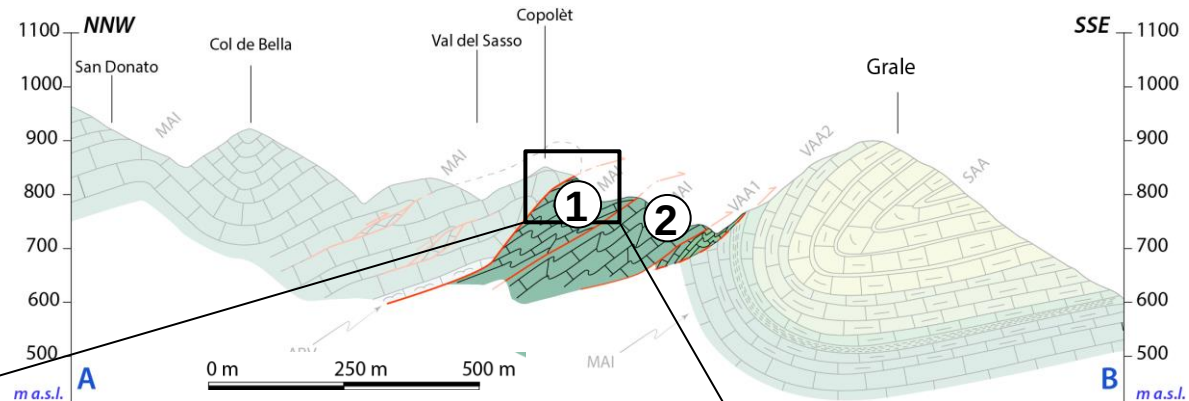
# Thrust zone domain (overturned succession)

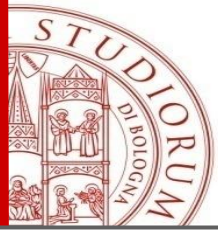


# Thrust zone domain (overturned succession)

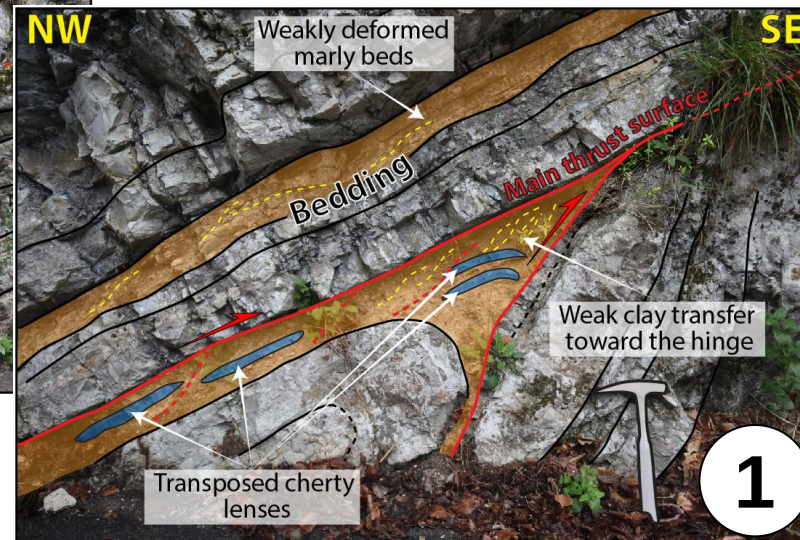
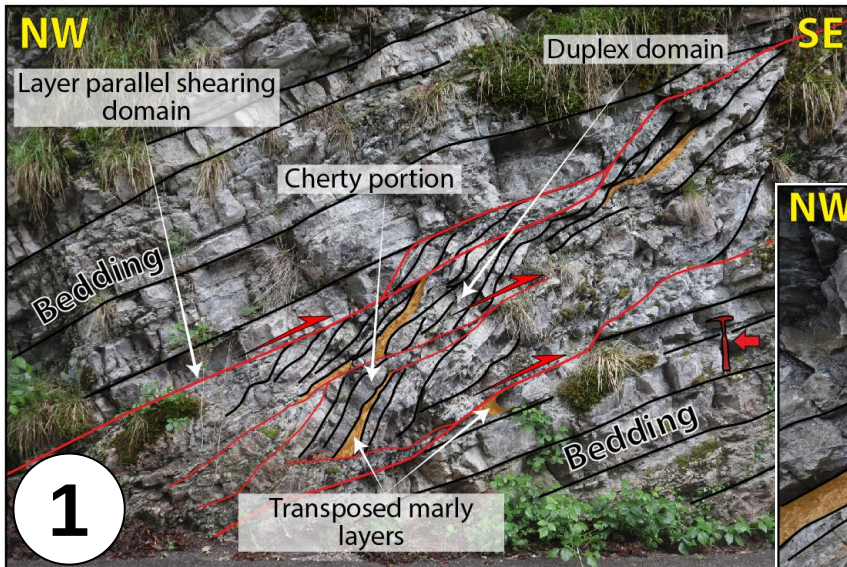
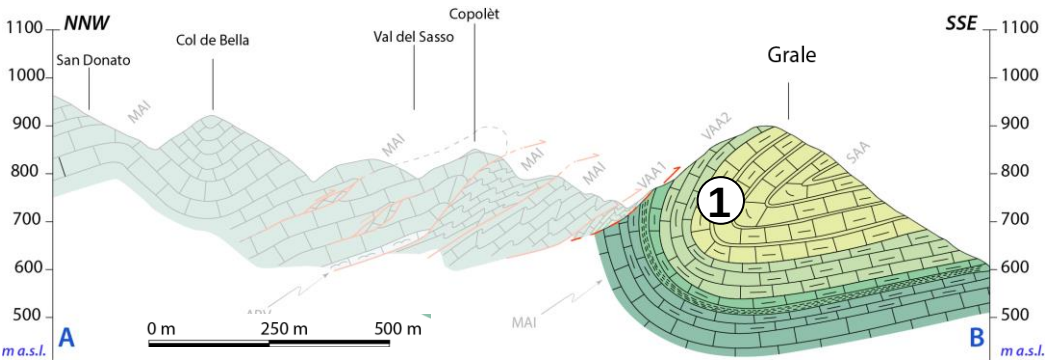


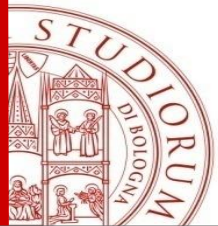
# Thrust zone domain (overturned succession)



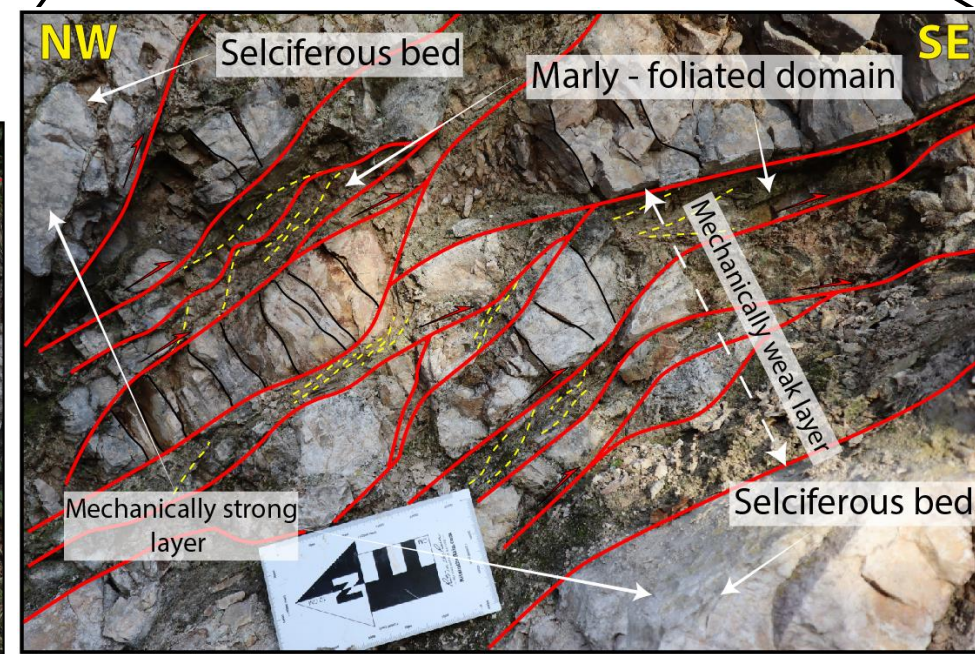
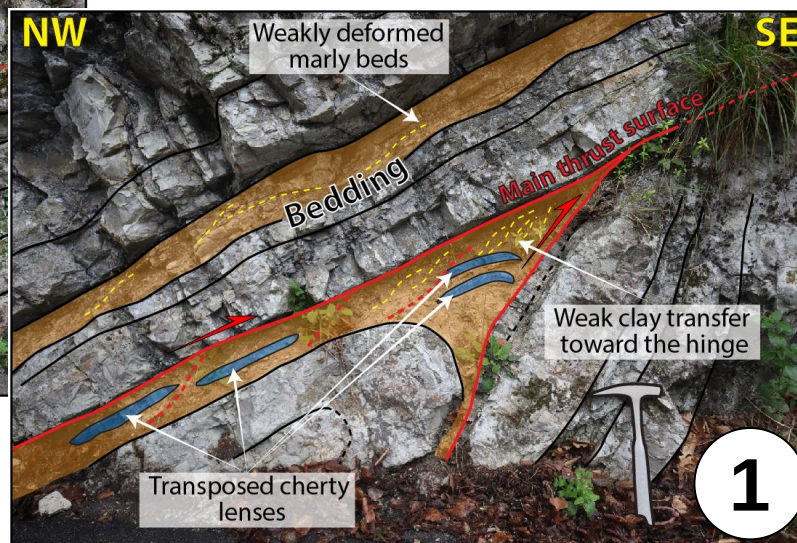
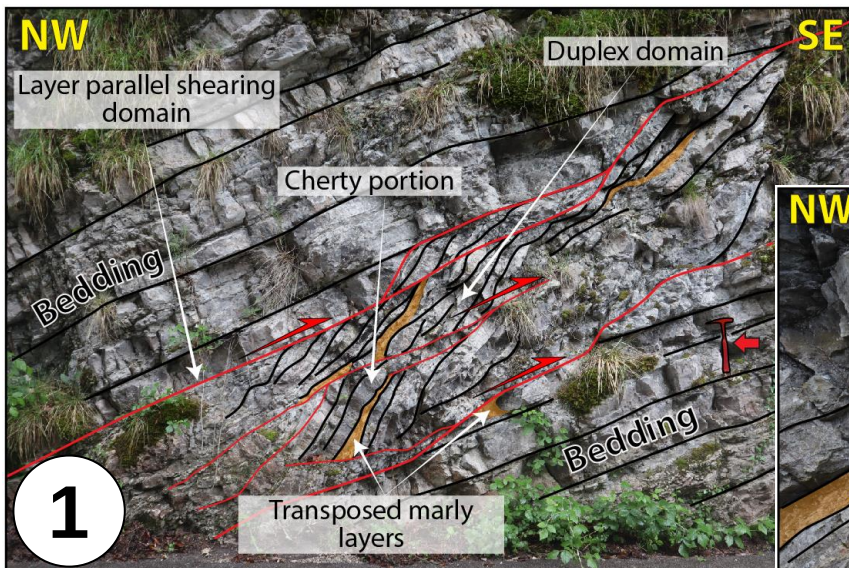
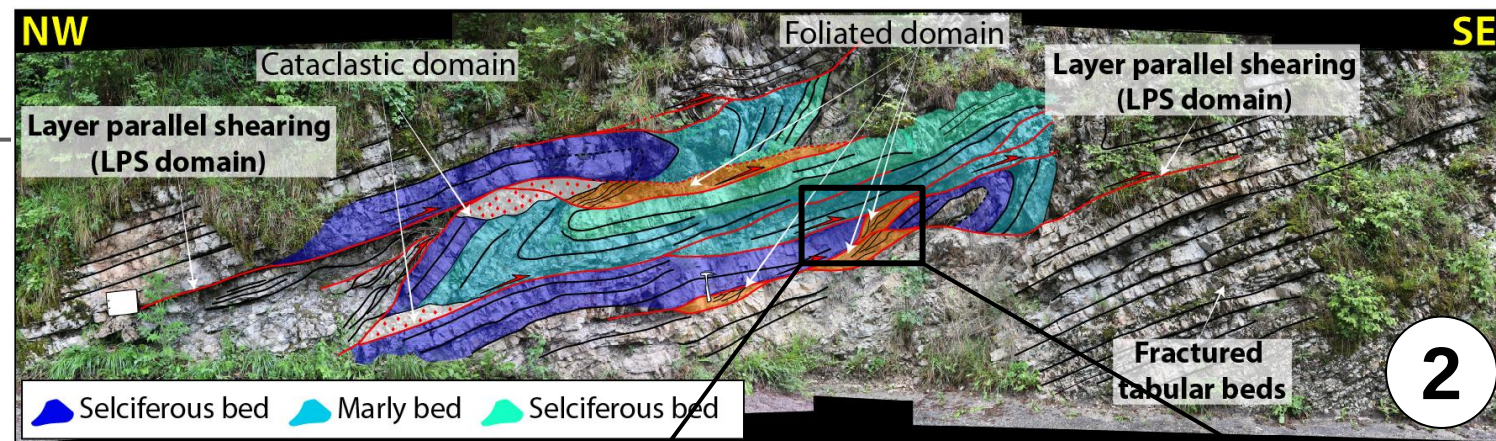
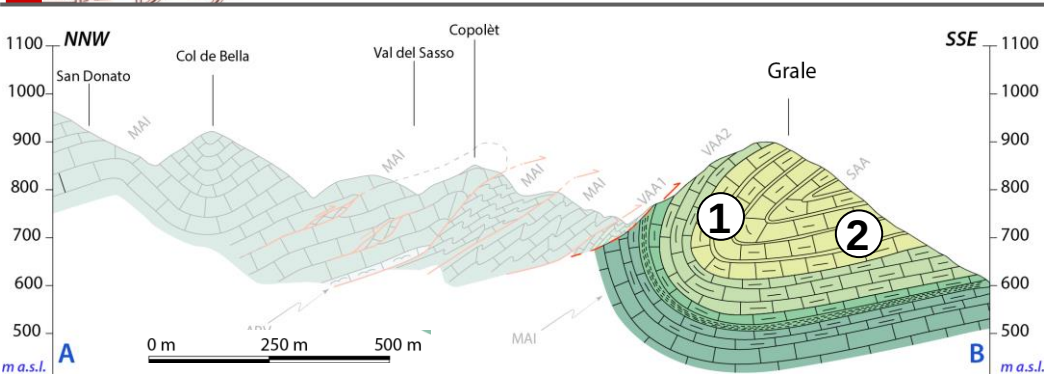


# Footwall domain (overturned and normal succession)

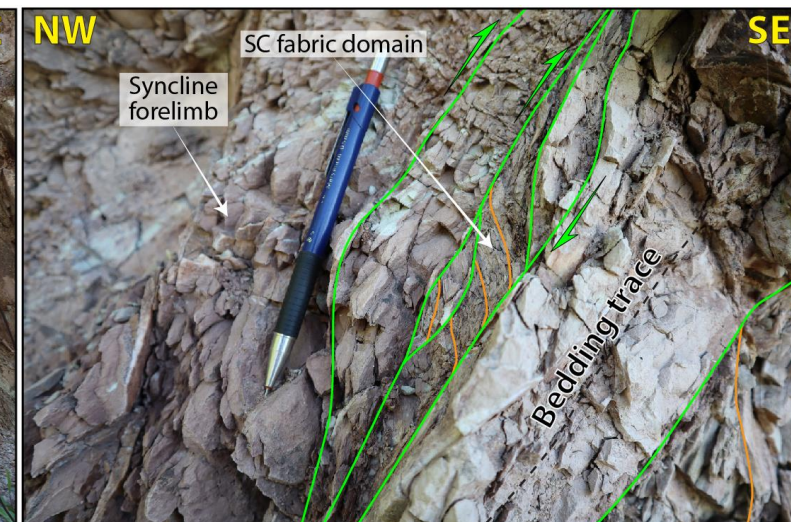
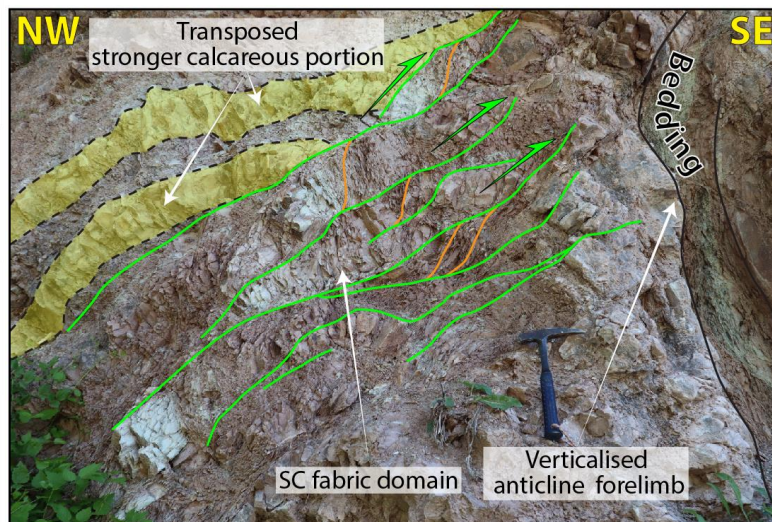
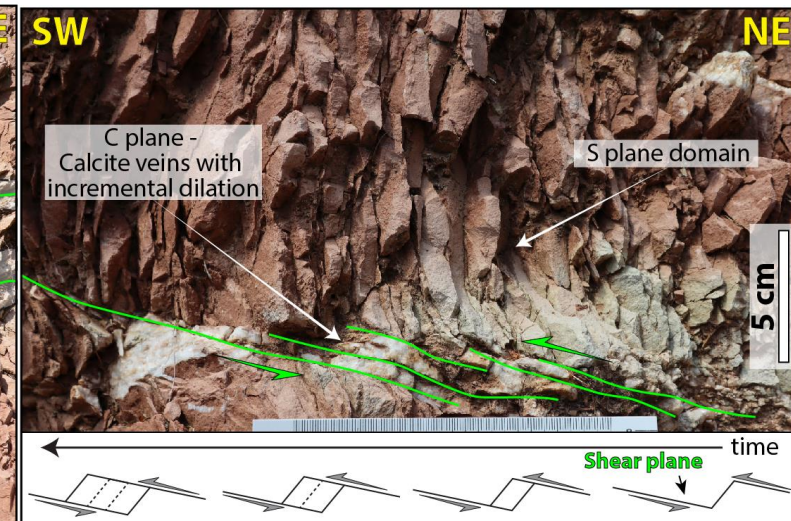
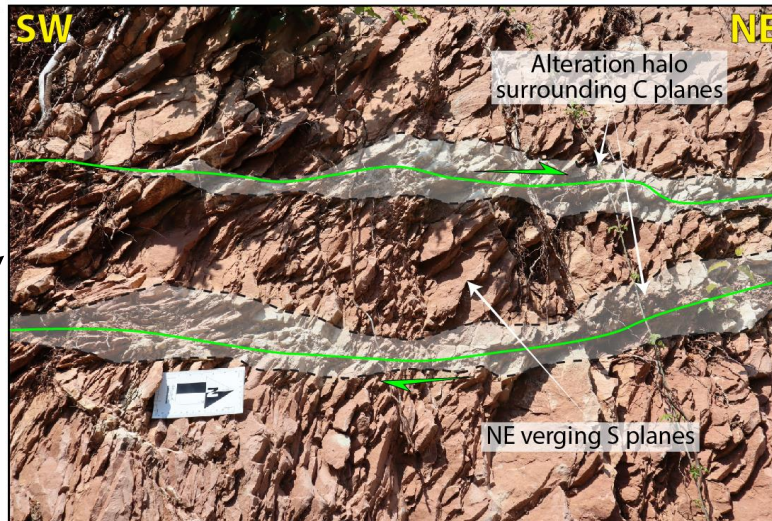
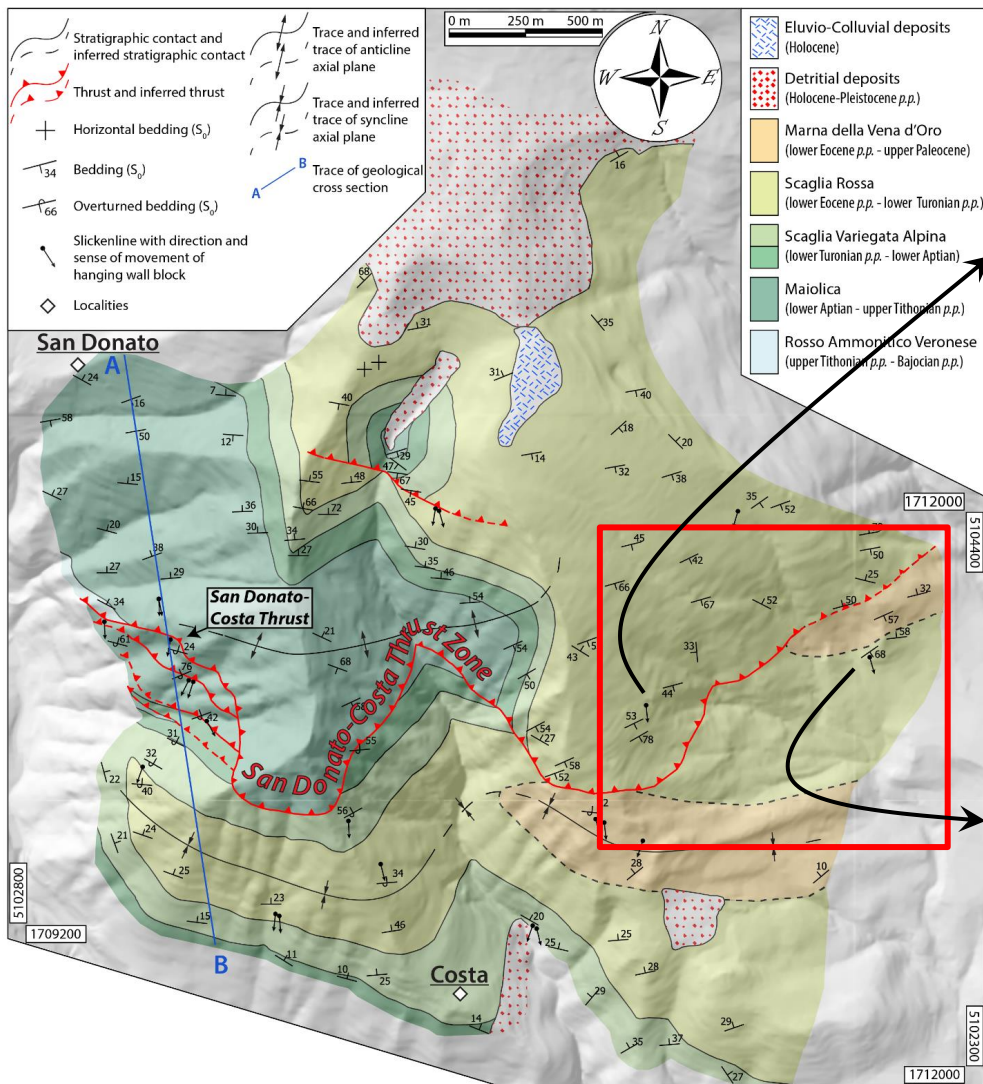




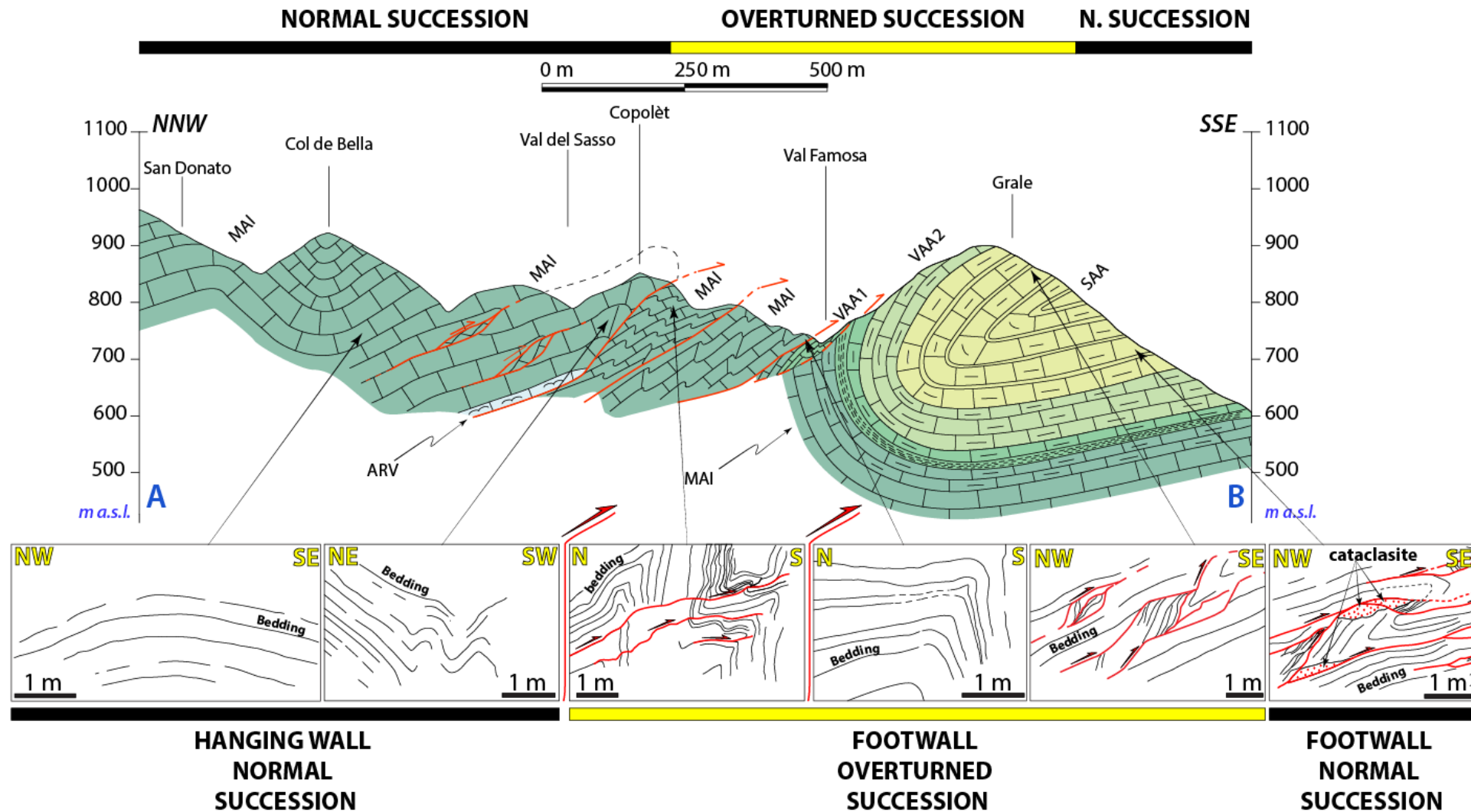
# Footwall domain (overturned and normal succession)

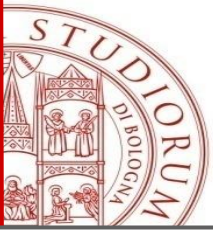


# Eastern hanging wall and footwall domains



# Deformation through the San Donato-Costa Thrust Zone (SCTZ)





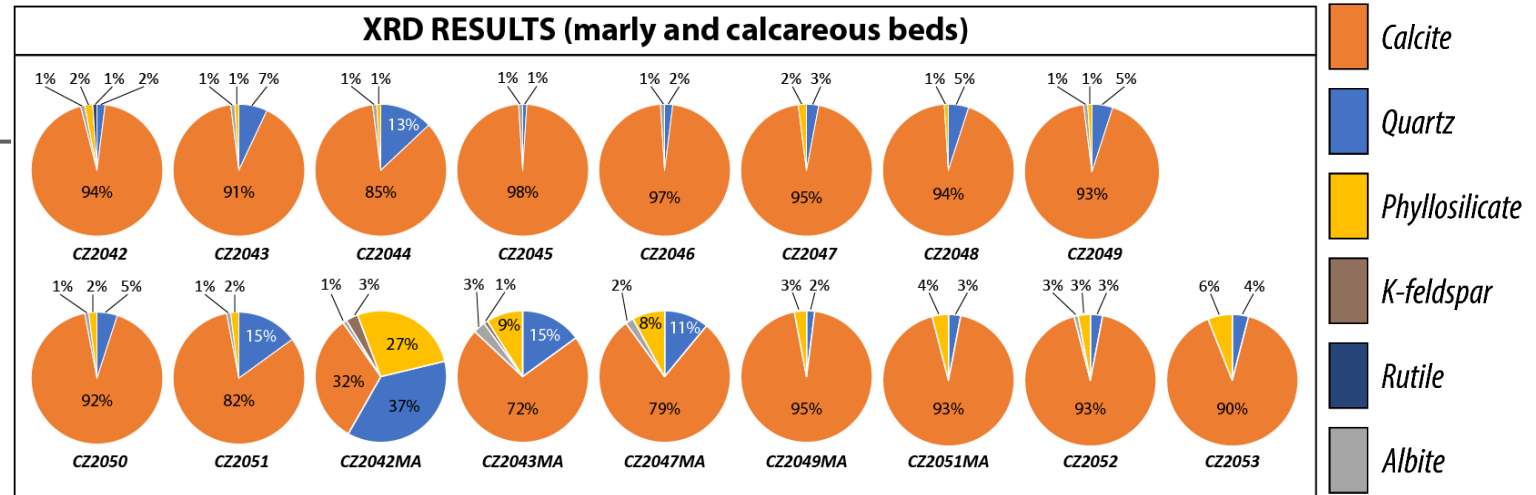
# Parameters steering deformation

## 1- LITHOLOGY

XRD analysis of calcareous and marly beds to identify the principal mineralogical components

## 2- MARLY LAYER THICKNESS

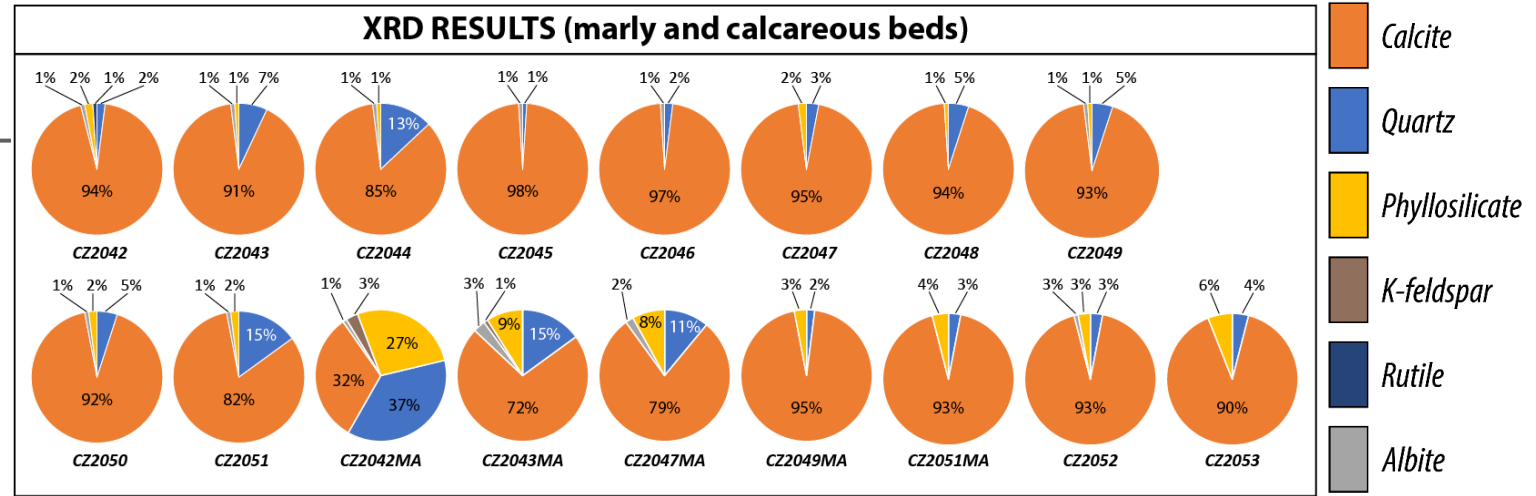
## 3- SPATIAL ORGANISATION OF MARLY BEDS



# Parameters steering deformation

## 1- LITHOLOGY

XRD analysis of calcareous and marly beds to identify the principal mineralogical components



## 2- MARLY LAYER THICKNESS

$$\frac{M.l.t.}{T.t.} \%$$

## 3- SPATIAL ORGANISATION OF MARLY BEDS

$$\frac{n.M.l.}{T.t.} (m^{-1})$$

M.l.t./T.t.= 10%

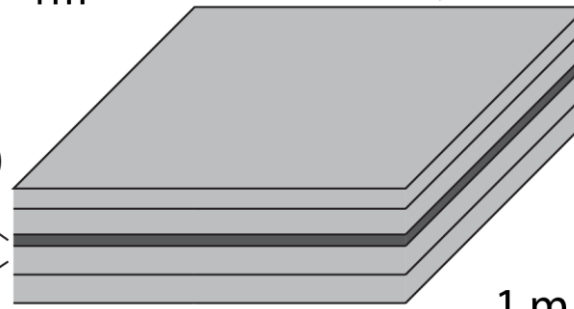
n.M.l./T.t.=1m<sup>-1</sup>

t1<<t2

t1(10cm)

t2 (~30cm)

*"Maiolica type"*



M.l.t./T.t.= 45%

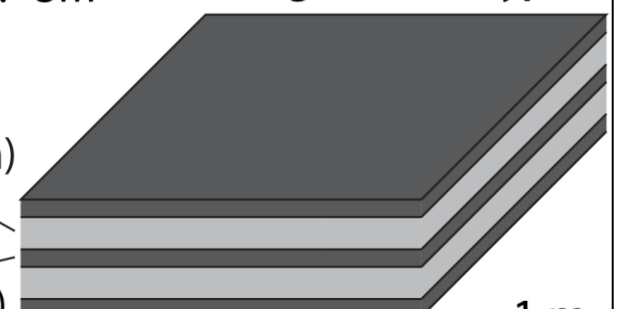
n.M.l./T.t.=3m<sup>-1</sup>

t1<t2

t2 (25cm)

t1(15cm)

*"Scaglia Rossa type"*



**M.l.t./T.t.**

Ratio between measured thickness of marly beds with respect to the measured succession

**n.M.l./T.t.**

Number of marly beds / m



Limestone (rheologically strong lithology)



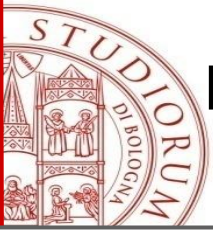
Marl (rheologically weak lithology)

**t1**

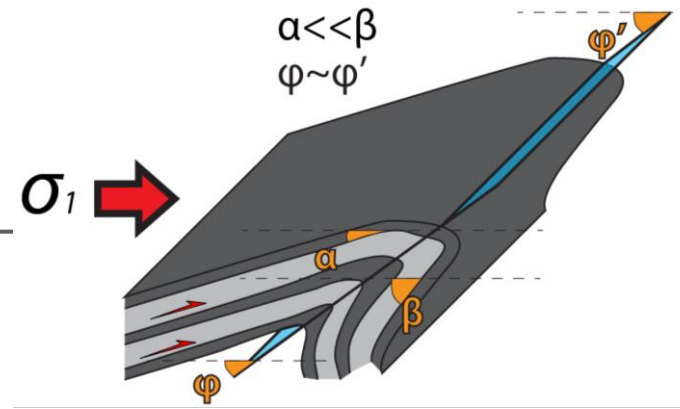
Thickness of marly bed

**t2**

Thickness of calcareous bed

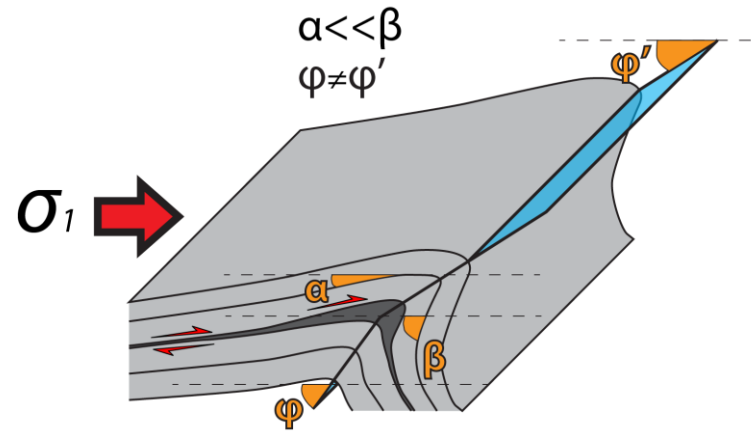


## Parameters steering deformation



### 4- OBLIQUITY OF INHERITED SURFACES WITH RESPECT TO THE STRESS FIELD

- $\alpha$ : dip angle of the back limb bedding
- $\beta$ : dip angle of the forelimb bedding
- $\varphi$ : dip angle of the axial plane (basal portion of fold)
- $\varphi'$ : dip angle of the axial plane (upper portion of fold)



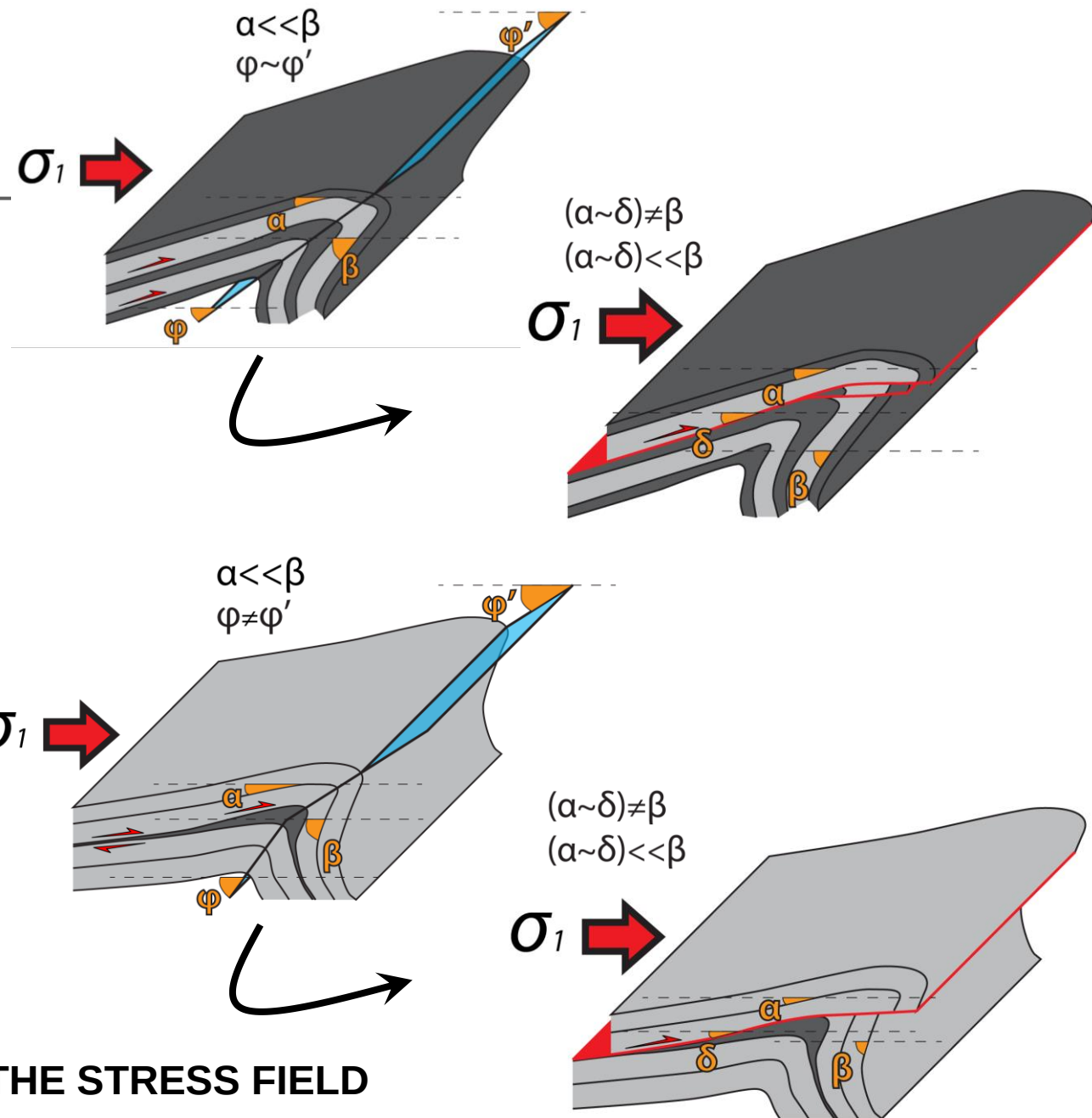
### 5- INVOLVEMENT OF FLUIDS

### 6- GEOMETRICAL FRAMEWORK WITH RESPECT TO THE STRESS FIELD

# Parameters steering deformation

## 4- OBLIQUITY OF INHERITED SURFACES WITH RESPECT TO THE STRESS FIELD

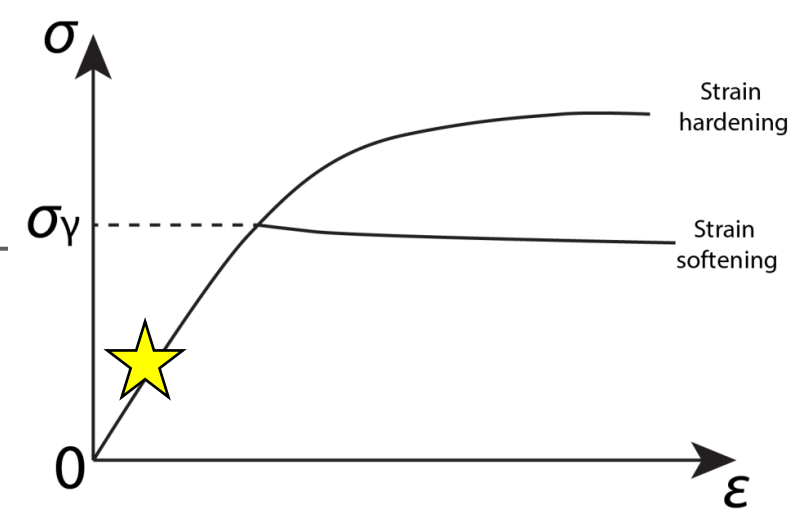
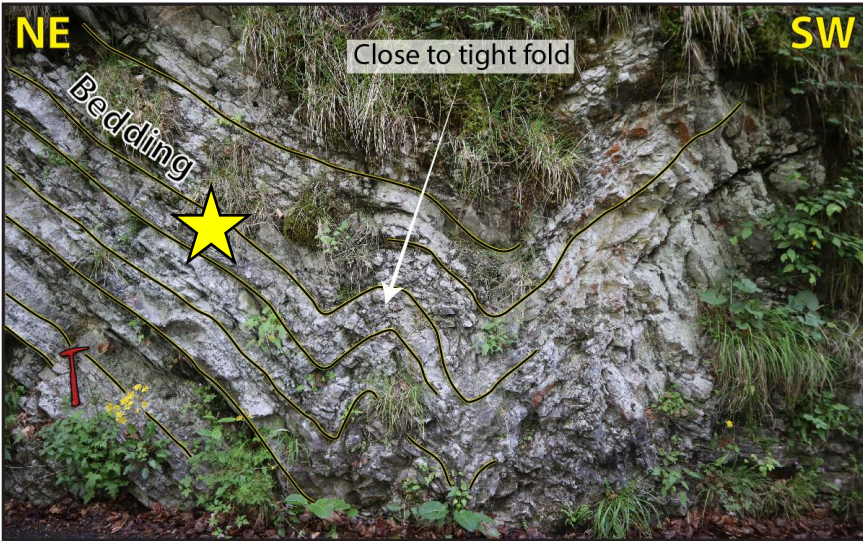
- $\alpha$ : dip angle of the back limb bedding
- $\beta$ : dip angle of the forelimb bedding
- $\varphi$ : dip angle of the axial plane (basal portion of fold)
- $\varphi'$ : dip angle of the axial plane (upper portion of fold)
- $\delta$ : dip angle of the shear surface



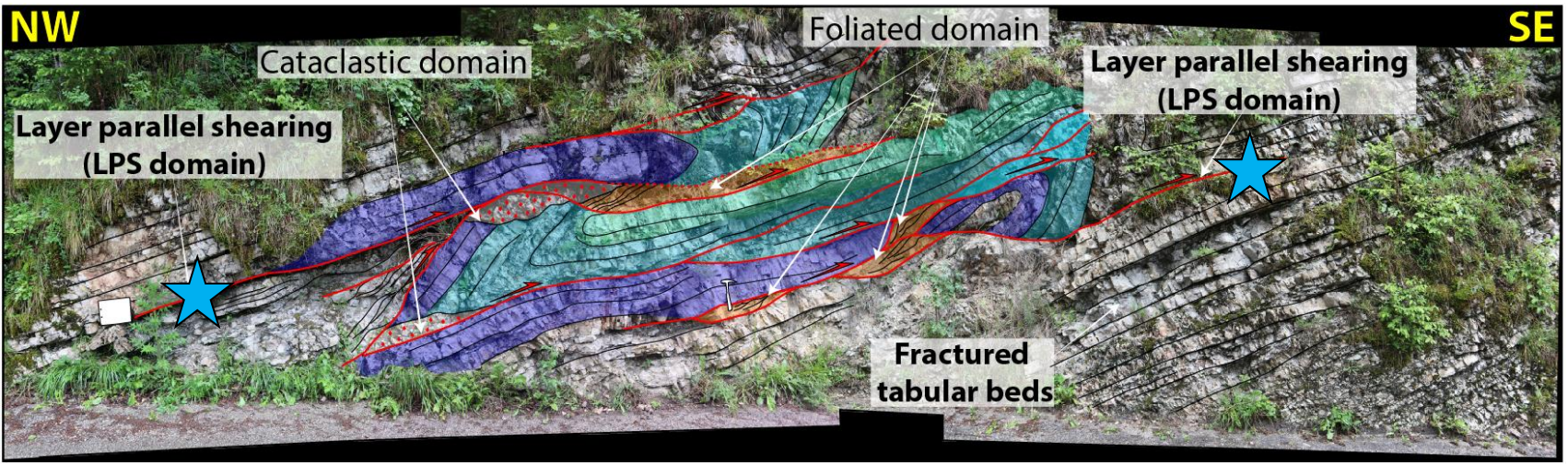
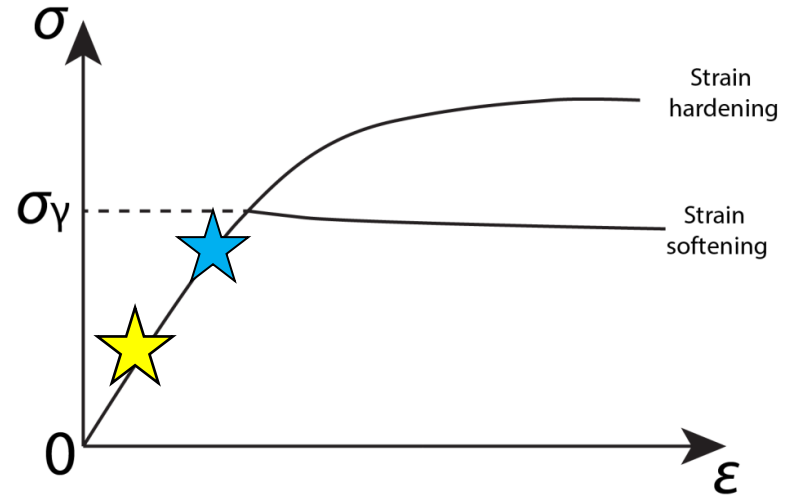
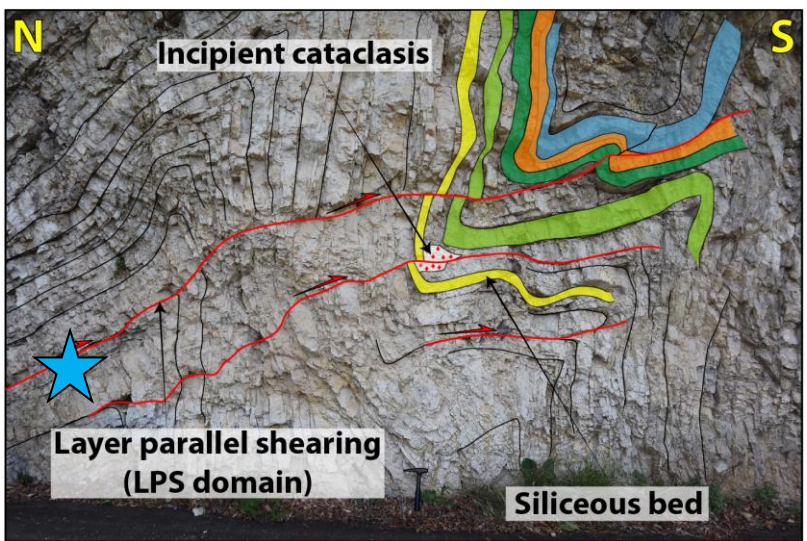
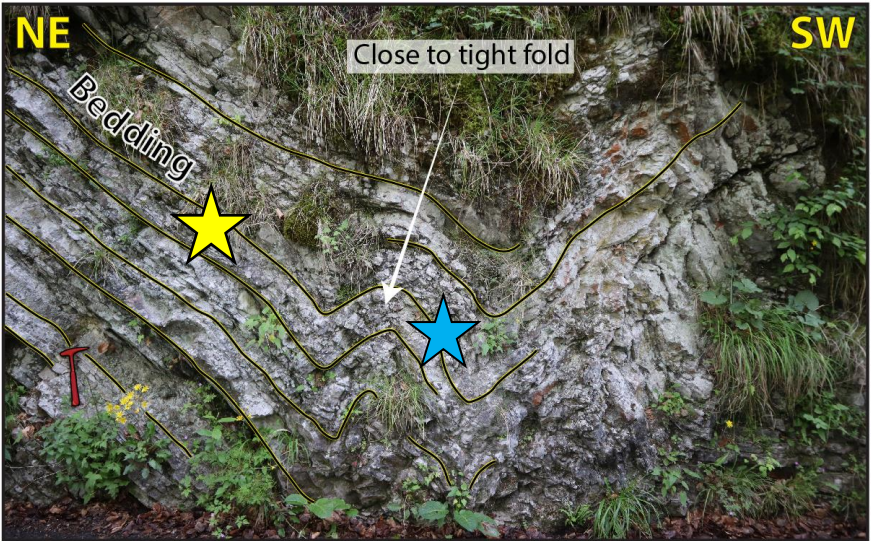
## 5- INVOLVEMENT OF FLUIDS

## 6- GEOMETRICAL FRAMEWORK WITH RESPECT TO THE STRESS FIELD

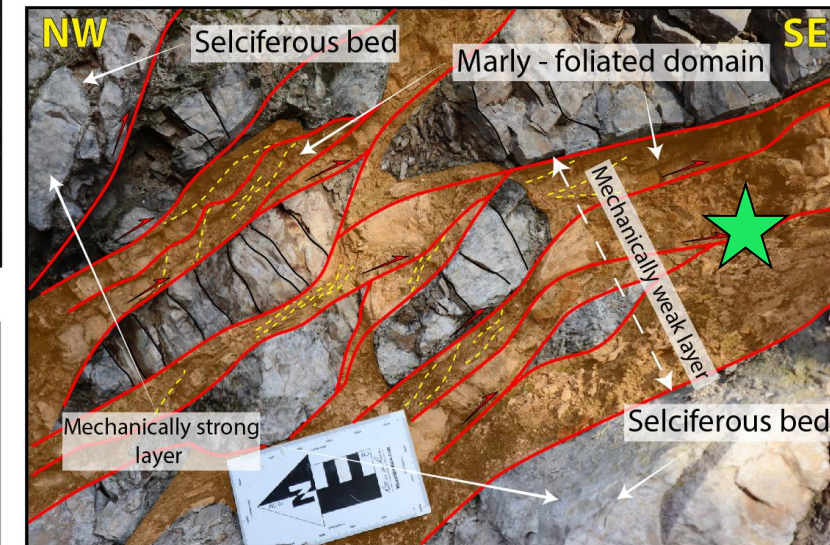
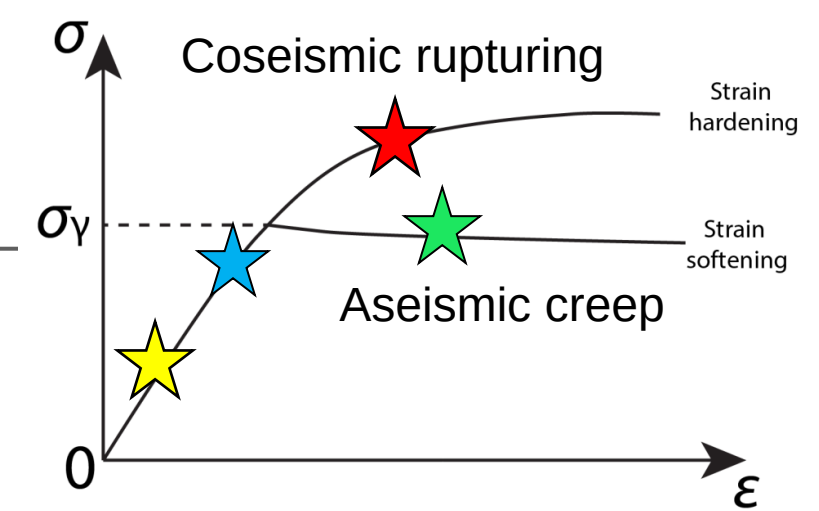
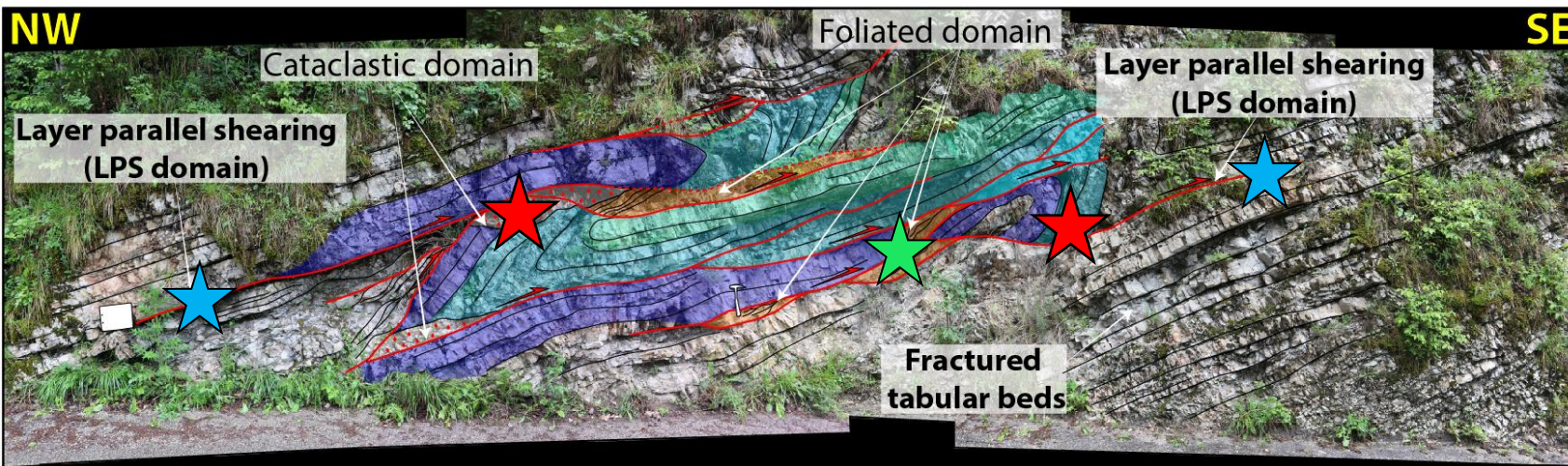
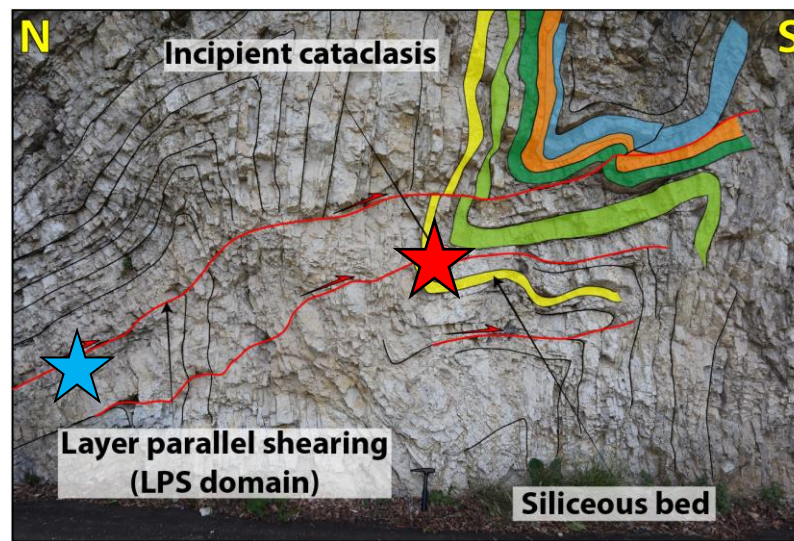
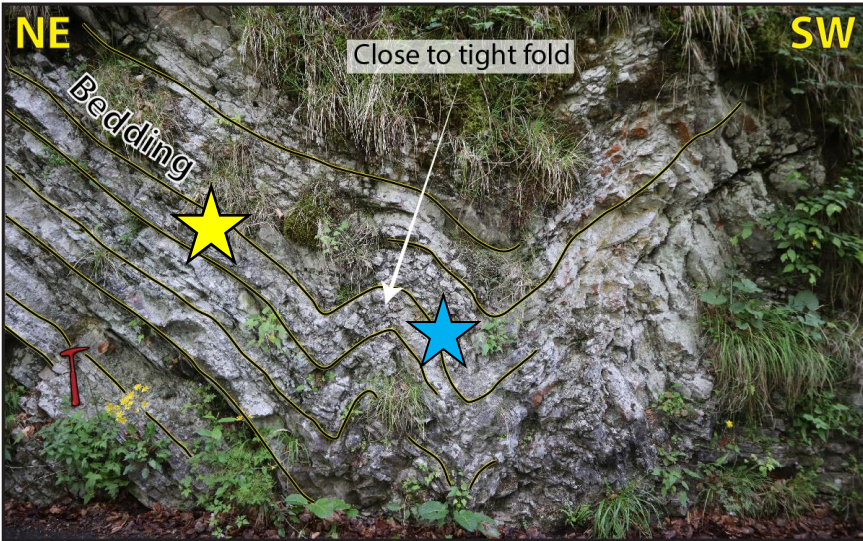
# Implications for the seismic cycle



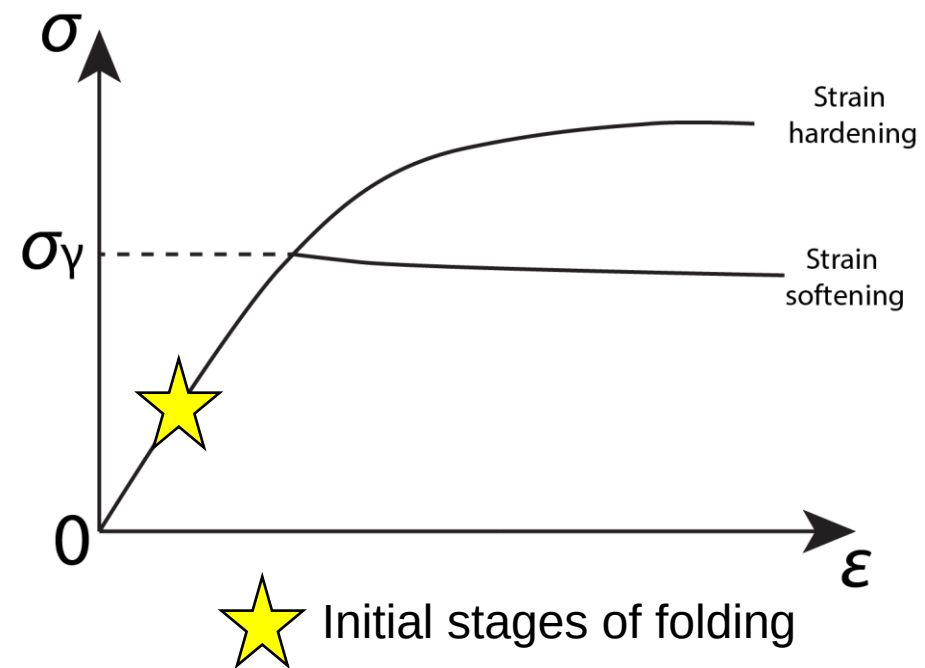
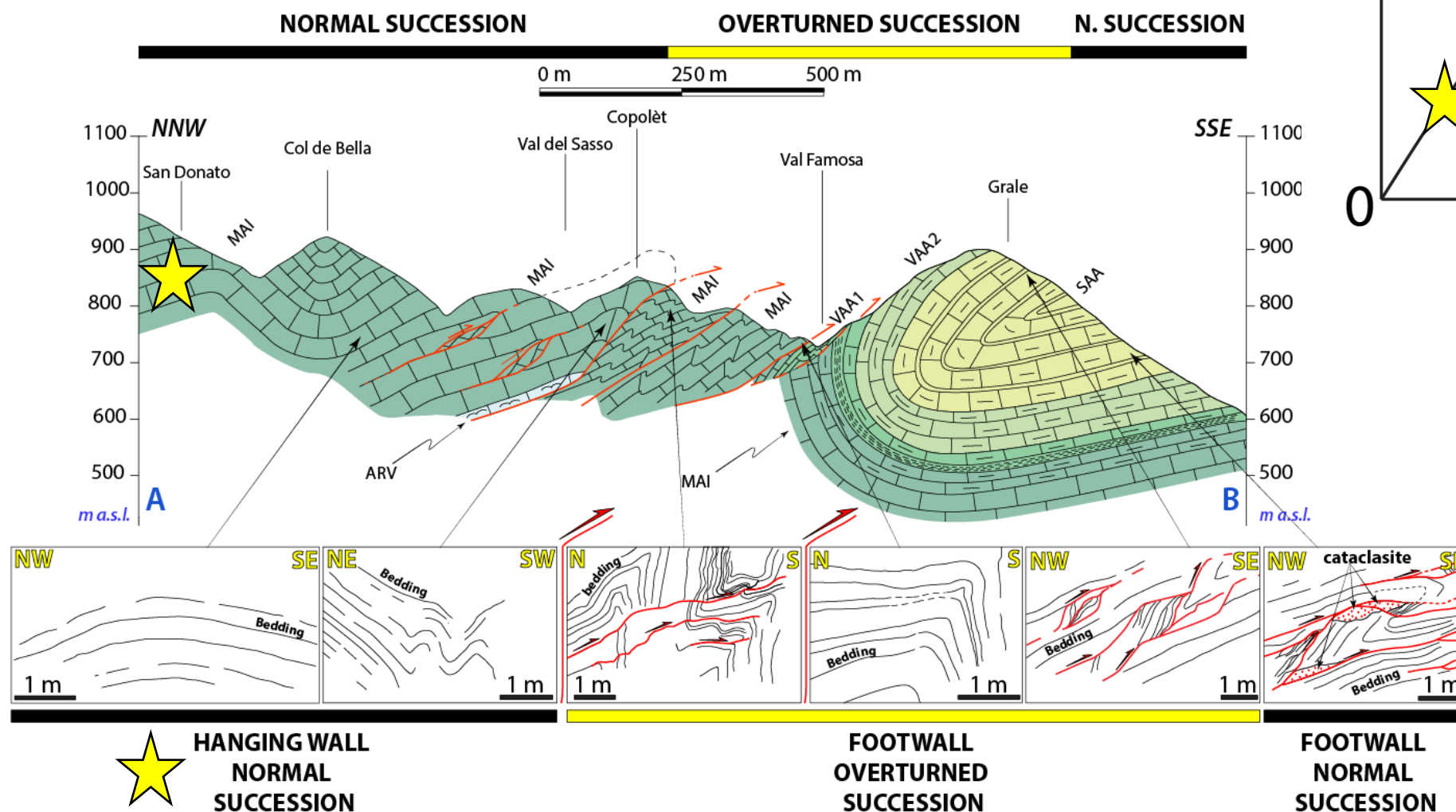
# Implications for the seismic cycle



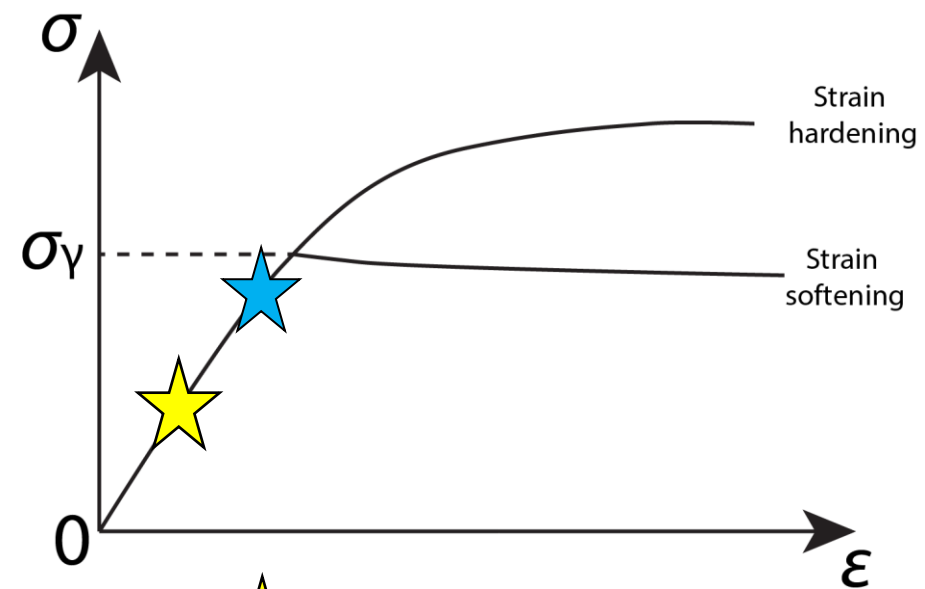
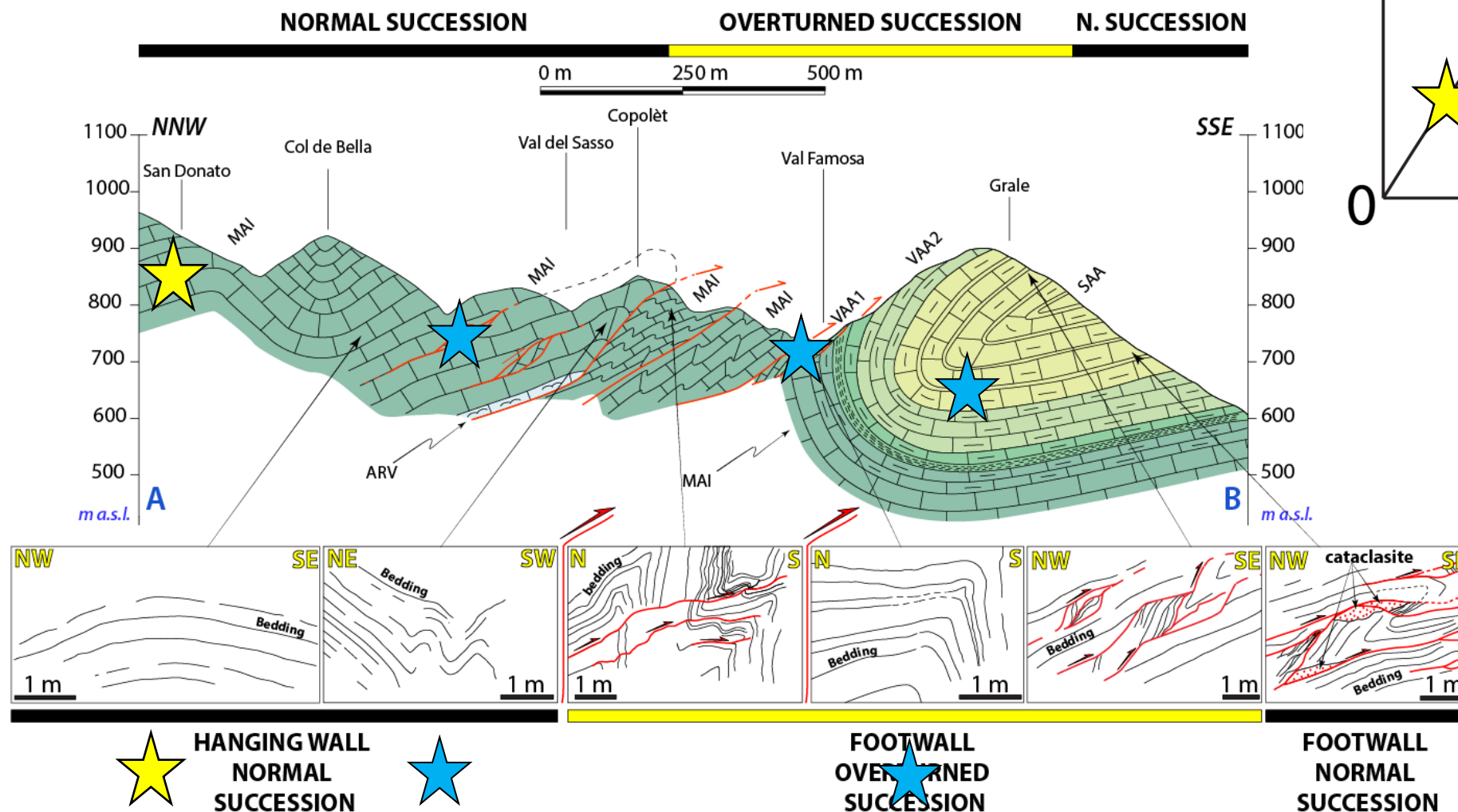
# Implications for the seismic cycle



# Implications for fold-and-thrust belt formation

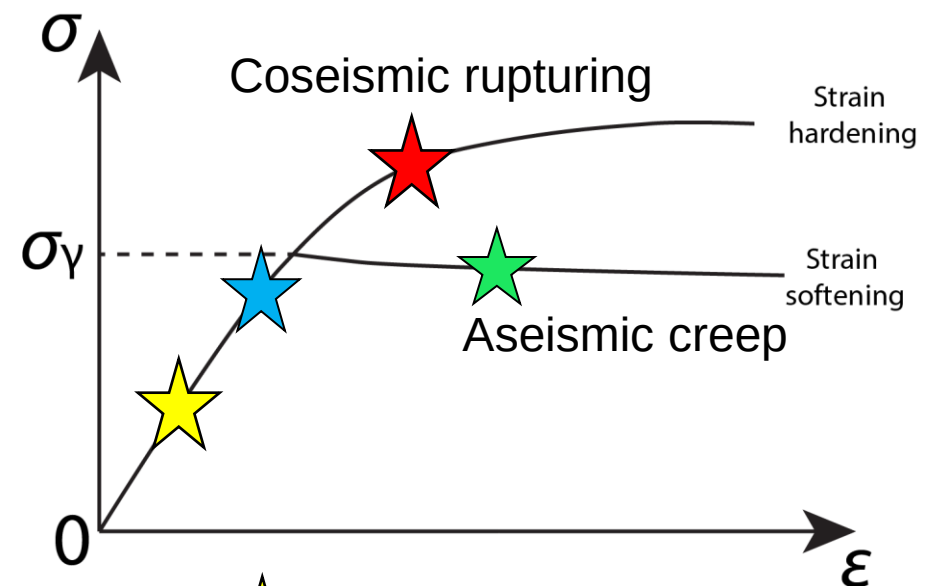
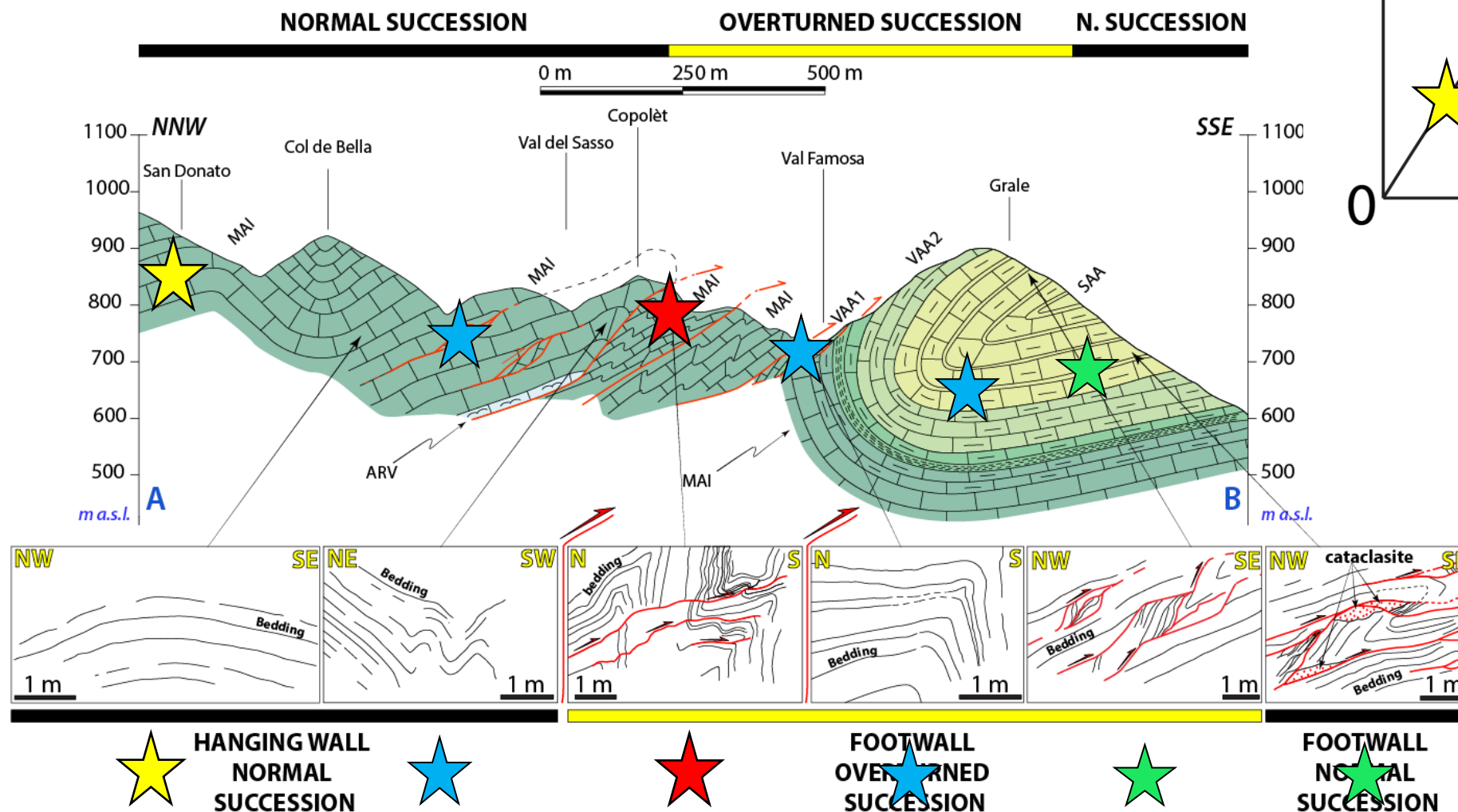


# Implications for fold-and-thrust belt formation

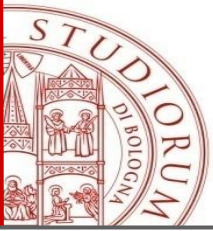


- ★ Initial stages of folding
- ★ LPS: layer parallel shearing

# Implications for fold-and-thrust belt formation



- ★ Initial stages of folding
- ★ LPS (layer parallel shearing)
- ★ Coseismic rupturing
- ★ Aseismic creep



## References

---

Castellarin, A., Cantelli, L., 2000. Neo-Alpine evolution of the Southern Eastern Alps. *Journal of Geodynamics* 30, 251–274. [https://doi.org/10.1016/S0264-3707\(99\)00036-8](https://doi.org/10.1016/S0264-3707(99)00036-8).

Delle Piane, C., Clennell, M. Ben, Keller, J.V.A., Giwelli, A., Luzin, V., 2017. Carbonate hosted fault rocks: A review of structural and microstructural characteristic with implications for seismicity in the upper crust., *Journal of Structural Geology*. <https://doi.org/10.1016/j.jsg.2017.09.003>.

Doglioni, C., 1990. Thrust tectonics examples from the Venetian Alps.pdf. *Studi Geologici Camerti Special Vo*, 117–129.

Tesei, T., Collettini, C., Barchi, M.R., Carpenter, B.M., Di Stefano, G., 2014. Heterogeneous strength and fault zone complexity of carbonate-bearing thrusts with possible implications for seismicity. *Earth and Planetary Science Letters* 408, 307–318. <https://doi.org/10.1016/j.epsl.2014.10.021>.

Vignaroli, G., Viola, G., Diamanti, R., Zuccari, C., Garofalo, P.S., Bonini, S., Selli, L., 2020. Multistage strain localisation and fluid-assisted cataclasis in carbonate rocks during the seismic cycle: Insight from the Belluno Thrust (eastern Southern Alps, Italy). *Journal of Structural Geology* 141. <https://doi.org/10.1016/j.jsg.2020.104216>.