Post-orogenic sediment drape and flux of mountain range-foreland basin systems: An example from the Northern Pyrenees

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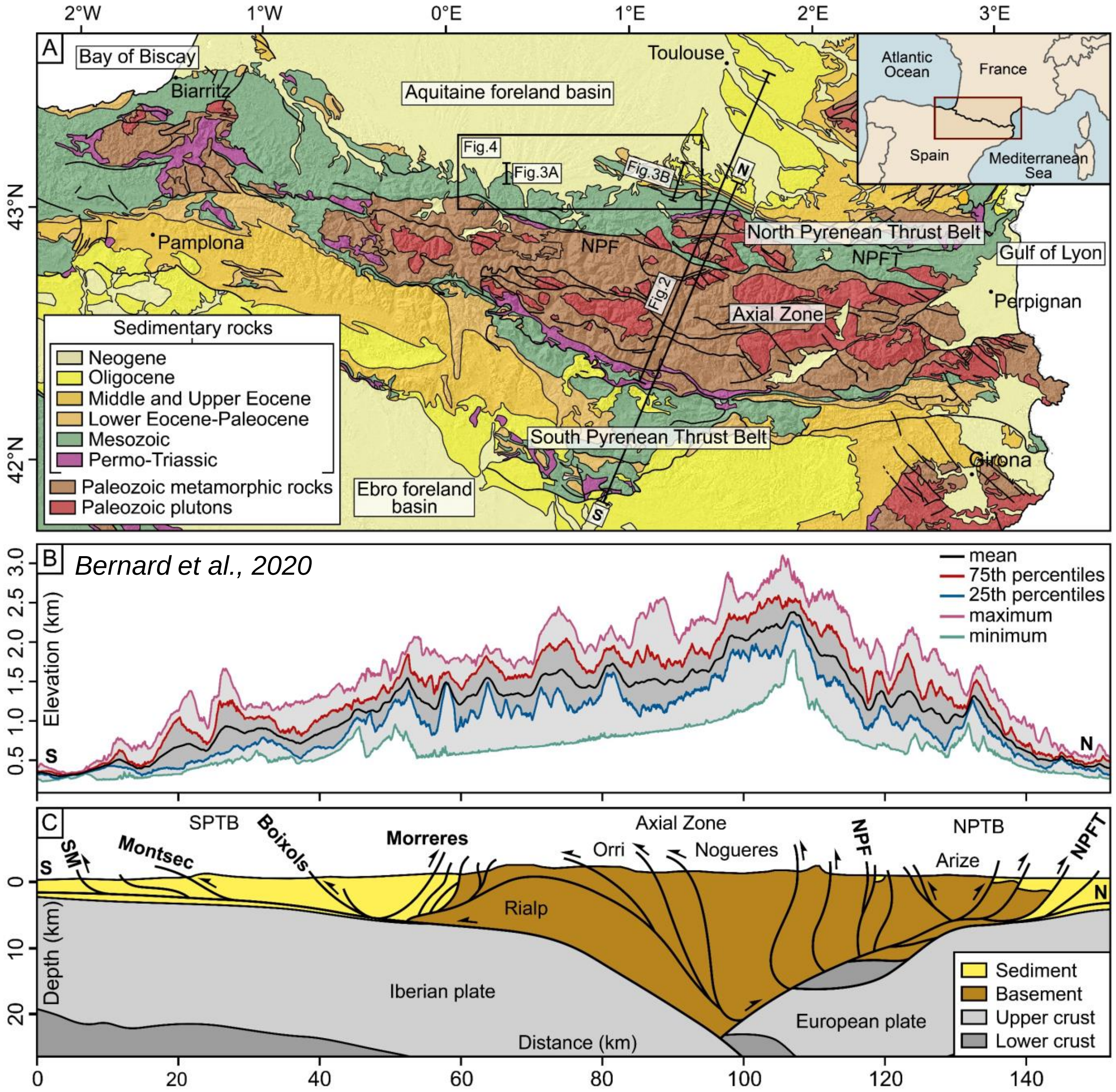
STUDY AREA: NORTHERN PYRENEES AND AQUITAINE FORELAND BASIN



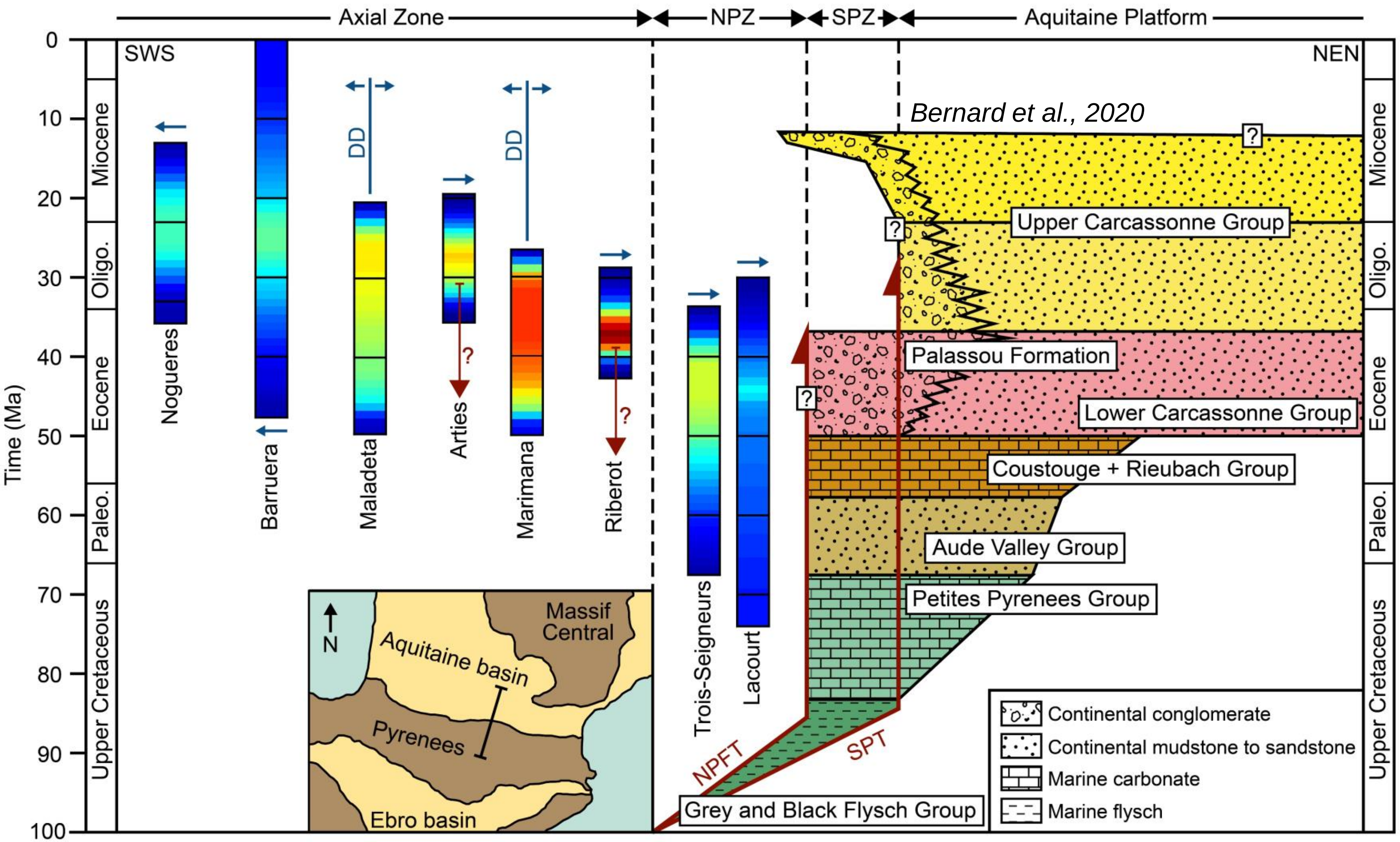
Pyrenean System:

- Linear east-west orographic barrier of 450 km long and 150 km wide between Spain and France (a)
- Characterized by a shorter and steeper northern thrust-wedge compared to a wider and gentler southern thrust wedge (b)
- Doubly-vergent collisional orogen (c)

Northern Pyrenean System:

- North Axial Zone + North Pyrenean Thrust Belt + Aquitaine Retro-Foreland Basin

SEDIMENTATION AND EXHUMATION OF THE CENTRAL PYRENEES



Observations:

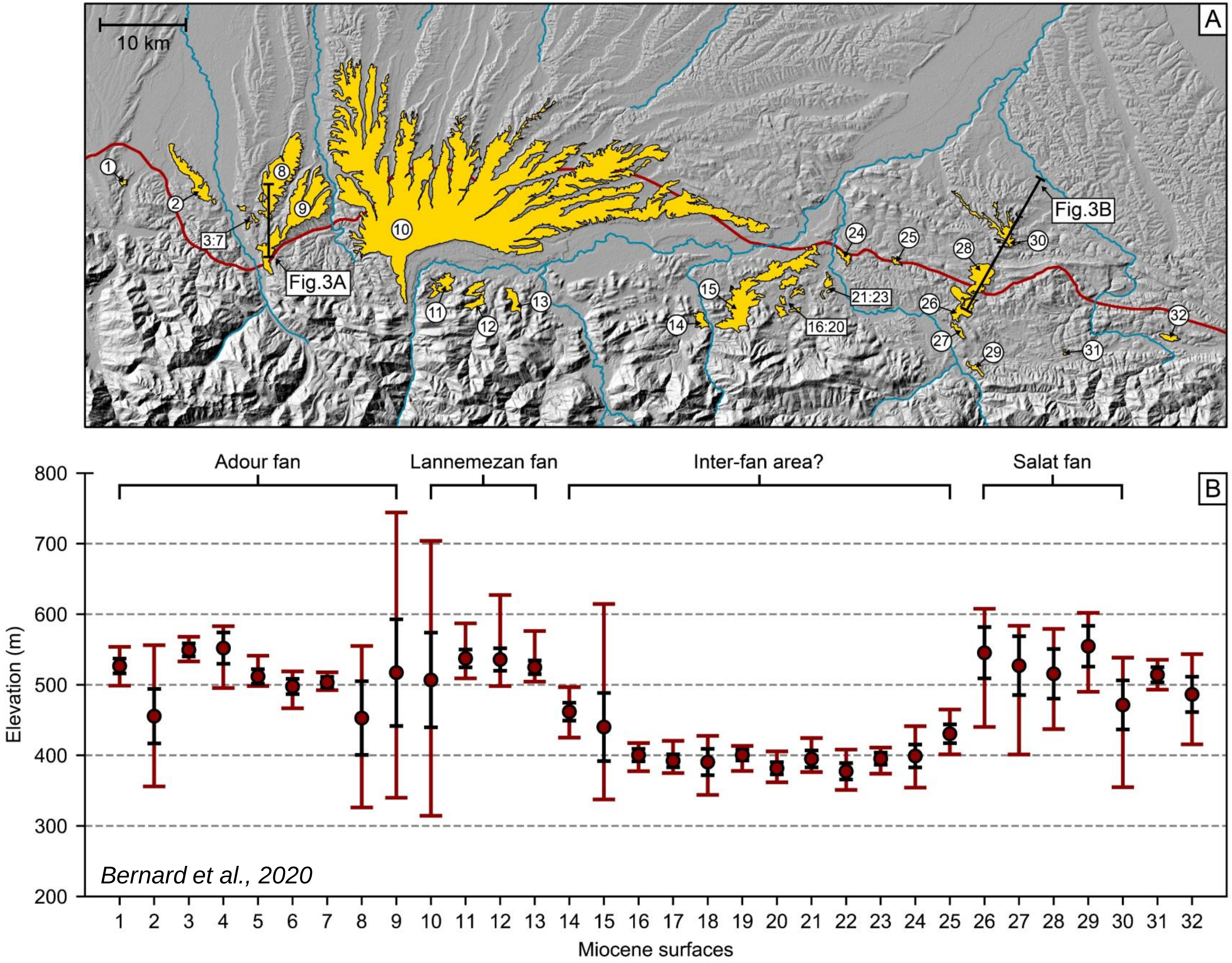
- Post-orogenic transition in the Central Pyrenees from thermochronological data: ~23 Ma
- Aquitaine basin records post-orogenic sediments (i.e. Miocene): drape and seal structures of the Northern Pyrenees

Why is it important:

- Implication for long topographic survival after cessation of convergence (relief reduction + alluvial cover)
- Implication for formation of low-relief surfaces at high altitudes in the range

NPZ: North Pyrenean Zone; **SPZ**: Sub-Pyrenean Zone; **NPFT**: North-Pyrenean Frontal Thrust; **SPT**: Sub-Pyrenean Thrust

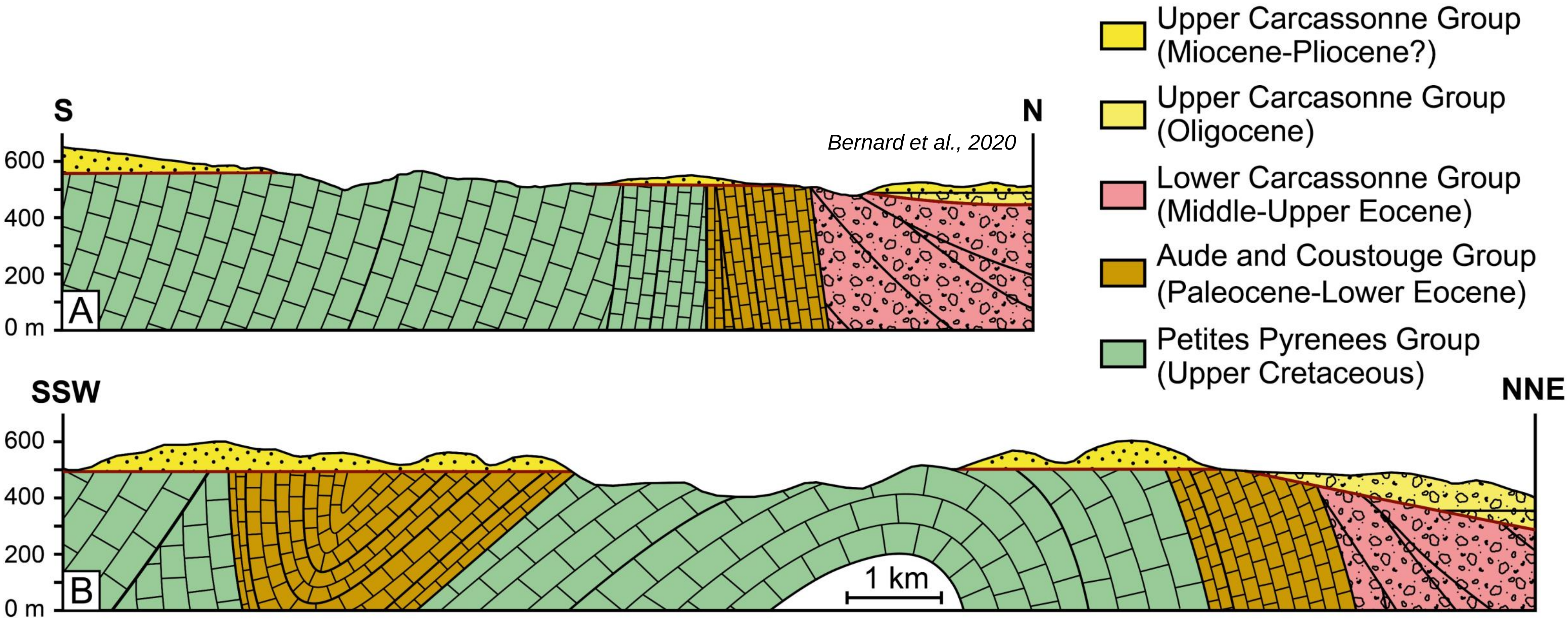
SPATIAL DISTRIBUTION OF POST-OROGENIC SEDIMENTS



Post-orogenic sediments:

- Miocene sediments of the Upper Carcassonne Group represented in yellow correspond to deposition of large alluvial fans (a)
- Located in the foothills of the range from ~300 m to 600m with a mean elevation of ~500 m (b)

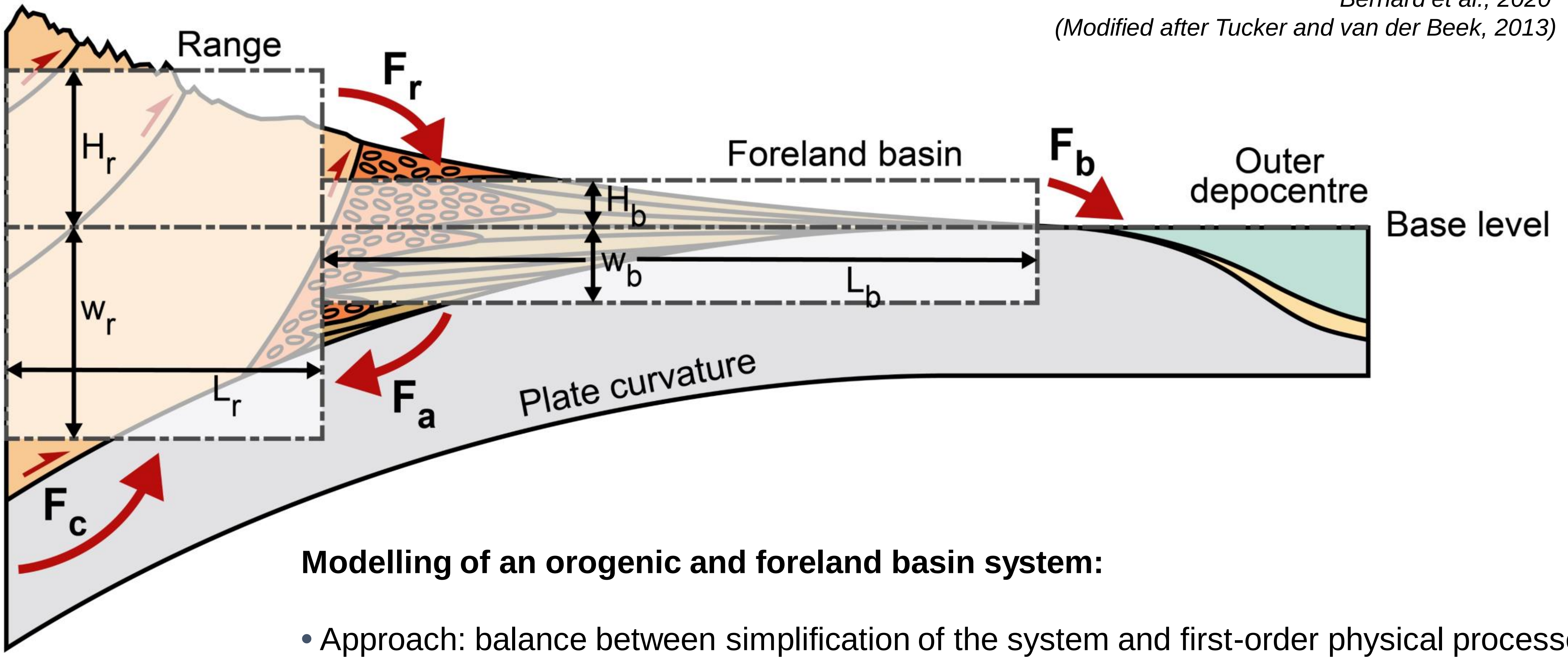
EXAMPLE OF POST-OROGENIC SEDIMENTS THROUGH CROSS-SECTIONS



- Example of geologic cross-section in the Northern Pyrenees highlighting the drape and seal of syn-orogenic structures of the thrust-wedge by post-orogenic structures (Miocene Upper Carcassonne Group)

MODEL THE SYN- TO POST-OROGENIC EVOLUTION USING A BOX-MODEL

Bernard et al., 2020
(Modified after Tucker and van der Beek, 2013)



Modelling of an orogenic and foreland basin system:

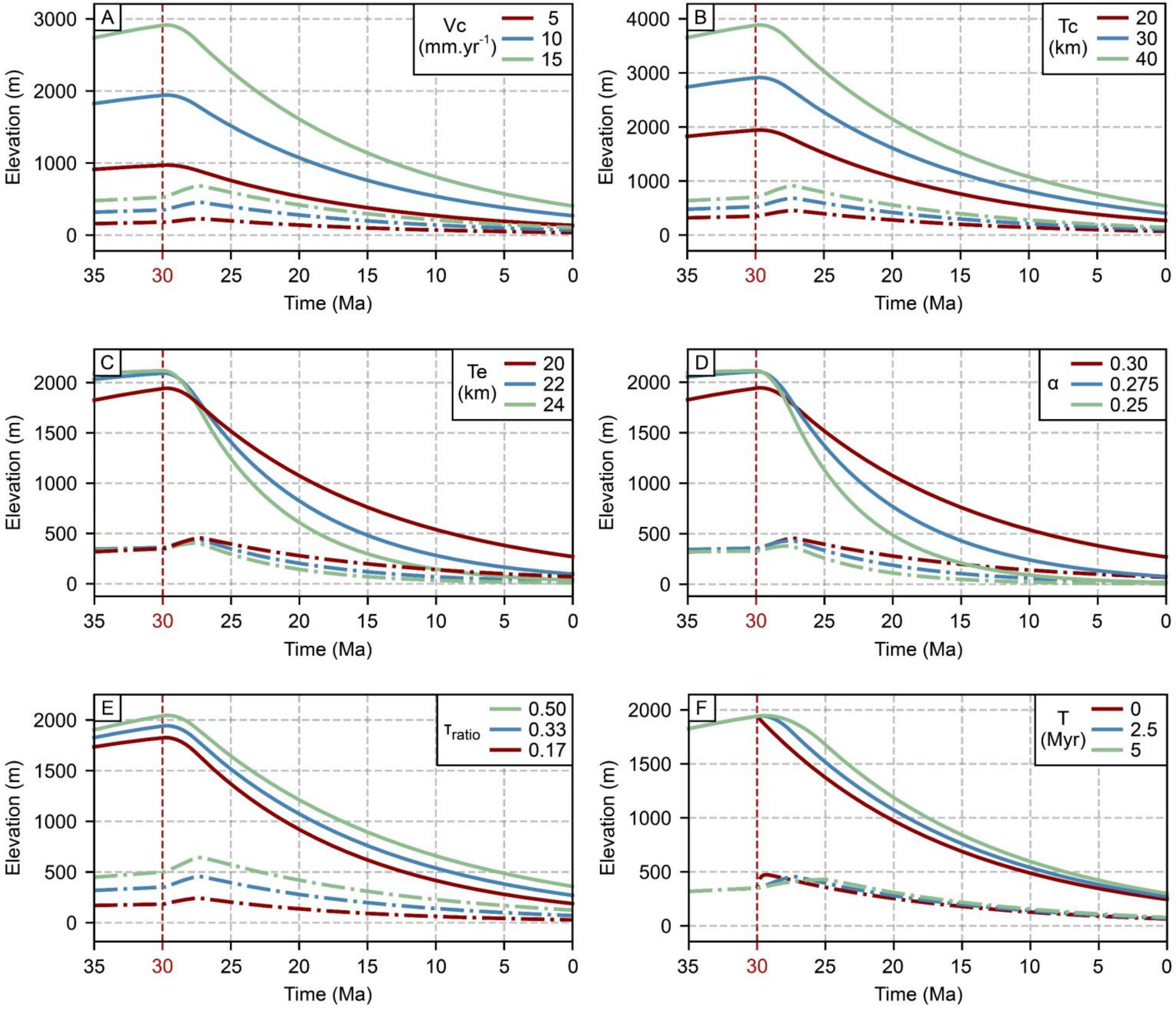
- Approach: balance between simplification of the system and first-order physical processes of a coupling mountain range and foreland basin (tectonic deformation + flexural isostasy + surface processes)

- Investigation: coupling of topography and sediment flux during the evolution of a mountain range/foreland basin system (particularly at the syn- to post-orogenic transition)

- Method: modified version of a box-model introduced by Tucker and van der Beek (2013)

GENERIC MODEL SENSITIVITY TESTS

Bernard et al., 2020



Reference model for model sensitivity:

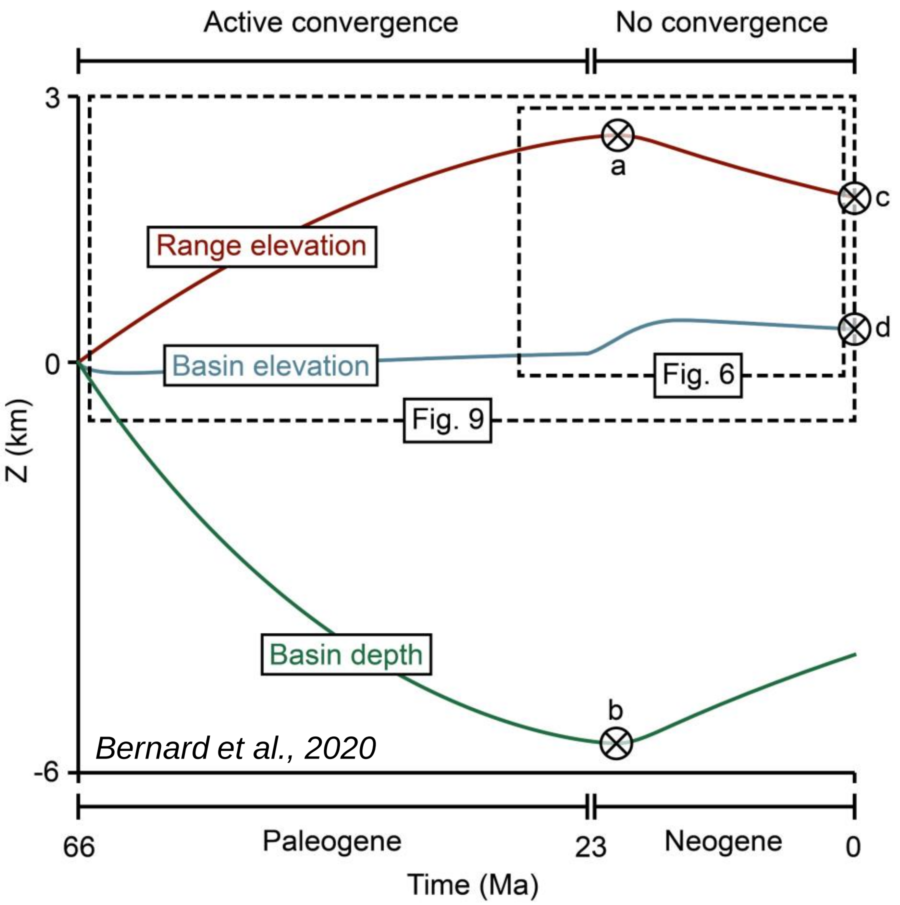
• Simple model history with following initial parameters:
→ Convergence velocity (V_c) = 10 mm.yr^{-1}
→ Convergence thickness (T_c) = 20 km
→ Lithosphere elastic thickness (T_e) = 30 km
→ Thrust wedge proportion (α) = 0.3
→ Response time ratio = 0.33
→ Convergence time deceleration = 2.5 Myrs

• Convergence active from 60 to 30 Ma followed by a post-orogenic stage lasting 30 Myrs (transition highlighted by vertical red dash line)

• For all experiment: increase in the elevation of the basin during the initial post-orogenic stage

• We now explore the implications of this evolution for post-orogenic topography and stratigraphy of the Aquitaine Basin.

APPLICATION OF THE BOX-MODEL TO THE NORTHERN PYRENEES



Inverse modelling search with key parameters:

- Lithosphere elastic thickness: 15 to 40 km
- Range transport coefficient: 100 to 5,000 m^2/yr
- Basin transport coefficient : 1,000 to 50,000 m^2/yr
- Time of convergence velocity decrease : 2.5 to 7.5 Myrs

Replicate first order data of the Northern Pyrenees:

- Maximum range mean elevation of ~2 km (a; Curry et al., 2019; Huyghe et al., 2012)
- Basin depth of ~5 km at 23 Ma (b; Ford et al., 2015)
- Modern mean elevation of the range of ~1.5 km (c) and of the basin of ~0.25 km (d)

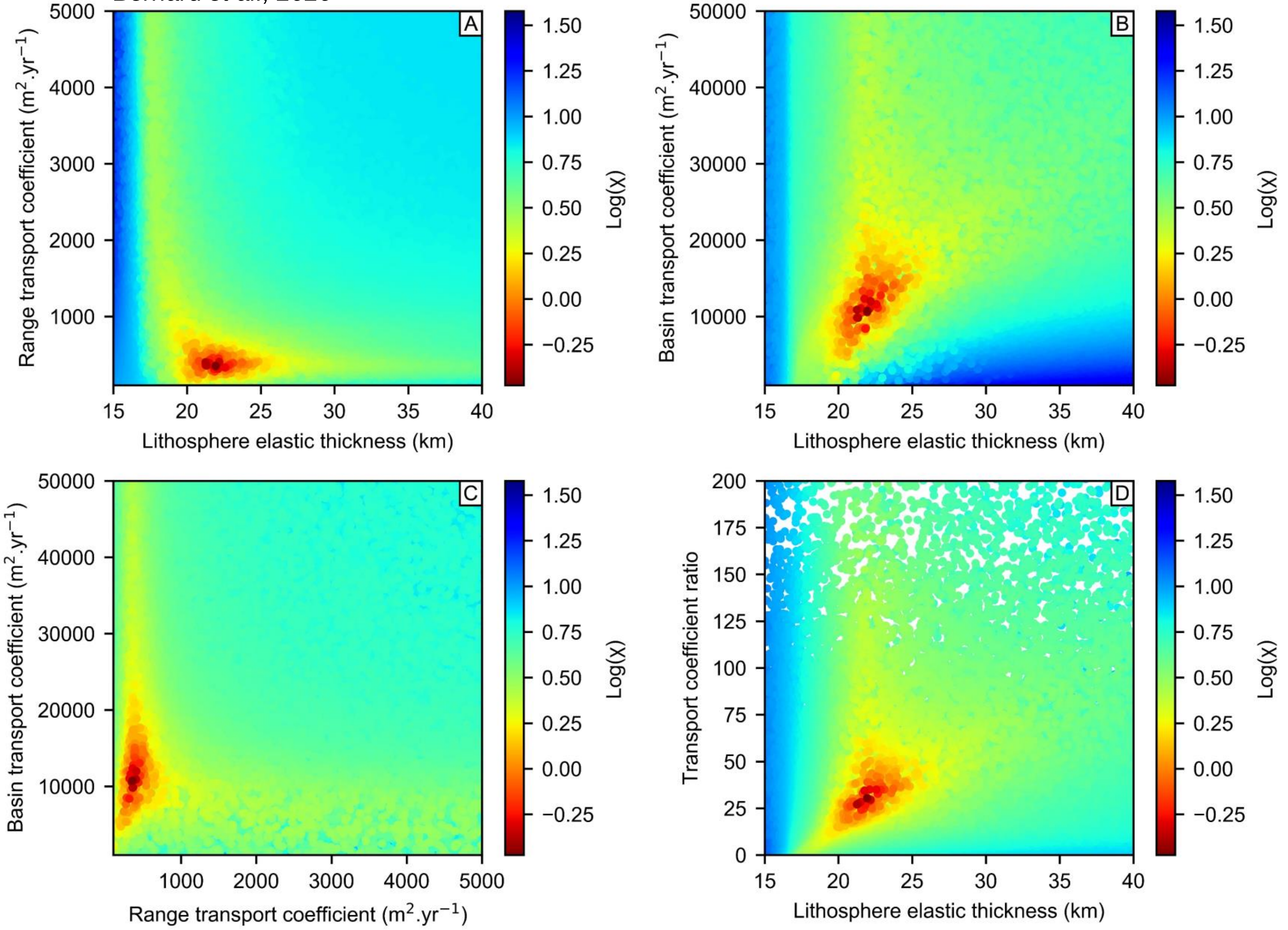
Misfit function (*χ*):

- evaluate discrepancy between the observed data (obs) and the predicted results (pre)

$$\chi = \frac{1}{4}\sqrt{\frac{\left(H^{obs}_{r,max} - H^{pre}_{r,max}\right)^2}{{\delta H^{obs}_{r,max}}^2} + \frac{\left(H^{obs}_{r,t0} - H^{pre}_{r,t0}\right)^2}{{\delta H^{obs}_{r,t0}}^2} + \frac{\left(H^{obs}_{b,t0} - H^{pre}_{b,t0}\right)^2}{{\delta H^{obs}_{b,t0}}^2} + \frac{\left(w^{obs}_{b,t23} - w^{pre}_{b,t23}\right)^2}{{\delta w^{obs}_{b,t23}}^2}}$$

RESULTS OF THE INVERSE MODELLING SEARCH

Bernard et al., 2020

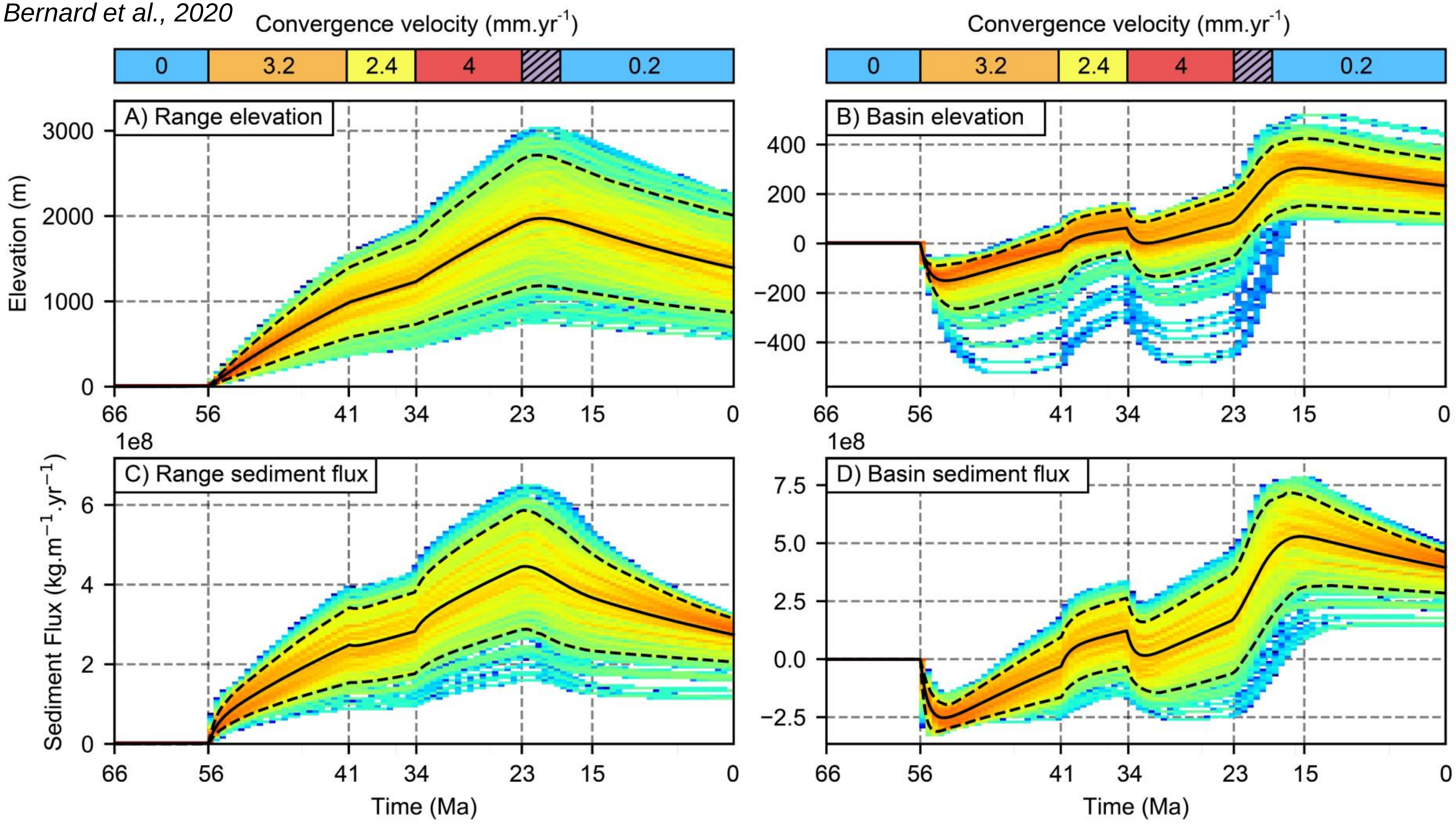


Replication of the Northern Pyrenees:

- Lithosphere elastic thickness: 22.2±1.6 km
- Range transport coefficient : 430±140 $m^2.yr^{-1}$
- Basin transport coefficient: 13200±4400 $m^2.yr^{-1}$

TOPOGRAPHIC AND SEDIMENT FLUX RESULTS

Bernard et al., 2020

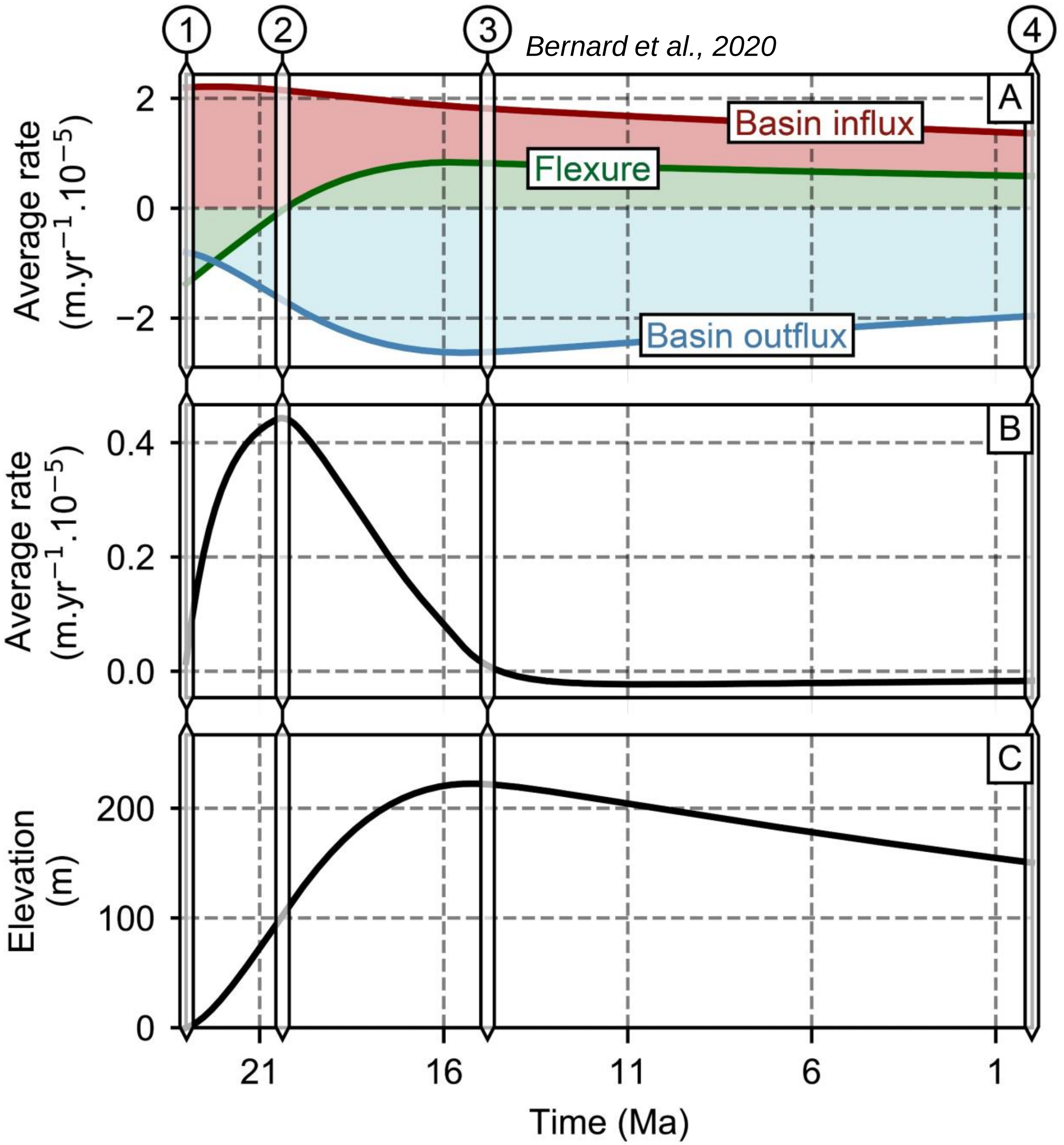


- Range and basin topographic (a, b) and sediment flux evolutions (c, d) for the best models of the inverse modelling
- Important results at the syn- to post-orogenic transition (~23 Ma):

→ Limited range topography and sediment flux (a, c) decrease

→ Important basin topography and sediment flux (b, d) increase

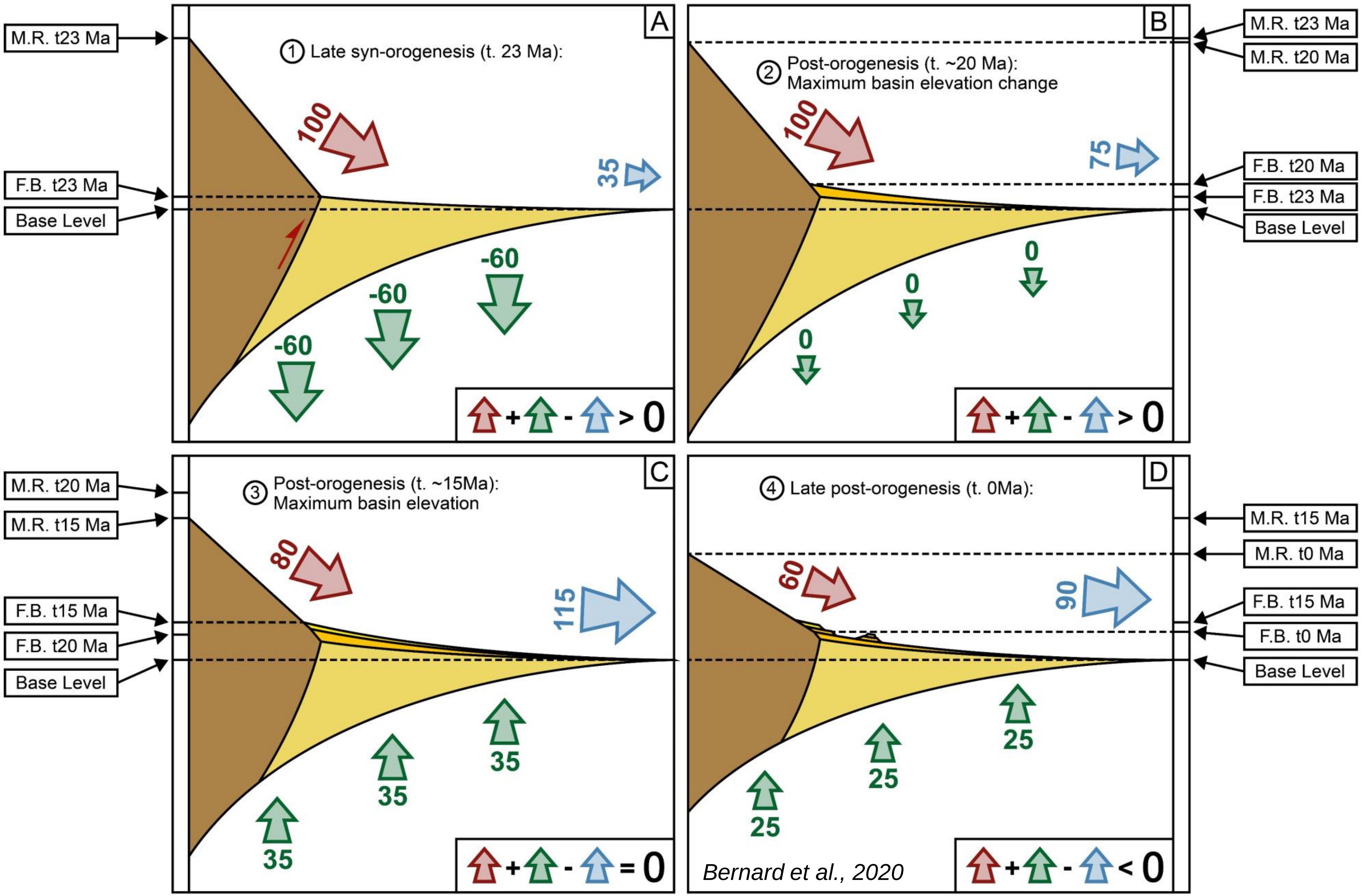
BASIN TOPOGRAPHIC AND SEDIMENT FLUX RESULTS



Basin influx (range sediment flux), basin outflux (basin sediment flux) and flexure (subsidence or rebound of the basin) evolution through time:

- Early post-orogenic phase (1 → 2): combination of reduction of flexural subsidence + continue high basin influx = sediment aggradation and increase of basin elevation
- Middle post-orogenic phase (2 → 3): higher basin outflux than basin influx = increase of basin elevation by isostatic rebound
- Late post-orogenic phase (3 → 4): higher basin outflux than basin influx + isostatic rebound = decrease of basin evolution

SYSTEM SCHEMATIC REPRESENTATION FROM LATE SYN- TO POST-OROGENESIS



Bernard et al., 2020

CONCLUSION

- **The northern Pyrenees are characterized by a post-orogenic sediment drape on the thrust wedge. Sediment drapes form low gradient surfaces that range in elevation from ~300 to 600 m.**

- **Using a box-model that approximate dynamic coupling of a thrust wedge/foreland basin we replicate the northern Pyrenees with a lithosphere elastic thickness of 22.2±1.6 km, a range transport coefficient of 430±140 $m^2.yr^{-1}$ and a basin transport coefficient of 13200±4400 $m^2.yr^{-1}$.**

- **Model results indicate that at the transition from syn-orogenesis to post-orogenesis, sediment flux from the range remains high, while basin subsidence slows; this combination results in accumulation of continental sediment that can drape over the frontal portions of thrust wedges.**

- **Inverse modelling results explain the persistence of Pyrenean topography long after cessation of orogenic activity with low lithosphere elastic thickness and low range transport coefficient parameters and a reduction of relief between the range and basin.**