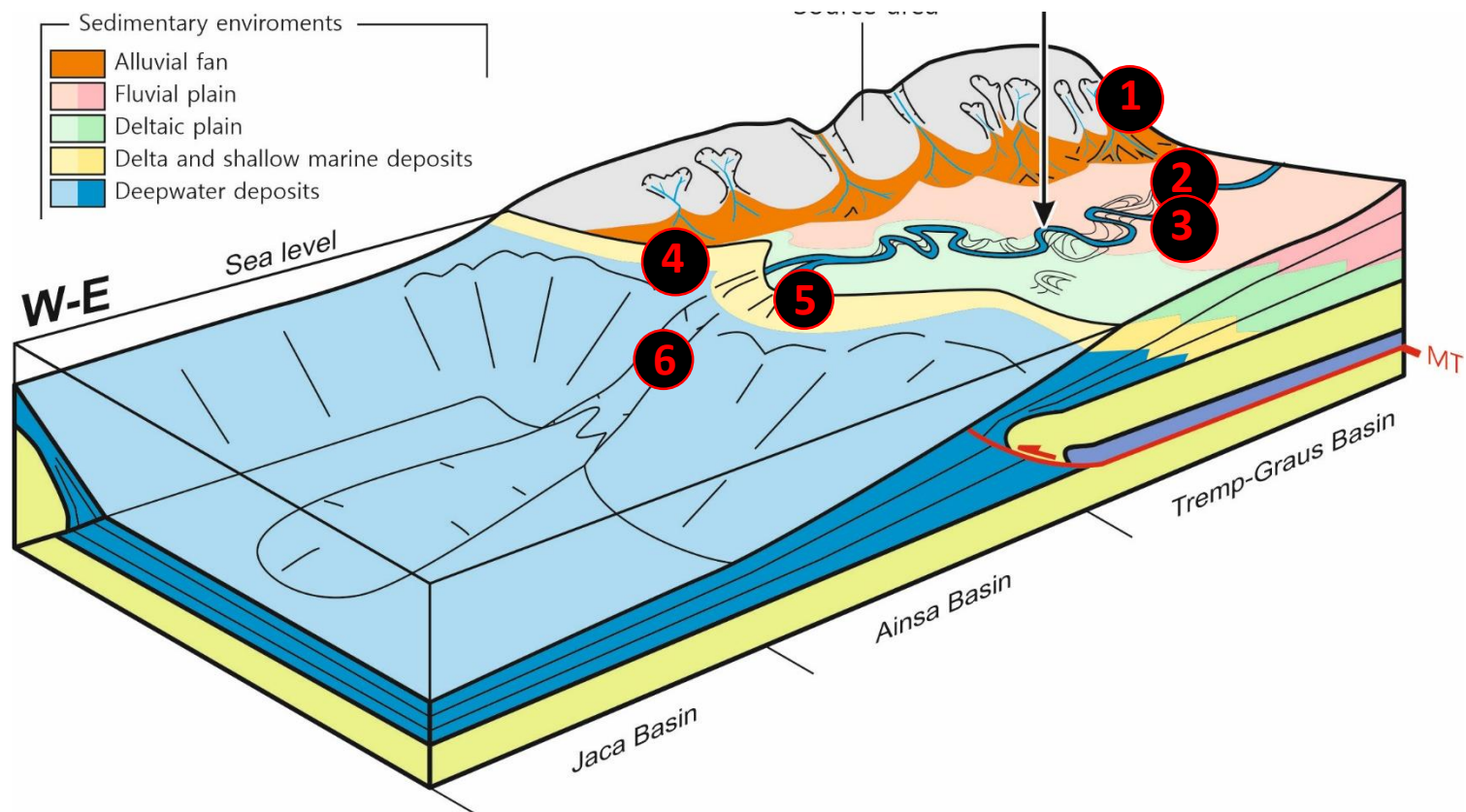


# *Campament Virtual Estratigrafia*

2019-2020



# Organització

- Què farem:
  - 6 Sessions teorico-pràctiques.
  - Exercicis per fer “a casa”. Lliuraments via moodle.
- Com ho farem:
  - Micròfons tancats. Abans de parlar, demanem paraula aixecant la mà.
  - Text-xat. un professor de support pendent del xat.
  - Comentaris sobre lliuraments (primers 20 min de la propera sessió).
- Com ho tancarem:
  - Sessió de Conclusions / Enquesta

# Programa de sessions

- 12 maig:
  - Introducció al Context de la Conca Sudpirenenca
  - Els sistemes al·luvials de La Pobla de Segur ①
- 15 maig:
  - El Sistema fluvial del Grup Montanyana ② ③
- 19 maig:
  - Sistema deltaic de Roda ④
- 22 maig:
  - Sistema deltaic de Sobrarbe ⑤
- 26 maig:
  - Sistemes de talús i canals turbidítics d'Ainsa ⑥
- 29 maig:
  - Conclusions (enquesta)

# *Introduction to the South Central Pyrenean Foreland*

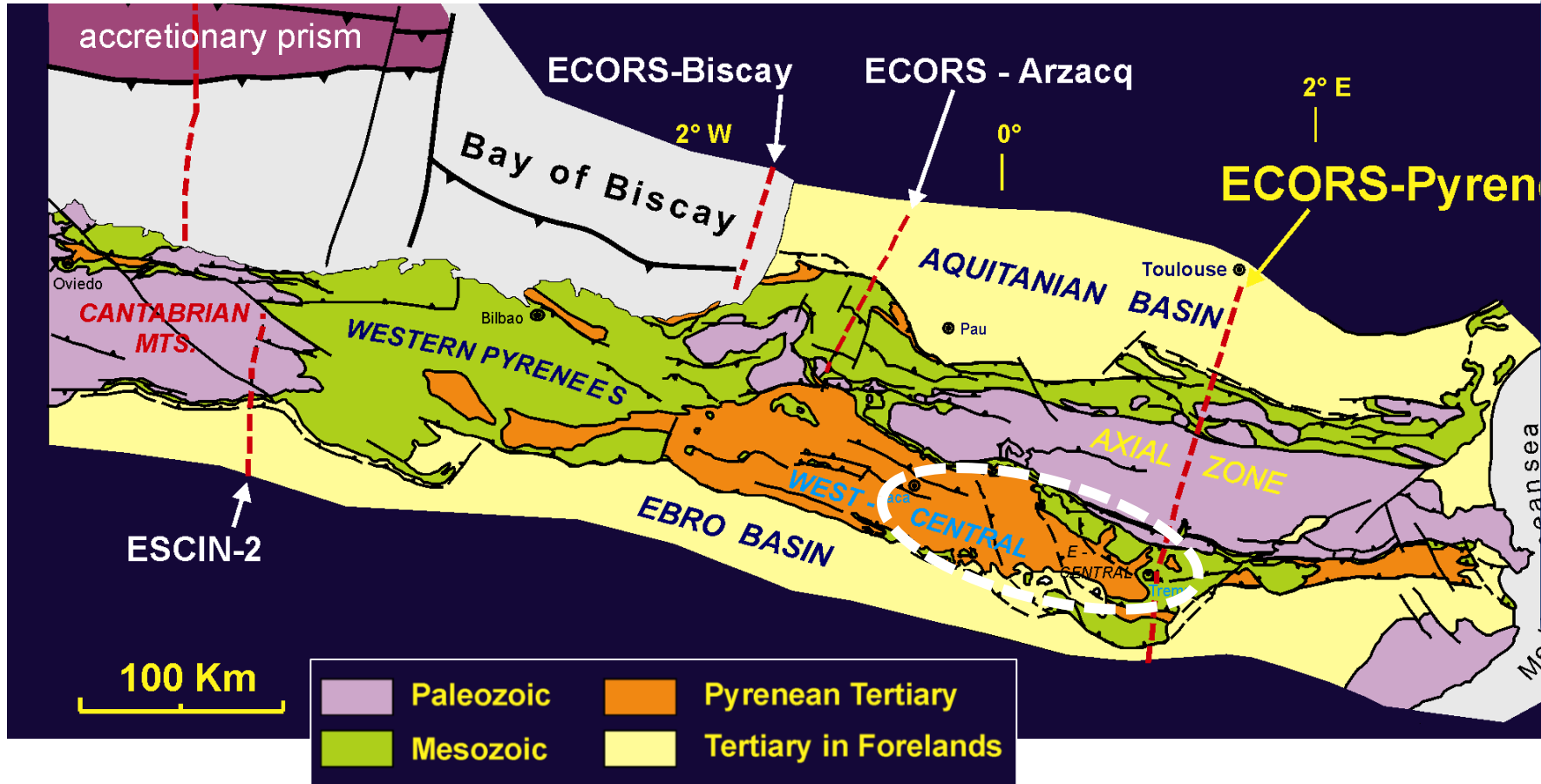
- Structural Context
- Stratigraphy
- Paleogeographic evolution



# Structural context

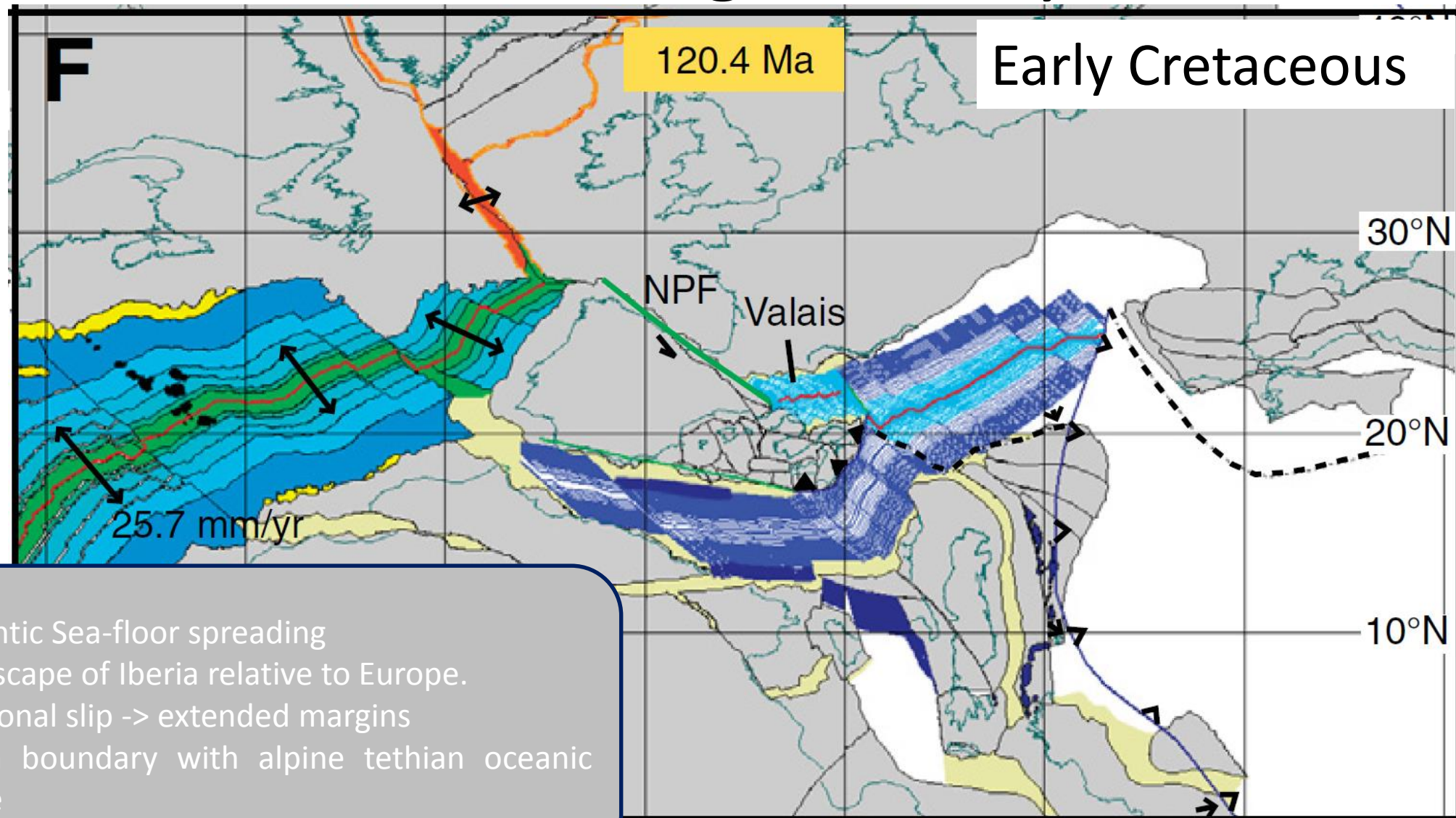
- Regional Plate Tectonics
- Crustal section of the Pyrenees
- Structural Units
- Deformation sequence

# Structural context

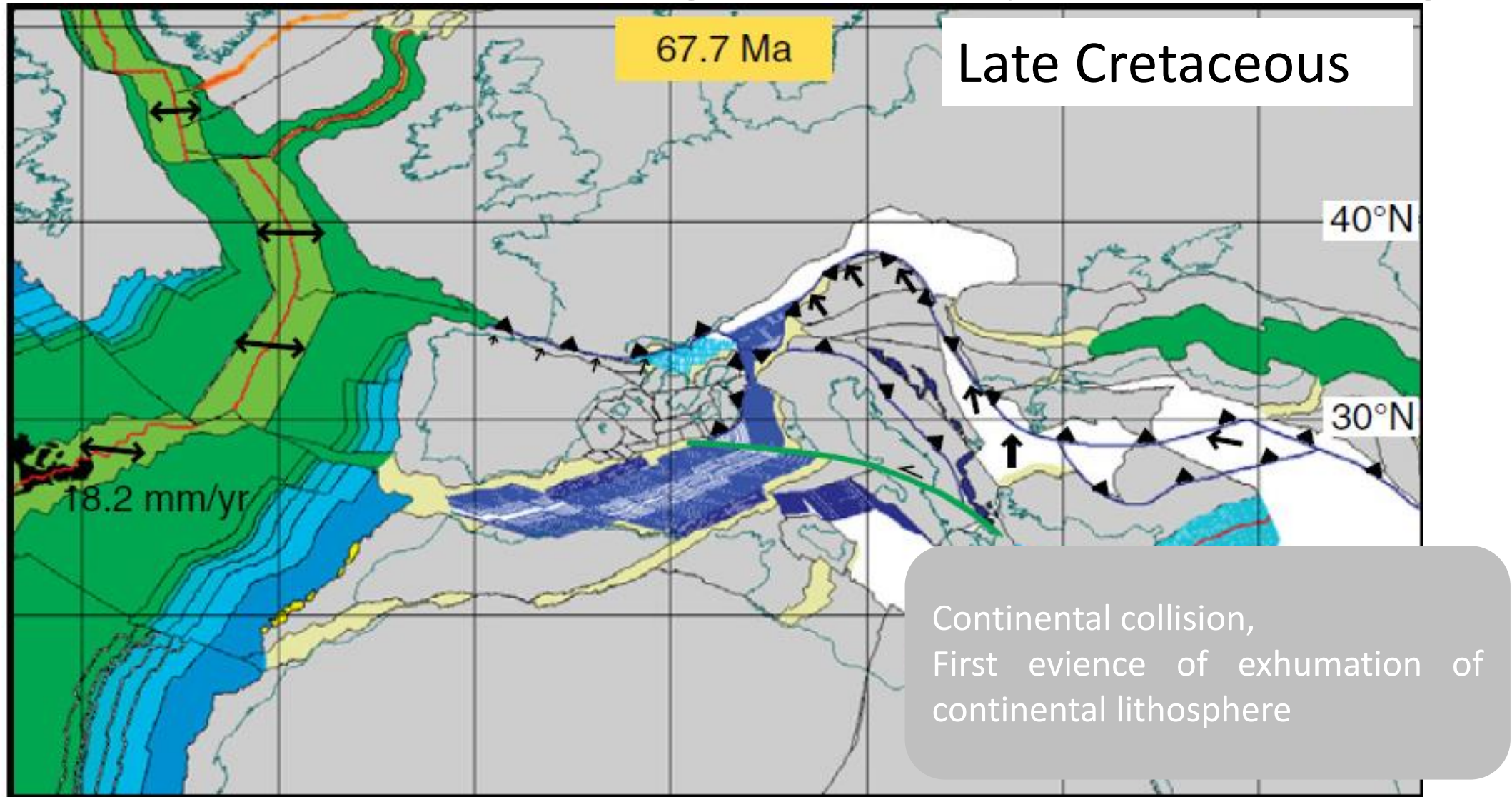


The northwards directed Iberia-Europe collision led to the formation of the Pyrenean orogen. A set of imbricate thrust sheets developed in a piggy-back sequence from Late Cretaceous to Early Miocene. The inherited heterogeneous structure of the plate margins governed the along-strike different evolution of the foreland system.

# Plate tectonics setting of the Pyrenean orogen

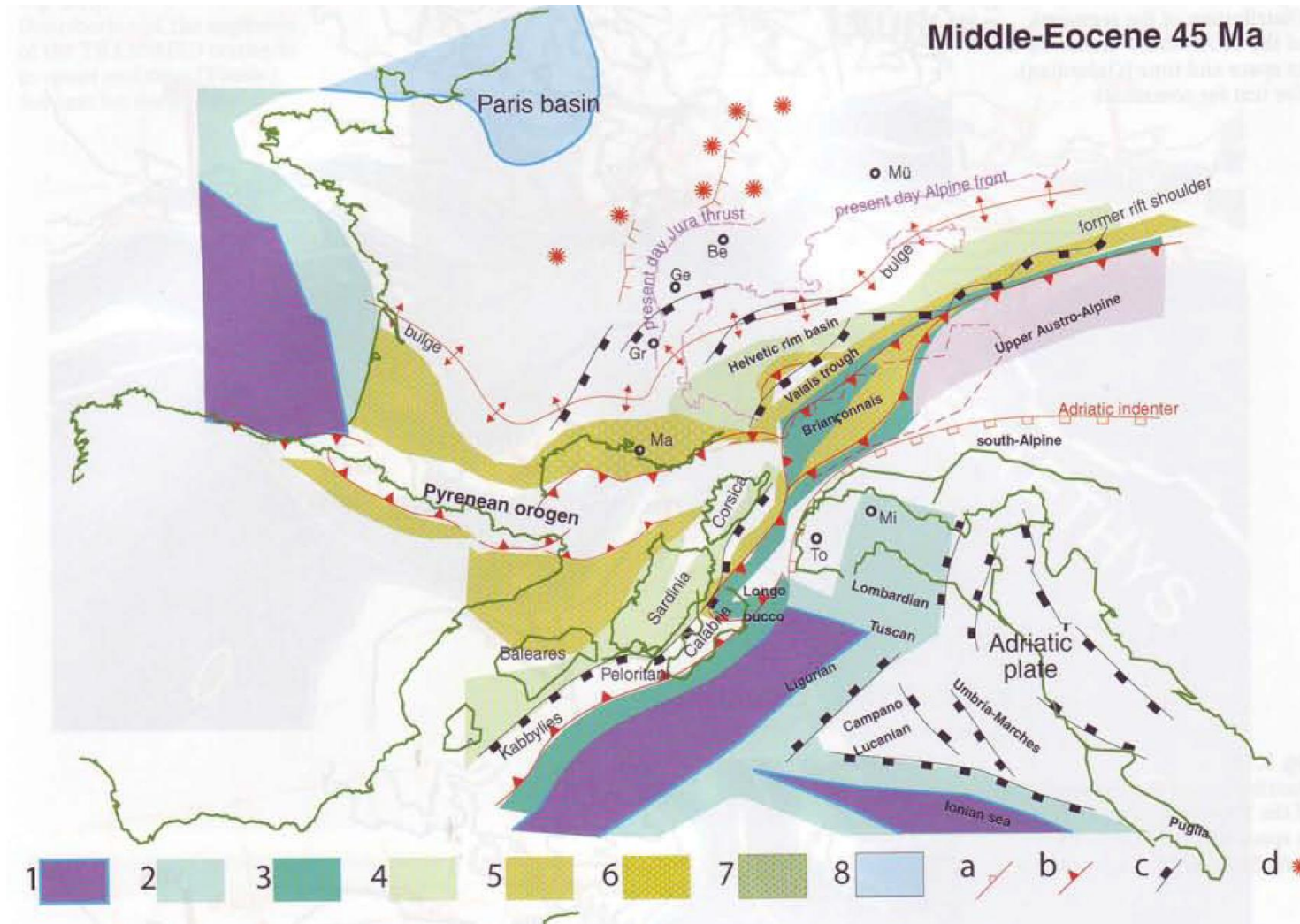


# Plate tectonics setting of the Pyrenean orogen

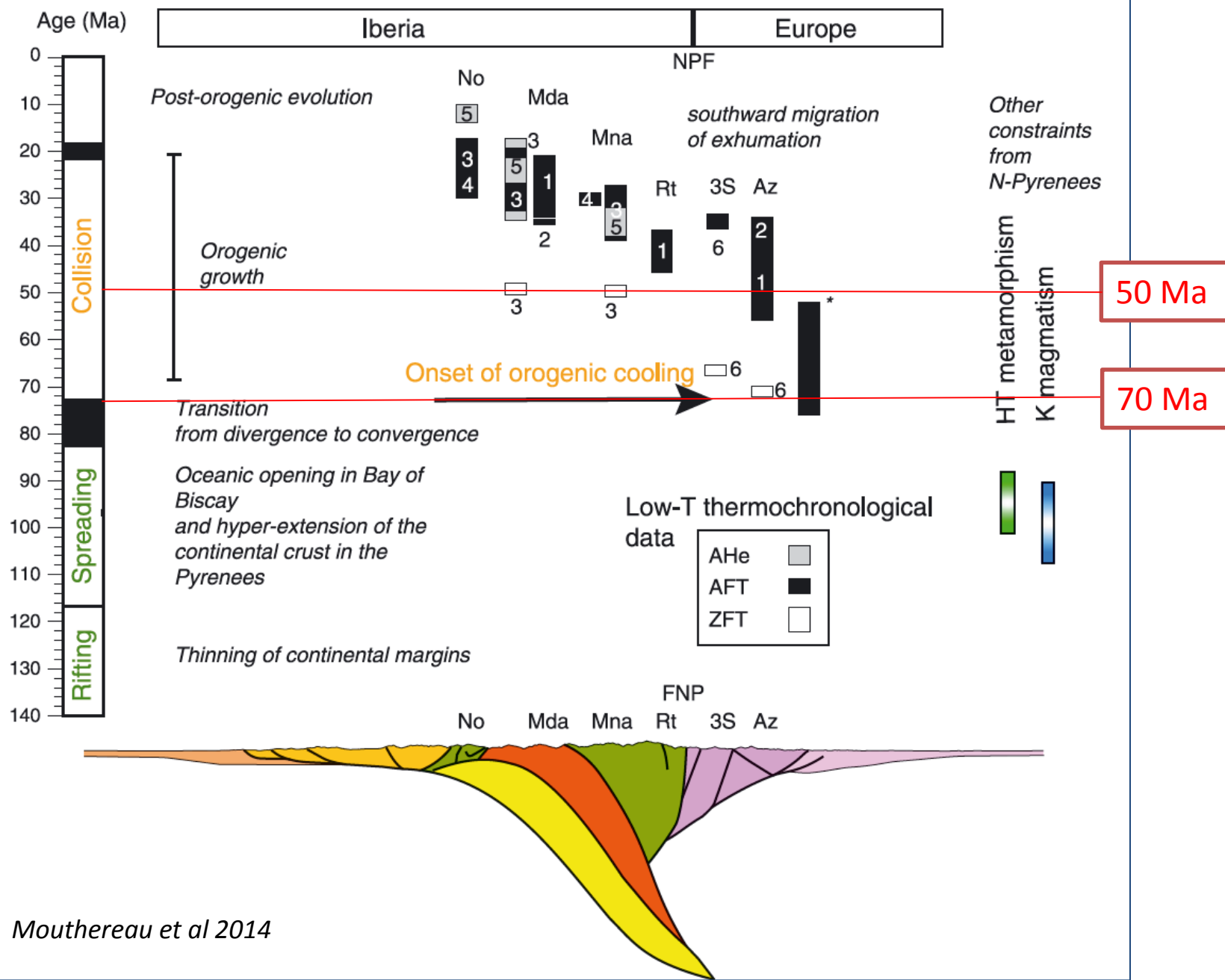




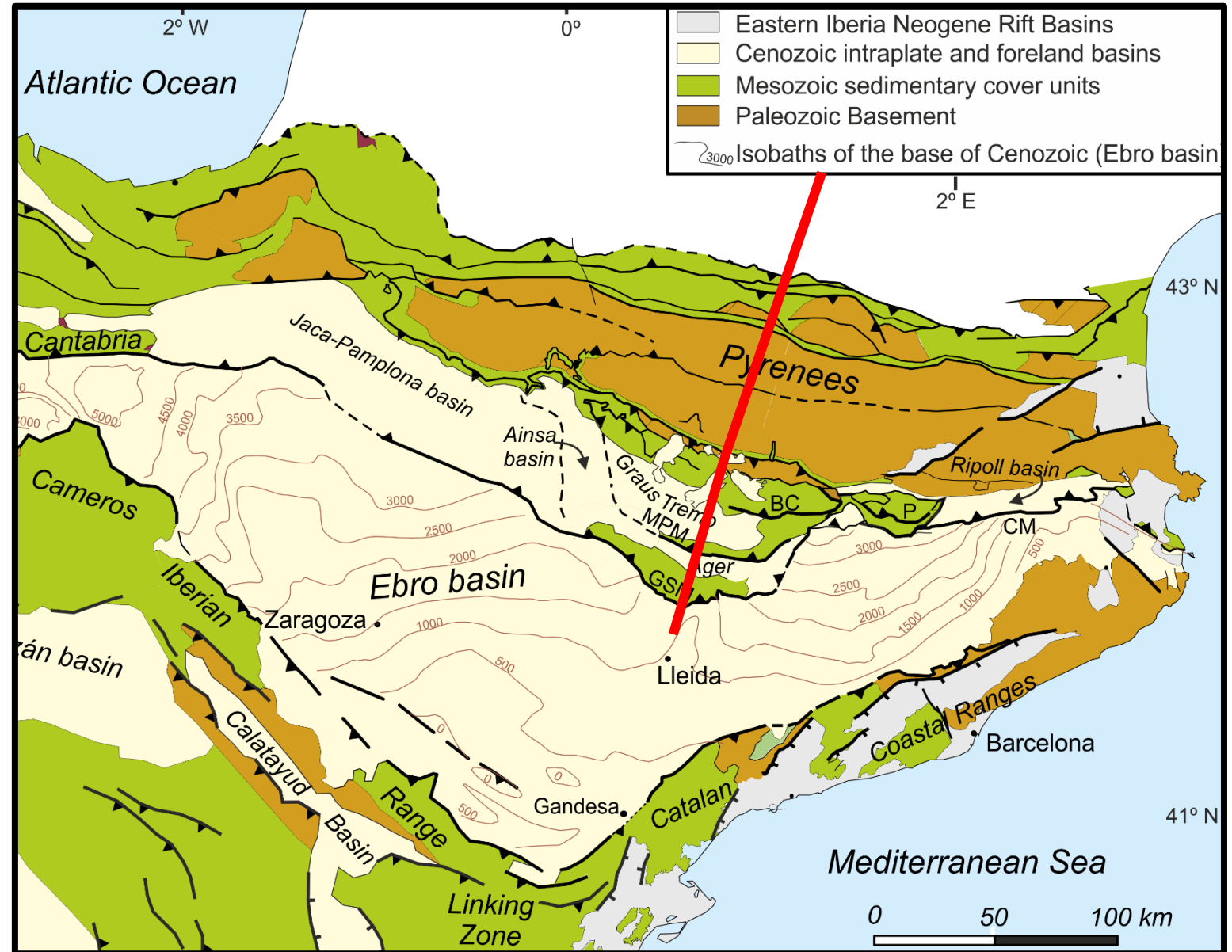
# Middle Eocene



# Phases from Rifting to collision



# The ECORS-Pyrenees Section

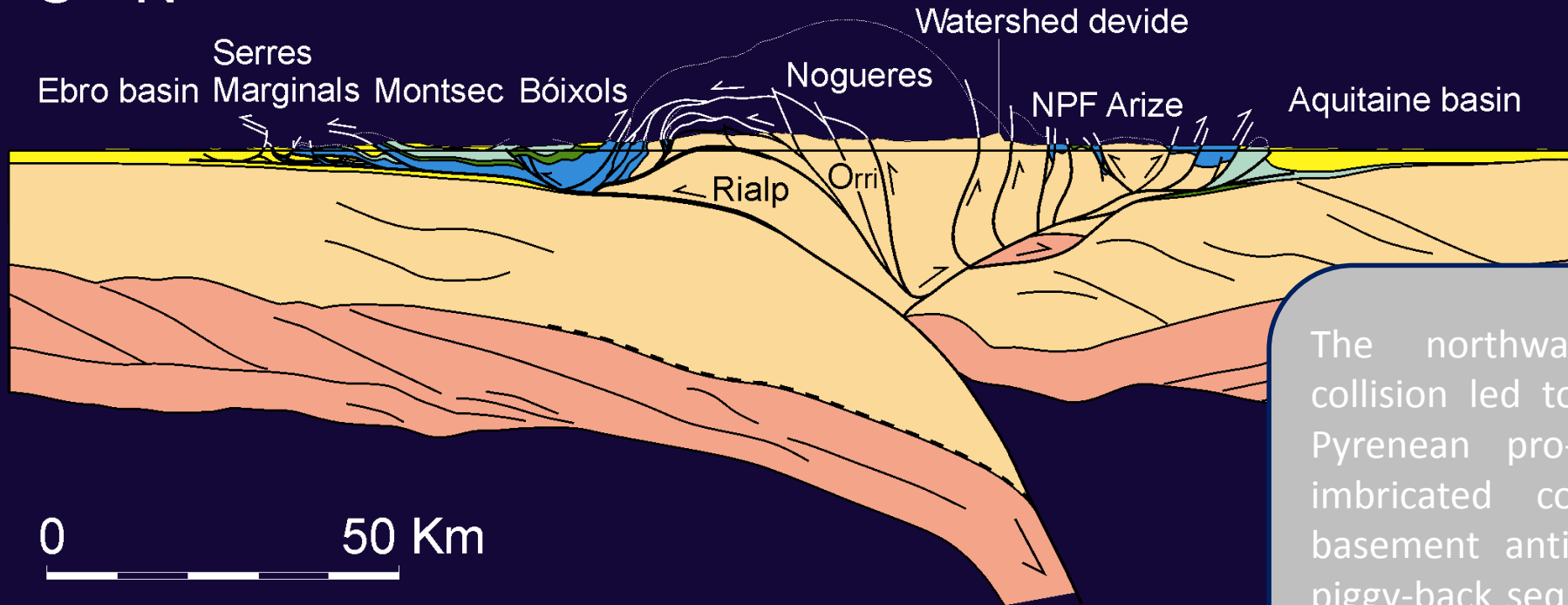


Map modified from Vergès et al. (2002)<sup>1</sup>

# Crustal structure

## ECORS CENTRAL PYRENEES CROSS-SECTION

S - N



The northwards directed Iberia-Europe collision led to the formation of the South Pyrenean pro-foreland system. A set of imbricated cover thrust sheets and a basement antiformal stack developed in a piggy-back sequence. Restored cross-sections show minimum total shortening of 150km in the Central Pyrenees (Muñoz, 1992).



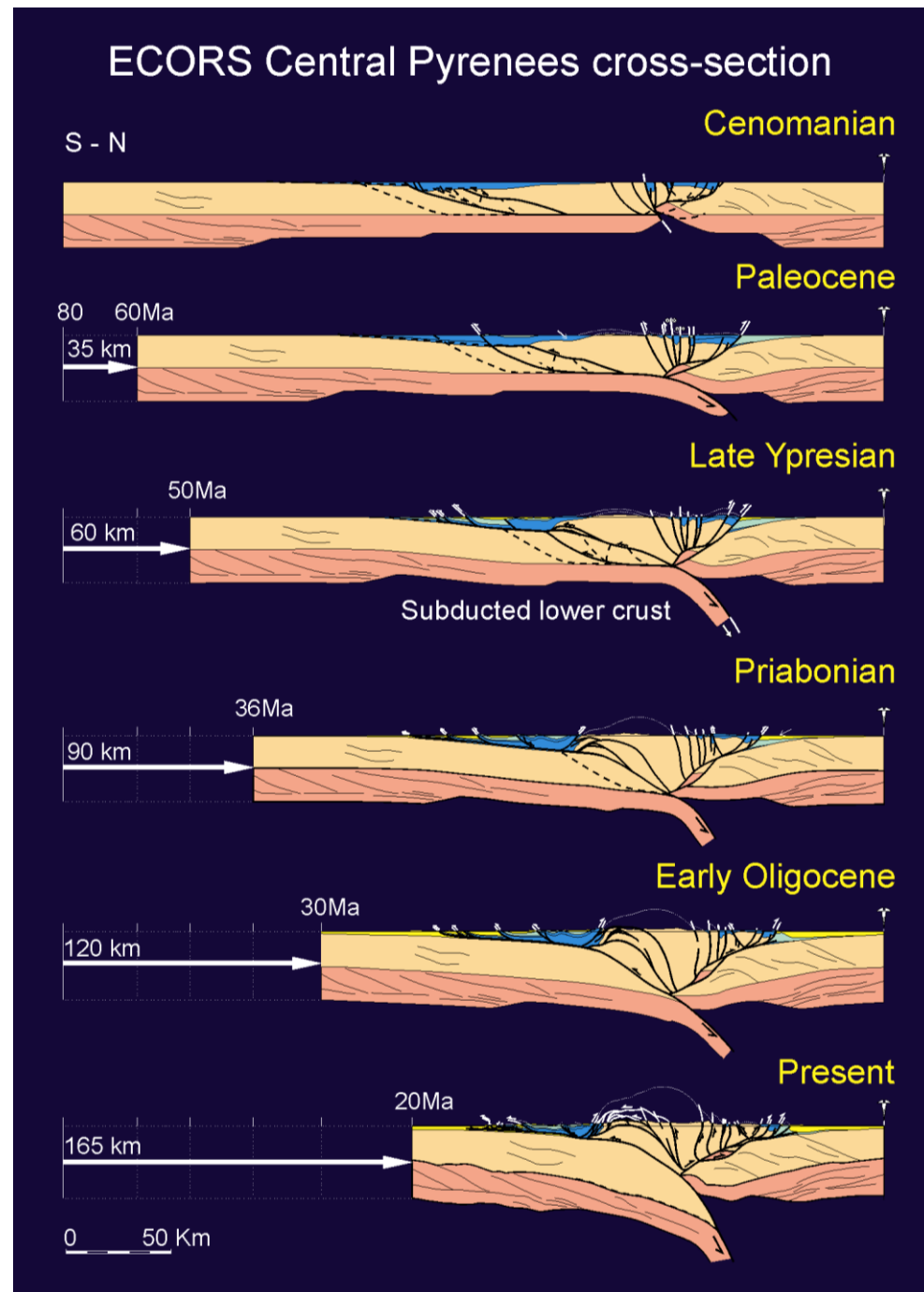
# The Pyrenees: an orogen of inversion tectonics

Restored cross-sections show total shortening of 165km in the Central Pyrenees (Muñoz, 1992).

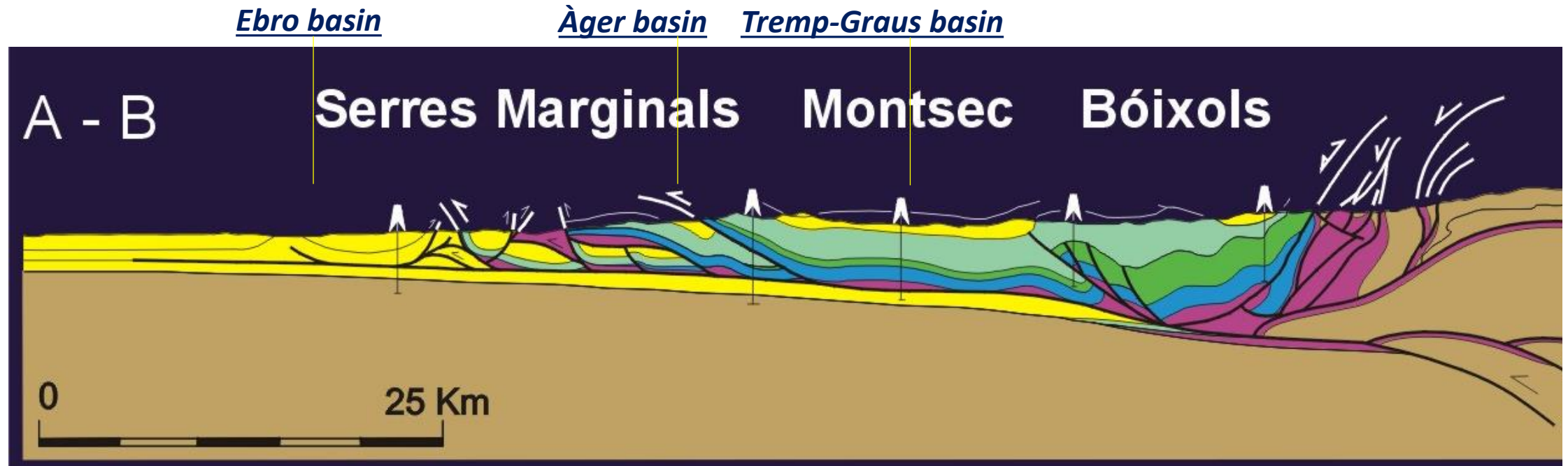
Thinned crust with  
Inherited weak zones →  
tectonic inversion

Growth of pro-wedge  
By frontal accretion and  
underplating  
(**piggy-back sequence**)

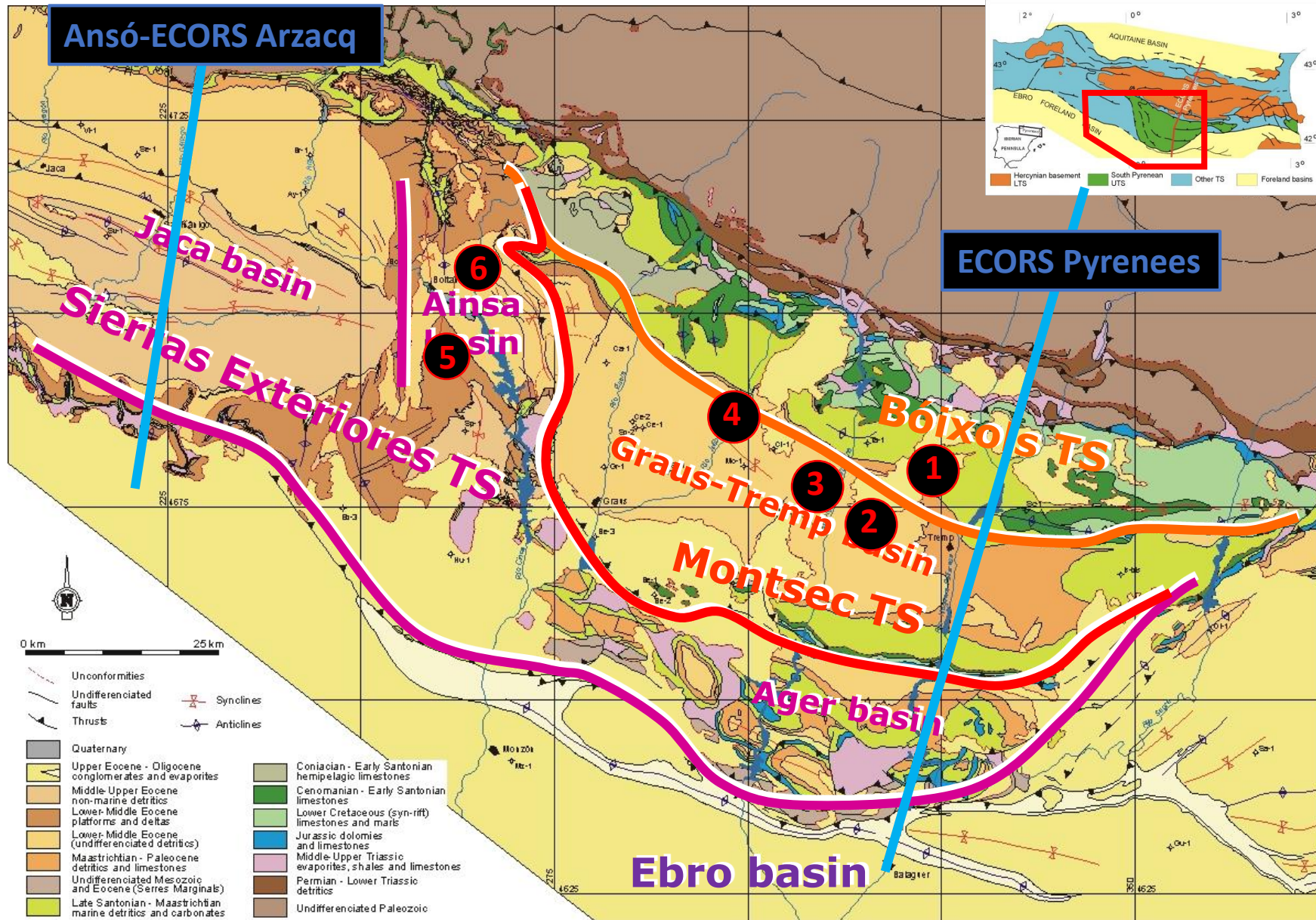
Stabilization of the  
orogenic wedge by  
sediment ponding.  
**Out-of-sequence** and  
back-thrusting.  
Rapid exhumation and  
erosion in the Axial  
Zone



# Compartmentalized South-Pyrenean foreland

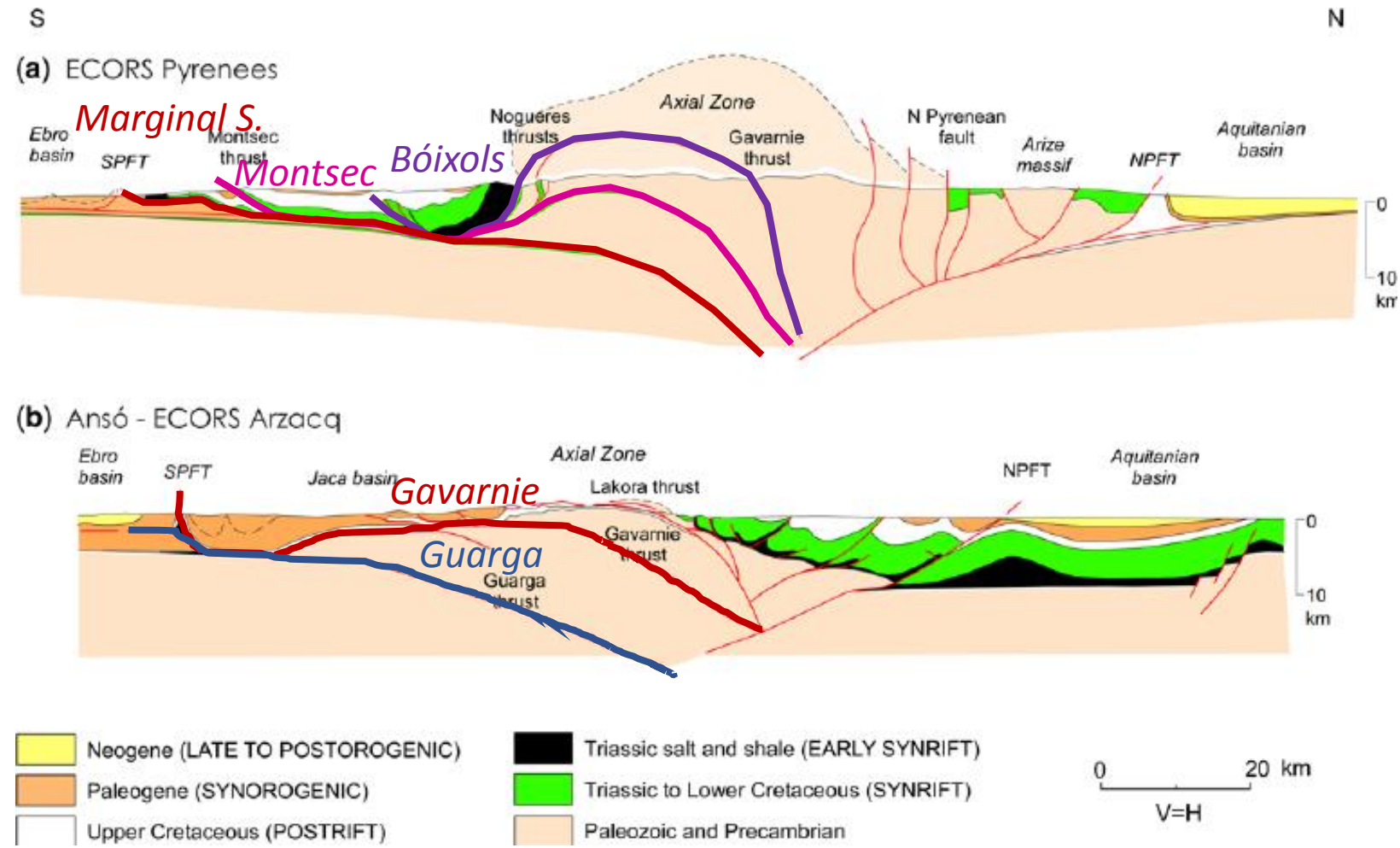


# South-Pyrenean foreland



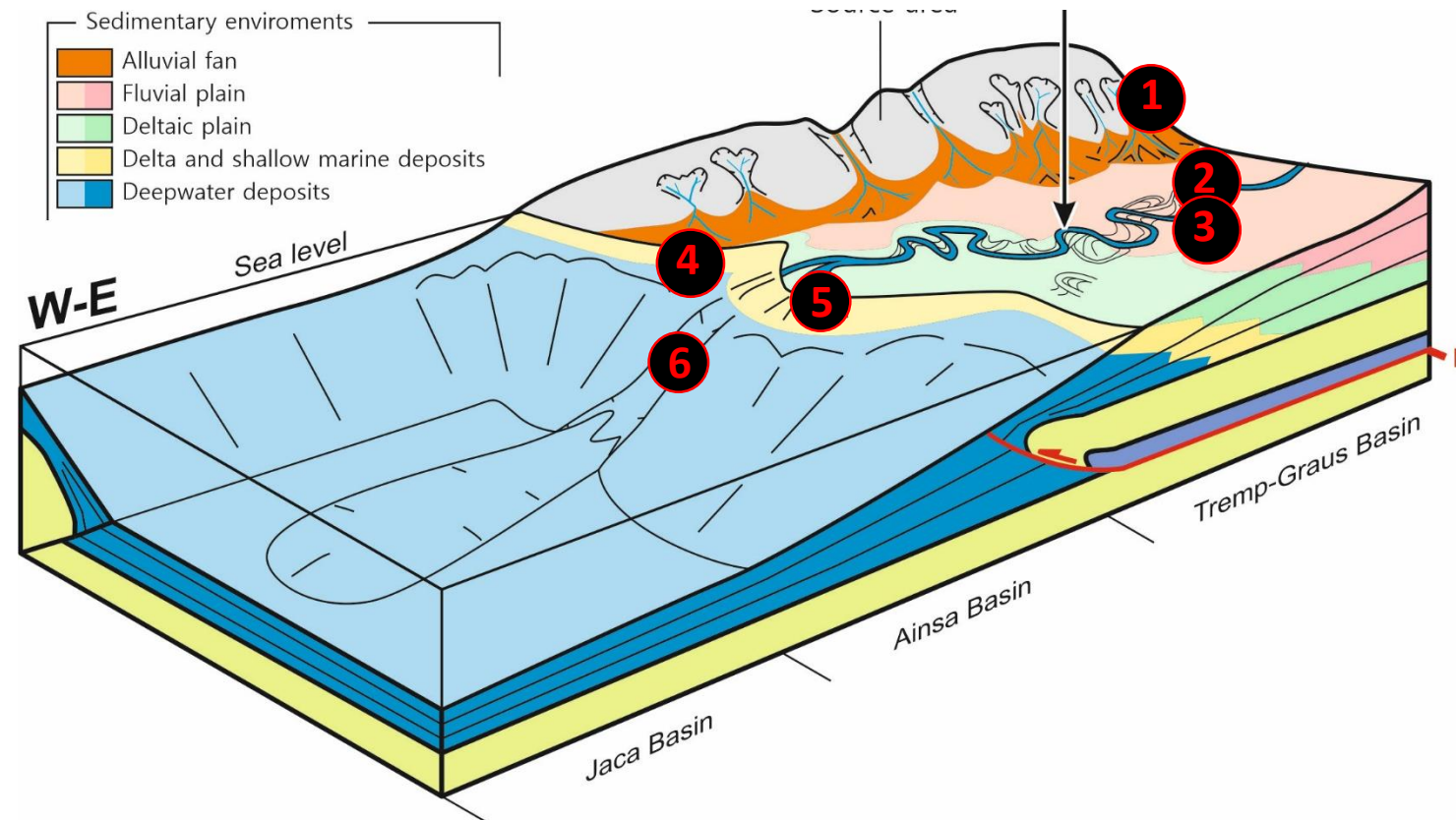


# Thrusting sequence



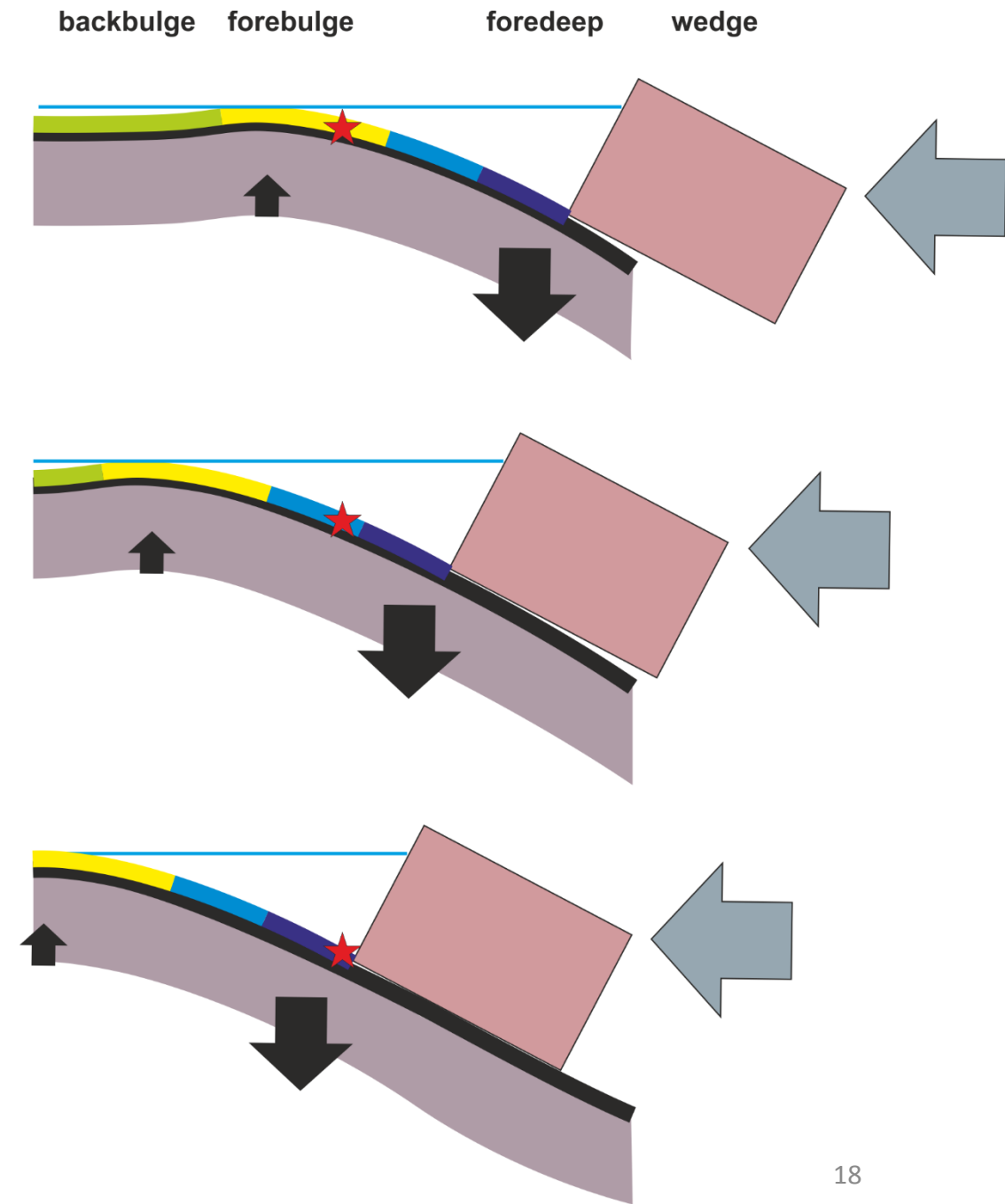
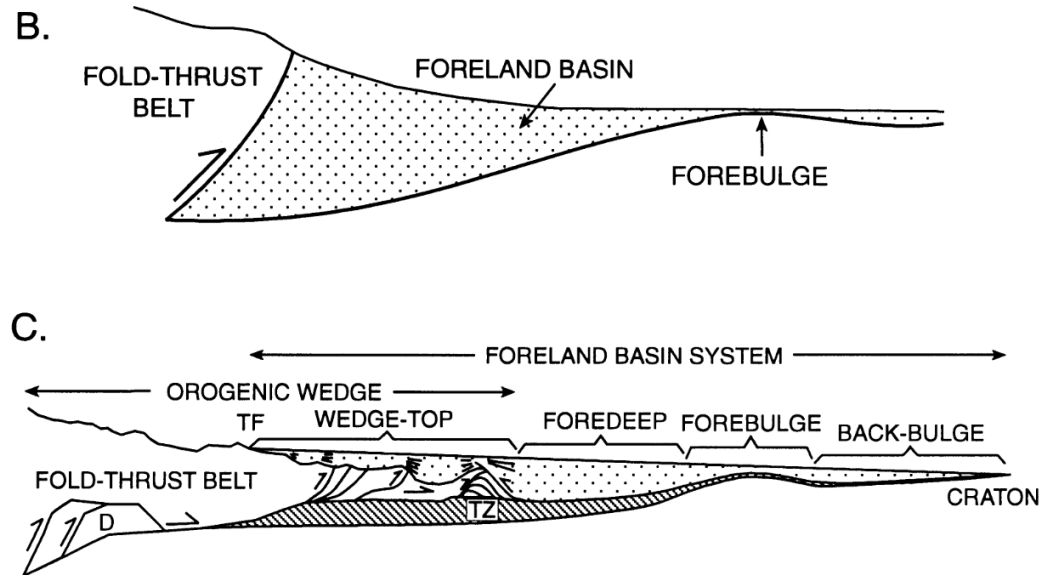
# Stratigraphic context

- Model of Foreland basins
  - Litospheric flexure
  - Foreland system depozones
  - Sedimentary evolution
- Compartmentalization of the South Pyrenean Foreland
- Stratigraphy of the Tremp-Graus-Jaca basins

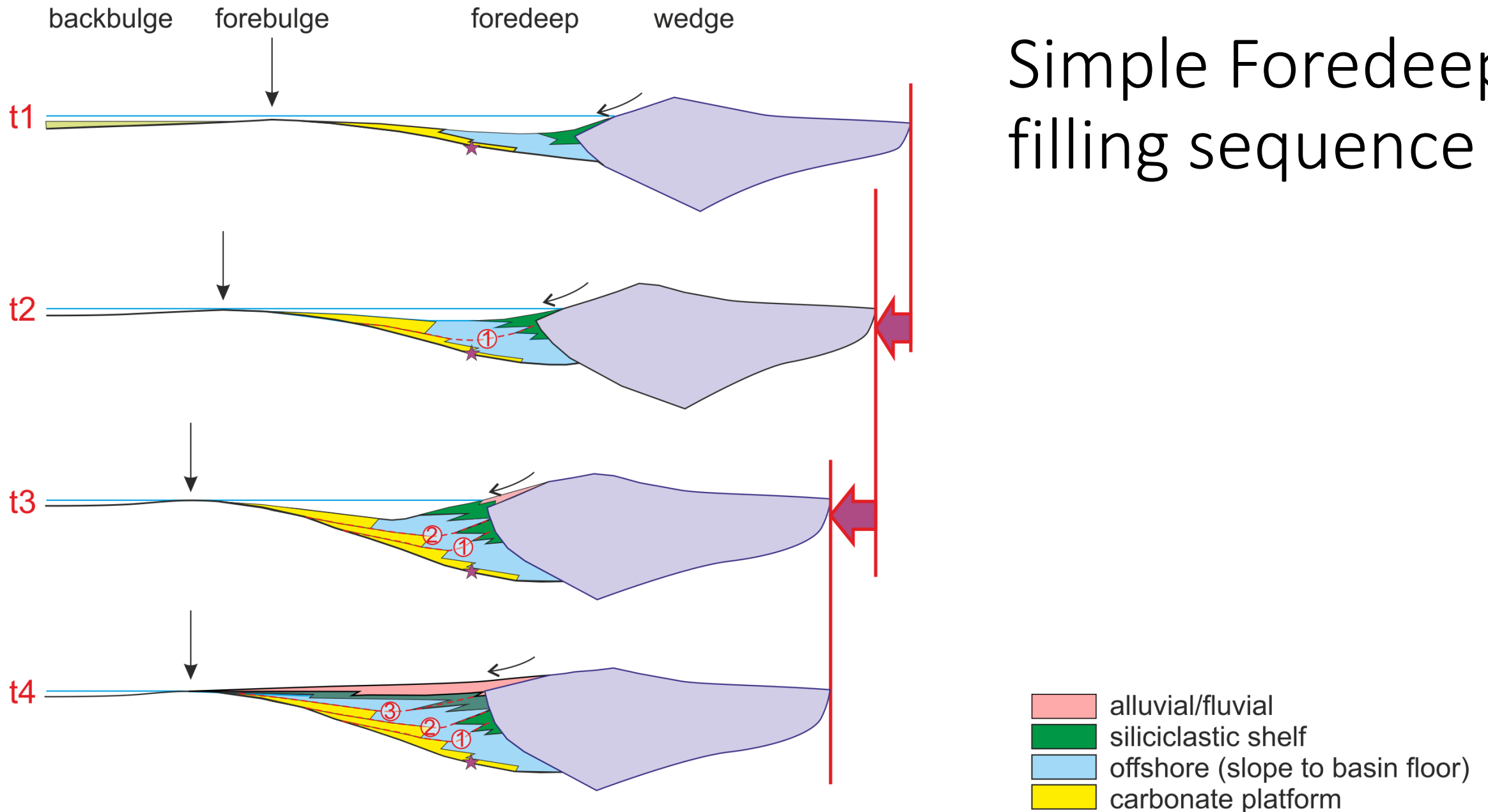




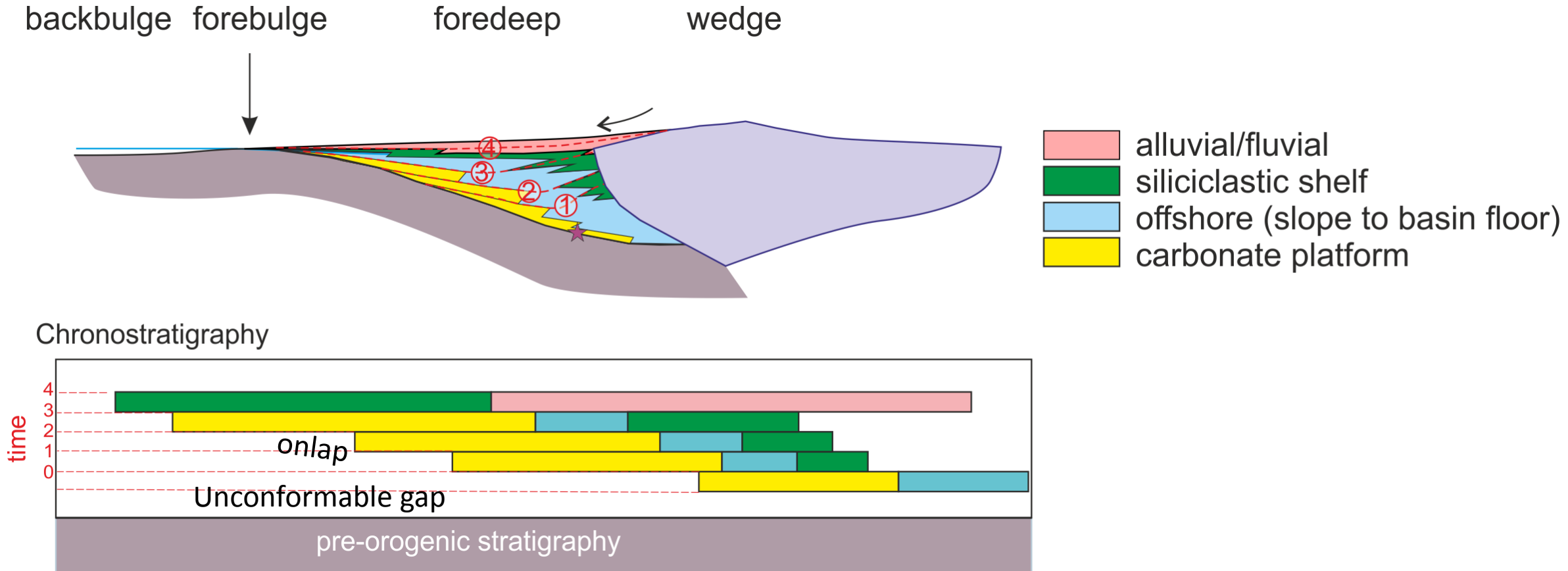
# Foreland flexure



# Simple Foredeep filling sequence



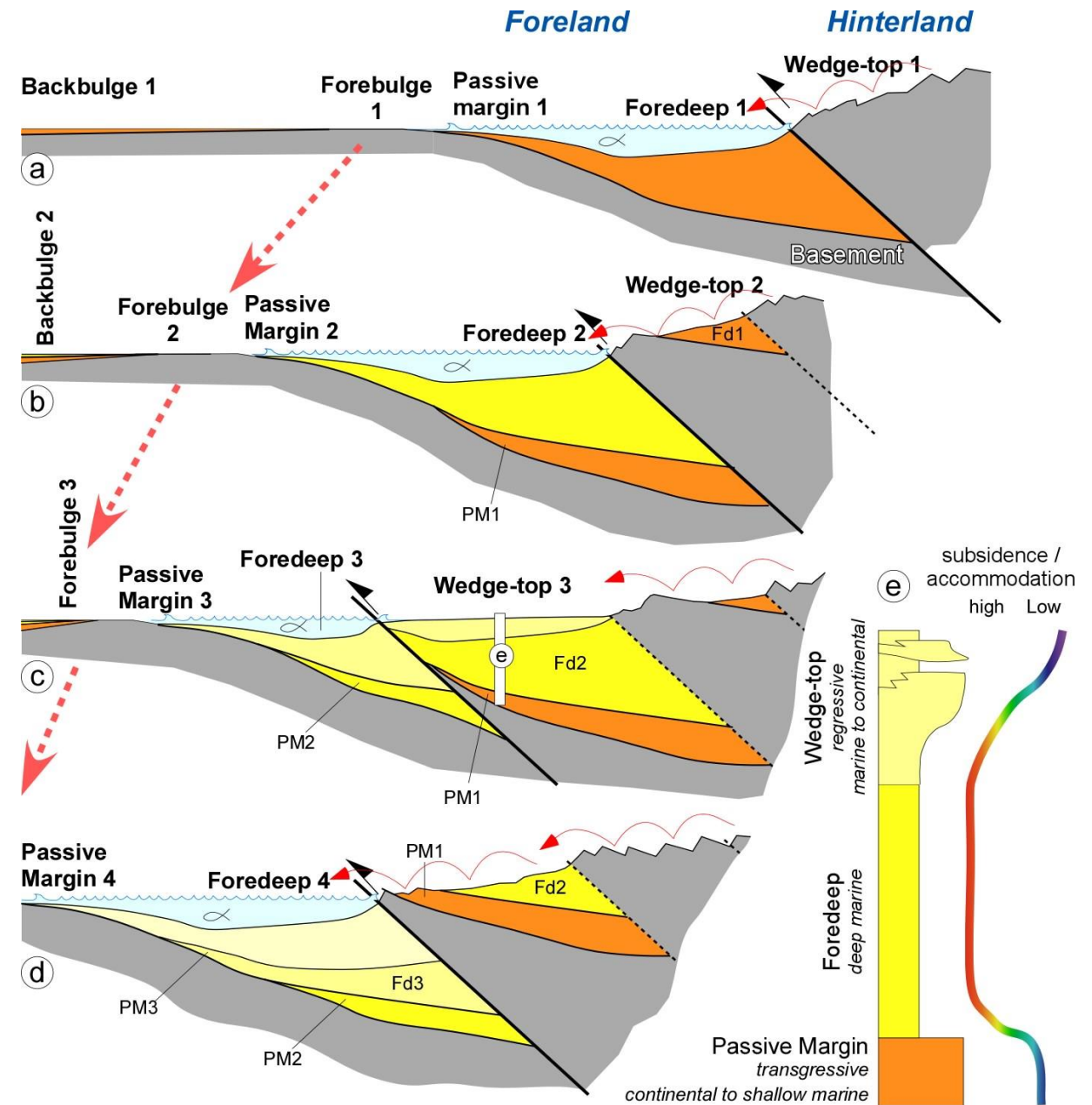
# Foreland filling chronostratigraphy



# Imbricated foreland systems: Foredeep to Wedge-top

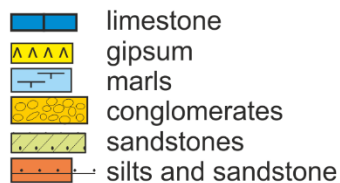
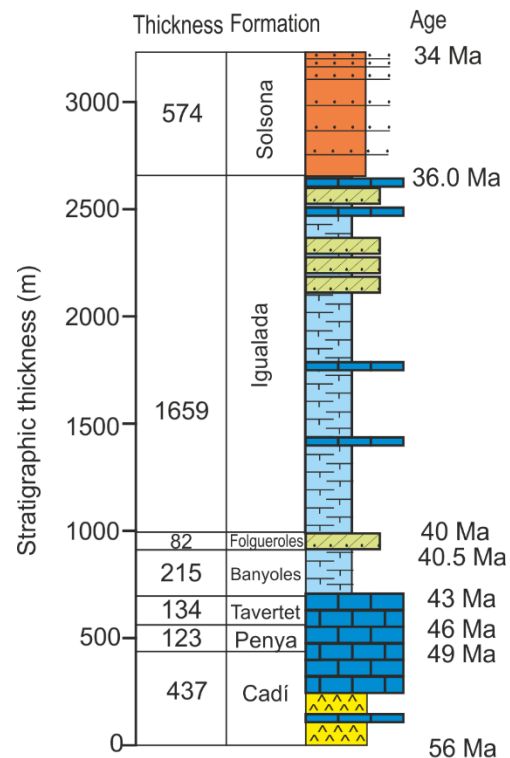
Basinwards propagation of the piggy-back thrusting sequence causes the incorporation of foredeep zones into active thrust-sheets.

Upwards Transition from:  
Foredeep → Wedge-top.

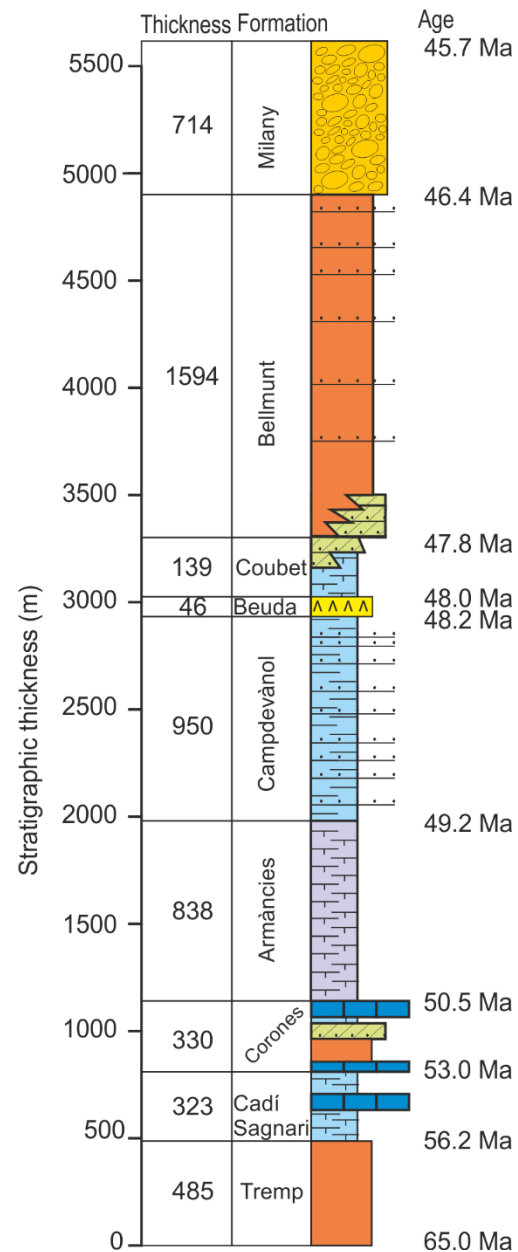




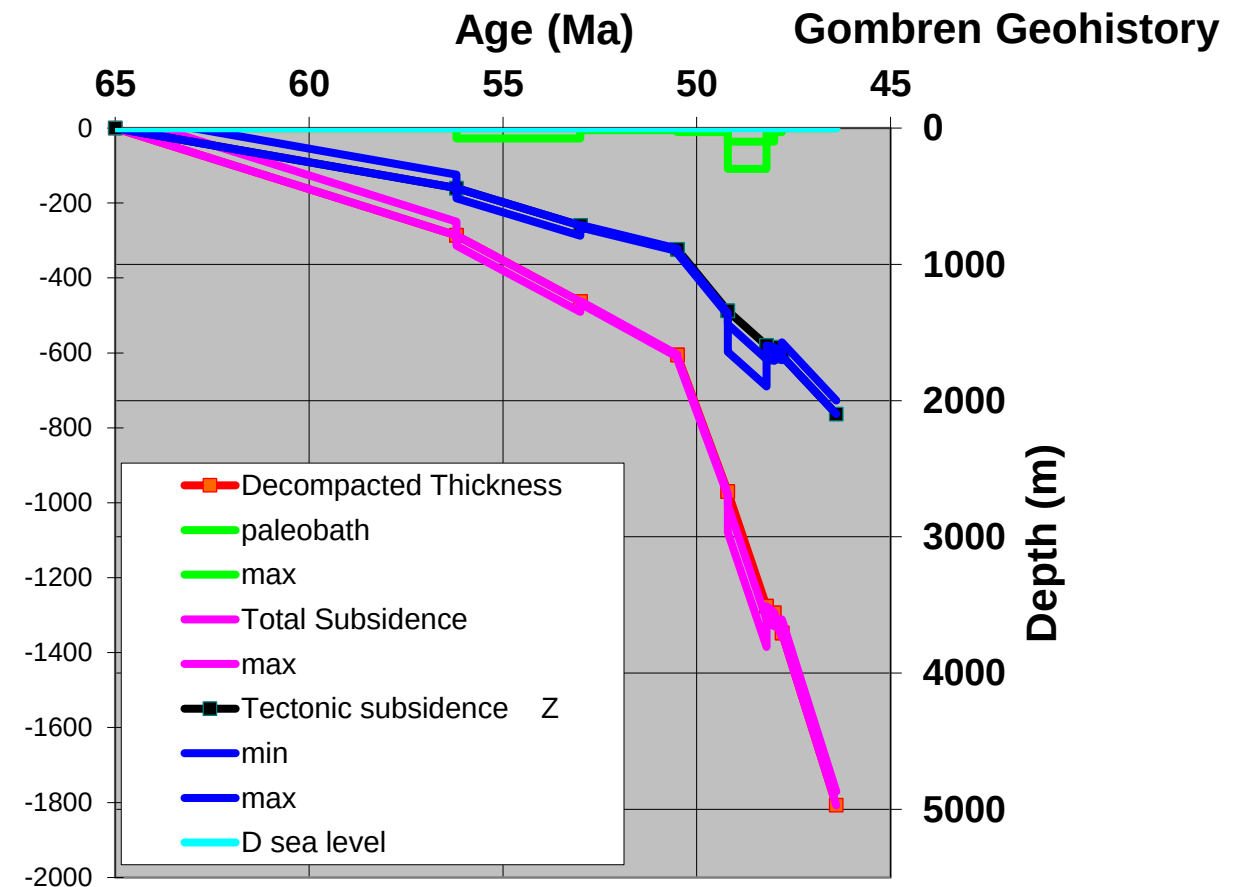
## Puigreig



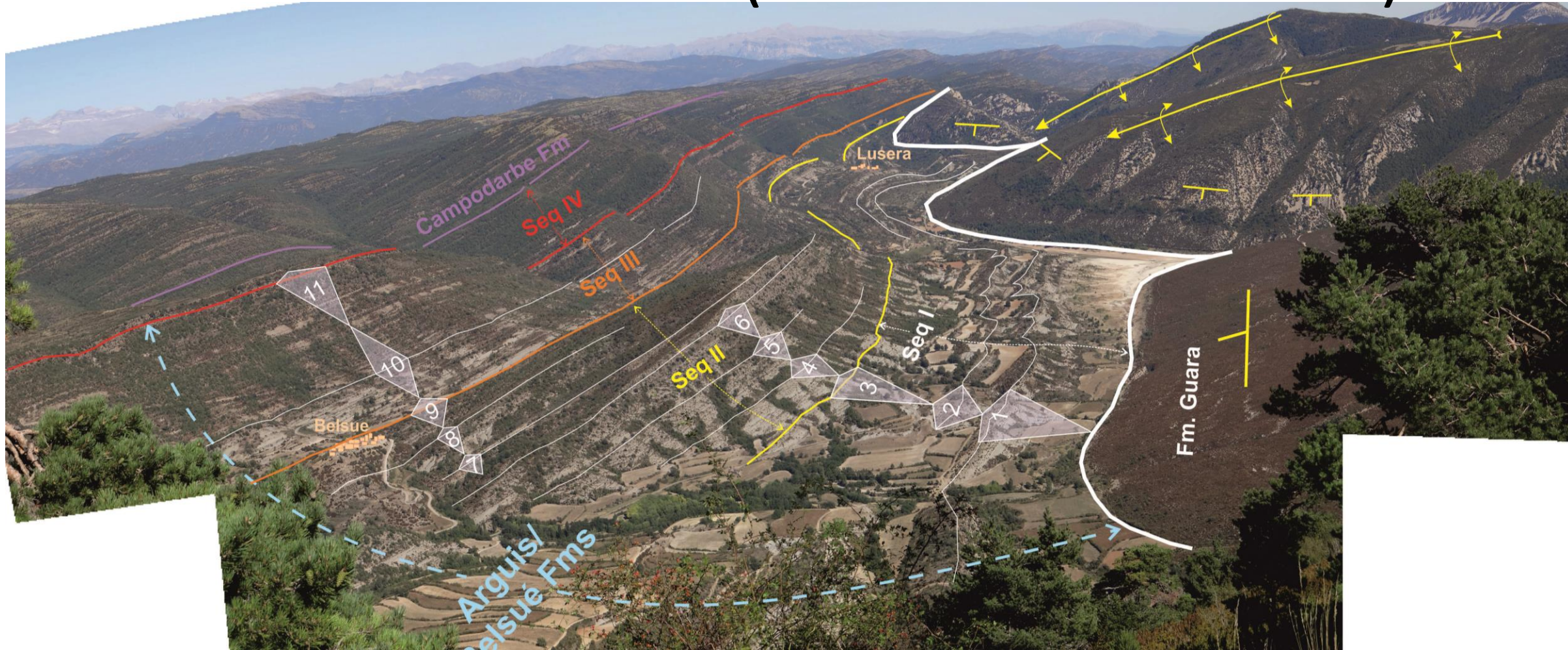
## Gombren



## Eastern Ebro



# The External Sierras (Middle-Late Eocene)



Transition from platform carbonates of Guara Fm (passive margin) into marine marls of Arguis Fm (foredeep) and fluvial sediments of Campodarbe Fm. (wedge-top).

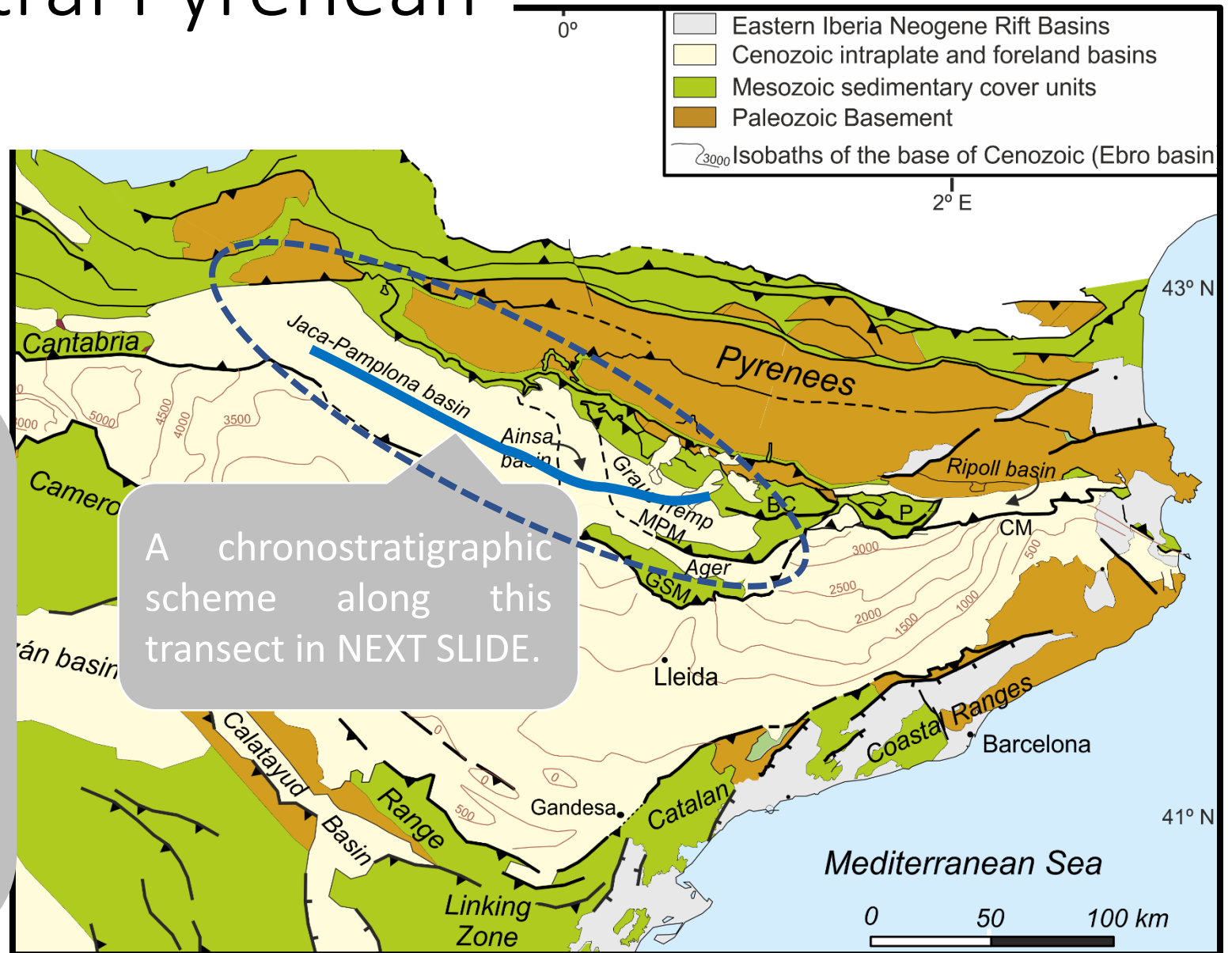


# The South-Central Pyrenean Foreland Basin

The Tremp-Graus, Ainsa and Jaca basins formed an ESE-WNW elongated trough that drained sediments towards the Atlantic ocean.

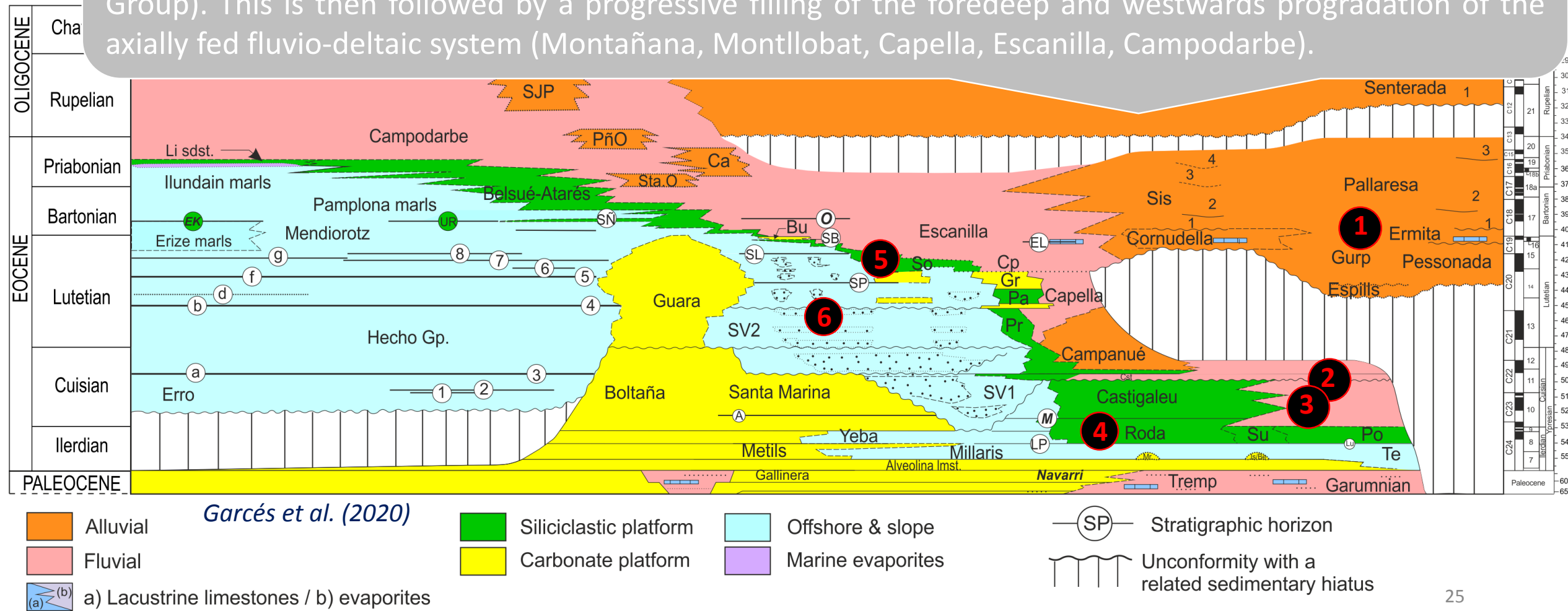
Basin compartmentalization started in the Lower Eocene (Montsec thrust-sheet) and continued until the Bartonian (Gavarnie-Sierras Exteriores thrust-sheet).

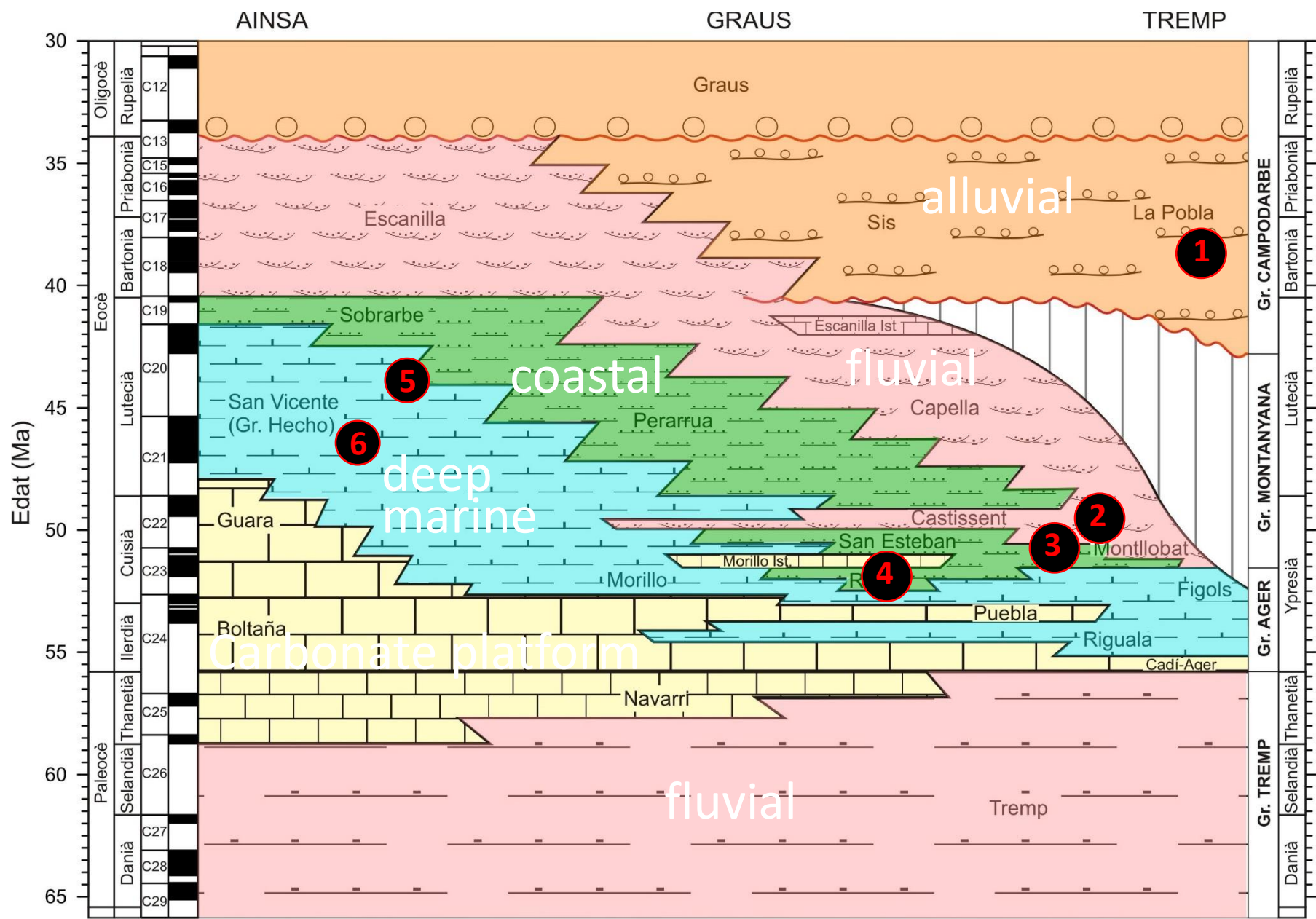
A chronostratigraphic scheme along this transect in NEXT SLIDE.



# Chronostratigraphy of the Tremp-Jaca-Pamplona

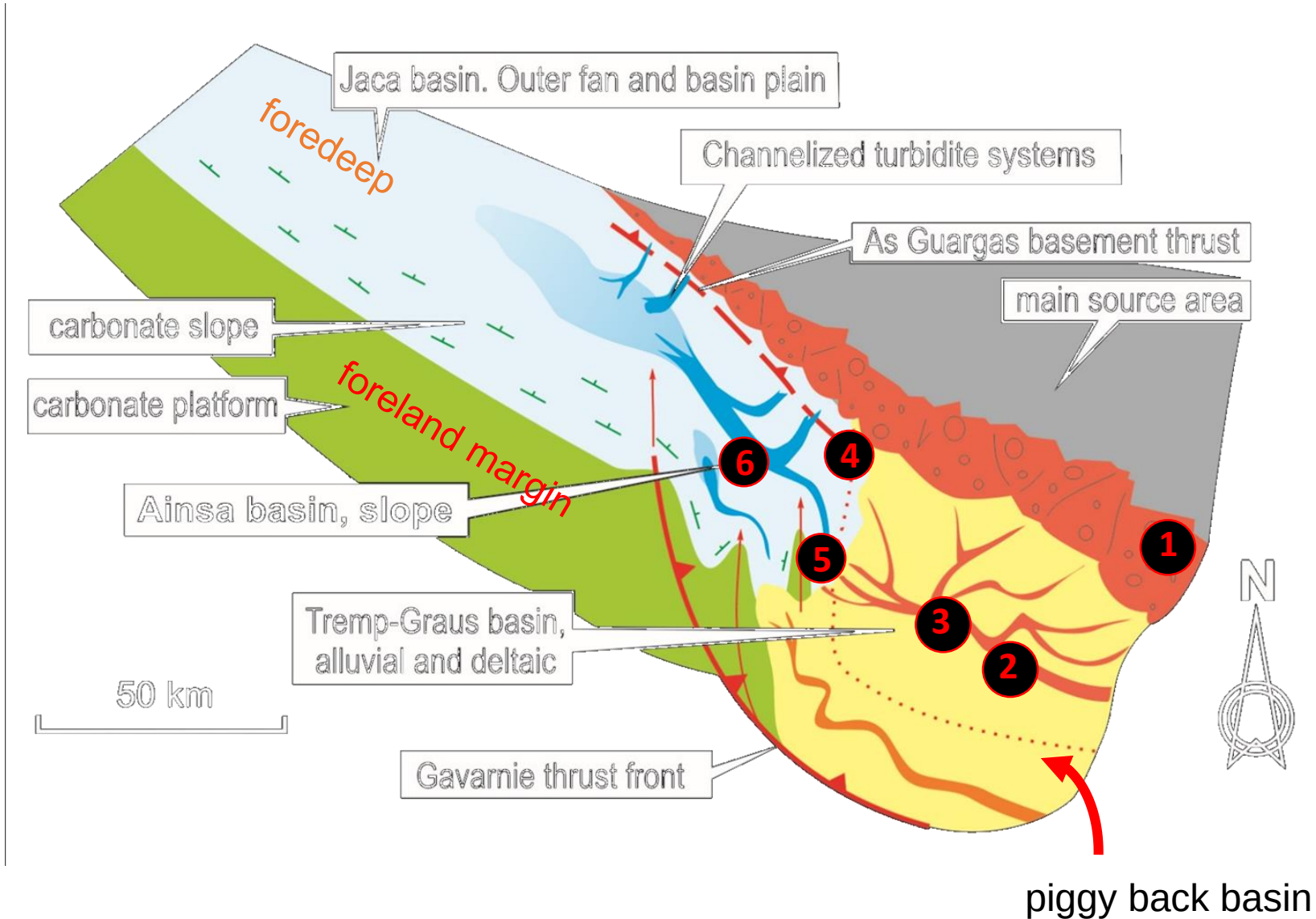
Facies belts are organized in a transgressive-regressive sequence from Paleocene to late Eocene. The lower transgressive trend represents the southwards migration of the plate flexure, with forebulge shallow-water carbonate platforms (Guara, Boltaña, etc.) being replaced by deep marine (foredeep) environments (Hecho Group). This is then followed by a progressive filling of the foredeep and westwards progradation of the axially fed fluvio-deltaic system (Montañana, Montllobat, Capella, Escanilla, Campodarbe).



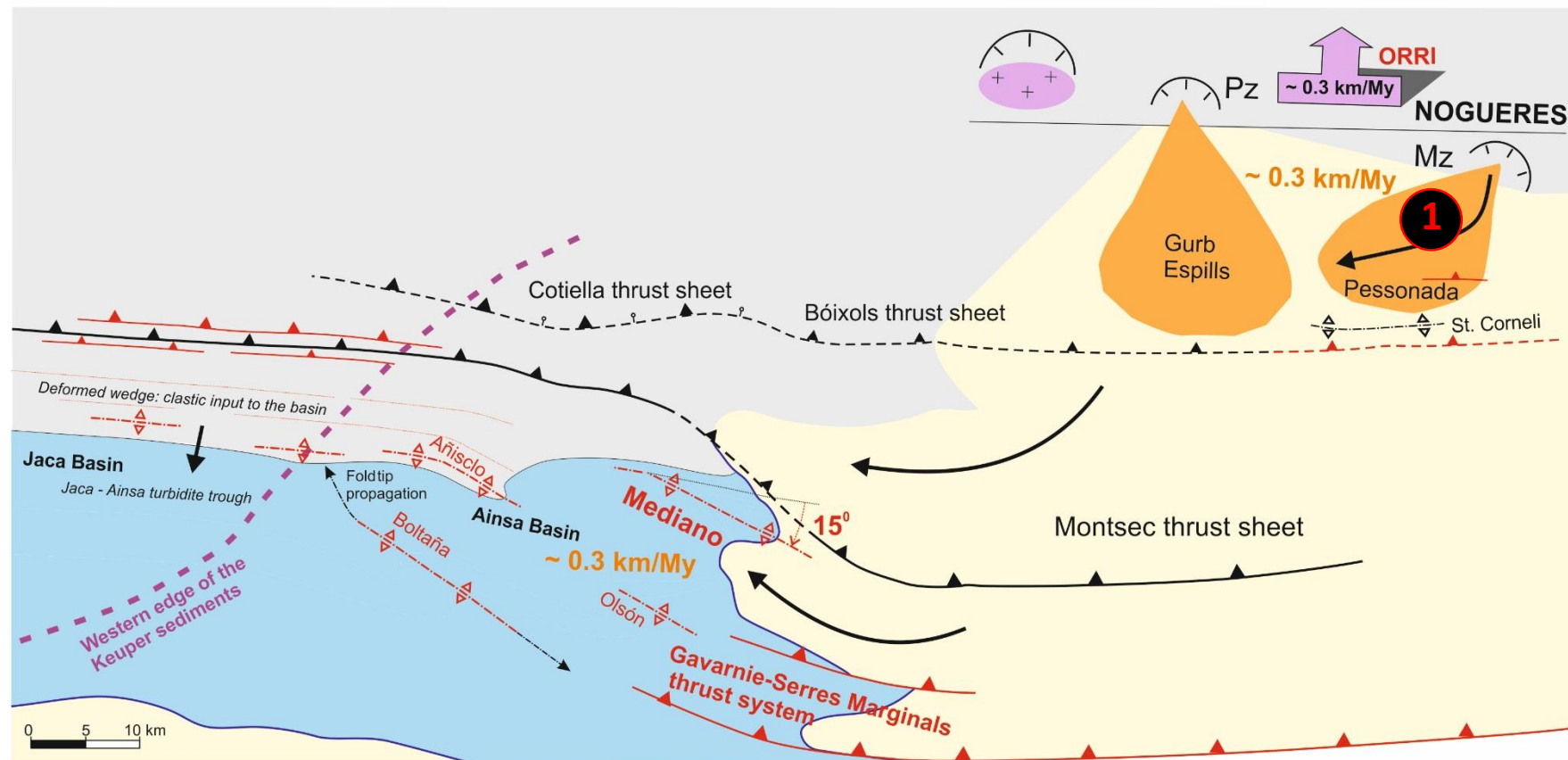




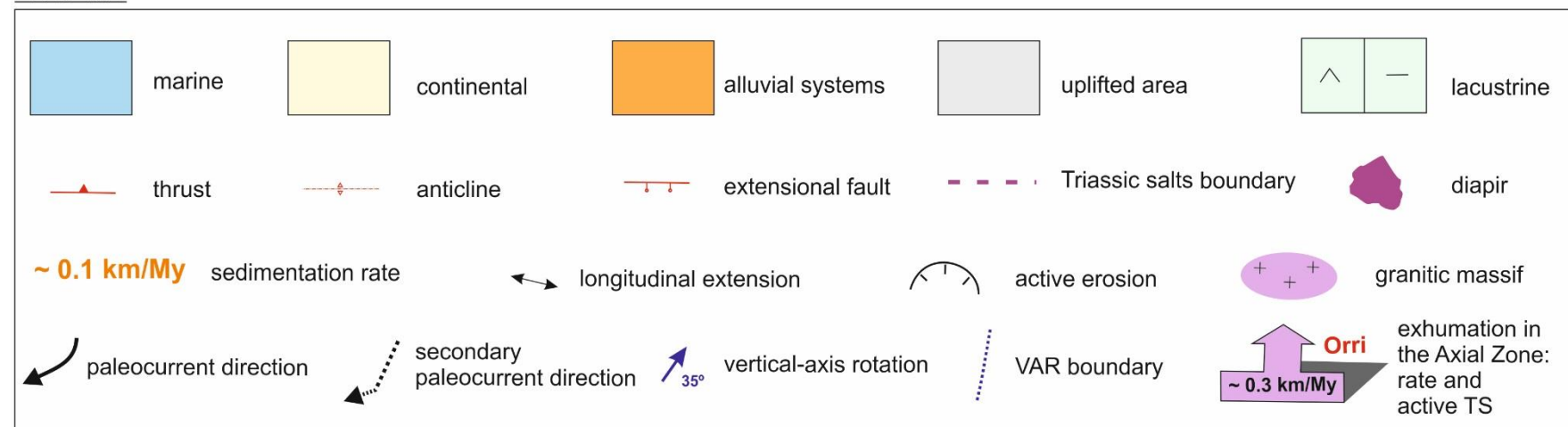
# The Tremp-Graus Jaca basins (middle Eocene)



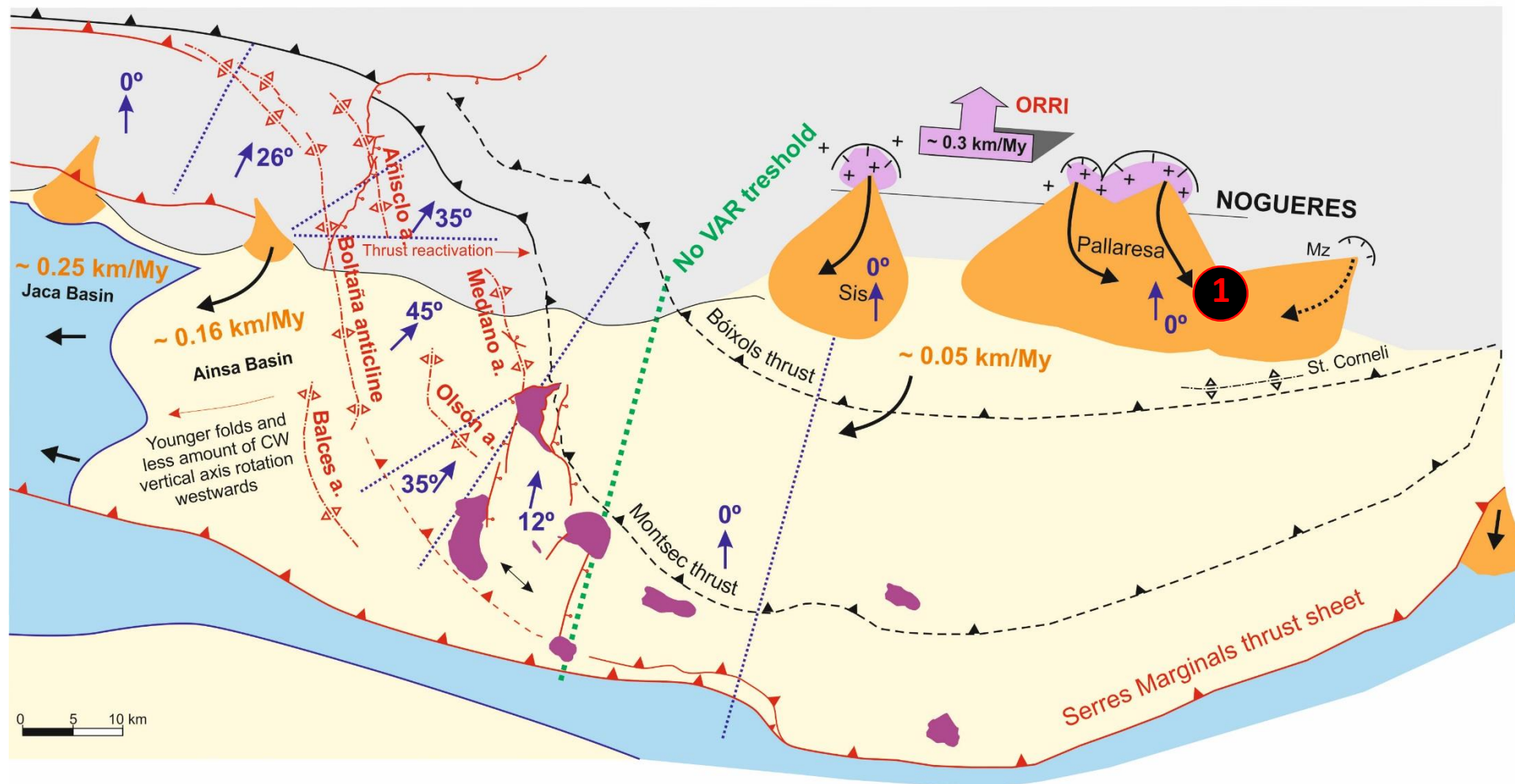
# Middle Lutetian (~ 42Ma)



## LEGEND



## Late Bartonian to early Priabonian (~ 37Ma)

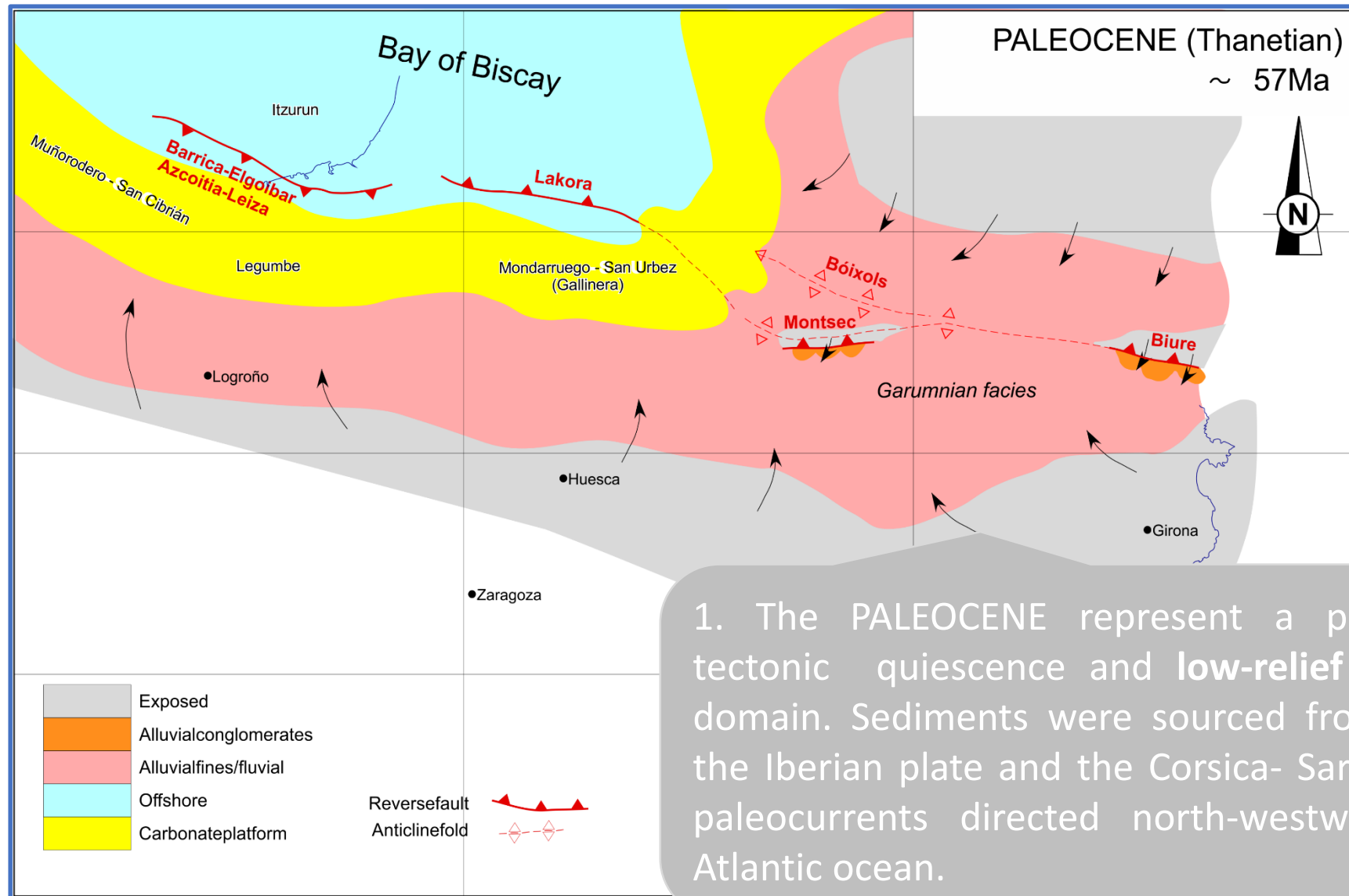


# Paleogeographic evolution

- Paleocene
- Early Eocene (Ilerdian)
- Early Eocene (Cuisian)
- Middle Eocene (Lutetian)
- Middle-Late Eocene
- Oligocene

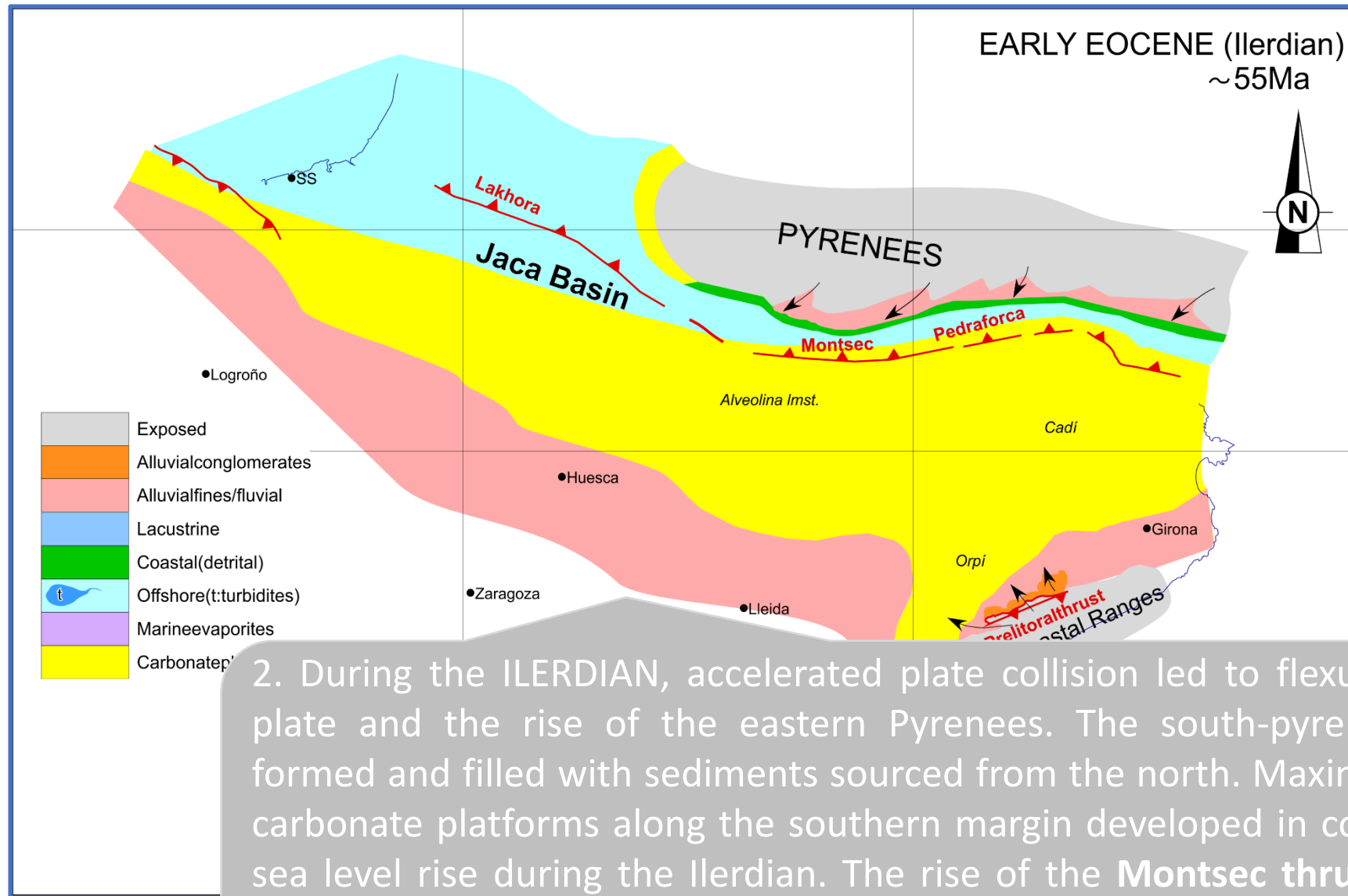


# The Paleocene



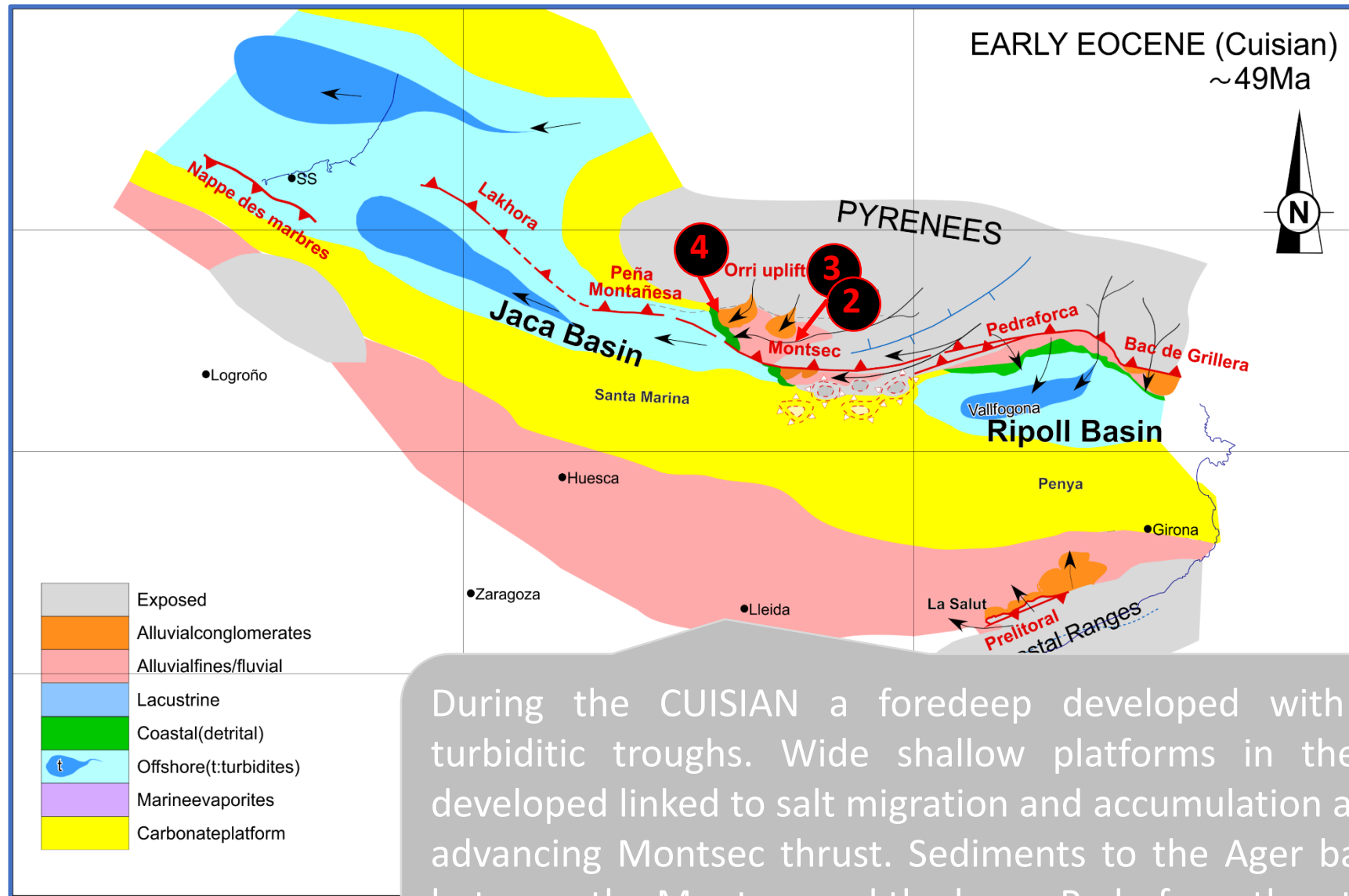
1. The PALEOCENE represent a period of relative tectonic quiescence and **low-relief** in the Pyrenean domain. Sediments were sourced from the interior of the Iberian plate and the Corsica- Sardinian block, with paleocurrents directed north-westward towards the Atlantic ocean.

# The Ilerdian



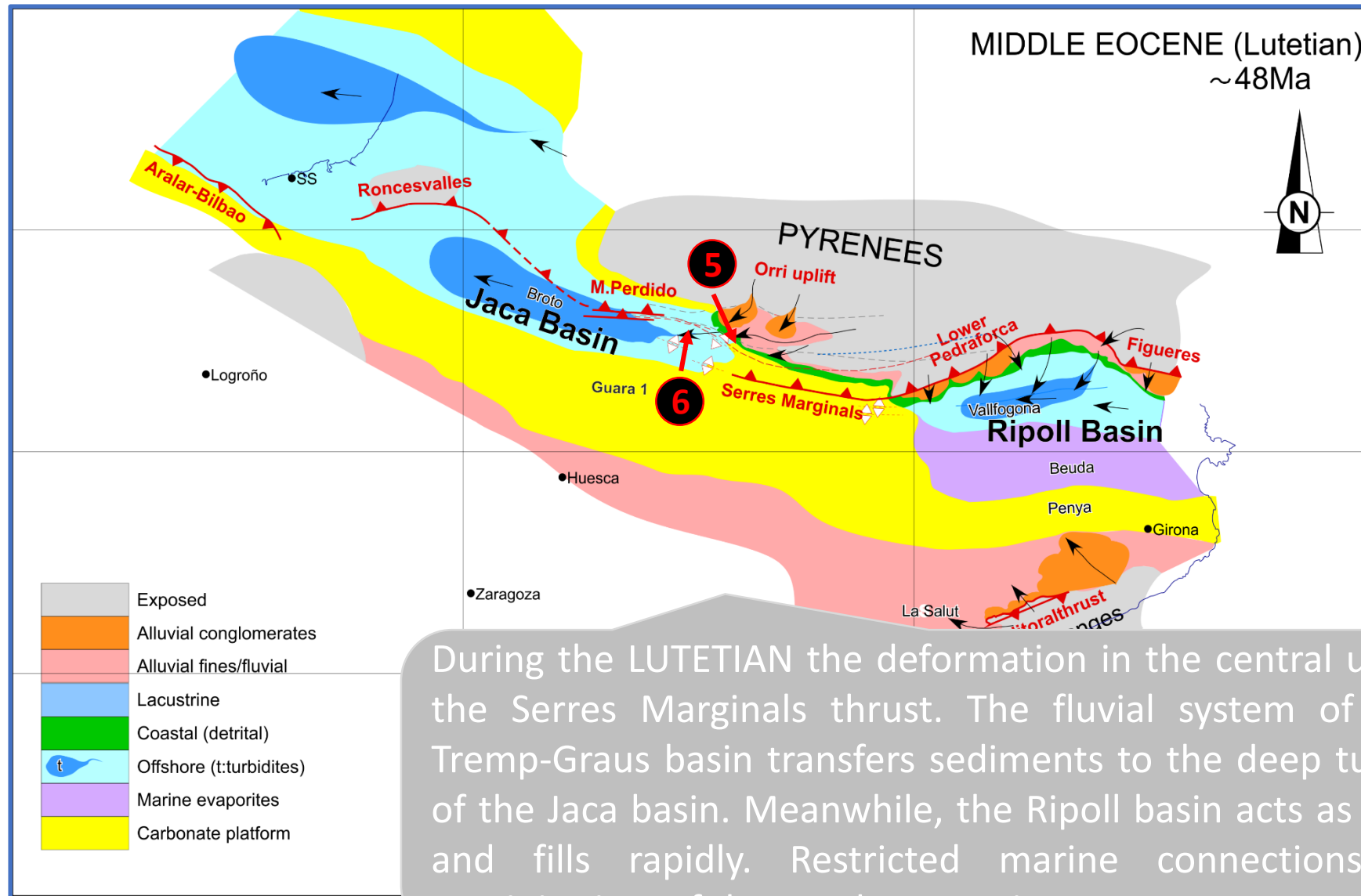
2. During the ILERDIAN, accelerated plate collision led to flexure of the Iberian plate and the rise of the eastern Pyrenees. The south-pyrenean foredeep is formed and filled with sediments sourced from the north. Maximum expansion of carbonate platforms along the southern margin developed in concurrence with a sea level rise during the Ilerdian. The rise of the **Montsec thrust** delineated the southern limit of the **Trempe-Graus basin**.

# Cuisian



During the CUISIAN a foredeep developed with two separated turbiditic troughs. Wide shallow platforms in the central region developed linked to salt migration and accumulation at the front of the advancing Montsec thrust. Sediments to the Ager basin were routed between the Montsec and the lower Pedraforca thrusts.

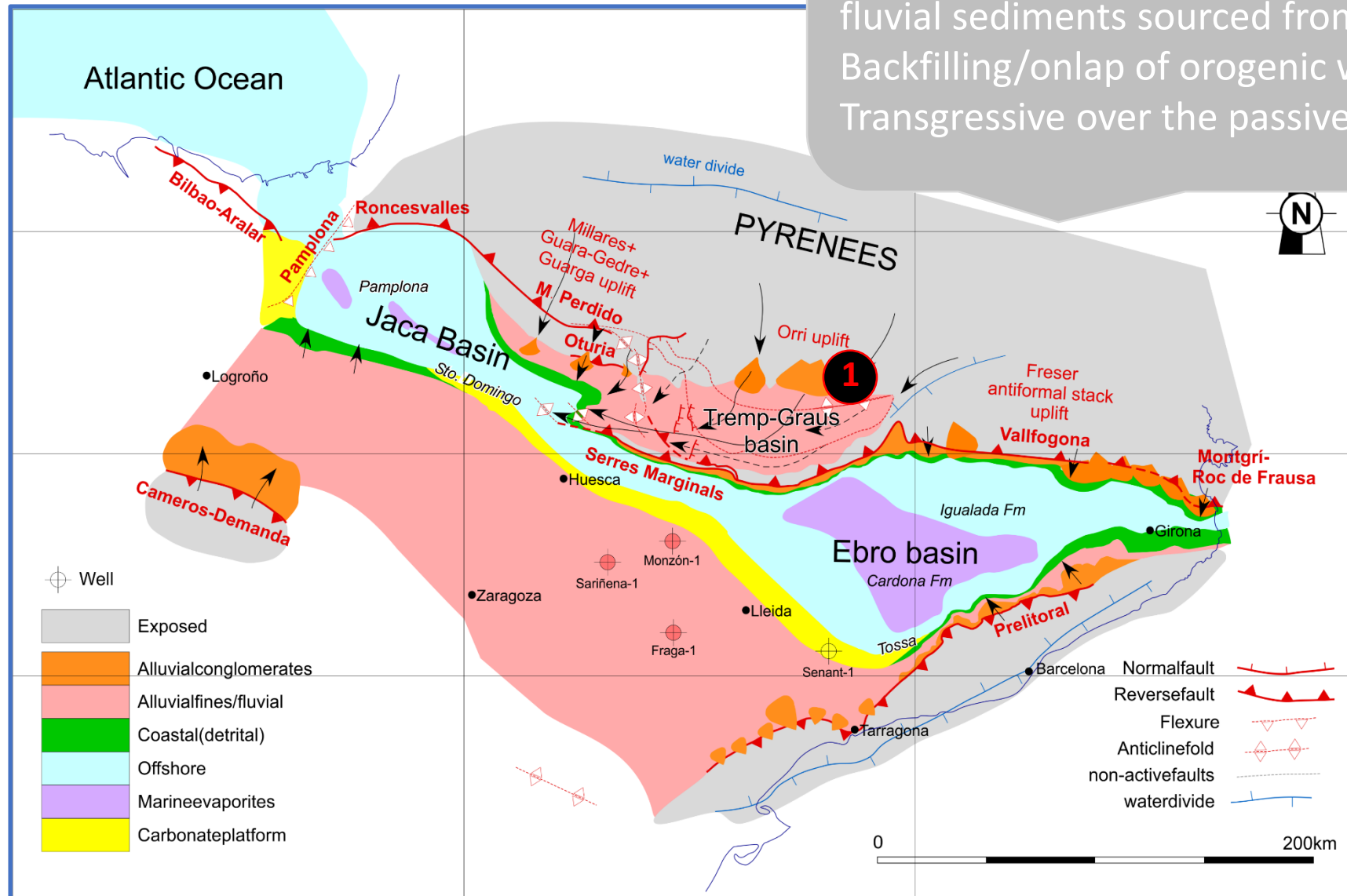
# Lutetian





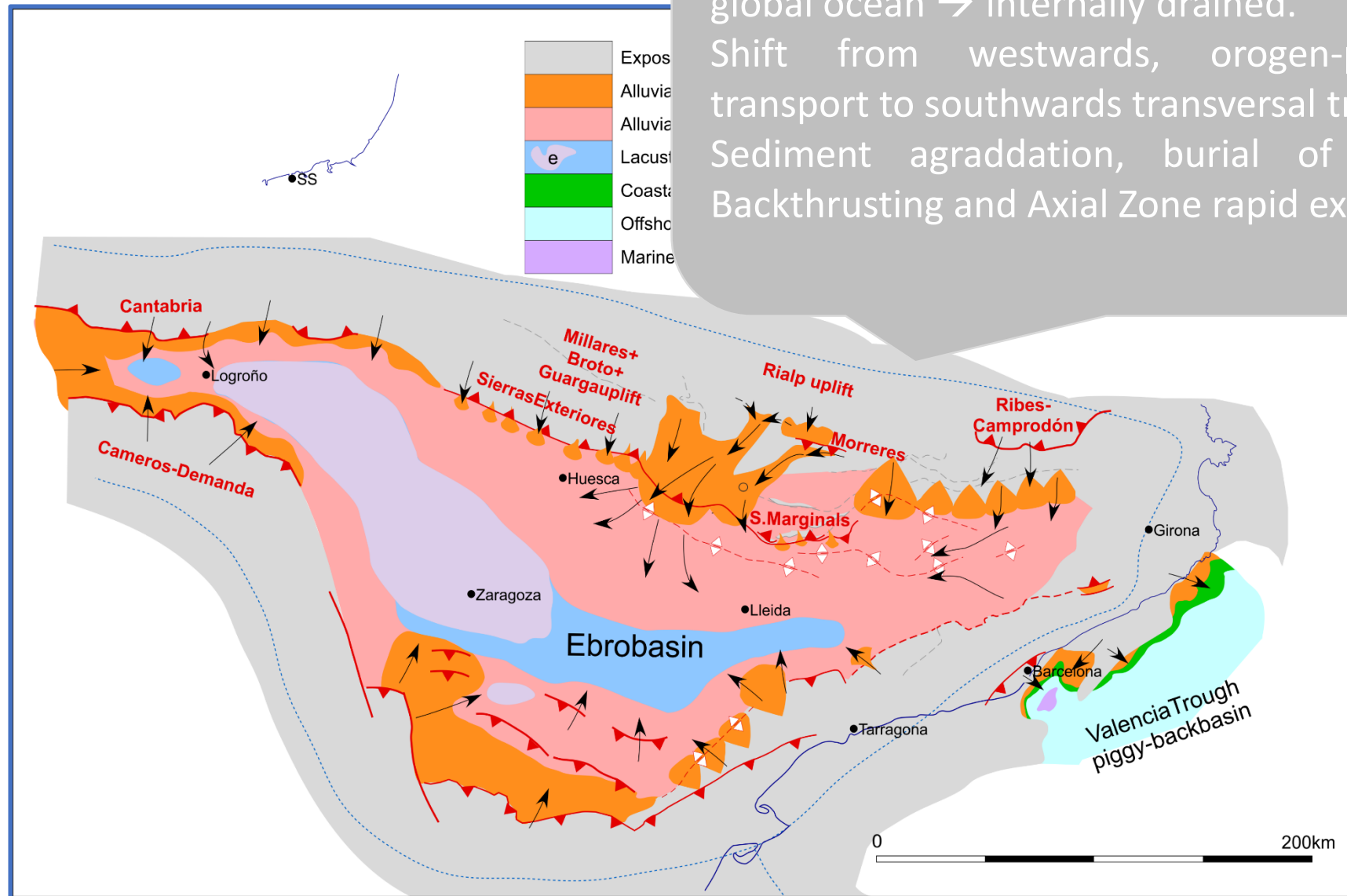
# Bartonian-early Priabonia

During the BARTONIAN a rapid regressional episode led to the filling of the Ainsa basin with fluvial sediments sourced from the Axial Zone. Backfilling/onlap of orogenic wedge. Transgressive over the passive margin



# Oligocene

During the PRIABONIAN the basin disconnects from the global ocean → internally drained.  
Shift from westwards, orogen-parallel sediment transport to southwards transversal transport  
Sediment aggradation, burial of orogenic wedge.  
Backthrusting and Axial Zone rapid exhumation



# Selected References

- ✓ Burbank, DW et al, 1992. The chronology of the Eocene tectonic and stratigraphic development of the eastern Pyrenean foreland basin, NE Spain. *Geol. Soc. Am. Bull.* 104, 1101–1120.
- ✓ Garcés, M, et al, 2020. Paleogeographic and sedimentary evolution of the south-pyrenean foreland basin. *Mar. Pet. Geol.* 113, 104105.
- ✓ Michael, N.A., Carter, A., Whittaker, A.C., Allen, P.A., 2014. Erosion rates in the source region of an ancient sediment routing system: comparison of depositional volumes with thermochronometric estimates. *J. Geol. Soc. London.* 171, 401–412. <https://doi.org/10.1144/jgs2013-108>
- ✓ Mochales, T., et al., 2012. Chronostratigraphy of the boltaña anticline and the Ainsa Basin (southern pyrenees). *Bull. Geol. Soc. Am.* 124, 1229–1250. <https://doi.org/10.1130/B30418.1>
- ✓ Muñoz, J.A., et al, 2013. The Ainsa Fold and Thrust Oblique Zone of the Central Pyrenees: Kinematics of a Curved Contractional System from Paleomagnetic and Structural Data. *Tectonics* 32, 1142–1175.
- ✓ Muñoz, J.A., et al, 2018. The structure of the South-Central Pyrenean fold and thrust belt as constrained by subsurface data. *Geol. Acta* 16, 439–460.
- ✓ Nijman, W., 1998. Cyclicity and basin axis shift in a piggyback basin: towards modelling of the Eocene Tremp-Ager Basin, South Pyrenees, Spain, Geological Society, London, Special Publications. <https://doi.org/10.1144/GSL.SP.1998.134.01.07>
- ✓ Odlum, M.L., Stockli, D.F., Capaldi, T.N., Thomson, K.D., Clark, J., Puigdefàbregas, C., Fildani, A., 2019. Tectonic and sediment provenance evolution of the South Eastern Pyrenean foreland basins during rift margin inversion and orogenic uplift. *Tectonophysics* 765, 226–248. <https://doi.org/10.1016/j.tecto.2019.05.008>
- ✓ Plaziat, J., 1981. Late Cretaceous to late Eocene paleogeographic evolution of southwest Europe. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 36, 263–320.
- ✓ Puigdefàbregas, C., Muñoz, J.A., Vergés, J., 1992. Thrusting and foreland basin evolution in the Southern Pyrenees, in: McClay, K.R. (Ed.), *Thrust Tectonics SE - 22*. Springer Netherlands, pp. 247–254.
- ✓ Puigdefàbregas, C., Muñoz, J.A., Marzo, M., 1986. Thrust Belt Development in the Eastern Pyrenees and Related Depositional Sequences in the Southern Foreland Basin, in: Allen, P.A., Homewood, P. (Eds.), *Foreland Basins, Spec. Publ. Int. Ass. Sediment.* 8. Blackwell Publishing Ltd., Oxford, UK, pp. 229–246.
- ✓ Schettino, A., Turco, E., 2011. Tectonic history of the western Tethys since the Late Triassic. *Geol. Soc. Am. Bull.* 123, 89–105.
- ✓ Sinclair, et al., 2005. Asymmetric Growth Of The Pyrenees Revealed Through Measurement And Modeling Of Orogenic Fluxes. *Am. J. Sci.* 305, 369–406.
- ✓ Thomson, K.D. Et al, 2019. Sediment provenance and routing evolution in the Late Cretaceous–Eocene Ager Basin, south-central Pyrenees, Spain. *Basin Res.* 1–20.
- ✓ Thomson, K.D., Stockli, D.F., Clark, J.D., Puigdefàbregas, C., Fildani, A., 2017. Detrital zircon (U-Th)/(He-Pb) double-dating constraints on provenance and foreland basin evolution of the Ainsa Basin, south-central Pyrenees, Spain. *Tectonics* 36, 1352–1375. <https://doi.org/10.1002/2017TC004504>
- ✓ Tosquella, J., Samsó, J.M., 1996. Bioestratigrafia y litoestratigrafia del paleoceno superior-eoceno inferior del sector oriental de la cuenca surpirenaica. *Acta Geol. Hispanica* 31, 3–21.
- ✓ Vacherat, A., Mouthereau, F., Pik, R., Huyghe, D., Paquette, J.L., Christophoul, F., Loget, N., Tibari, B., 2017. Rift-to-collision sediment routing in the Pyrenees: A synthesis from sedimentological, geochronological and kinematic constraints. *Earth-Science Rev.* <https://doi.org/10.1016/j.earscirev.2017.07.004>
- ✓ Vergés, J., Millán, H., Roca, E., Muñoz, J.A., Marzo, M., Cirés, J., Bezemer, T. Den, Zoetemeijer, R., Cloetingh, S., 1995. Eastern Pyrenees and related foreland basins: pre-, syn- and post-collisional crustal-scale cross-sections. *Mar. Pet. Geol.* 12, 903–915. [https://doi.org/10.1016/0264-8172\(95\)98854-X](https://doi.org/10.1016/0264-8172(95)98854-X)
- ✓ Vergés, J., Fernández, M., Martínez, A., 2002. The Pyrenean orogen : pre-, syn-, and post-collisional evolution. *J. Virtual Explor.* 8, 55–74.
- ✓ Vergés, J et al, 1998. Quantified vertical motions and tectonic evolution of the SE Pyrenean foreland basin, in: *Cenozoic Foreland Basins of Western Europe*. Geological Society Special Publications, 134, pp. 107–134.





# Dia 1

## Pobla de Segur

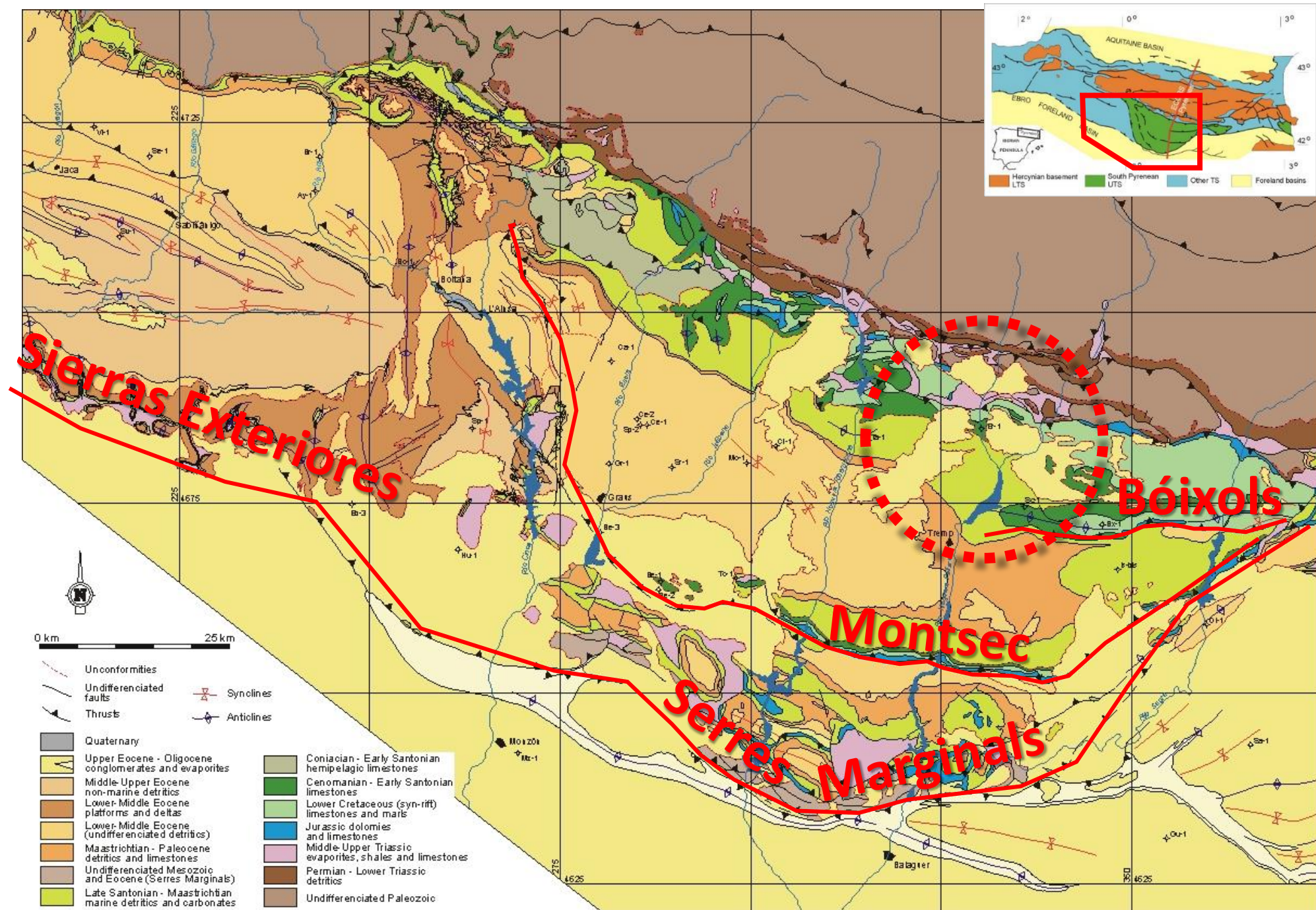
N-26 Pobla de Segur

C-13

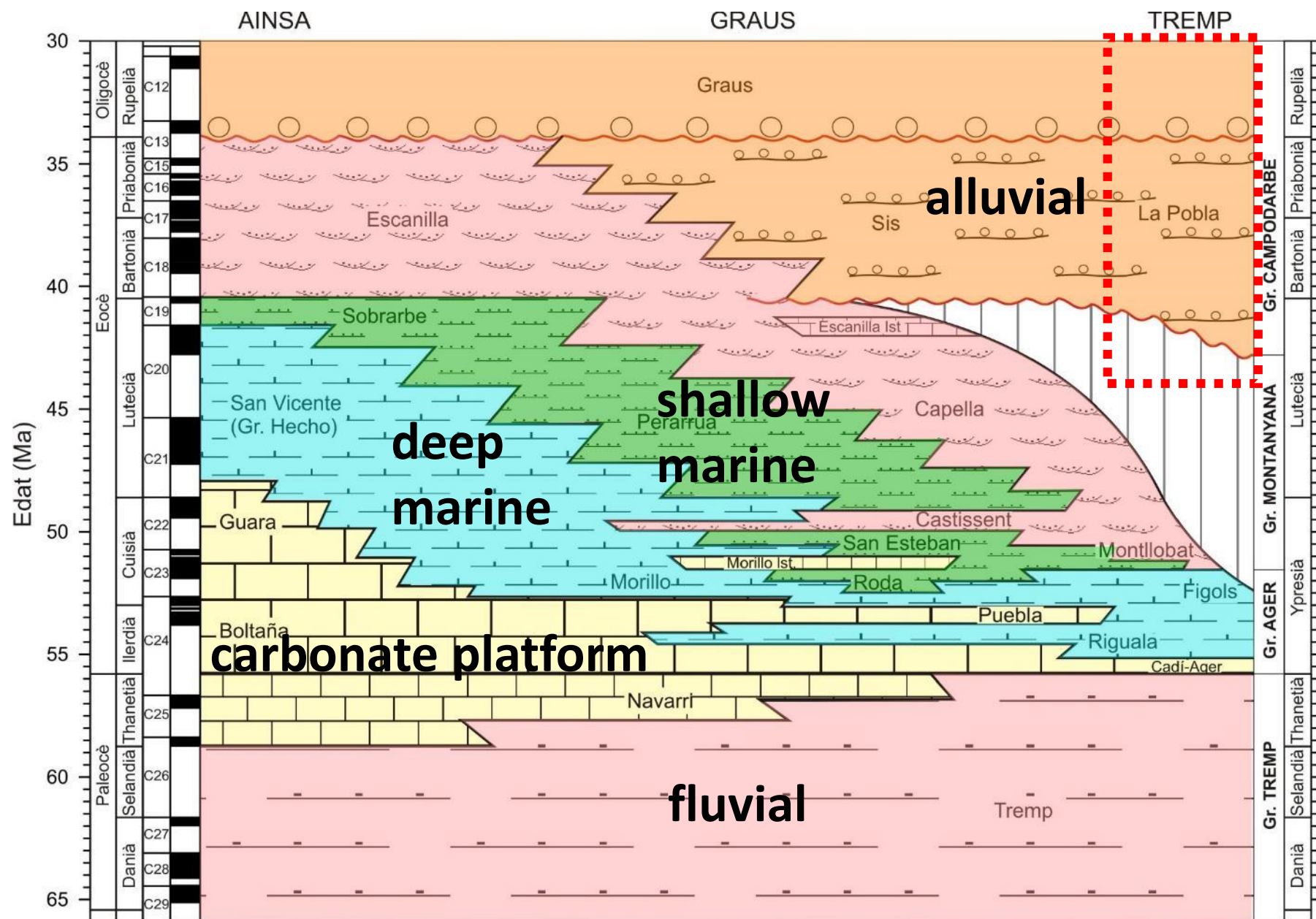




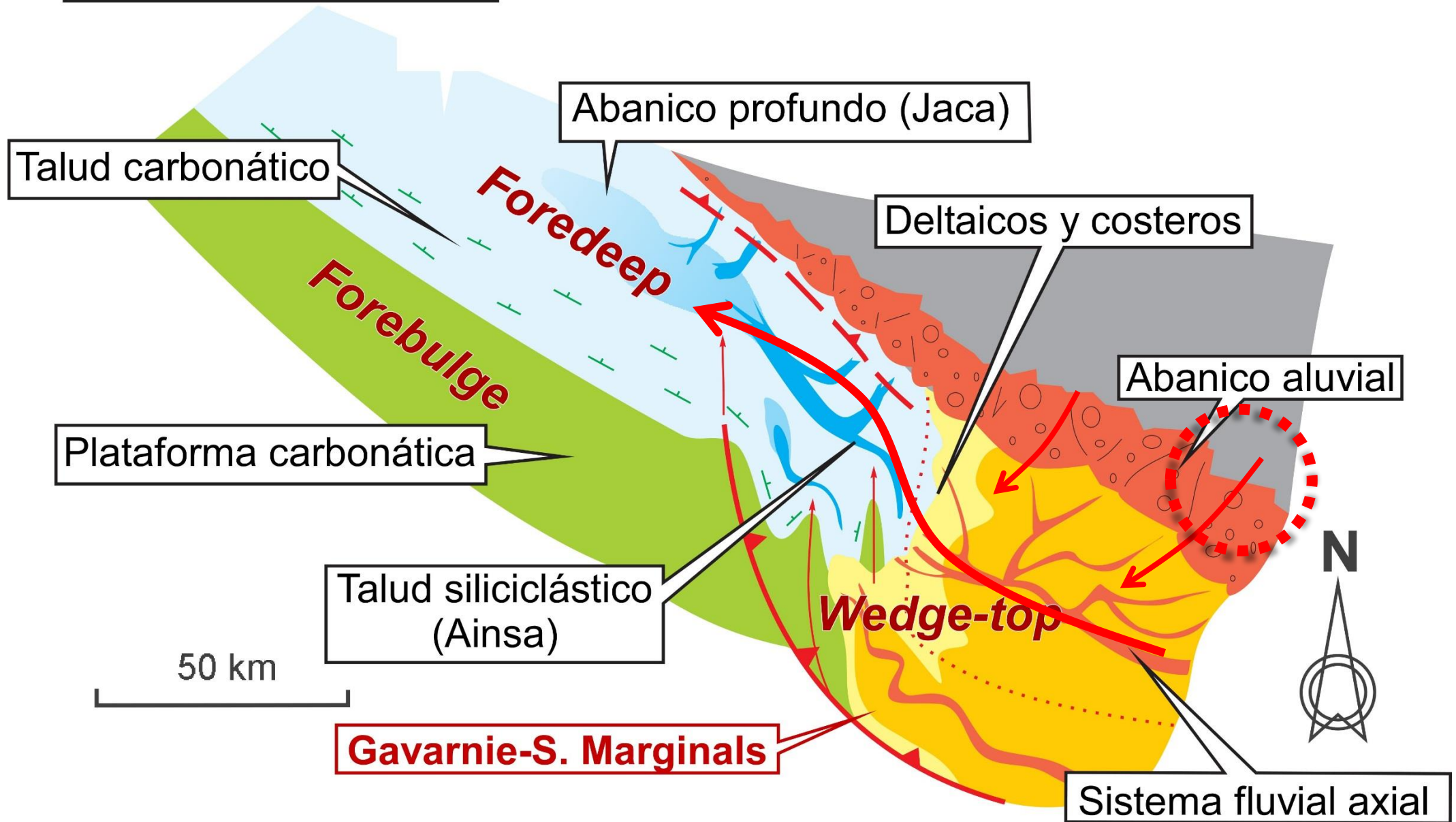




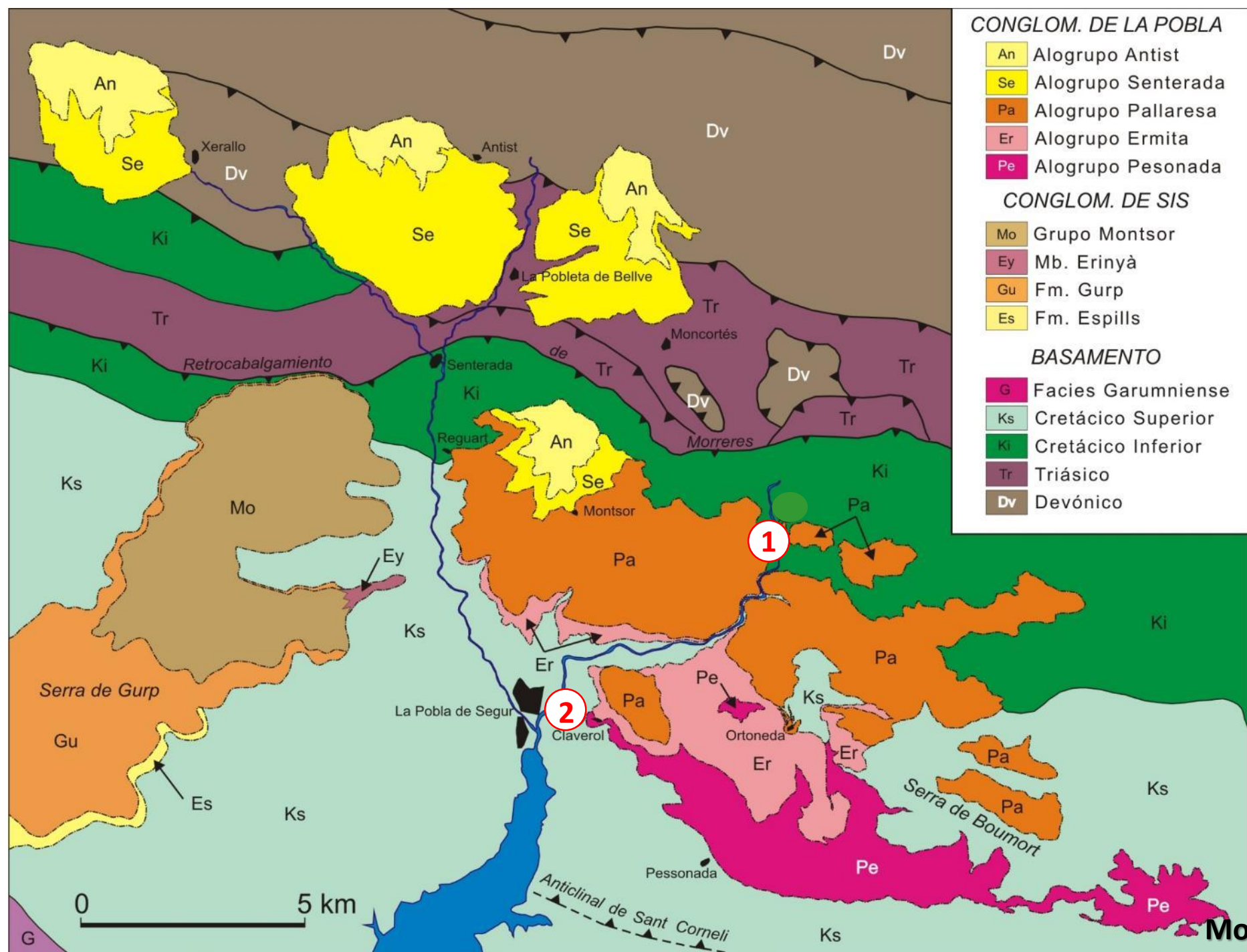


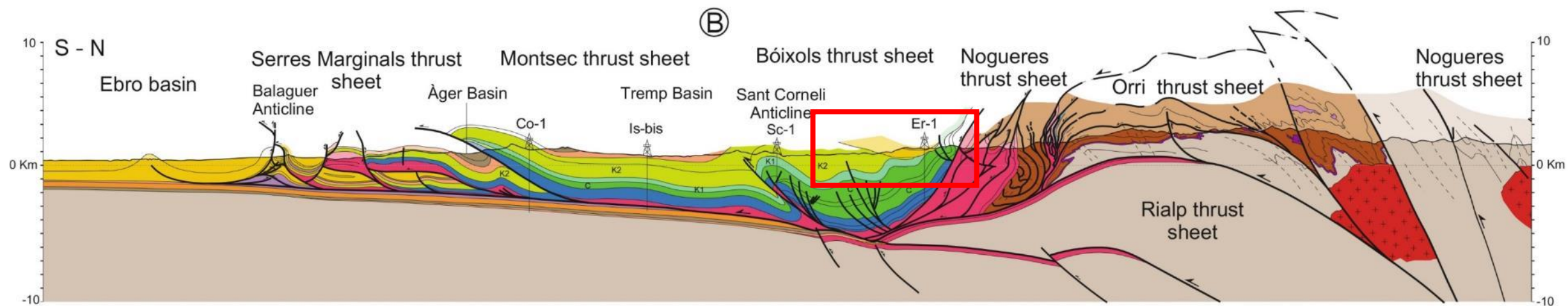


# Eoceno Medio

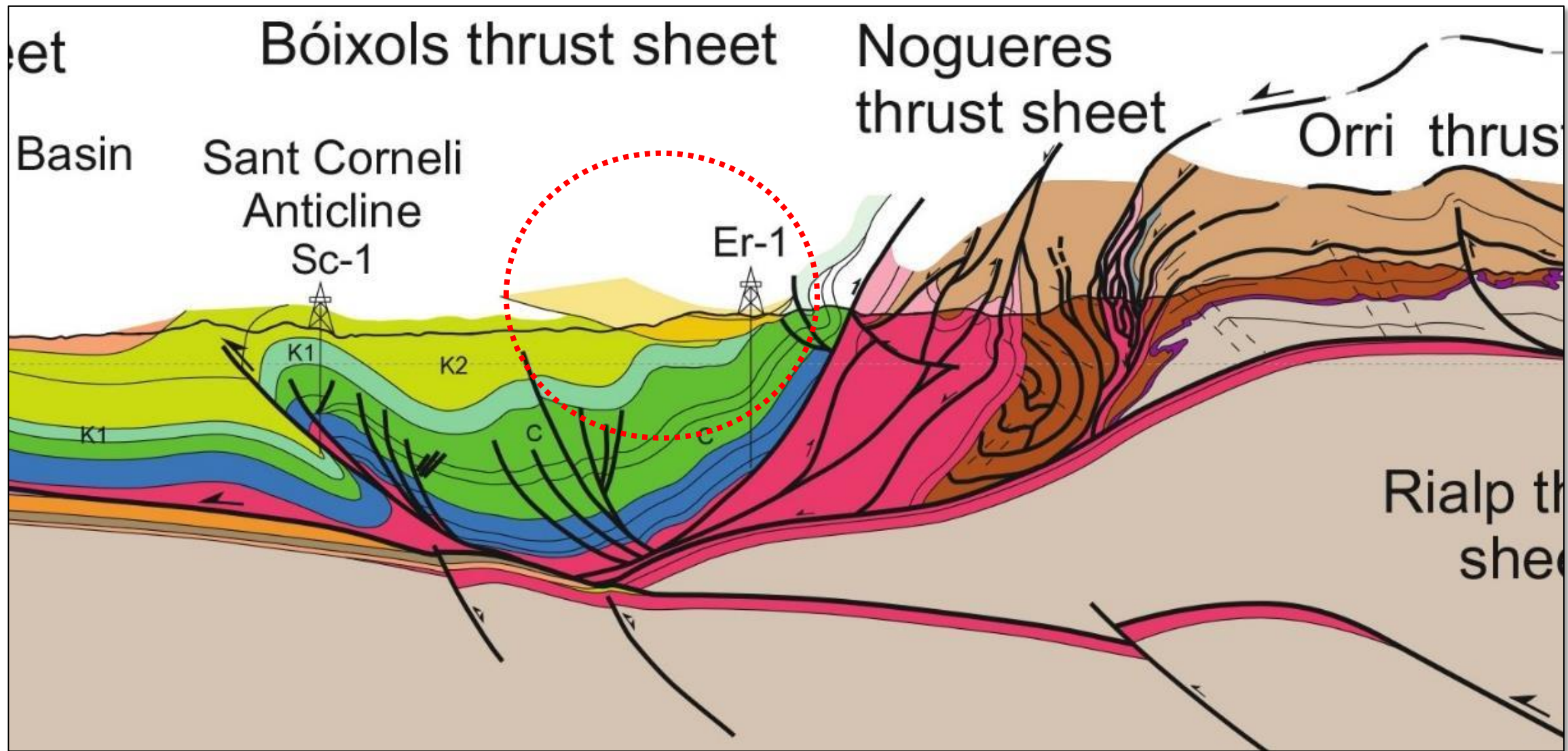














# N-260 al N de La Pobla de Segur





N-260 Boca S del tunel de L'Argenteria







N-

-S

Panorámica N-S en la explanada entre L'Argenteria y Collegats





## **TAREA: Realizar un corte geológico**

1. Diferenciación paisajística de litologías
2. Determinación de la disposición de la estratificación
3. Análisis de la relación entre las diferentes unidades litológicas
4. Interpretación de los contactos





N-

-S

1

5

5

2

3

4





## Unidades estratigráficas

- 1 Calizas de la Fm. Prada (Cretácico inferior)
- 2 y 3 Margas y Margocalizas de la Fm. Cabó (Cretácico inferior)
- 4 Calacarenitas del Mb. Roc del Diable de la Fm. Senyús (Cretácico inferior)
- 5 Conglomerados de la Pobla de Segur (unidad Pallaresa) (Eoceno medio-superior)









Badwater Rd







## **Disposición de la estratificación**

Cretácico inferior: fuerte-moderado al S (sucesión continua concordante)

Conglomerados eocenos: subhorizontales (sucesión continua concordante)





**Relación entre unidades**

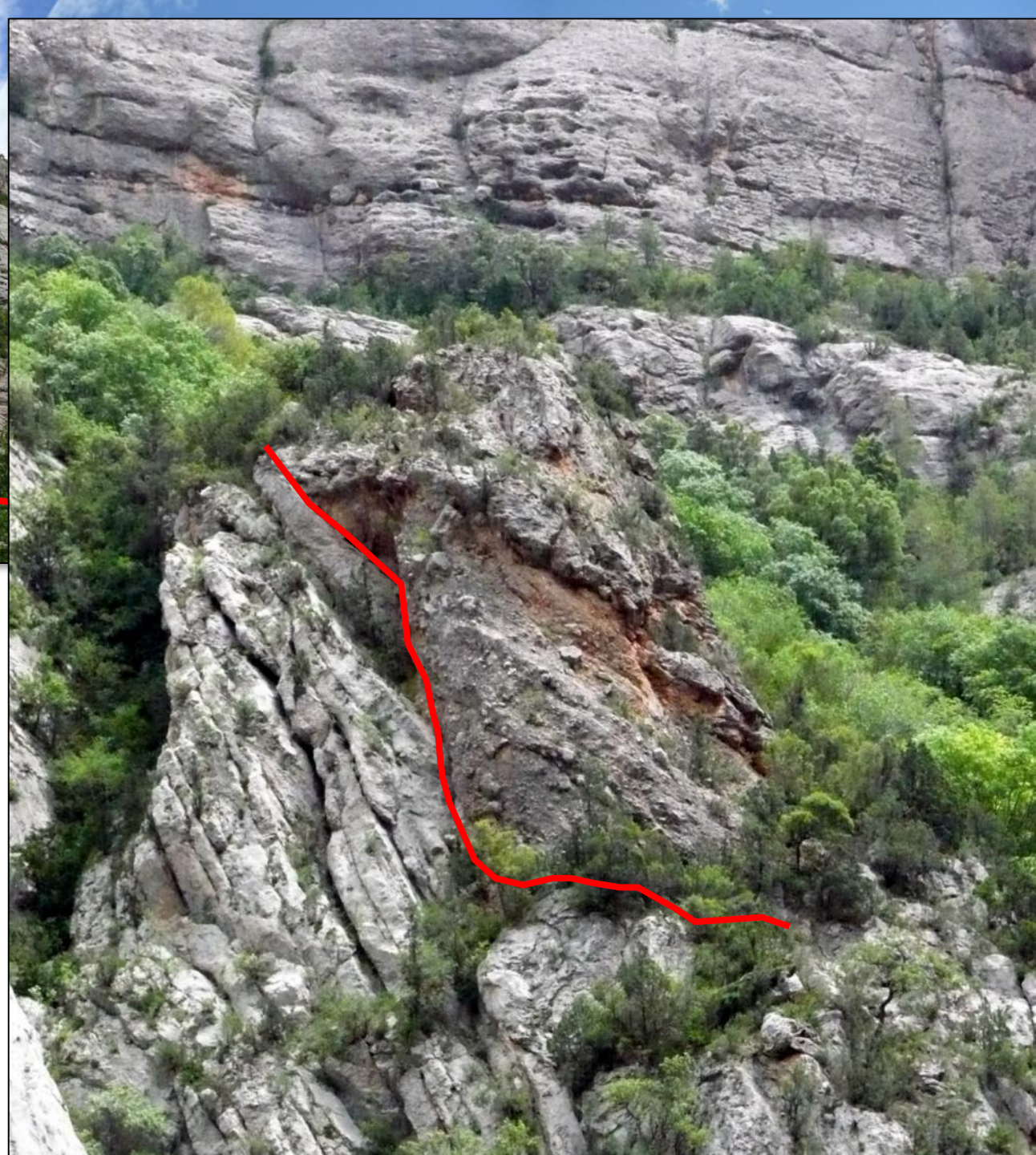


















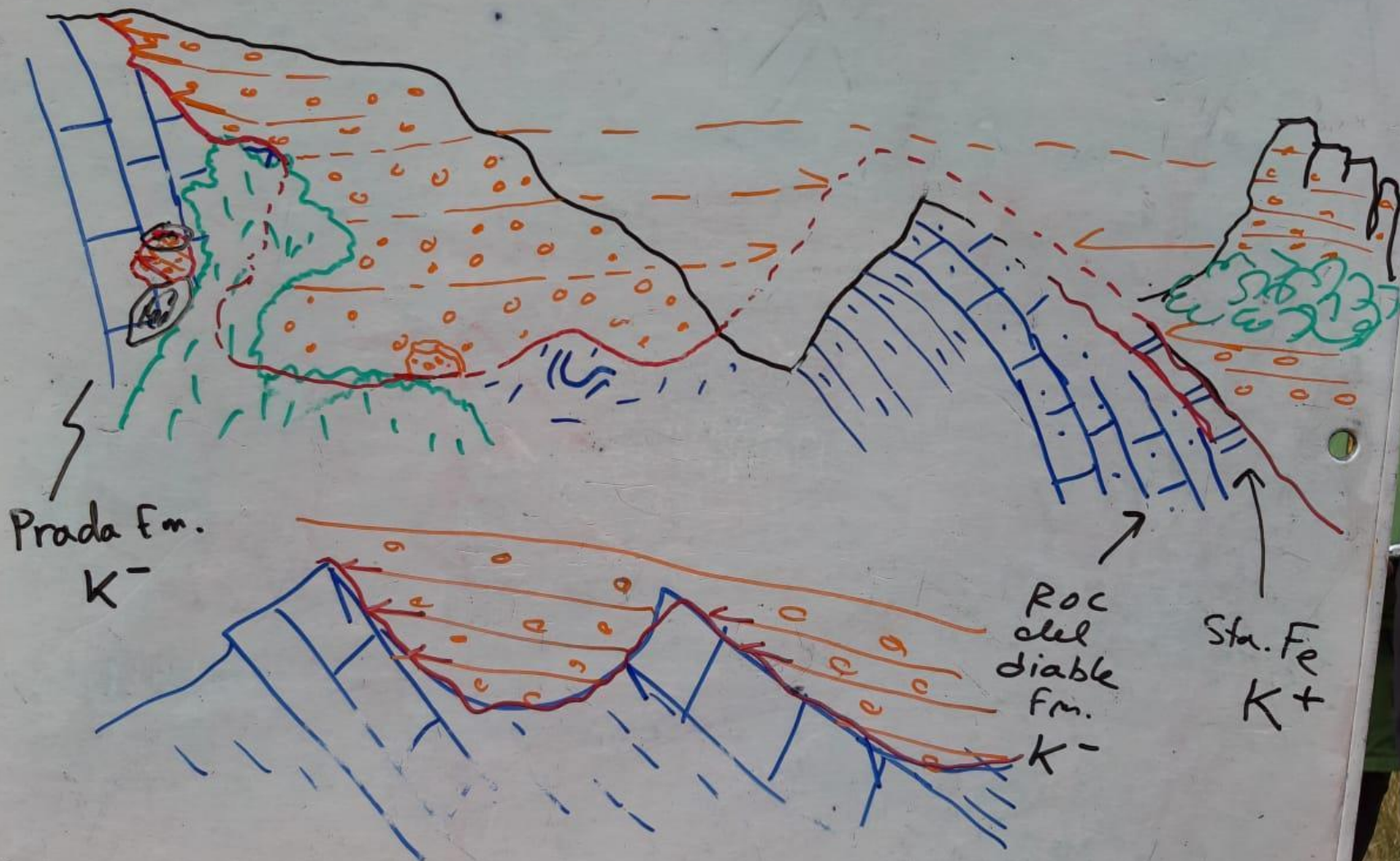




N-

# BOCA S TUNEL ARGENTERIA

-S











**Abancos aluviales rellenando relieves erosionados (paleovalles)**  
**Nevada, EEUU**





**Abanicos aluviales rellenando relieves erosionados (paleovalles)**

**Nevada, EEUU**

Google Earth

image © 2020 Maxar Technologies  
© 2020 Google

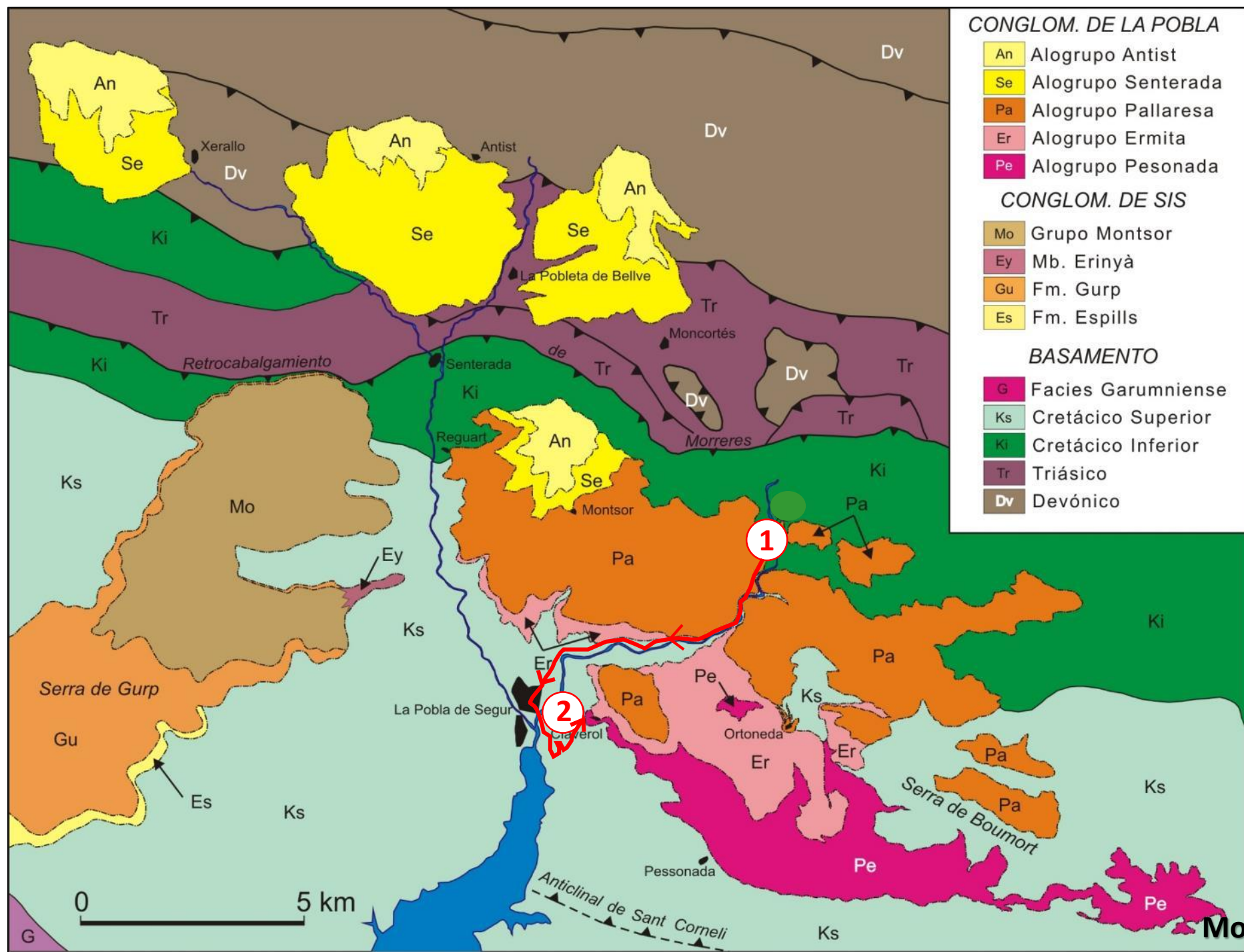
95

267

Scott's Castle Rd

2 km







## Claverol vista panorámica hacia en N





**WNW-**

**-ESE**

Panorámica WNW-ESE hacia el N de Claverol





**Facies proximales:**  
Conglomerados y brechas  
heterométricas mal  
seleccionadas (Debris Flow)



**Facies distales:** Lutitas rojas  
y areniscas tabulares de  
llanura aluvial







**Facies distales:** Lutitas rojas y areniscas tabulares con tendencias granodecrecientes de llanura aluvial



**Facies distales:** Lutitas grises, margocalizas y calizas de origen lacustre.



WNW-

-ESE



Panorámica WNW-ESE hacia el N de Claverol

## **TAREA: Realizar un corte de paisaje**

1. Diferenciación de la discordancia basal de los conglomerados de La Pobla de Segur
2. Observar y diferenciar grandes unidades conglomeráticas en el paisaje
  - ¿cuál es el origen del diferente color entre unidades?



WNW-

-ESE



## 1. Diferenciación de la discordancia basal de los conglomerados de La Población de Segur

- Conglomerados terciarios: buzamiento suave, estratificación definida, colores rojizos (no siempre)
- Cretácico: lutitas grises con intercalaciones arenosas, *badlands*, campos de cultivo



WNW-

-ESE



## 1. Diferenciación de la discordancia basal de los conglomerados de La Pobla de Segur

- Conglomerados terciarios: buzamiento suave, estratificación definida, colores rojizos (no siempre)
- Cretácico: lutitas grises con intercalaciones arenosas, *badlands*, campos de cultivo



WNW-

-ESE



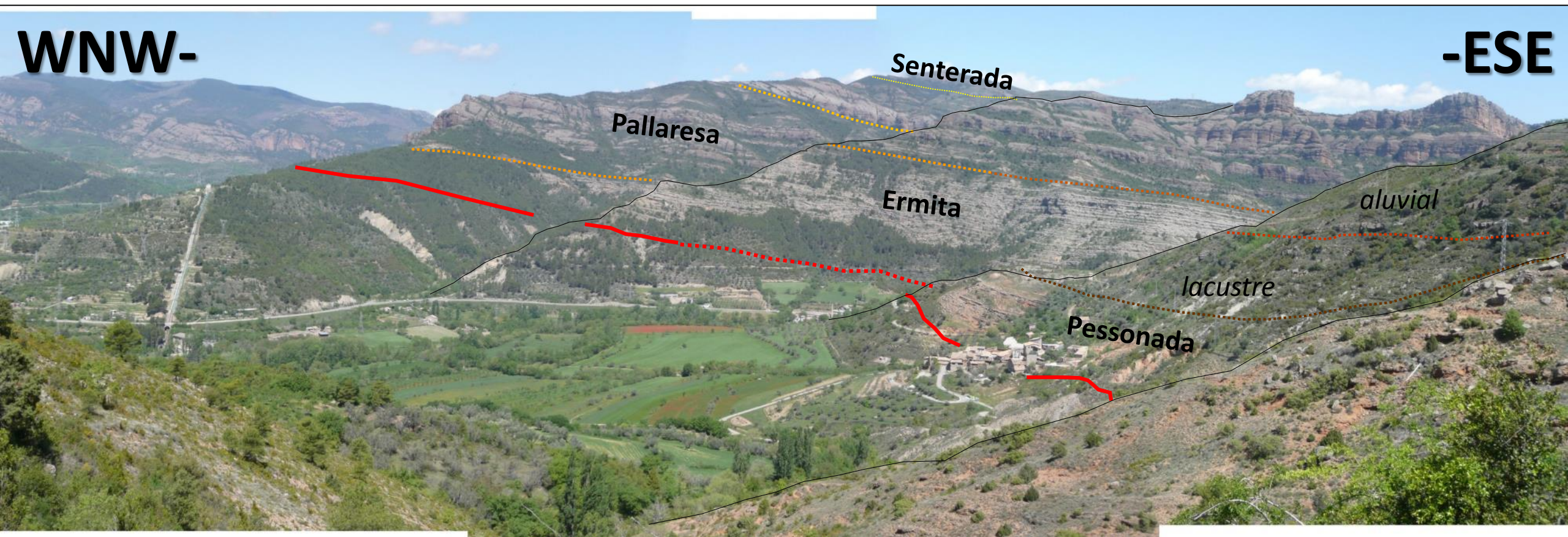
## 2. Observar y diferenciar grandes unidades conglomeráticas en el paisaje

- ¿cuál es el origen del diferente color entre unidades?



WNW-

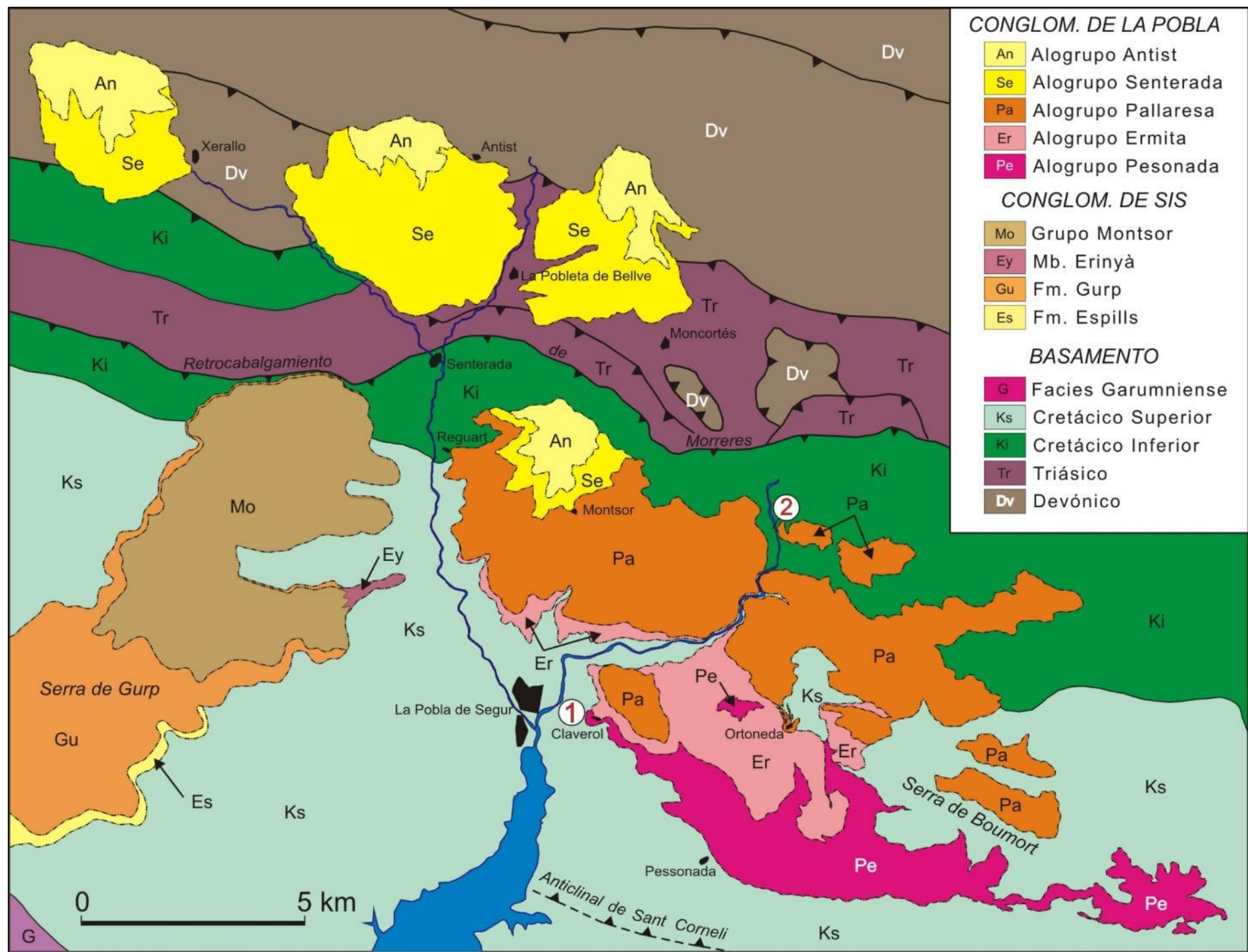
-ESE



## 2. Observar y diferenciar grandes unidades conglomeráticas en el paisaje

- ¿cuál es el origen del diferente color entre unidades?

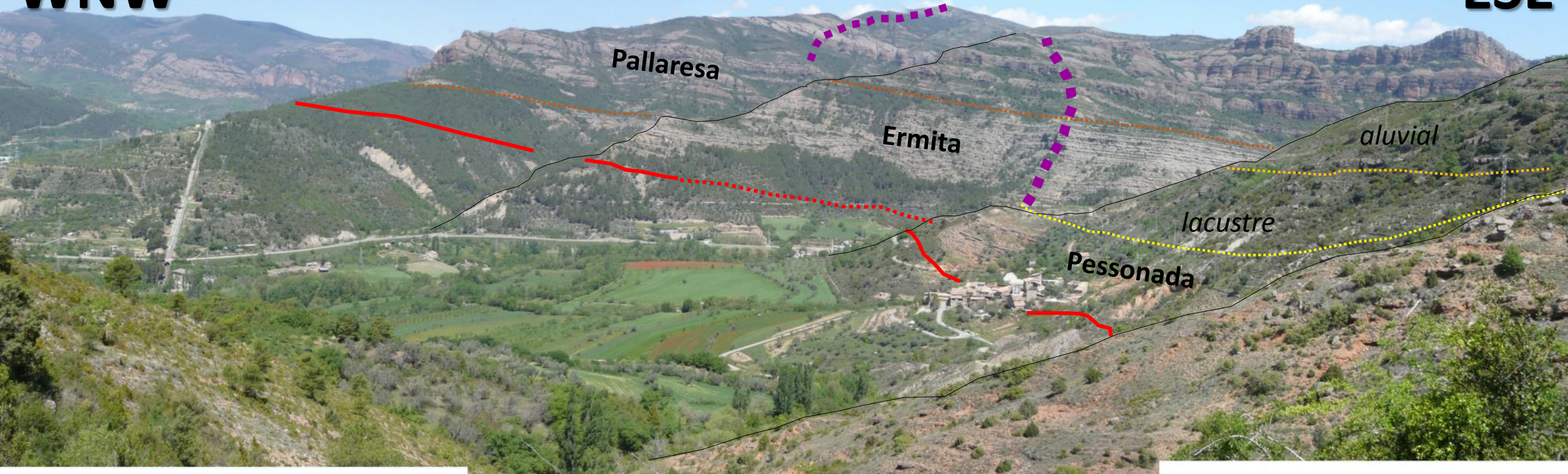






WNW-

-ESE



**Ejercicio individual:**

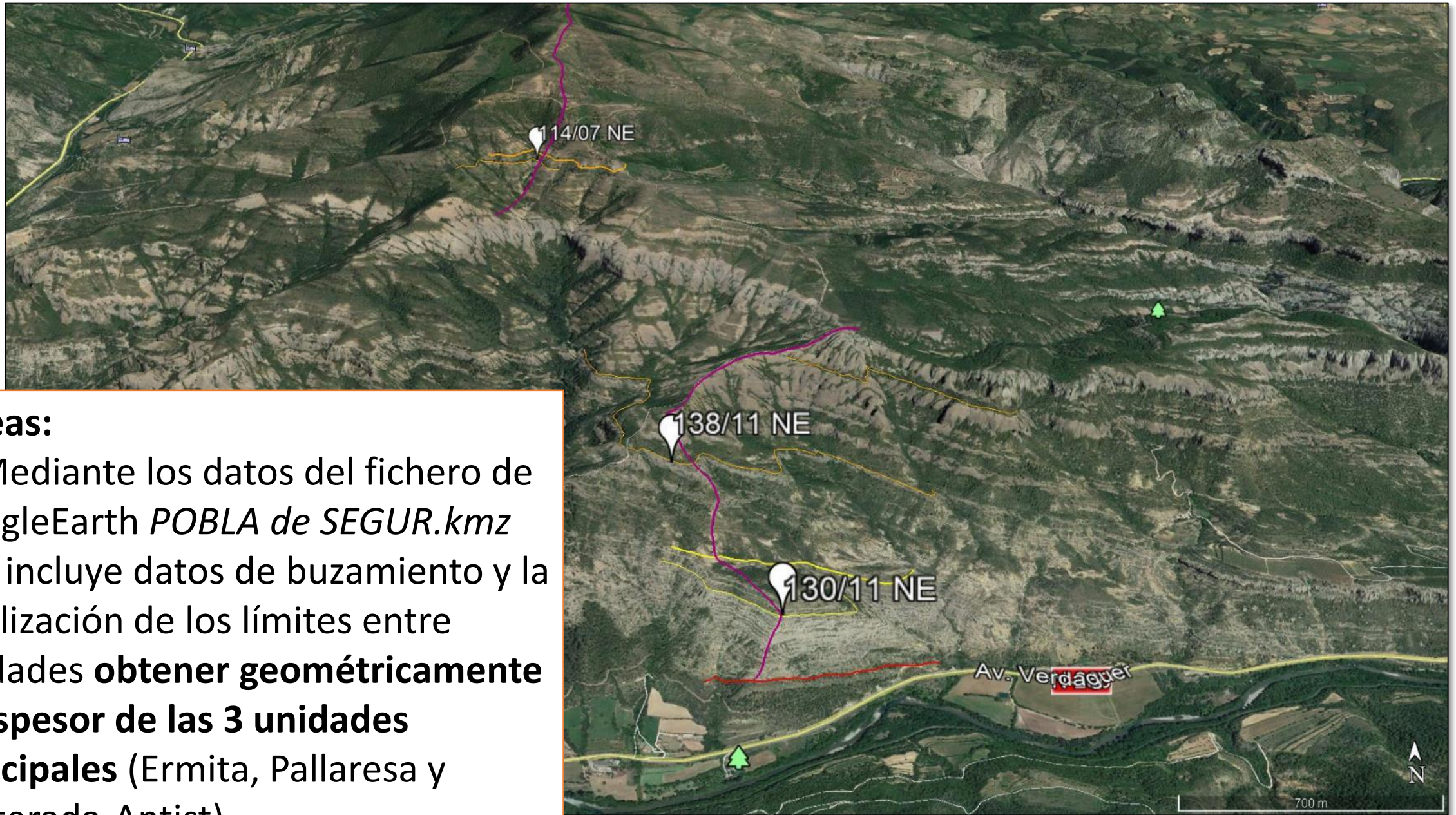
**Observar el espesor de las capas conglomeráticas vs. de grano fino para analizar las tendencias granulométricas en la vertical**

- ¿Qué nos dicen estas tendencias?



## Tareas:

1- Mediante los datos del fichero de GoogleEarth *POBLA de SEGUR.kmz* que incluye datos de buzamiento y la localización de los límites entre unidades **obtener geométricamente el espesor de las 3 unidades principales** (Ermita, Pallaresa y Senterada-Antist)





Trabajad directamente sobre **Google Earth**.

Mediante la herramienta “**Regla**” en modo “**línea**” donde podéis obtener la distancia horizontal entre dos puntos (**Longitud en el mapa**).

Con estas distancias, las cotas de base y techo de cada unidad y los buzamientos...



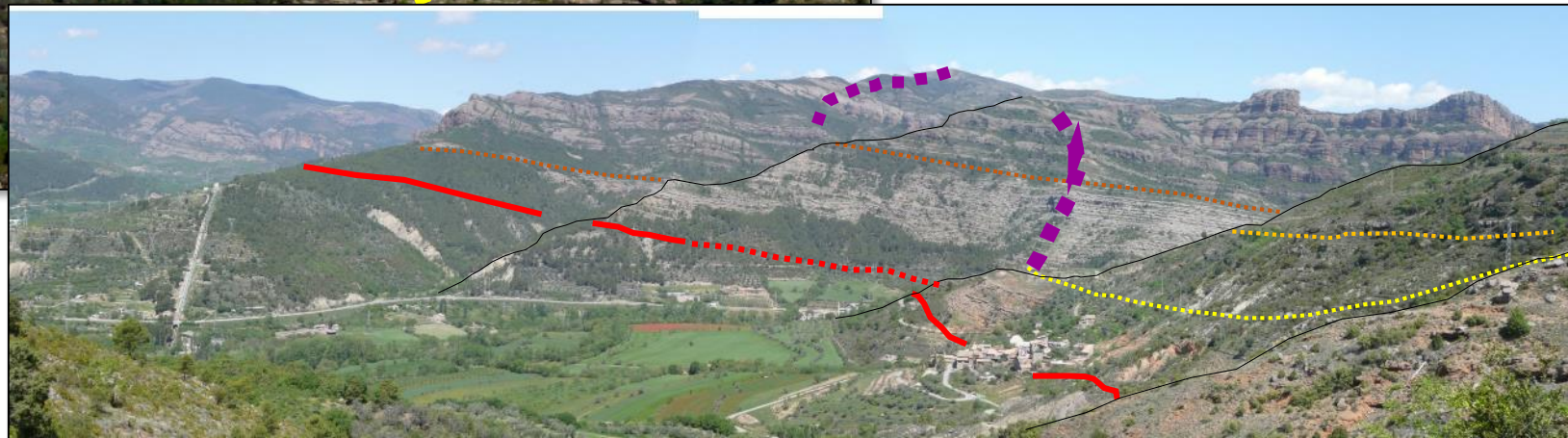
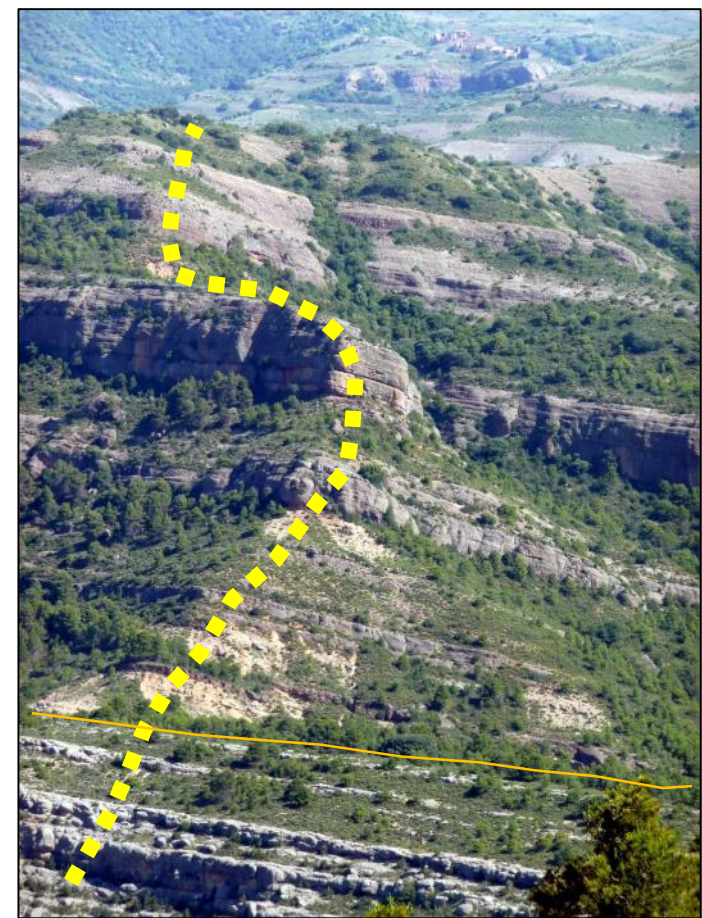
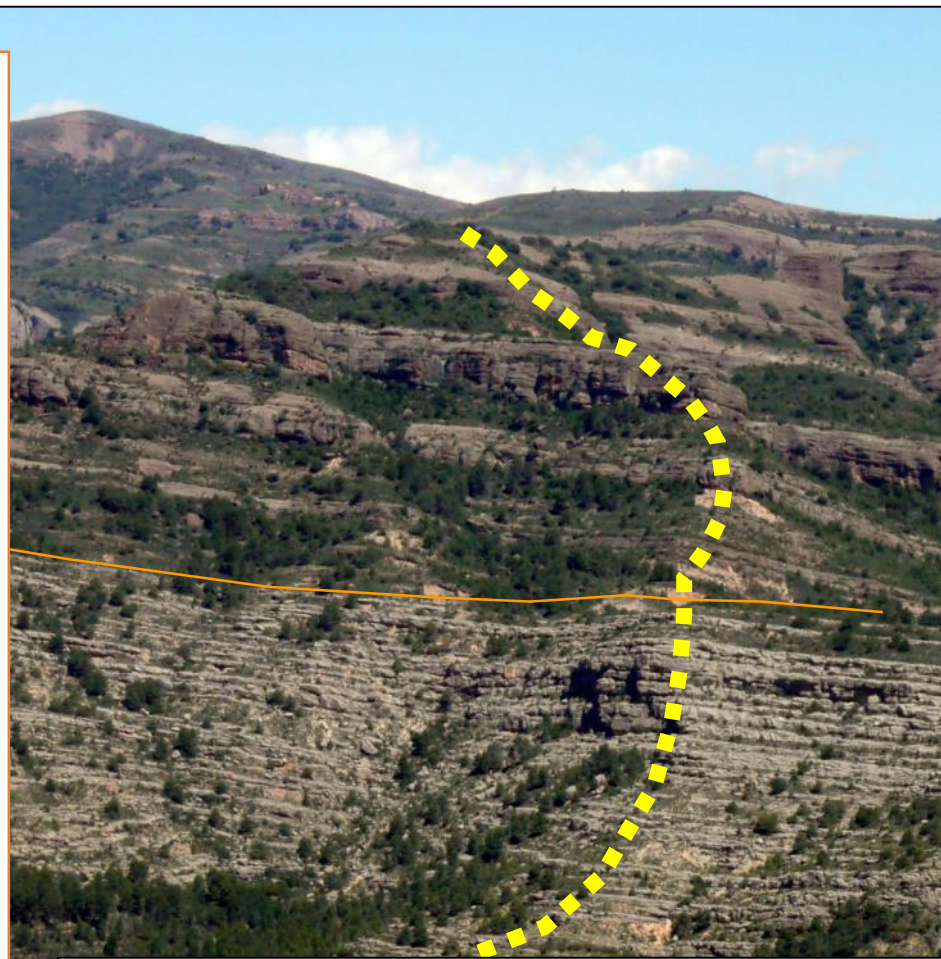


## Tareas:

2- Realizar una **columna estratigráfica esquemática** que muestre las **unidades principales** y diferenciando los tramos conglomeráticos de los lutíticos.

Haced una **columna general** que incluya los dos tramos señalados en Google Earth y otra **parcial**, de mayor detalle sólo de la columna inferior.

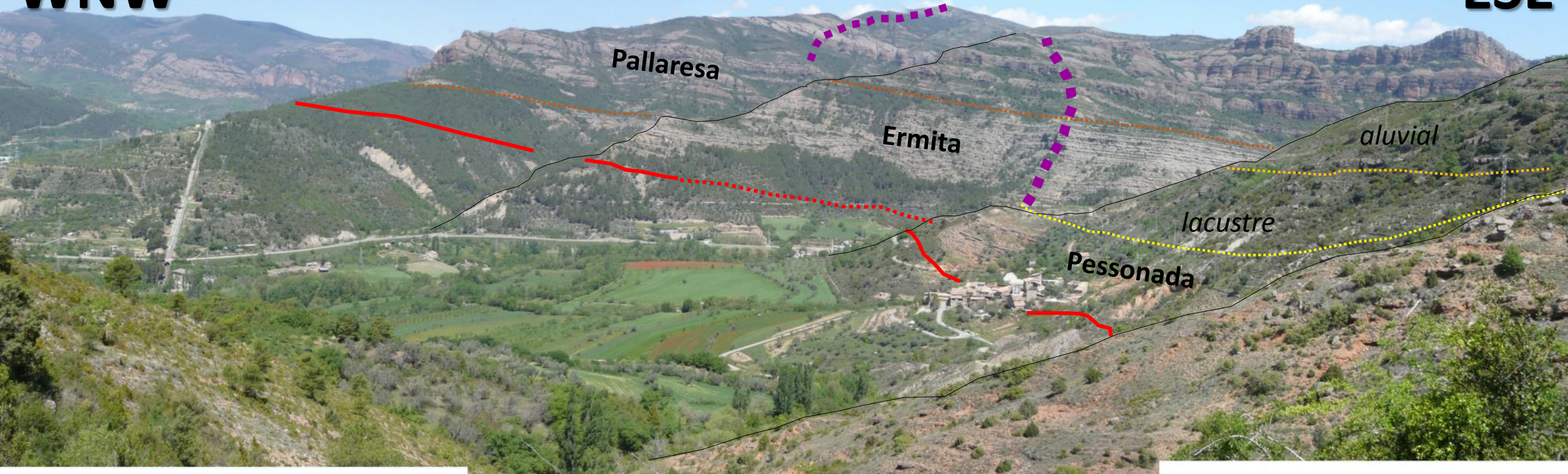
Utilizad las fotos incluidas en el Campus Virtual (fotos de detalle y panorámica general).





WNW-

-ESE



**Finalmente, a partir de las columnas realizadas:**

1. Analizar las tendencias generales granulométricas en la vertical
2. Interpretar dichas tendencias explicando su origen



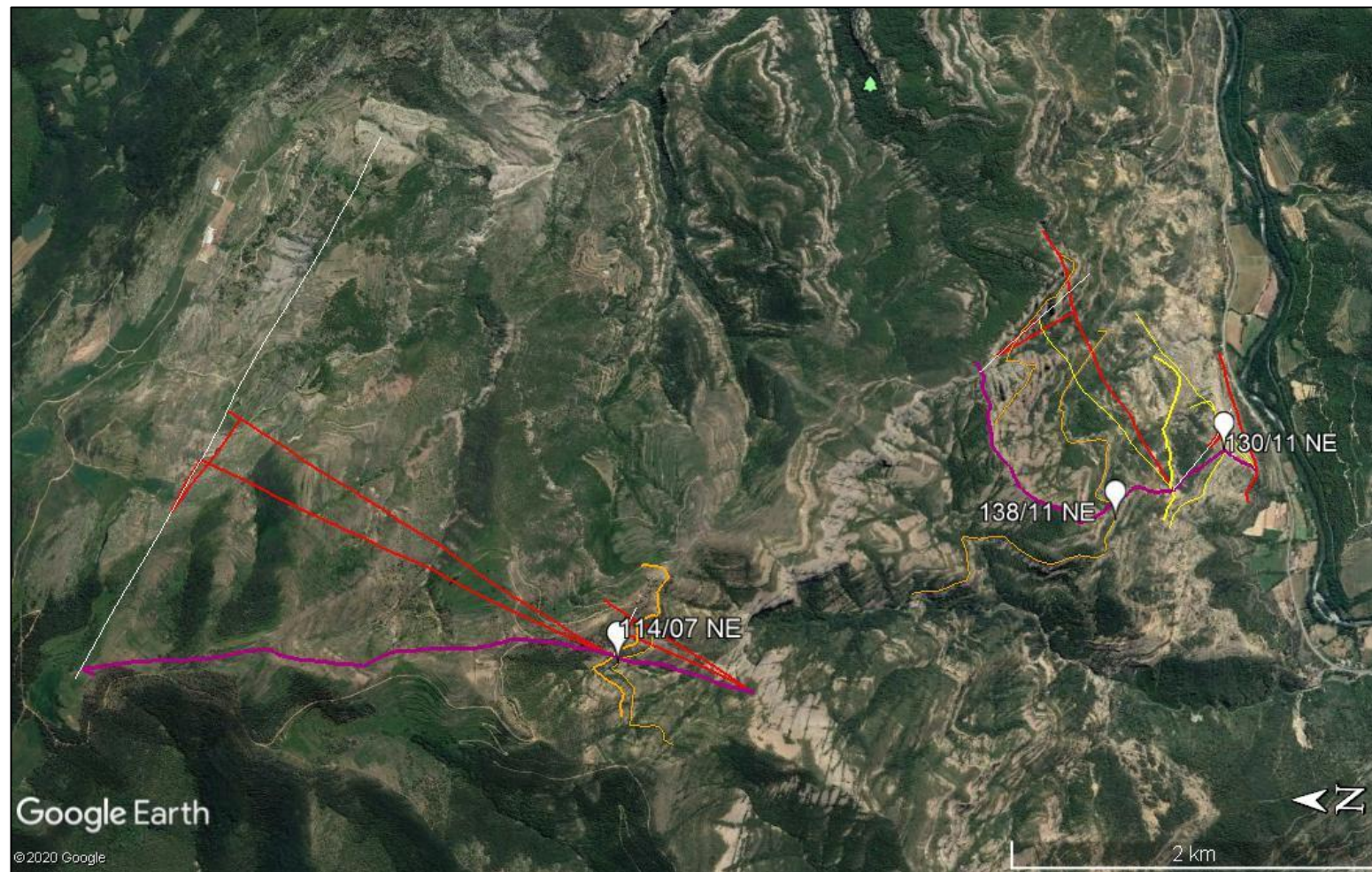
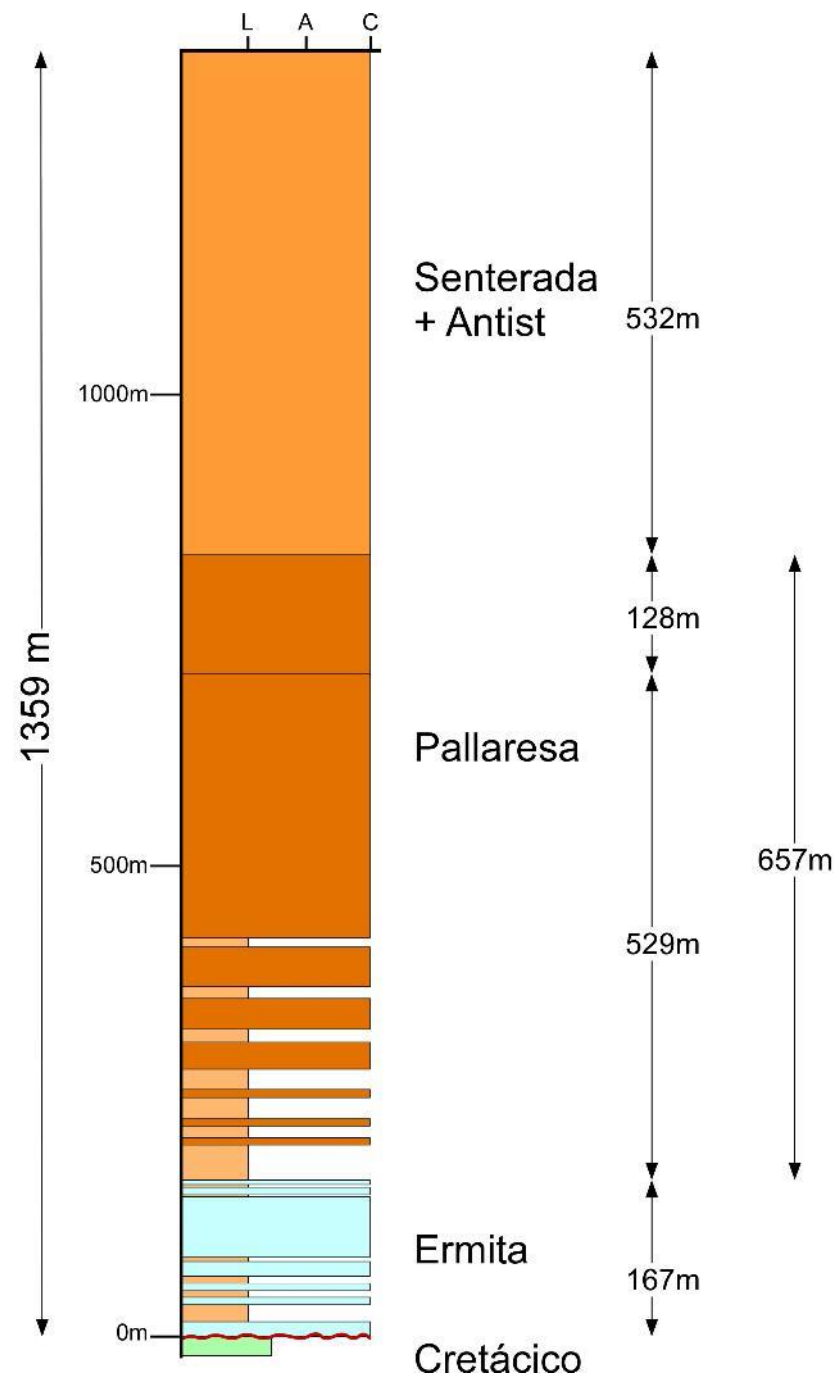
# Ejercicio Pobla de Segur

## Tareas:

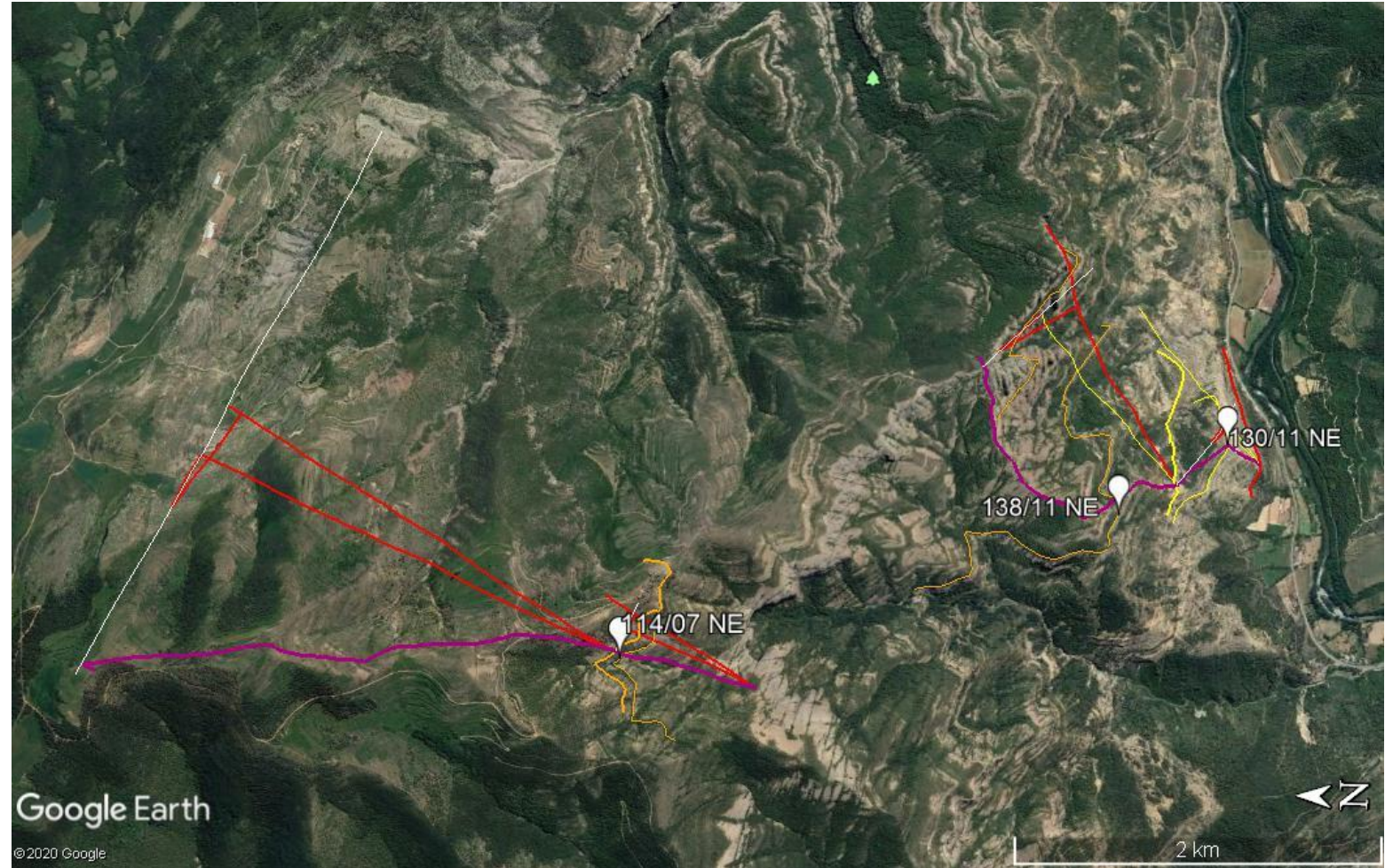
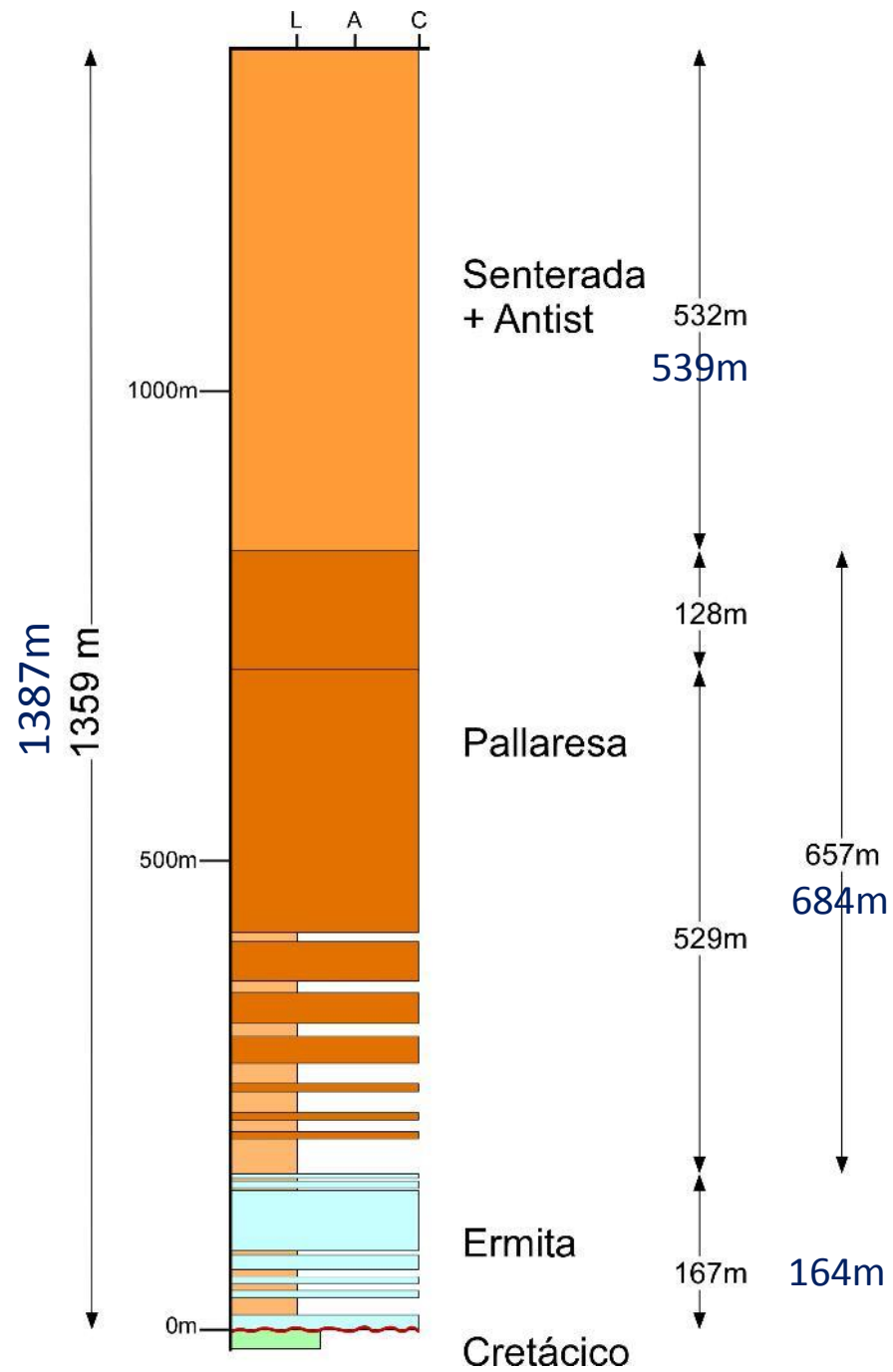
1- Mediante los datos del fichero de GoogleEarth *POBLA de SEGUR.kmz* que incluye datos de buzamiento y la localización de los límites entre unidades **obtener geométricamente el espesor de las 3 unidades principales** (Ermita, Pallaresa y Senterada-Antist)



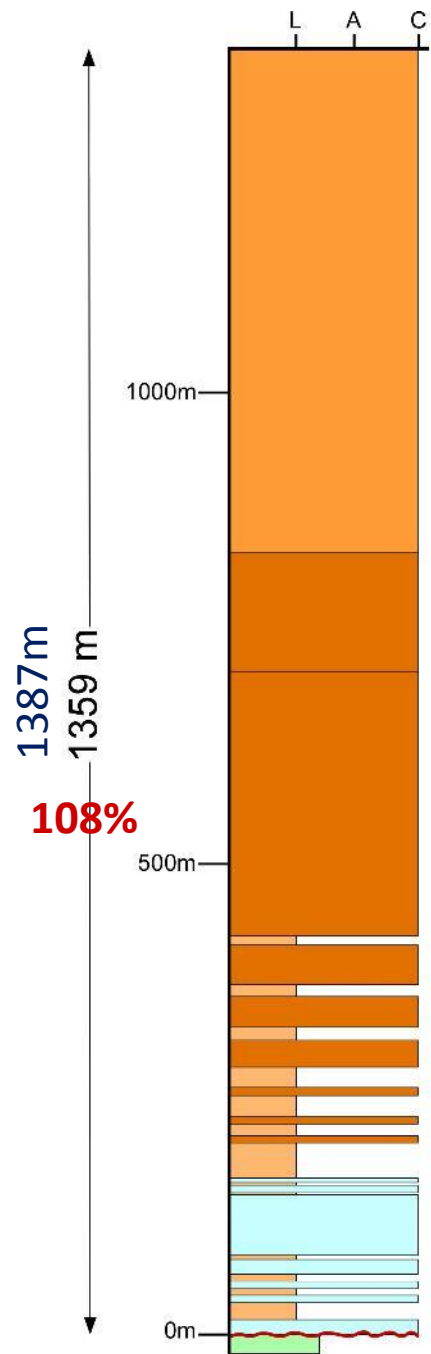












Senterada  
+ Antist

532m  
539m  
101%

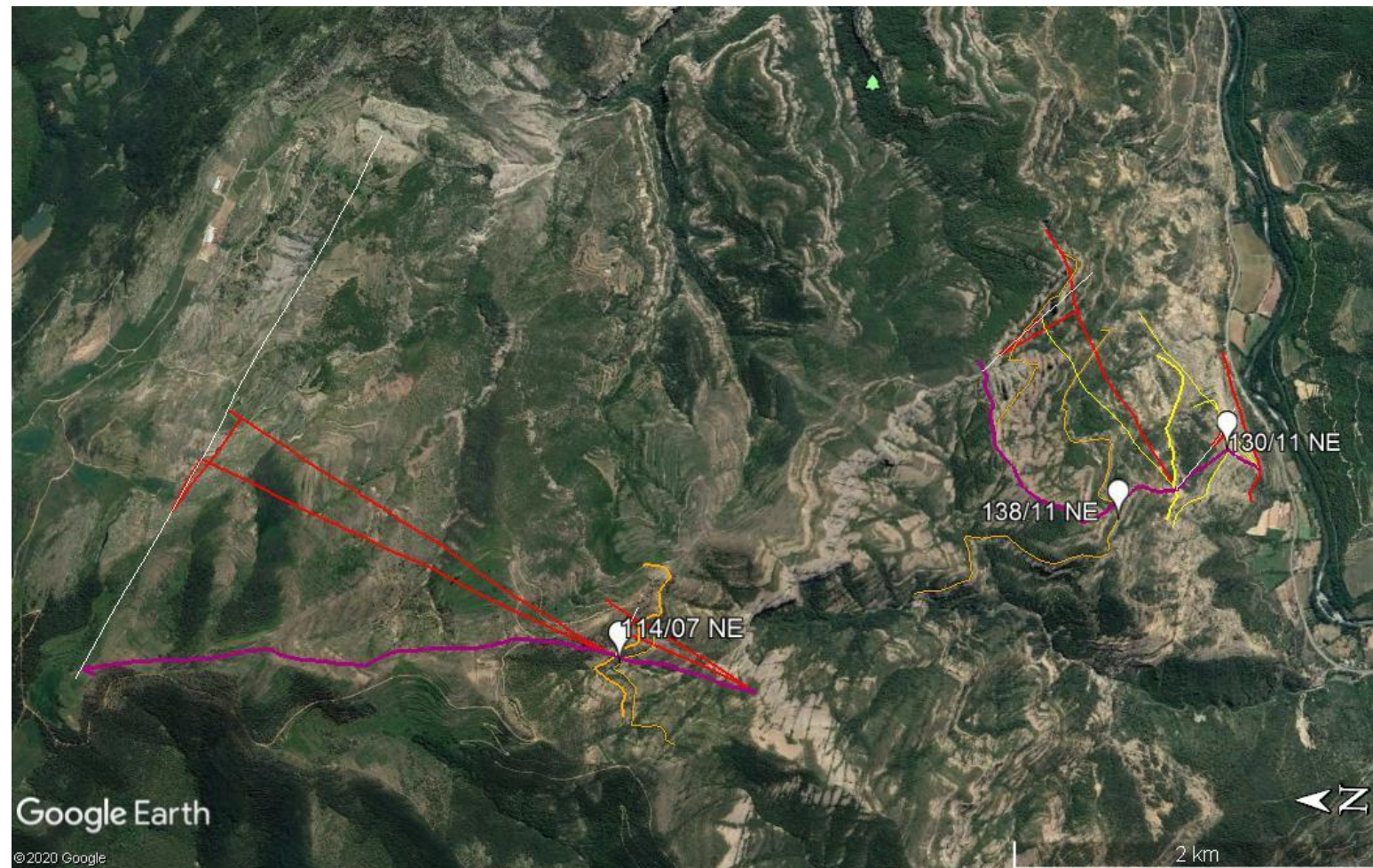
Pallaresa

128m  
529m  
657m  
684m  
115%

Ermita

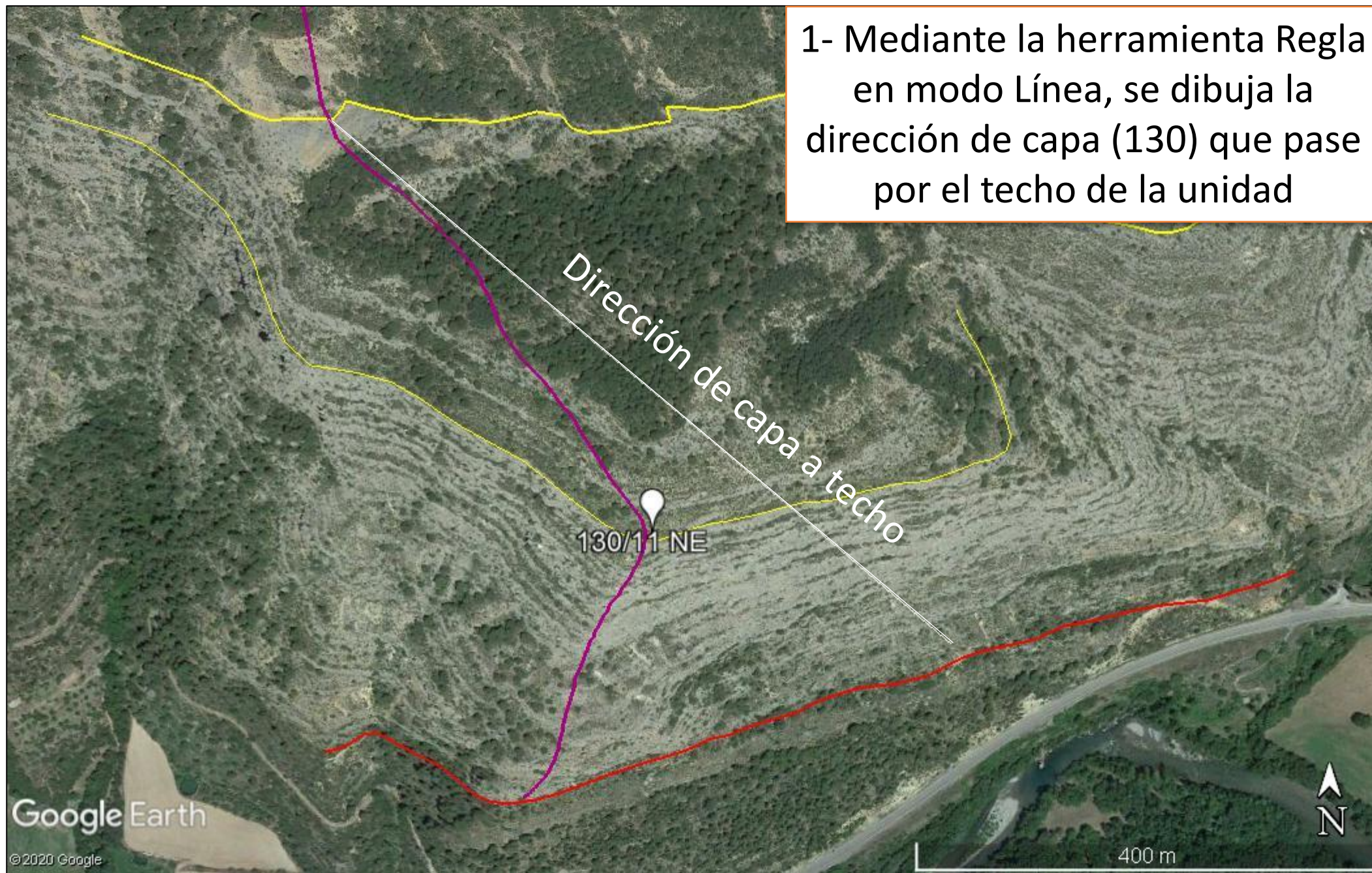
167m  
164m  
129%

Cretácico



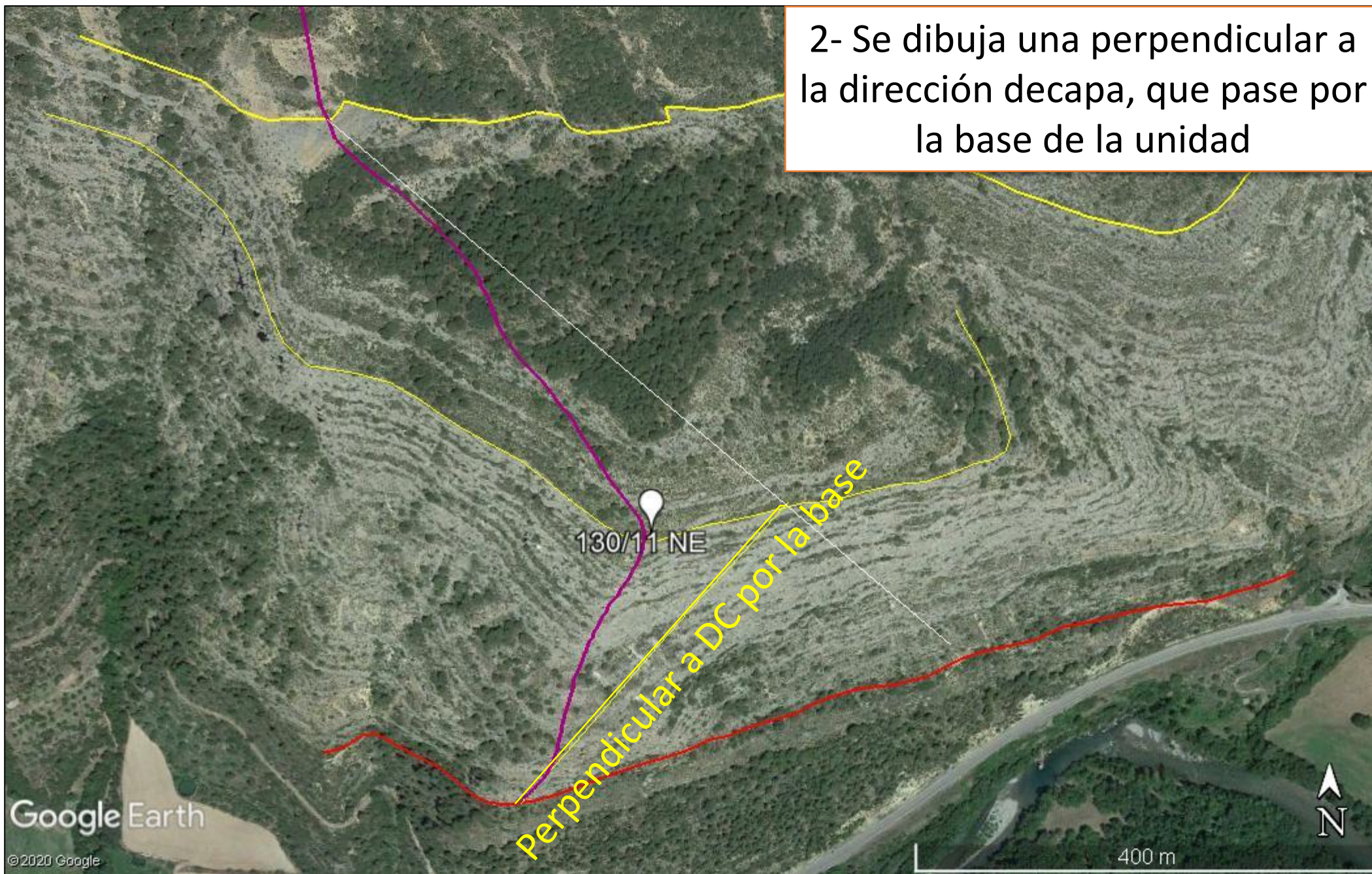


1- Mediante la herramienta Regla en modo Línea, se dibuja la dirección de capa (130) que pase por el techo de la unidad





2- Se dibuja una perpendicular a la dirección decapa, que pase por la base de la unidad





3- Se dibuja, a partir de la intersección entre la dirección de capa y su perpendicular, una línea de longitud igual a la diferencia de cota entre la base y el techo en los puntos escogidos. Esta línea se dibuja sobre la dirección de capa.

Diferencia de cota  
entre base y techo

130/11 NE

Google Earth

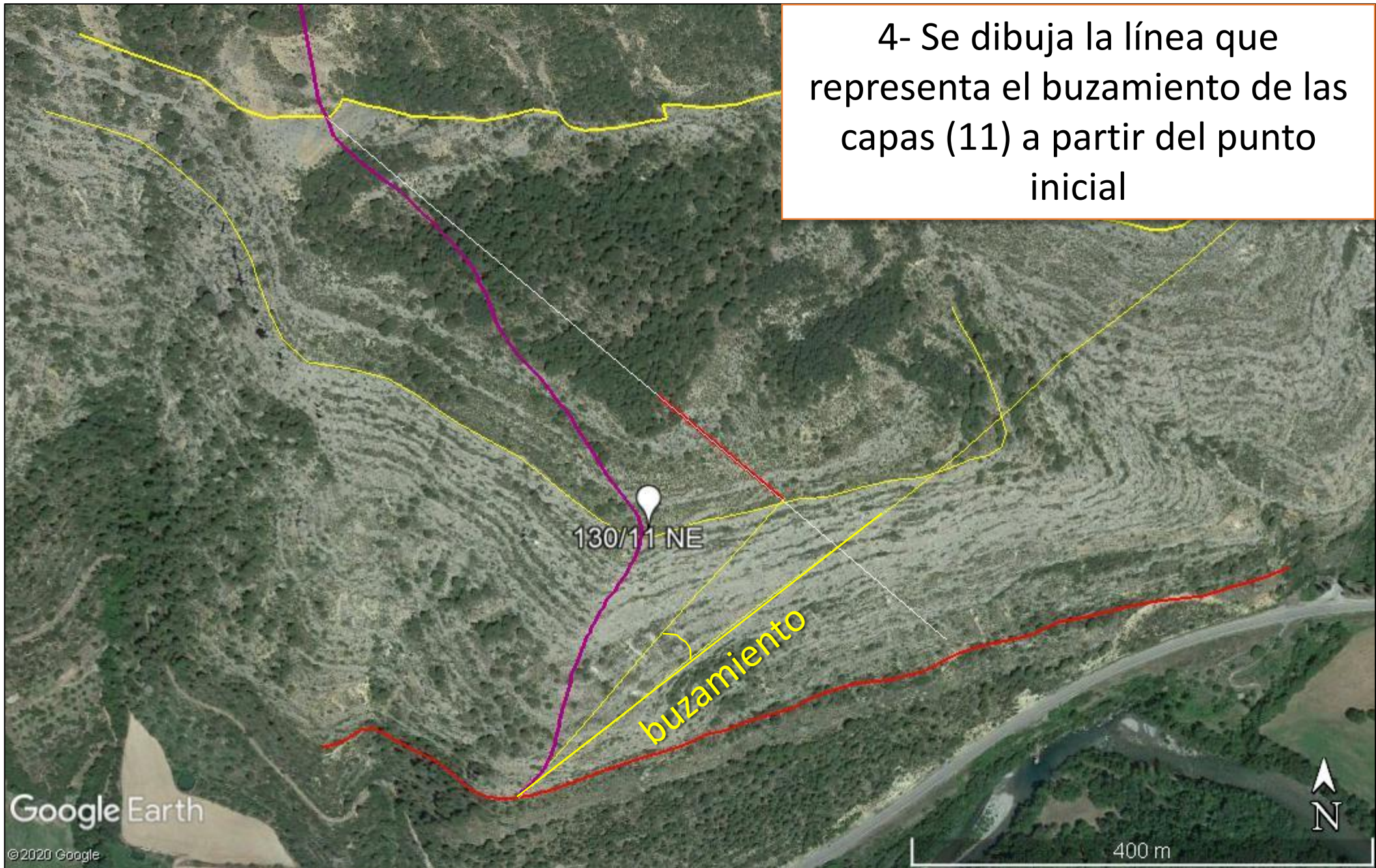
© 2020 Google

N

400 m

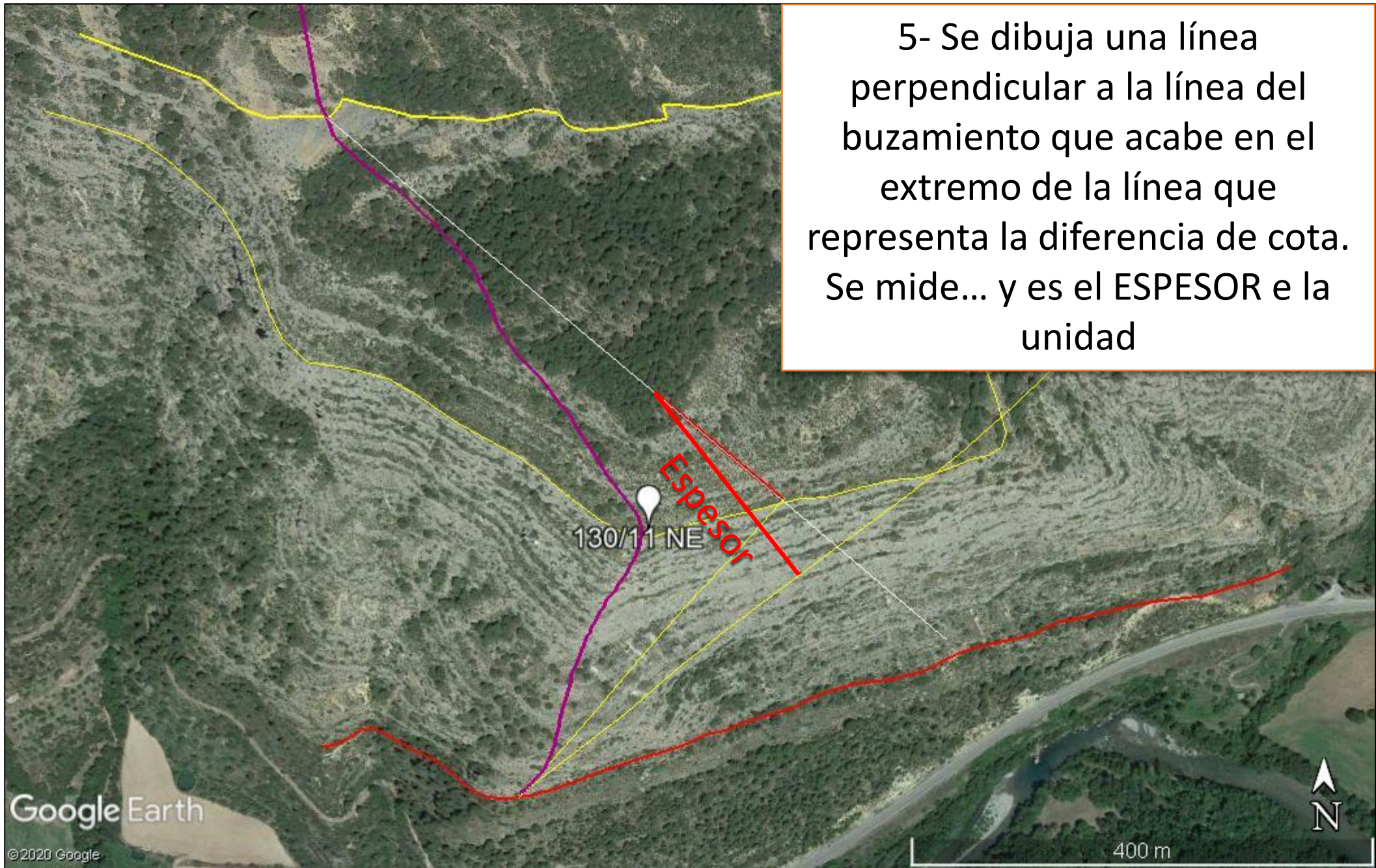


4- Se dibuja la línea que representa el buzamiento de las capas (11) a partir del punto inicial





5- Se dibuja una línea perpendicular a la línea del buzamiento que acabe en el extremo de la línea que representa la diferencia de cota. Se mide... y es el ESPESOR e la unidad



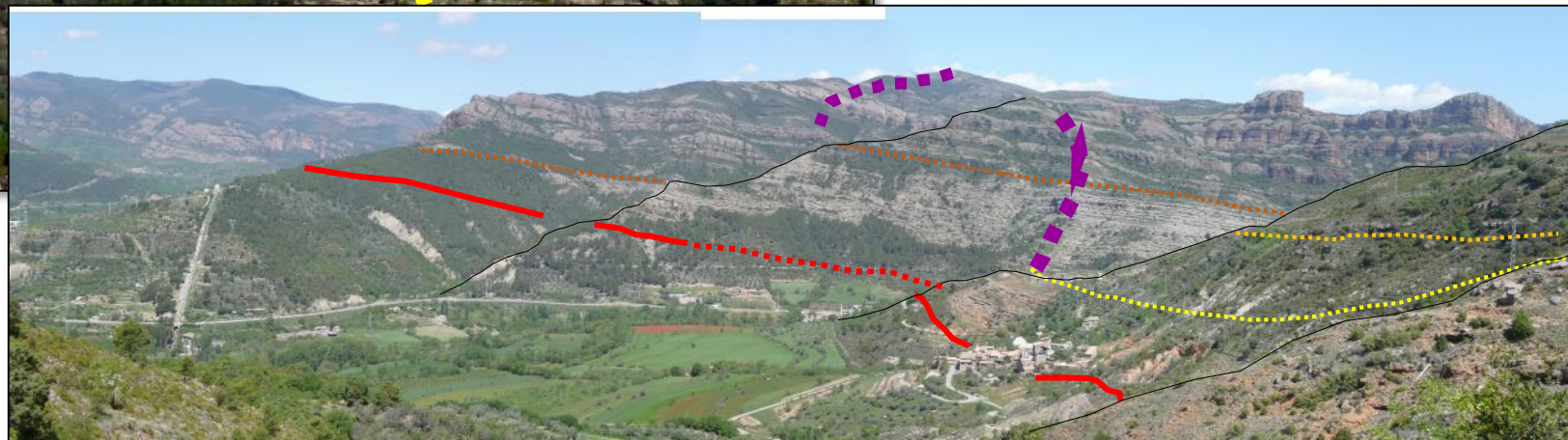
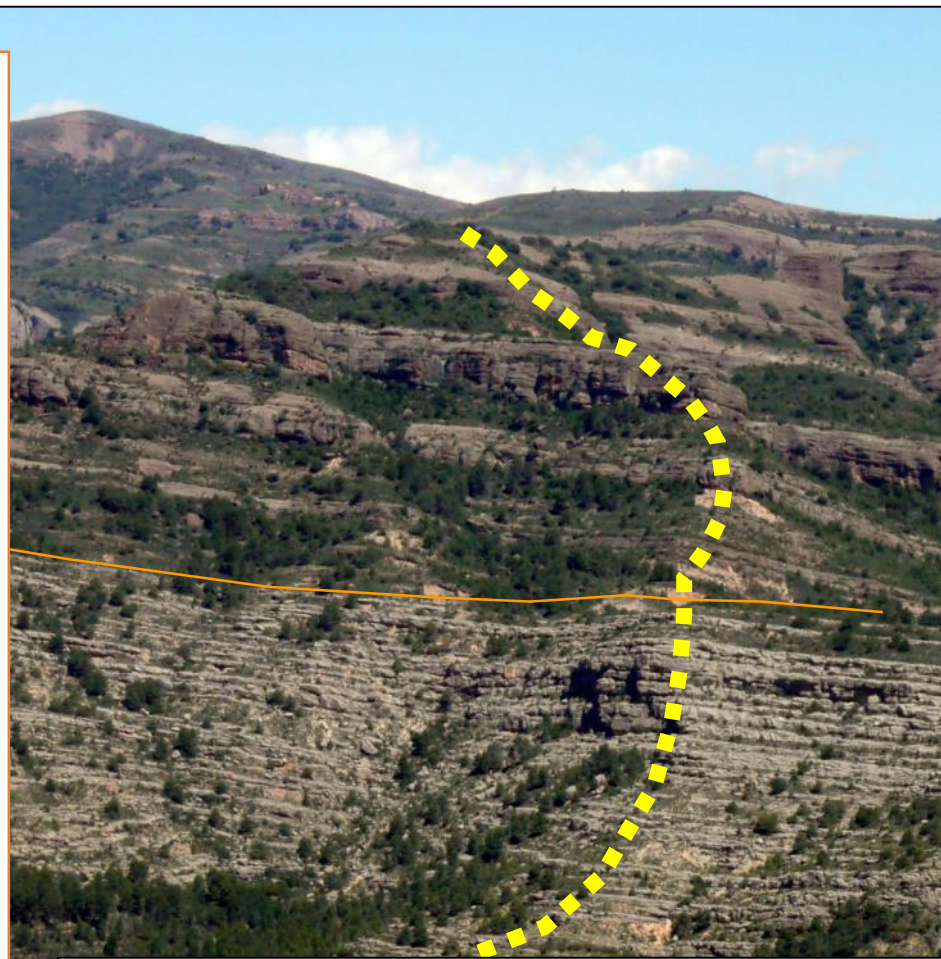


## Tareas:

2- Realizar una **columna estratigráfica esquemática** que muestre las **unidades principales** y diferenciando los tramos conglomeráticos de los lutíticos.

Haced una **columna general** que incluya los dos tramos señalados en Google Earth y otra **parcial**, de mayor detalle sólo de la columna inferior.

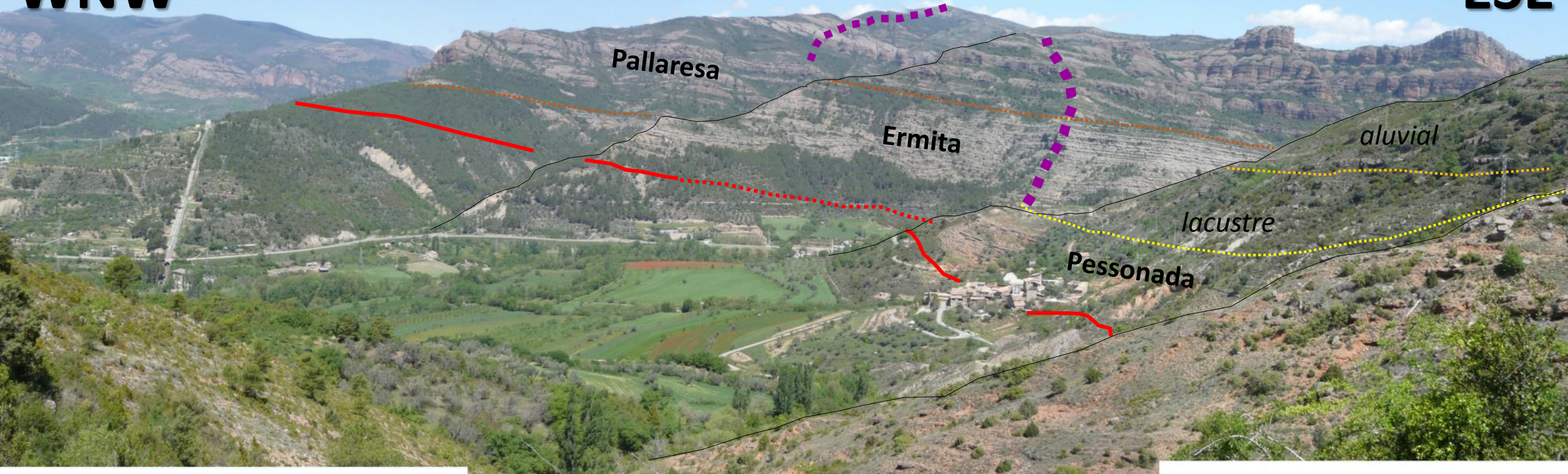
Utilizad las fotos incluidas en el Campus Virtual (fotos de detalle y panorámica general).





WNW-

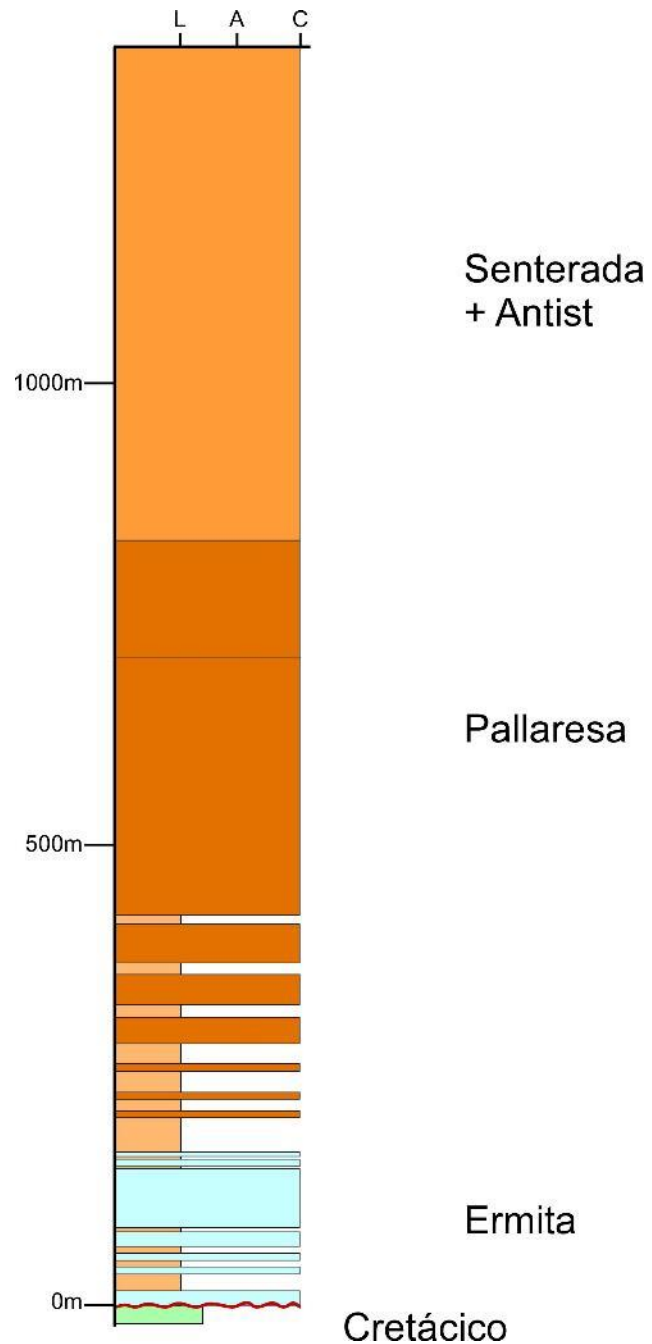
-ESE



**Finalmente, a partir de las columnas realizadas:**

1. Analizar las tendencias generales granulométricas en la vertical
2. Interpretar dichas tendencias explicando su origen

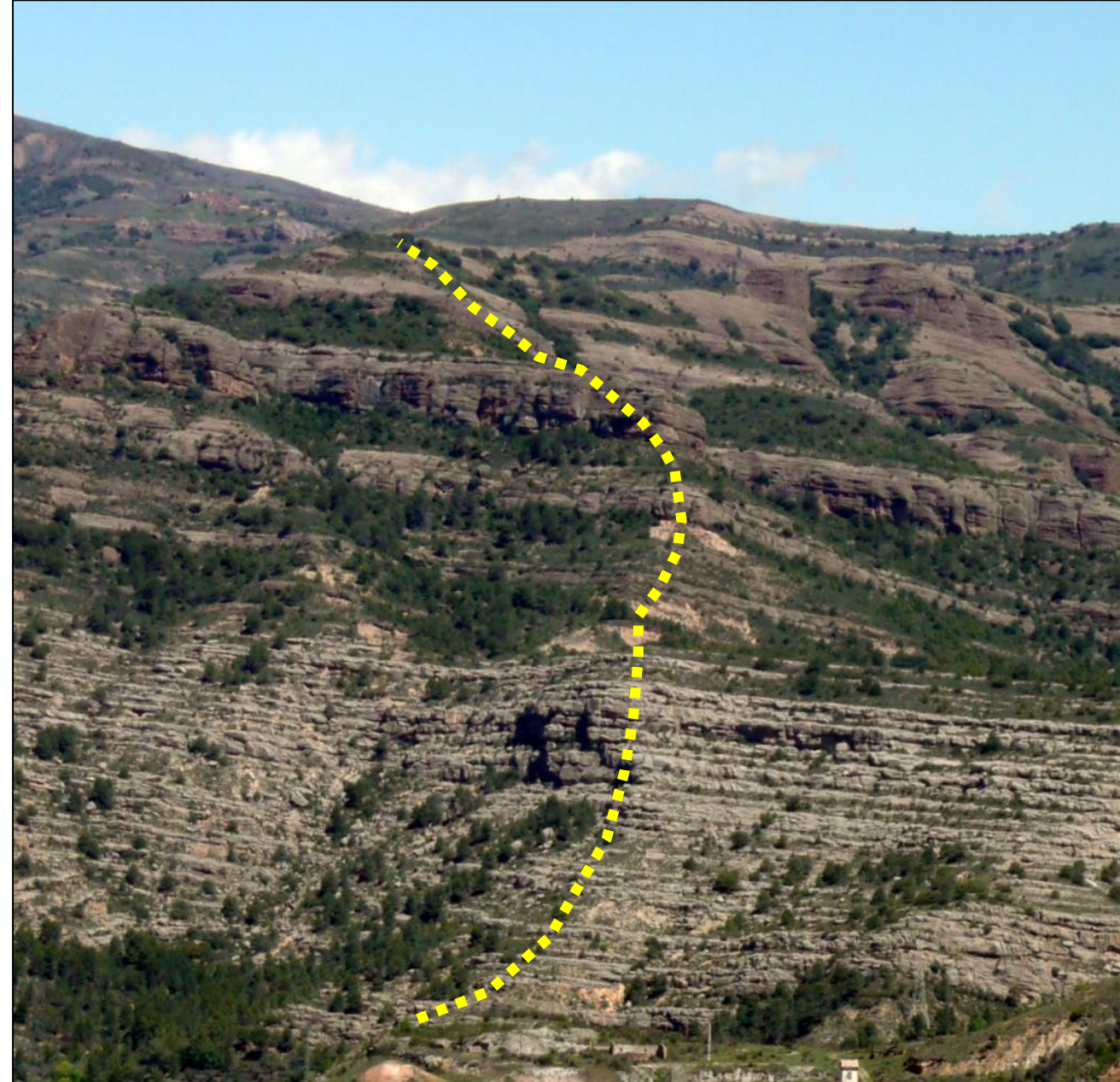
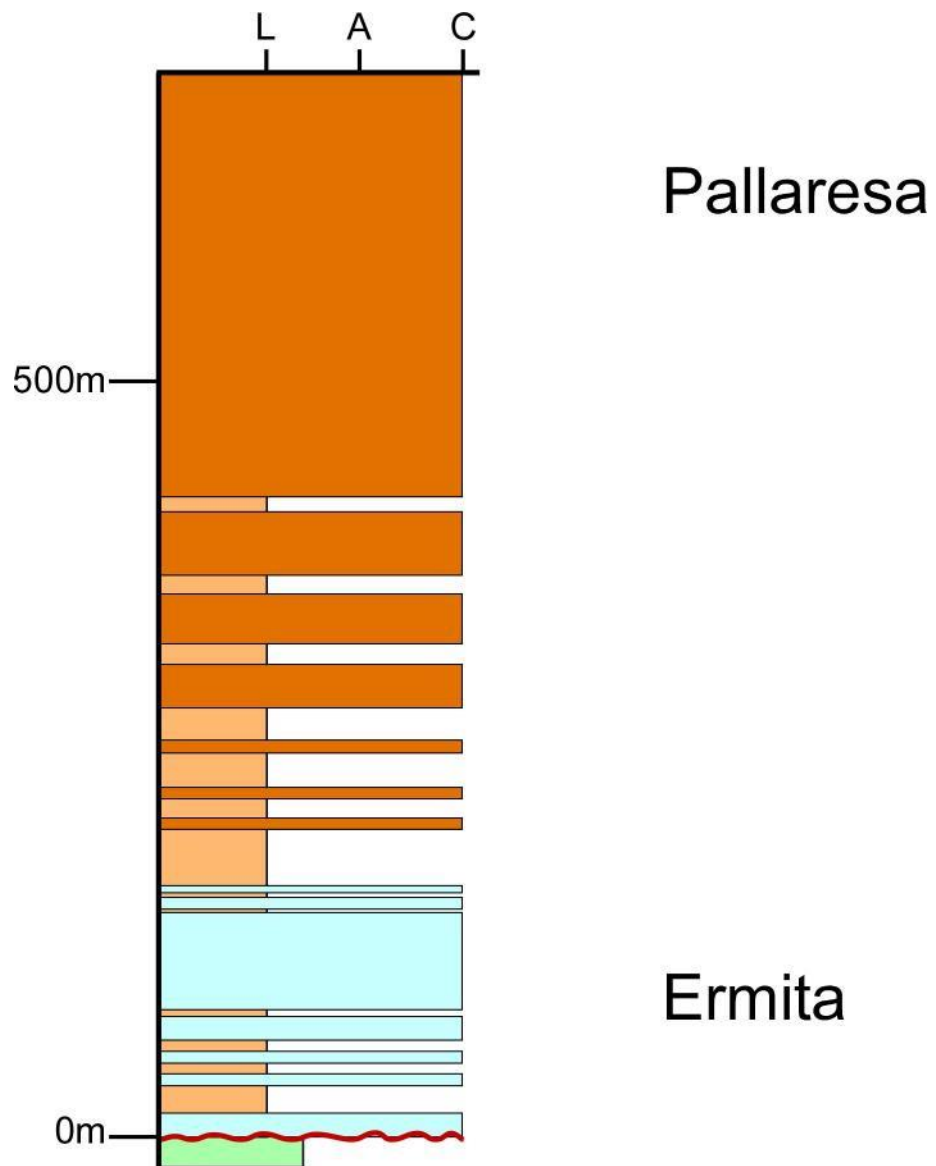




**3. Observar el espesor de las capas conglomeráticas vs. de grano fino para analizar las tendencias granulométricas en la vertical**

- ¿Qué nos dicen estas tendencias?



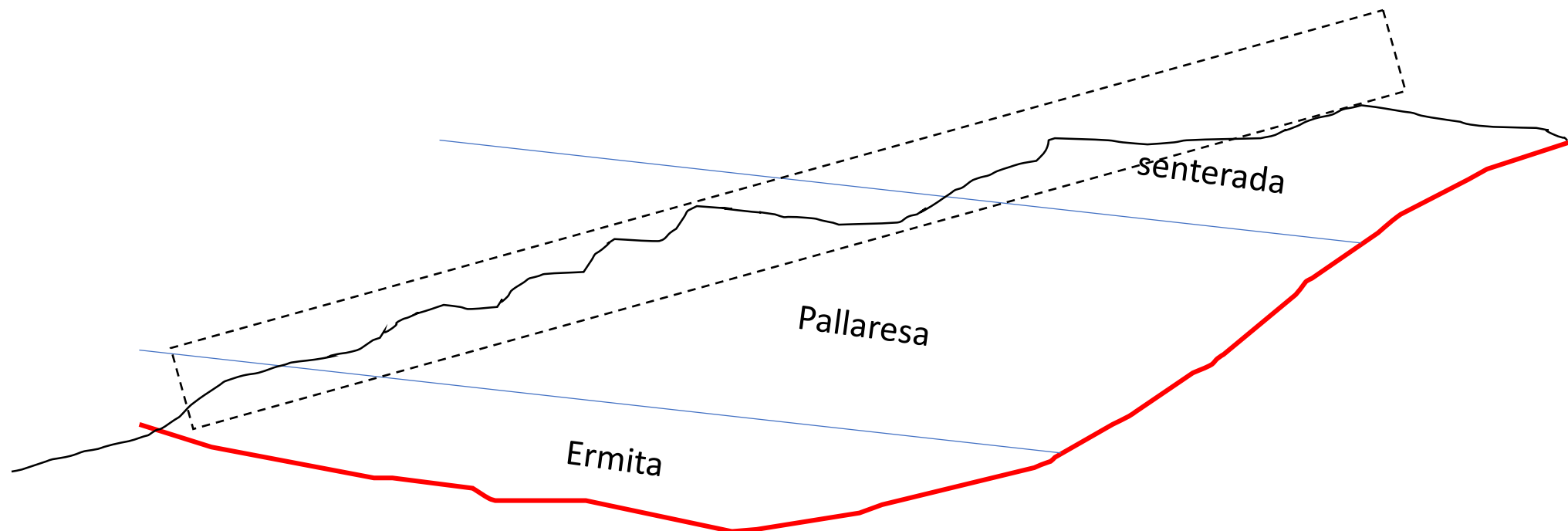


**3. Observar el espesor de las capas conglomeráticas vs. de grano fino para analizar las tendencias granulométricas en la vertical ¿Qué nos dicen estas tendencias?**



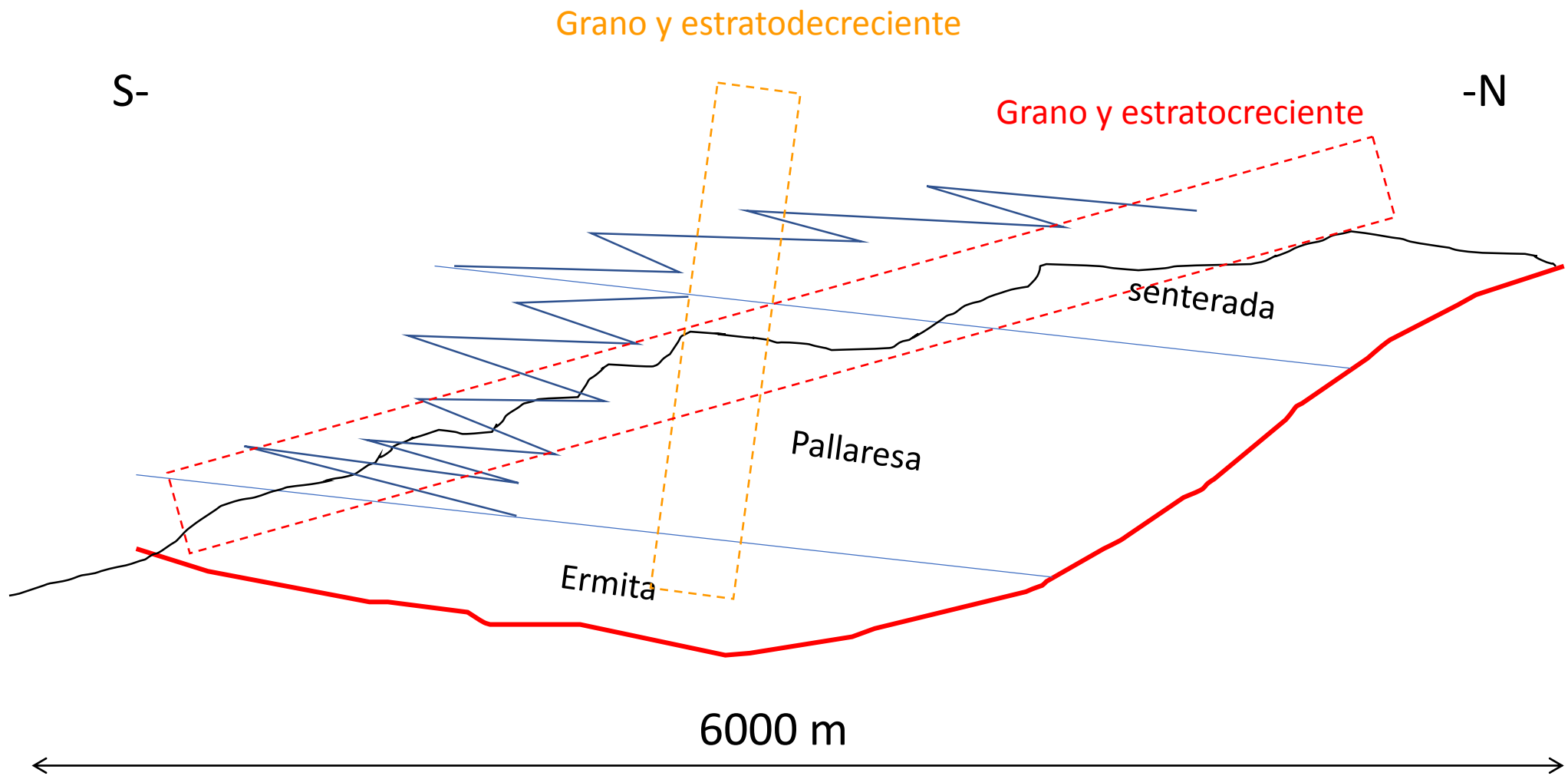
S-

-N



6000 m









Badwater Rd

