Extension of a lower plate passive margin coeval with subduction of the adjacent slab: The Western Alps and Maghrebides cases

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Study area and motivation

Where: The Briançonnais extends in the Western Alps. AlKaPeCa terranes extend in the Maghrebides from the Rif (northern Morocco) to the Peloritani Mountains of Sicily (e.g., Bouillin, 1986; Bouillin et al., 1986; ***Fig. 1***).

What we know: Both the Briançonnais and AlKaPeCa terranes were:

- Passive paleomargin units of the European side of the Alpine Tethys.
- Inverted during the closure of the Alpine Tethys (suture = Jurassic ophiolites;.
- Change in the movement of Africa vs Eurasia at~85-80 Ma = onset of convergence and subduction.
- Alpine Tethys extended from the Alps to the Central Atlantic, bordered to the southeast by Adria-Africa, and to the northwest by Briançonnais-Alkapeca

Our motivation:

Why: We seek to decipher what happened to the Alpine Tethys between 80 and ~40 Ma on the Maghrebian transect of AlKaPe(Ca), the northern Tethyan paleomargin of the Maghrebian Tethys.

How: Building on what is known about the Alpine transect to shed light on the Maghrebian transect.

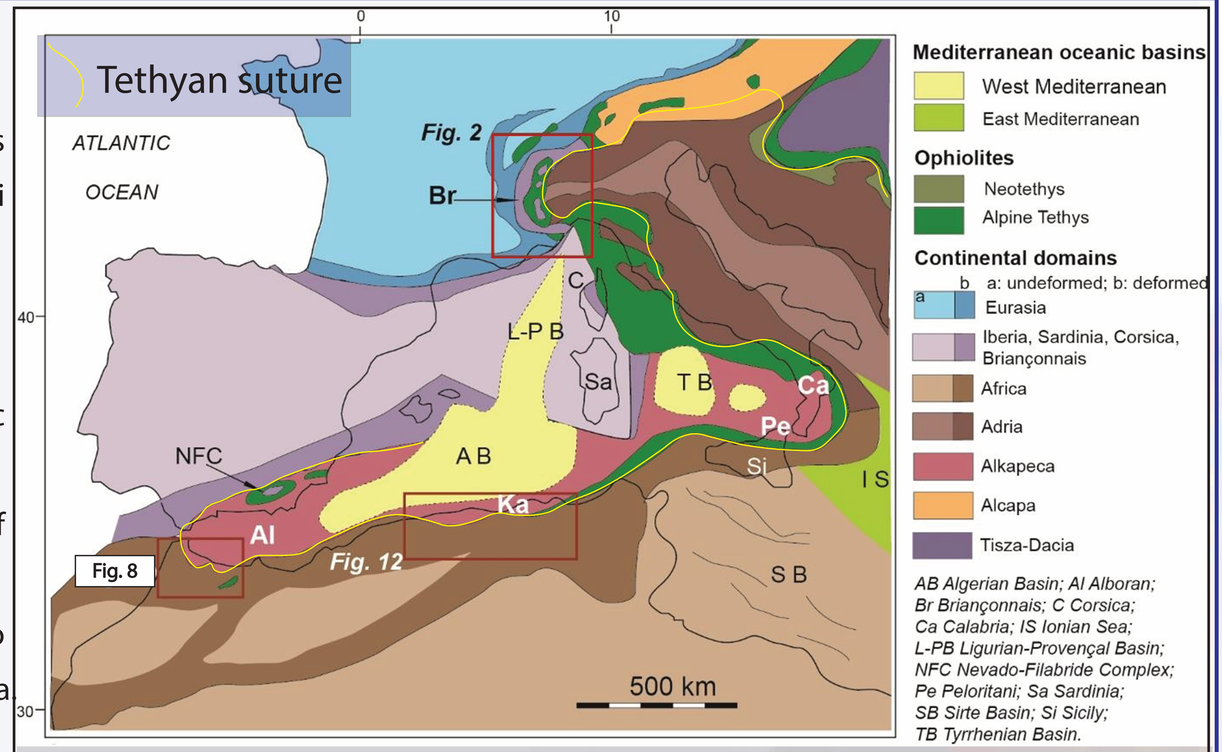


Fig. 1 . The Alpine belts of Western Europe and North-Africa with location of the Briançonnais, Maghrebides (Al-Ka-Pe terranes and associated units) and Mediterranean basins, after Handy et al. (2010), modified by Michard et al. (BSGF, submitted).

- Looking at the Alps to better understand and interpret the Maghrebides

1. What we know about the Late Cretaceous-Early Eocene in the Alps?

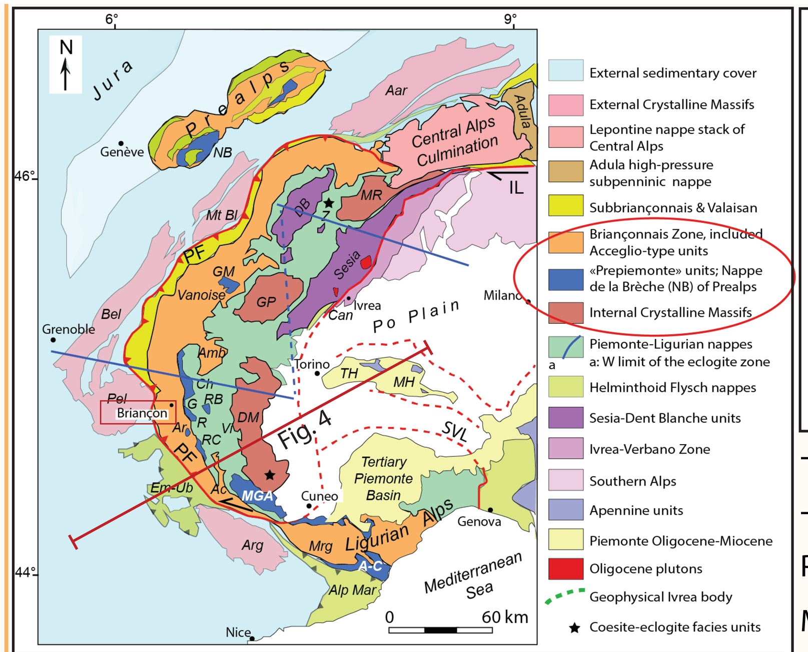


Fig. 2 **.** Structural map of the Western Alps, after Michard et al. (2022a).

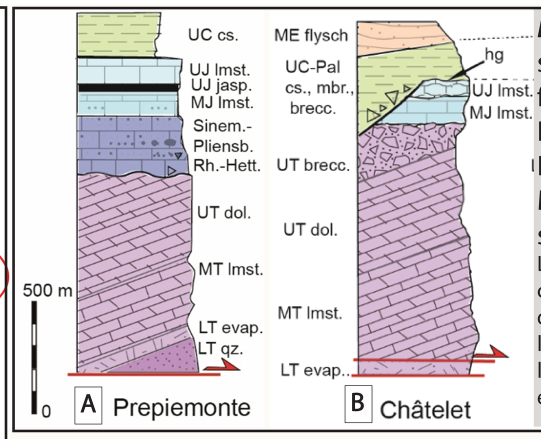


Fig. 3. Typical stratigraphic series from the Briançonnais Domain (in Michard et al., submitted). Litho: cs. clastic/pure calcschists; jasp. jaspers; dol. bedded dolostones; lmst. clastic/pure limestones; evap. evaporites; qz.

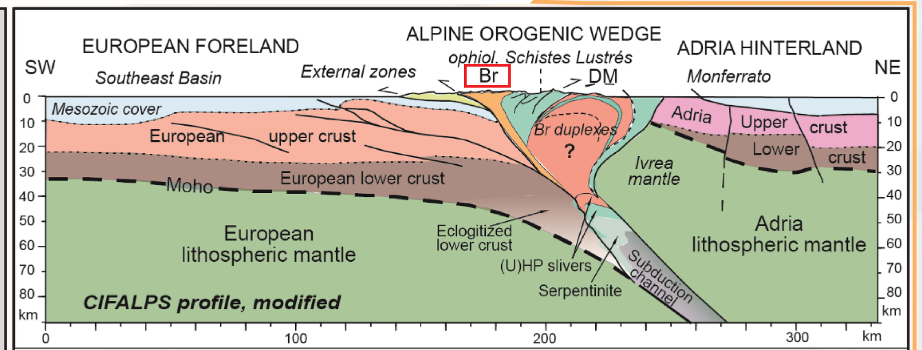


Fig. 4 **.** Crustal-scale profile of the southern Western Alps along the CIFALPS transect (Malusà et al., 2021), modified in Michard et al. (2022a).

- Briançonnais was the distal European paleomargin during the Mesozoic.
- The Briançonnais included the "Prepiemonte" units mainly consist of Mesozoic-Early Cenozoic series, with Carboniferous and Permian clastic and volcanic rocks at their base (***Fig. 3A***). These stratigraphic series record: Upper Triassic-Lower Jurassic rifting; Middle Jurassic-Lower Cretaceous thermal subsidence; Upper Cretaceous-Paleocene renewed extension (***Fig. 3B***).
- Briançonnais = tectonic wedge of (U)HP-LT metamorphic nappes (***Figs. 2 et 4***).
- Briançonnais units are overlain by the ophiolitic Schistes Lustrés and by the Sesia-Dent Blanche units = former Adria (African microplate) extensional allochthon (***Fig. 4***)

THE STRIKING LINK BETWEEN EXTENSION AND SUBDUCTION IN THE BRIANCONNAIS MARGIN

- While the Briançonnais was again extending, the lithosphere of the Piemonte-Liguria Ocean was subducting beneath Adria(***Fig. 5***). This tectonic process occurred from ~84 Ma to 35 Ma (Handy et al., 2010).
- The onset of the southeast-ward subduction of the Piemonte-Liguria slab ("Alpine subduction") is correlated with the abrupt change in the displacement of Africa vs. fixed Eurasia at 84 Ma (Rosenbaum et al., 2002) (***Fig. 5C***).
- The Late Cretaceous extension occurred when the Briançonnais was approaching the subduction zone (***Fig. 5C***). This extensional tectonic event could originate from the extrados of the bending zone in Briançonnais (Bellahsen et al., 2005) or an increase of slab pull caused by avalanching of the slab into the lower mantle (Capitanio et al., 2009) and stress in western Alps curvature of the subduction zone (***Fig. 6***)
- The Briançonnais was totally subducted between 40-35 Ma (Bonnet et al., 2022) (***Fig. 5A and 7***).

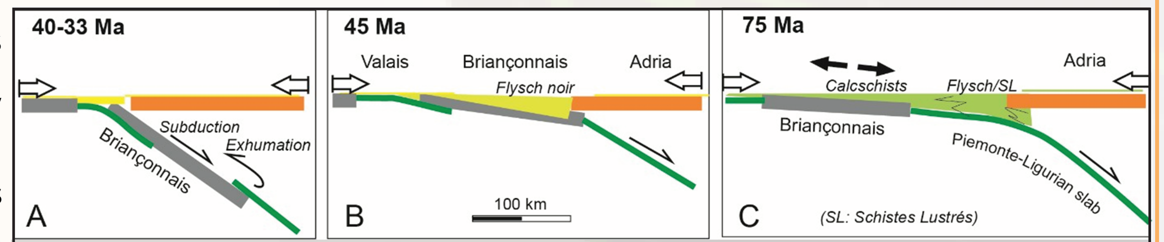


Fig. 5 **.** Restoring the location of the Briançonnais with respect to the Alpine subduction zone at three particular times (2D cartoons, starting from the youngest episodes).

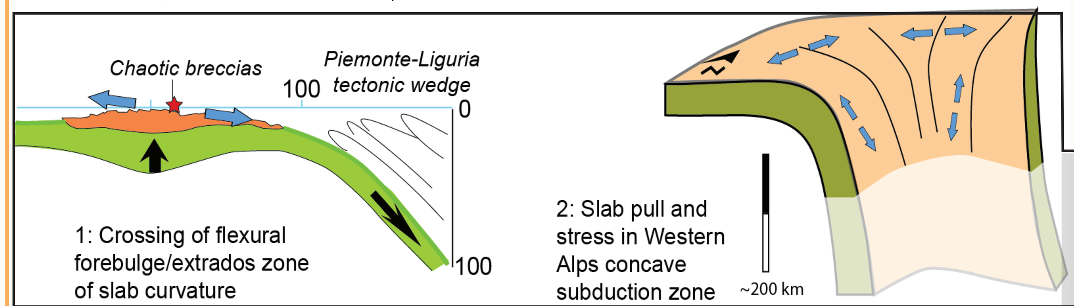


Fig. 6 **.** Possible origin of extensional stress: ***1.*** the extrados of the bending zone in Briançonnais. ***2.*** An increase of slab pull and curvature of the subduction zone

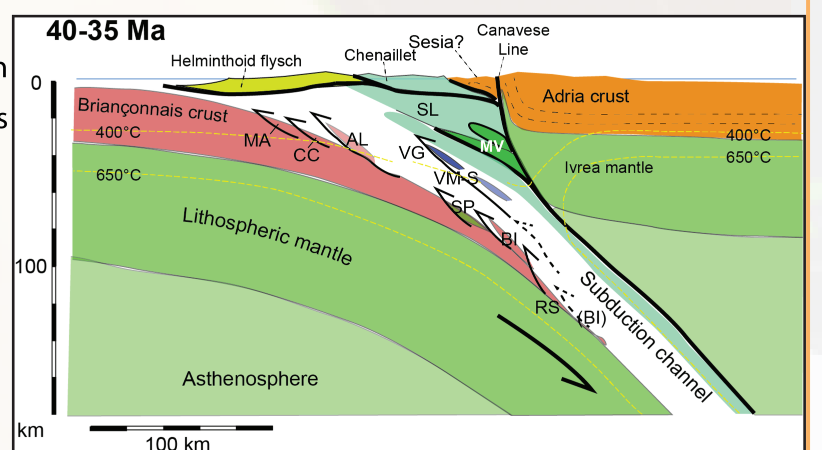


Fig. 7 **.** End of Briançonnais subduction and ongoing exhumation processes.

2. Late Cretaceous-Paleocene extension in the Internal Zones of the Maghrebides (AlKaPeCa terranes)

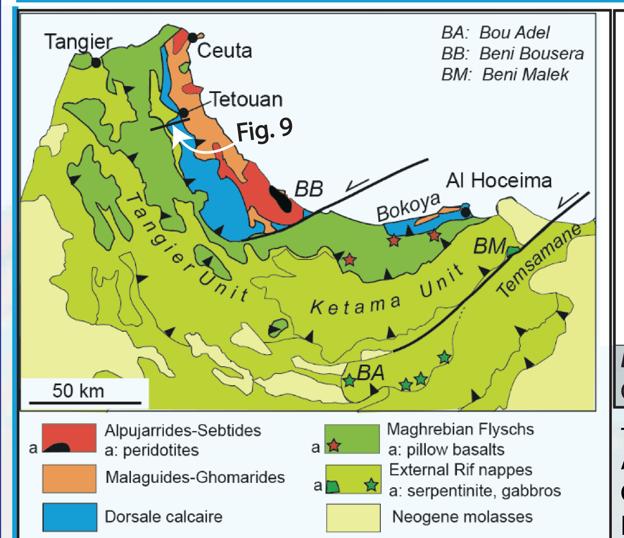


Fig. 8. Sketch map of the northern Rif after Michard et al. (2018), modified.

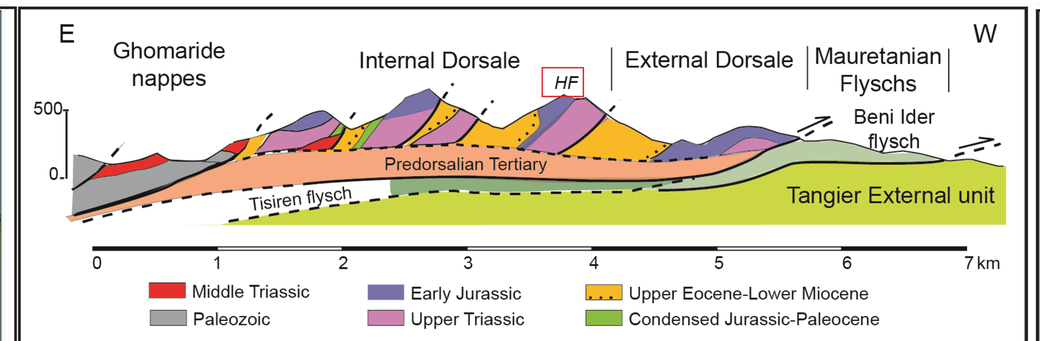


Fig. 9. Profile of the Alkapeca transported paleomargin in Alboran transect. after Chalouan et al. (2011). see *Fig. 8*. for location. HF: Hafat Ferkenich unit.

- The Internal Zones of the Maghrebides correspond to the western and central Alkapeca terranes (Bouillin, 1986), namely the Alboran Domain in the Gibraltar Arc, the Greater and Lesser Kabylias (Algeria), and the Peloritan Mountains of Sicily (***Fig. 8 et 12***) In the Rif belt, the potential records of Late Cretaceous-Paleocene deformation should be sought in the so-called "Dorsale calcaire" units (***Fig. 9***). They form elongated crests ("Dorsales") of carbonate rocks (dolostones and limestones) that were first defined in the Rif belt (Fallot, 1937).

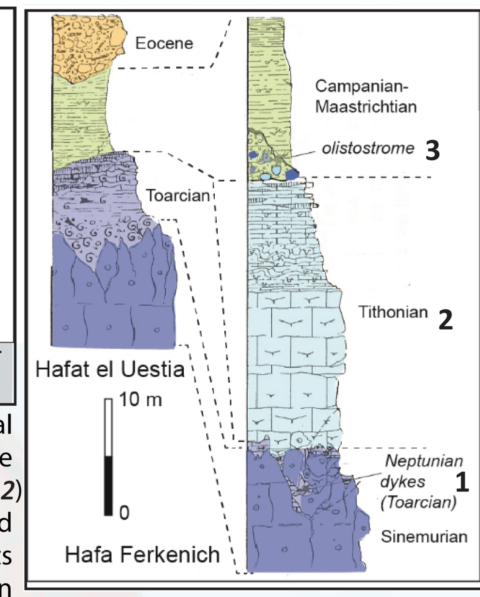


Fig. 10. Stratigraphic columns of the Internal Dorsale, from the Tetuan area, El Kadiri et al. (1989), modified

- Three extensional events are highlighted: (**1**)End of Early Jurassic, (**2**)Tithonian and Late Cretaceous. (**3**)The Campanian olistostrome contains elements of the various Jurassic facies ***(Fig. 10***).

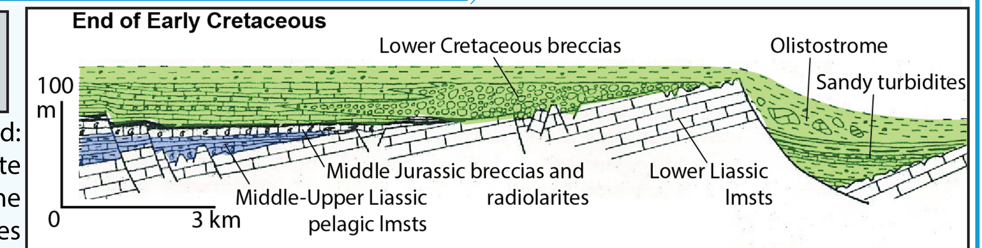


Fig. 11. Jurassic-Cretaceous extension of the Internal Rif paleomargin. after El Hatimi and Duée (1989).

- The Jebel Musa Group (southern Hercules Column of the Strait of Gibraltar), which is transitional between the Internal and External Dorsales, offers clear records of Lower Cretaceous syn-sedimentary normal faults and tilted blocks (***Fig. 11;*** El Hatimi and Duée, 1989).
- The "Predorsalian" units (Olivier, 1990) are transitional between the External Dorsale and the uppermost Maghrebian Flyschs units.
- The extensional faults were permanently active on these Predorsalian" units = most external Dorsale (Olivier, 1990).
- Post-rift extensional setting from the Malm to the Late Cretaceous-Paleocene

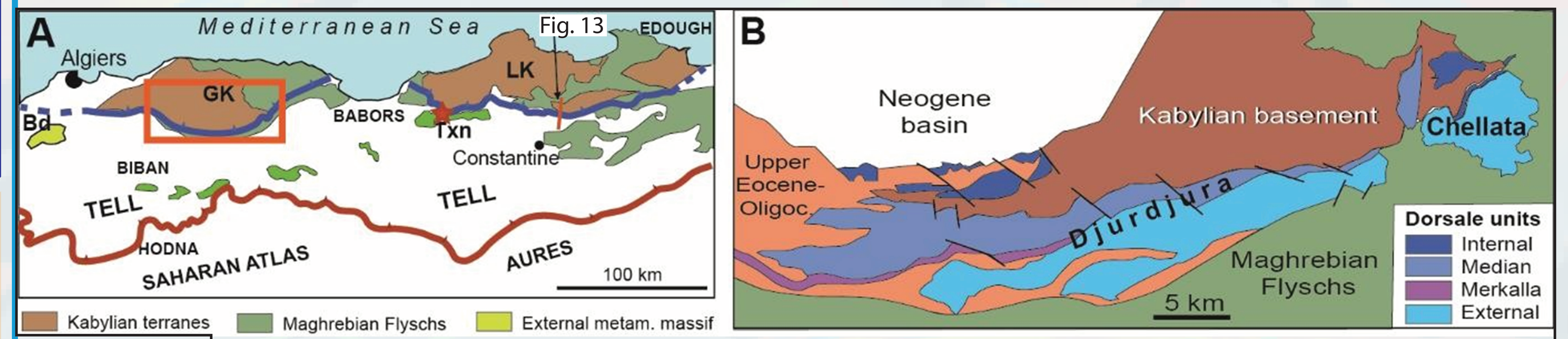
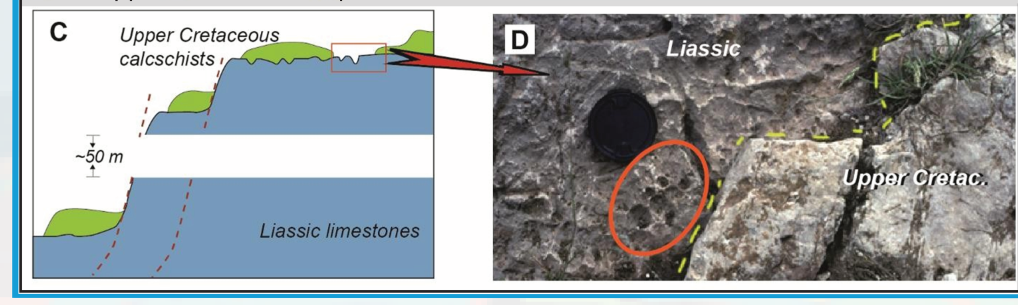


Fig. 12. A: Structural map of the Kabylias and adjacent units, redrawn after Leprêtre et al. (2018), modified by Michard et al., submitted. GK: Greater Kabylia. ***B:*** Map of the Dorsale units in Greater Kabylia (framed in A) after Cattaneo et al. (1999), modified. ***C*** and ***D***: Upper Cretaceous onlap on faulted Liassic limestones in the External Dorsale, close to the Merkalla Lower Cretaceous basin.



Greater Kabylia (***Fig. 12. A***):

- In The Merkalla unit of the External Dorsale (***Fig. 12. B***); The Upper Cretaceous pelagic foliated marls (calcschists) directly overlie Liassic limestones affected by small normal faults; beneath the pelagic Cretaceous beds, the surface of the Liassic limestones are perforated by lithophagous animals, consistent with an extensional tectonic regime under submarine conditions (***Fig. 12. C and D***)

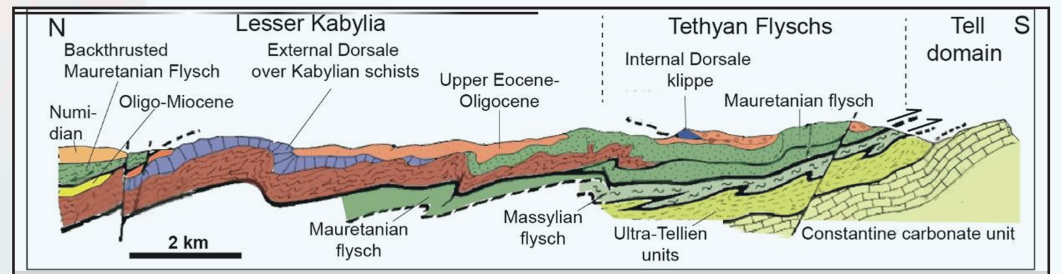


Fig. 13. Profile of the Alkapeca transported paleomargin in the Lesser Kabylia. after Raoult (1974), in Michard et al. BSGF, submitted, see *Fig. 12A.* for location.

In Lesser Kabylia, the External Dorsale partly remained attached onto its Paleozoic basement (***Fig. 13***). The detailed stratigraphical data in western and eastern parts of External Dorsal were made available by Durand-Delga (1955) and Raoult (1974)(***Fig. 14***), respectively. But The descriptions of some structures deserve tentative reinterpretations, there are two distinct events :

1) The Sinemurian breccias of the Rhedir unit records the rifting event responsible for the opening of the Central Atlantic and Alpine Tethys (***Fig. 14***).

2) The micro-breccias, calc-turbidites and coarse conglomerates of the Upper Cretaceous-Paleocene formations of the Rhedir and Tengout units (External dorsale, ***Fig. 14***) most likely formed due to extensional faulting since no preceding folding event is known and clearly described.

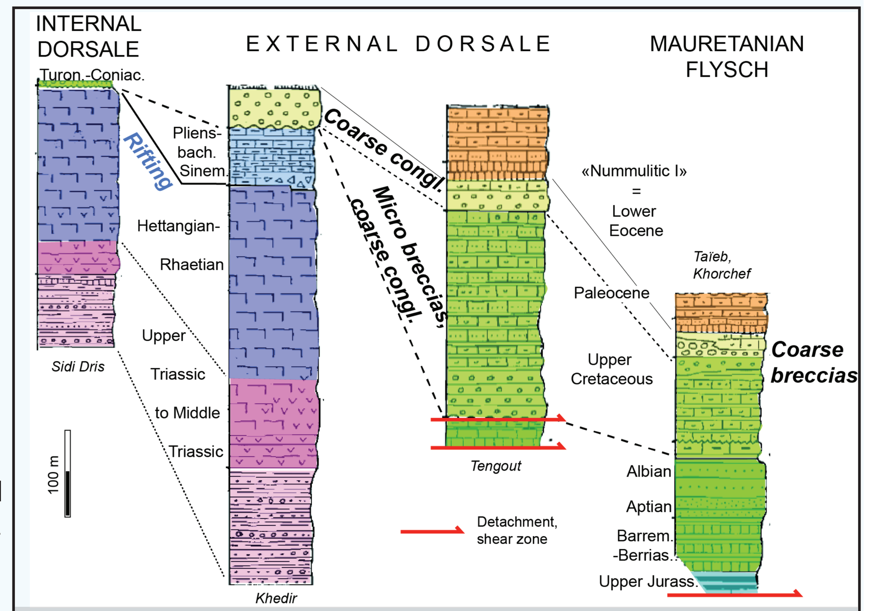


Fig. 14. Stratigraphic columns of the Lesser Kabylia Dorsale and adjoining Mauretanian Flysch after Raoult (1974, 1975), modified by Michard et al. submitted

Campanian-Paleocene conglomerates, breccias & turbidites in the External Dorsale and adjacent Flysch => markers of extension !

3. Discussion and interpretations

The determining role of the slab retreat process in the opening of the Mediterranean basins from the Late Eocene onward was recognized by Rehault et al. (1984).

A) Rehault et al. (1984)(***Fig. 15A***) considered that the European crust and adjacent oceanic lithosphere were subducting eastward during the Late Cretaceous, and then they assumed a "flip" in subduction polarity operated before the onset of the west-dipping, southeast retreating Eocene-Miocene subduction.

B) Vignaroli et al., 2008 and others proposed that a northwest-dipping subduction existed along southeast Iberia as early as the Late Cretaceous (***Fig. 15B***), which nourished a still vivid controversy.

C) Molli 2008 (***Fig. 15C***): The model is based on that of Rehault et al. (1984): Late Cretaceous "Alpine subduction" along the "Betic Ocean" between Iberia and Alkapeca, and Eocene-Oligocene "Apenninic subduction" along the opposite border of Alkapeca.

D) Michard et al. submitted; (***Fig. 15D***): Late Cretaceous-Paleocene subduction of the Ligurian-Maghrebian slab located along the North-African margin, then Eocene Subduction Polarity Reversal (SPR) accompanied by a shift of the subduction zone to the southeastern border of Alkapeca.

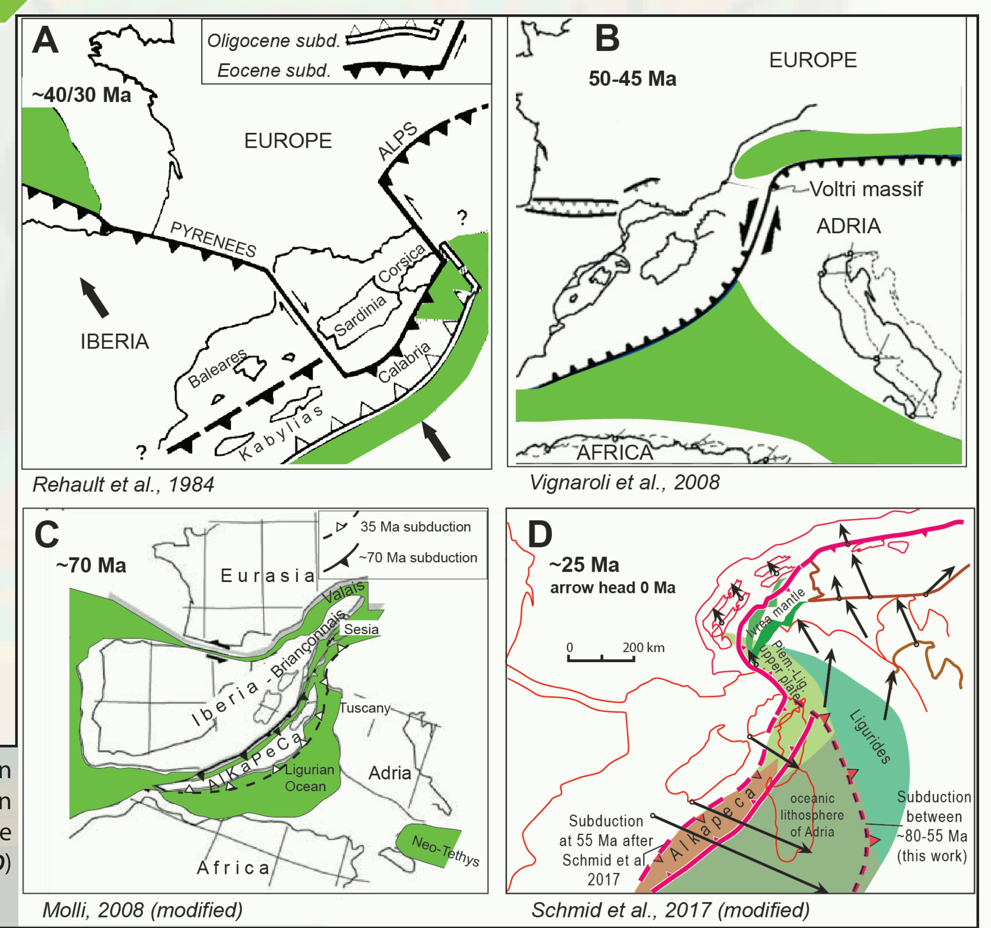


Fig. 15. Location of the subduction zones and interpretation of the Subduction Polarity Reversal (SPR) during Africa-Eurasia convergence in the Western Alps-Maghrebides area. ***A***) SPR occurred along time, at about 35 Ma; ***B***)opposite polarities occurred contemporaneously along the plate boundary. ***C***) Molli (2008); ***D***) Michard et al. submitted, background map after Schmid et al. (2017), modified.

Alpine-type subduction before the Apennine-type subduction in the Westernmost Mediterranean

- The Alpine-type subduction was active along North-Africa between 85-60 Ma (***Fig. 16A***): During Late Cretaceous-Paleocene times, the Tethyan slab would subduct beneath Africa ("Alpine subduction"); continental allochthons could have been included in the slab (e.g., Ketama unit of central Rif???).
- This implies that a SPR occurred at some time between the Paleocene and the middle-late Eocene inception of the new Apennine-type subduction in between Iberia and North-Africa (***Fig. 16B***): After the middle-late Eocene Subduction Polarity Reversal, the "Apenninic subduction" is going on beneath the Alkapeca orogenic arc, which rift off Iberia and thus allows the Mediterranean basin to open.
- SPR due to collision of continental allochthons against Africa?? ? Rather by age of slab greater to the North. or related to the collision in the Alpine Mountain belts (Jolivet and Faccenna (2000) and Jolivet et al. (2008)).

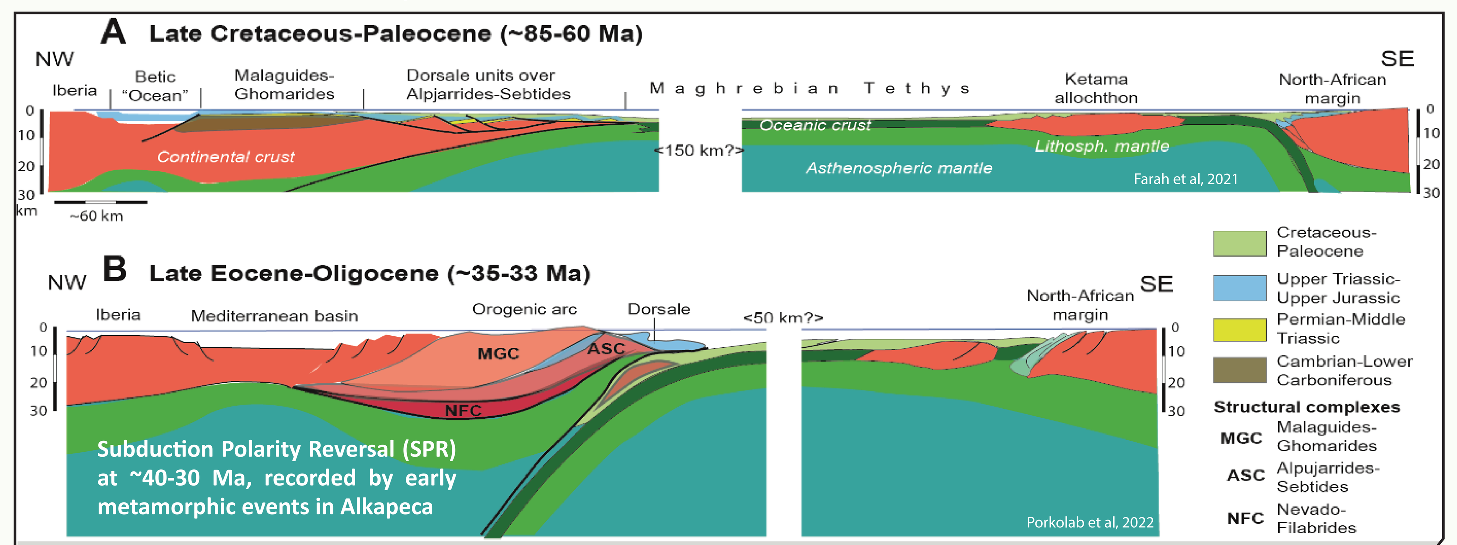


Fig. 16. New proposal for the evolution of the westernmost Tethys in the frame of the Africa-Eurasia convergence.

Take-home message

1) **In the Western Alps transect, the Briançonnais European margin kept extending from the initial rifting until it encroached the Alpine subduction (Early Eocene).**

2) **The extensional regime is also recorded in the "Dorsale calcaire" units which originate from the northwest margin of the Maghrebian Tethys for the Late Cretaceous-Paleocene times.**

3) **An Alpine subduction must be also considered for the Maghrebides transects during the Late Cretaceous-Paleocene.**

4) **Subduction Polarity Reversal operated along the Adria and North Africa passive margin from the Western Alps-Apennines connection to Sicily, Kabylias and the westernmost Maghrebides (Rif-Betic orogen) during the Middle-Late Eocene times, with a shift of the subduction zone from the southern margin to the northern margin of the Ligurian-Maghrebian Tethys.**

References Contact Abstract

SCAN ME!