

LES ALPES FRANCO-ITALIENNES

Olivier LACOMBE





INTERNATIONAL STRATIGRAPHIC CHART



International Commission on Stratigraphy

| Phanerozoic | Eonothem Eon | Erathem Era | System Period | Series Epoch | Stage Age | Age Ma | GSSP | | | | | | | |
|-------------|-----------------|----------------|------------------|-----------------|--------------|-----------|------|------------|------------|---------------|--------------|-------------|--------|------------|
| | | | | | | | | Cenozoic | | | | | | |
| Phanerozoic | Eon | Era | Period | Epoch | Age | Ma | GSSP | | | | | | | |
| | | | | | | | | Cenozoic | Quaternary | Holocene | | 0.0117 | ↗ | |
| | | | | | | | | | | Pleistocene | Upper | | 0.126 | |
| | | | | | | | | | | | "Ionian" | | 0.781 | |
| | | | | | | | | | | | Calabrian | | 1.806 | ↗ |
| | | | | | | | | | | | Gelasian | | 2.588 | ↗ |
| | | | | | | | | | Neogene | Pliocene | Piacenzian | | 3.800 | ↗ |
| | | | | | | | | | | | Zanclean | | 5.332 | ↗ |
| | | | | | | | | | | Miocene | Messinian | | 7.246 | ↗ |
| | | | | | | | | | | | Tortonian | | 11.808 | ↗ |
| | | | | | | | | | | | Serravallian | | 13.82 | ↗ |
| | | | | | | | | | | | Langhian | | 15.97 | ↗ |
| | | | | | | | | | | | Burdigalian | | 20.43 | ↗ |
| | | | | | | | | | | | Aquitanian | | 23.03 | ↗ |
| | | | | | | | | | | | Oligocene | Chattian | | 28.4 ± 0.1 |
| Rupelian | | 33.9 ± 0.1 | ↗ | | | | | | | | | | | |
| Eocene | Priabonian | | 37.2 ± 0.1 | ↗ | | | | | | | | | | |
| | Bartonian | | 40.4 ± 0.2 | ↗ | | | | | | | | | | |
| | Lutetian | | 48.6 ± 0.2 | ↗ | | | | | | | | | | |
| | Ypresian | | 55.8 ± 0.2 | ↗ | | | | | | | | | | |
| | Thanetian | | 58.7 ± 0.2 | ↗ | | | | | | | | | | |
| Paleocene | Selandian | | ~ 61.1 | ↗ | | | | | | | | | | |
| | Danian | | 65.5 ± 0.3 | ↗ | | | | | | | | | | |
| Mesozoic | Eon | Era | Period | Epoch | Age | Ma | GSSP | | | | | | | |
| | | | | | | | | Cretaceous | Upper | Maastrichtian | | 70.6 ± 0.6 | ↗ | |
| | | | | | | | | | | Campanian | | 83.5 ± 0.7 | ↗ | |
| | | | | | | | | | | Santonian | | 85.8 ± 0.7 | ↗ | |
| | | | | | | | | | | Coniacian | | ~ 88.6 | ↗ | |
| | | | | | | | | | | Turonian | | 93.6 ± 0.8 | ↗ | |
| | | | | | | | | | Lower | Cenomanian | | 99.6 ± 0.9 | ↗ | |
| | | | | | | | | | | Albian | | 112.0 ± 1.0 | ↗ | |
| | | | | | | | | | | Aptian | | 125.0 ± 1.0 | ↗ | |
| | | | | | | | | | | Barremian | | 130.0 ± 1.5 | ↗ | |
| Hauterivian | | ~ 133.9 | ↗ | | | | | | | | | | | |
| Valanginian | | 140.2 ± 3.0 | ↗ | | | | | | | | | | | |
| Berriasian | | 145.5 ± 4.0 | ↗ | | | | | | | | | | | |

| Phanerozoic | Eonothem Eon | Erathem Era | System Period | Series Epoch | Stage Age | Age Ma | GSSP | | | | | | | |
|---------------|-----------------|----------------|------------------|-----------------|--------------|-----------|------|---------------|--------------|---------------|--------------|-------------|-------------|---|
| | | | | | | | | Mesozoic | | | | | | |
| Phanerozoic | Eon | Era | Period | Epoch | Age | Ma | GSSP | | | | | | | |
| | | | | | | | | Mesozoic | Jurassic | Upper | Tithonian | | 145.5 ± 4.0 | ↗ |
| | | | | | | | | | | | Kimmeridgian | | 150.8 ± 4.0 | ↗ |
| | | | | | | | | | | | Oxfordian | | ~ 155.6 | ↗ |
| | | | | | | | | | | Middle | Callovian | | 161.2 ± 4.0 | ↗ |
| | | | | | | | | | | | Bathonian | | 164.7 ± 4.0 | ↗ |
| | | | | | | | | | Lower | Bajocian | | 167.7 ± 3.5 | ↗ | |
| | | | | | | | | | | Aalenian | | 171.6 ± 3.0 | ↗ | |
| | | | | | | | | | | Toarcian | | 175.6 ± 2.0 | ↗ | |
| | | | | | | | | | | Pliensbachian | | 183.0 ± 1.5 | ↗ | |
| | | | | | | | | | | Sinemurian | | 189.6 ± 1.5 | ↗ | |
| | | | | | | | | | | Hettangian | | 196.5 ± 1.0 | ↗ | |
| | | | | | | | | | | Rhaetian | | 199.6 ± 0.6 | ↗ | |
| | | | | | | | | | | Norian | | 203.6 ± 1.5 | ↗ | |
| | | | | | | | | | Triassic | Upper | Carnian | | 216.5 ± 2.0 | ↗ |
| Ladinian | | ~ 228.7 | ↗ | | | | | | | | | | | |
| Middle | Anisian | | ~ 245.9 | ↗ | | | | | | | | | | |
| | Olenekian | | ~ 249.5 | ↗ | | | | | | | | | | |
| Lower | Induan | | 251.0 ± 0.4 | ↗ | | | | | | | | | | |
| | Changhsingian | | 253.8 ± 0.7 | ↗ | | | | | | | | | | |
| Paleozoic | Eon | Era | Period | Epoch | Age | Ma | GSSP | | | | | | | |
| | | | | | | | | Paleozoic | Permian | Lopingian | | 260.4 ± 0.7 | ↗ | |
| | | | | | | | | | | Wuchiapingian | | 260.4 ± 0.7 | ↗ | |
| | | | | | | | | | Guadalupian | Capitanian | | 265.8 ± 0.7 | ↗ | |
| | | | | | | | | | | Wordian | | 268.0 ± 0.7 | ↗ | |
| | | | | | | | | | Roadian | Kungurian | | 270.6 ± 0.7 | ↗ | |
| | | | | | | | | | | Artinskian | | 275.6 ± 0.7 | ↗ | |
| | | | | | | | | | Cisuralian | Sakmarian | | 284.4 ± 0.7 | ↗ | |
| | | | | | | | | | | Sakmarian | | 284.4 ± 0.7 | ↗ | |
| | | | | | | | | | Asselian | Asselian | | 294.6 ± 0.8 | ↗ | |
| Asselian | | 294.6 ± 0.8 | ↗ | | | | | | | | | | | |
| Carboniferous | Eon | Era | Period | Epoch | Age | Ma | GSSP | | | | | | | |
| | | | | | | | | Pennsylvanian | Gzhelian | | 299.0 ± 0.8 | ↗ | | |
| | | | | | | | | | Kasimovian | | 303.4 ± 0.9 | ↗ | | |
| | | | | | | | | | Moscovian | | 307.2 ± 1.0 | ↗ | | |
| | | | | | | | | | Bashkirian | | 311.7 ± 1.1 | ↗ | | |
| | | | | | | | | Mississippian | Serpukhovian | | 318.1 ± 1.3 | ↗ | | |
| | | | | | | | | | Serpukhovian | | 318.1 ± 1.3 | ↗ | | |
| | | | | | | | | | Visean | | 328.3 ± 1.6 | ↗ | | |
| Tournaisian | | 345.3 ± 2.1 | ↗ | | | | | | | | | | | |
| Tournaisian | | 359.2 ± 2.5 | ↗ | | | | | | | | | | | |

| Phanerozoic | Eonothem Eon | Erathem Era | System Period | Series Epoch | Stage Age | Age Ma | GSSP | | | | | | | | | | | | | | |
|-------------|-----------------|----------------|------------------|-----------------|--------------|-----------|------|------------|-------------|------------|-------------|-------------|-------------|-----|----|------|------------|--------------|-------------|-------------|---|
| | | | | | | | | Paleozoic | | | | | | | | | | | | | |
| Phanerozoic | Eon | Era | Period | Epoch | Age | Ma | GSSP | | | | | | | | | | | | | | |
| | | | | | | | | Paleozoic | Devonian | Upper | Famennian | | 359.2 ± 2.5 | ↗ | | | | | | | |
| | | | | | | | | | | | Frasnian | | 374.5 ± 2.6 | ↗ | | | | | | | |
| | | | | | | | | | | Middle | Givetian | | 385.3 ± 2.6 | ↗ | | | | | | | |
| | | | | | | | | | | | Eifelian | | 391.8 ± 2.7 | ↗ | | | | | | | |
| | | | | | | | | | | | Emsian | | 397.5 ± 2.7 | ↗ | | | | | | | |
| | | | | | | | | | Lower | Pragian | | 407.0 ± 2.8 | ↗ | | | | | | | | |
| | | | | | | | | | | Lochkovian | | 411.2 ± 2.8 | ↗ | | | | | | | | |
| | | | | | | | | | Silurian | Eon | Era | Period | Epoch | Age | Ma | GSSP | | | | | |
| | | | | | | | | | | | | | | | | | Pridoli | | 416.0 ± 2.8 | ↗ | |
| | | | | | | | | | | | | | | | | | Ludlow | Ludfordian | | 418.7 ± 2.7 | ↗ |
| | | | | | | | | | | | | | | | | | | Gorstian | | 421.3 ± 2.6 | ↗ |
| | | | | | | | | | | | | | | | | | Wenlock | Homerian | | 422.9 ± 2.5 | ↗ |
| | | | | | | | | | | | | | | | | | | Sheinwoodian | | 426.2 ± 2.4 | ↗ |
| | | | | | | | | | | | | | | | | | Llandovery | Telychian | | 428.2 ± 2.3 | ↗ |
| Aeronian | | 436.0 ± 1.9 | ↗ | | | | | | | | | | | | | | | | | | |
| Rhuddanian | Rhuddanian | | 439.0 ± 1.8 | ↗ | | | | | | | | | | | | | | | | | |
| | Rhuddanian | | 443.7 ± 1.5 | ↗ | | | | | | | | | | | | | | | | | |
| Ordovician | Eon | Era | Period | Epoch | Age | Ma | GSSP | | | | | | | | | | | | | | |
| | | | | | | | | Upper | Hirnantian | | 445.6 ± 1.5 | ↗ | | | | | | | | | |
| | | | | | | | | | Katian | | 445.8 ± 1.6 | ↗ | | | | | | | | | |
| | | | | | | | | Middle | Sandbian | | 455.8 ± 1.6 | ↗ | | | | | | | | | |
| | | | | | | | | | Darriwilian | | 460.9 ± 1.6 | ↗ | | | | | | | | | |
| Lower | Dapingian | | 468.1 ± 1.6 | ↗ | | | | | | | | | | | | | | | | | |
| | Dapingian | | 471.8 ± 1.6 | ↗ | | | | | | | | | | | | | | | | | |
| Cambrian | Eon | Era | Period | Epoch | Age | Ma | GSSP | | | | | | | | | | | | | | |
| | | | | | | | | Furongian | Floian | | 478.6 ± 1.7 | ↗ | | | | | | | | | |
| | | | | | | | | | Tremadocian | | 478.6 ± 1.7 | ↗ | | | | | | | | | |
| | | | | | | | | Stage 10 | Stage 10 | | 488.3 ± 1.7 | ↗ | | | | | | | | | |
| | | | | | | | | | Stage 9 | | ~ 492 * | ↗ | | | | | | | | | |
| | | | | | | | | Paibian | Paibian | | ~ 496 * | ↗ | | | | | | | | | |
| | | | | | | | | | Paibian | | ~ 496 * | ↗ | | | | | | | | | |
| | | | | | | | | Guzhangian | Guzhangian | | ~ 499 | ↗ | | | | | | | | | |
| Guzhangian | | ~ 503 | ↗ | | | | | | | | | | | | | | | | | | |
| Drumian | Drumian | | ~ 506.5 | ↗ | | | | | | | | | | | | | | | | | |
| | Drumian | | ~ 510 * | ↗ | | | | | | | | | | | | | | | | | |
| Stage 5 | Stage 5 | | ~ 510 * | ↗ | | | | | | | | | | | | | | | | | |
| | Stage 4 | | ~ 515 * | ↗ | | | | | | | | | | | | | | | | | |
| Stage 3 | Stage 3 | | ~ 521 * | ↗ | | | | | | | | | | | | | | | | | |
| | Stage 2 | | ~ 528 * | ↗ | | | | | | | | | | | | | | | | | |
| Fortunian | Fortunian | | ~ 528 * | ↗ | | | | | | | | | | | | | | | | | |
| | Fortunian | | 542.0 ± 1.0 | ↗ | | | | | | | | | | | | | | | | | |

| Precambrian | Eonothem Eon | Erathem Era | System Period | Age Ma | GSSP GSSA | | | | | | | |
|-------------------|-----------------|----------------|------------------|-----------|--------------|-------------|-------------|-------------------|----------------|--|-------|---|
| | | | | | | Proterozoic | | | | | | |
| Precambrian | Eon | Era | Period | Age | Ma | GSSP | | | | | | |
| | | | | | | | Proterozoic | Neo-proterozoic | Ediacaran | | 542 | ↗ |
| | | | | | | | | | Cryogenian | | ~ 635 | ↗ |
| | | | | | | | | | Tonian | | 850 | ↗ |
| | | | | | | | | Meso-proterozoic | Stenian | | 1000 | ↗ |
| | | | | | | | | | Ectasian | | 1200 | ↗ |
| | | | | | | | | | Calymnian | | 1400 | ↗ |
| | | | | | | | | | Statherian | | 1600 | ↗ |
| | | | | | | | | | Orosirian | | 1800 | ↗ |
| | | | | | | | | Paleo-proterozoic | Rhyacian | | 2050 | ↗ |
| | | | | | | | | | Rhyacian | | 2300 | ↗ |
| | | | | | | | | | Siderian | | 2500 | ↗ |
| | | | | | | | | Archean | Neoproterozoic | | 2800 | ↗ |
| | | | | | | | | | Mesoarchean | | 3200 | ↗ |
| | | | | | | | | | Paleoarchean | | 3600 | ↗ |
| Hadean (informal) | Eoarchean | | 4000 | ↗ | | | | | | | | |
| | Eoarchean | | ~ 4600 | ↗ | | | | | | | | |

Subdivisions of the global geologic record are formally defined by their lower boundary. Each unit of the Phanerozoic (~542 Ma to Present) and the base of Ediacaran are defined by a basal Global Boundary Stratotype Section and Point (GSSP), whereas Precambrian units are formally subdivided by absolute age (Global Standard Stratigraphic Age, GSSA). Details of each GSSP are posted on the ICS website (www.stratigraphy.org).

Numerical ages of the unit boundaries in the Phanerozoic are subject to revision. Some stages within the Cambrian will be formally named upon international agreement on their GSSP limits. Most sub-Series boundaries (e.g., Middle and Upper Aptian) are not formally defined.

Colors are according to the Commission for the Geological Map of the World (www.cgmw.org).

The listed numerical ages are from 'A Geologic Time Scale 2004', by F.M. Gradstein, J.G. Ogg, A.G. Smith, et al. (2004; Cambridge University Press) and 'The Concise Geologic Time Scale' by J.G. Ogg, G. Ogg and F.M. Gradstein (2008).

This chart was drafted by Gabi Ogg. Intra Cambrian unit ages with * are informal, and awaiting ratified definitions.

Copyright © 2009 International Commission on Stratigraphy

LES ALPES FRANCO-ITALIENNES

Introduction : Les Alpes au sein des chaînes téthysiennes

I. Les Alpes franco-italiennes : une chaîne de subduction-collision

- A. Les unités structurales: nature, origine, mise en place
 - 1. Le domaine dauphinois et les chaînes plissées de l'avant-pays alpin : un prisme d'accrétion Oligo-Miocène
 - 2. Les unités Briançonnaises et piémontaises : un prisme d'accrétion Eocène
 - 3. Les unités liguro-piémontaises : un prisme d'accrétion Crétacé supérieur - Paléocène
 - Les nappes ophiolitiques
 - Les nappes de flyschs à Helminthoïdes
 - 4. La Corse alpine
- B. La structure profonde vue par la géophysique
- C. Le métamorphisme alpin et les contraintes thermo-barométriques sur l'édification du prisme orogénique
- D. Une absence quasi-totale de magmatisme

II. Les Alpes franco-italiennes : une structure impliquant la fermeture d'un océan lent et l'inversion d'une paléomarge passive

- A. La superposition des nappes de charriage implique l'existence d'un ou plusieurs domaines océaniques alpins d'âges différents
- B. Les océans « alpins », liguro-piémontais et valaisan
 - 1. Les ophiolites alpines et les océans alpins
 - 2. L'océan liguro-piémontais : des fonds océaniques étroits de type Atlantique
- C. La marge européenne de l'océan ligure
 - 1. Les séries sédimentaires et les grands domaines paléogéographiques
 - 2. Le rifting « ligure »
 - * La tectonique de blocs basculés : observations directes et reconstitutions
 - * Reconstitution de la géométrie de la marge européenne
 - 3. L'évolution post-rift de la marge européenne
- D. Essai de reconstitution paléogéographique d'ensemble

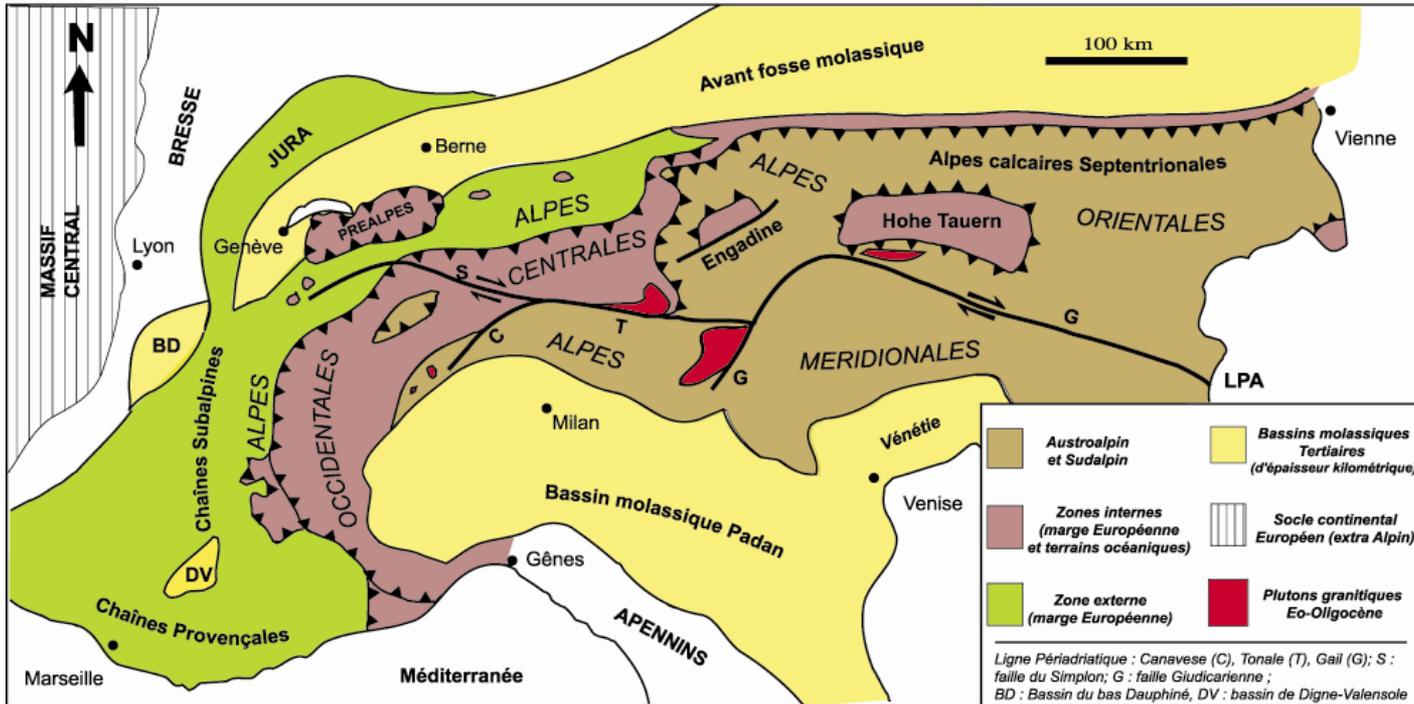
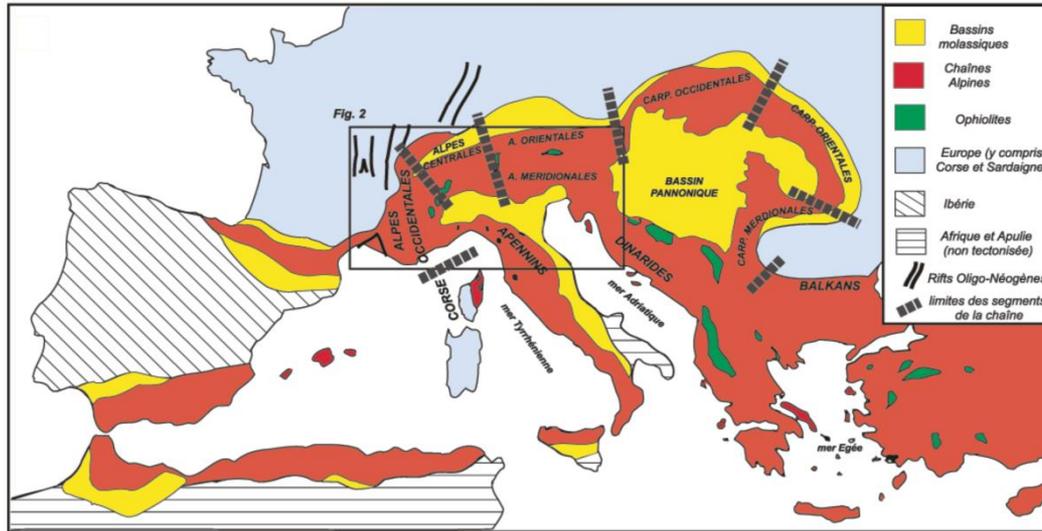
III. Calendrier et modèle d'évolution des Alpes franco-italiennes; évolution récente; réflexion sur la structure

- A. Calendrier et modèle d'évolution
- B. Evolution récente à actuelle
- C. Une structure résultant d'un poinçonnement mantellique et de l'emboîtement de 3 prismes d'accrétion dans le temps et dans l'espace

BIBLIOGRAPHIE

- Boillot et al. : "Les marges continentales, actuelles et fossiles autour de la France", Masson
- Lemoine et al. : "De l'océan à la chaîne de montagnes; tectonique des plaques dans les Alpes", Gordon et Breach
- Dercourt : "Géologie et Géodynamique de la France, Dunod
- Agard et Lemoine : "Visages des Alpes : structure et évolution géodynamique", CCGM
- Debelmas et Masclé : "Les grandes structures géologiques", Masson
- Lallemand, Jolivet, Huchon, Prouteau : « Convergence lithosphérique », Vuibert

(Agard et Lemoine, 2003)

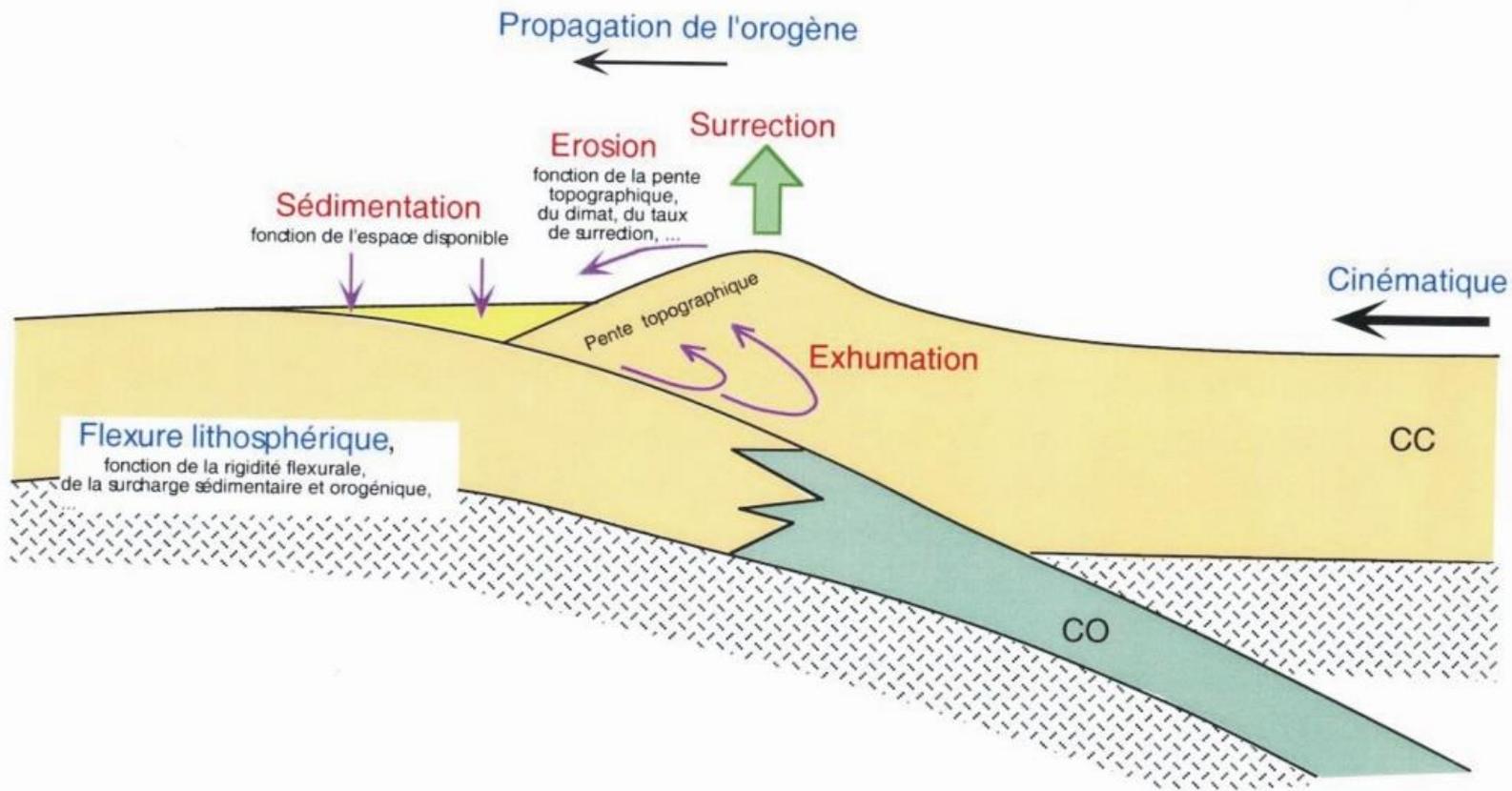


I. Les Alpes franco-italiennes : une chaîne de subduction-collision

I. Les Alpes franco-italiennes : une chaîne de subduction-collision

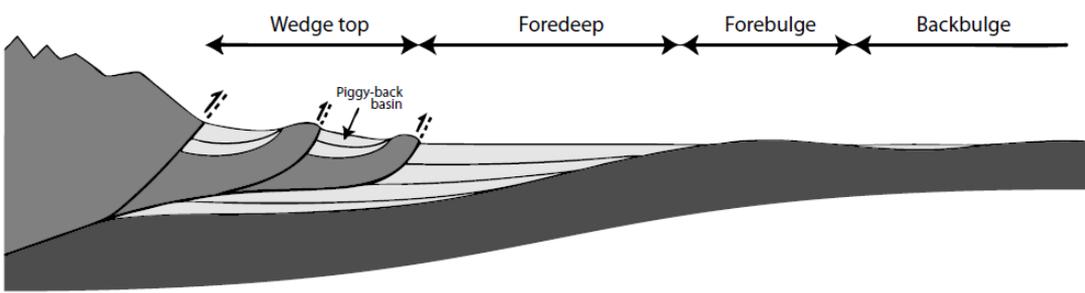
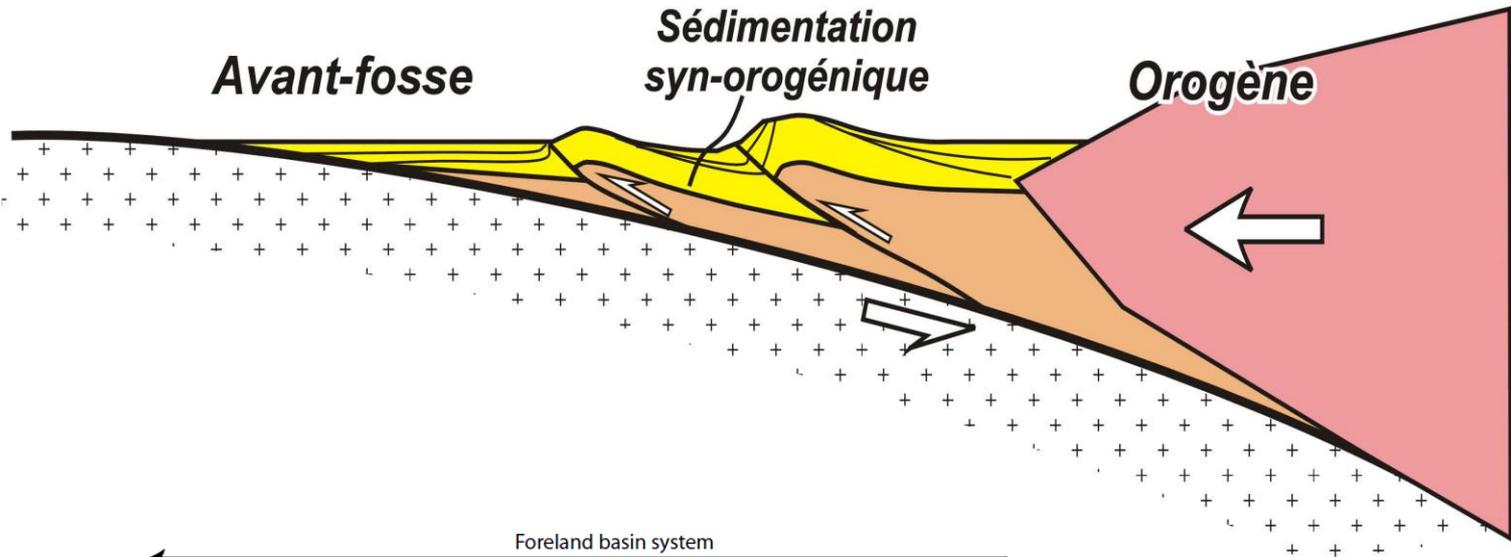
A. Les unités structurales

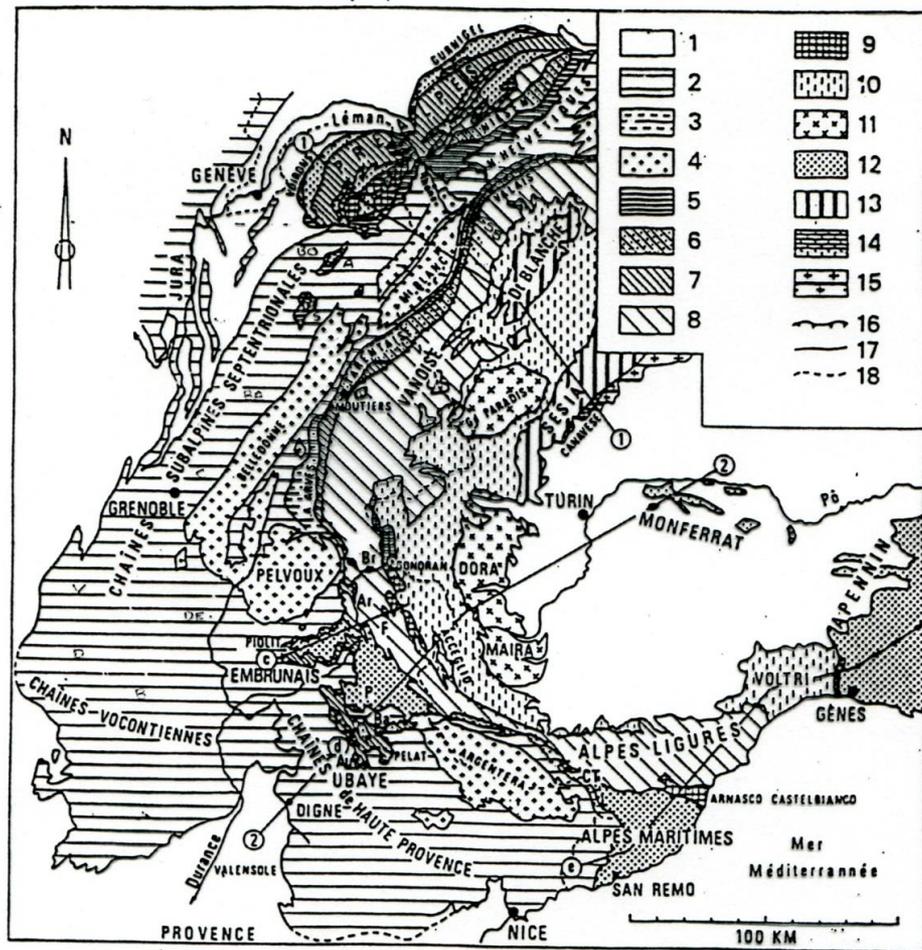
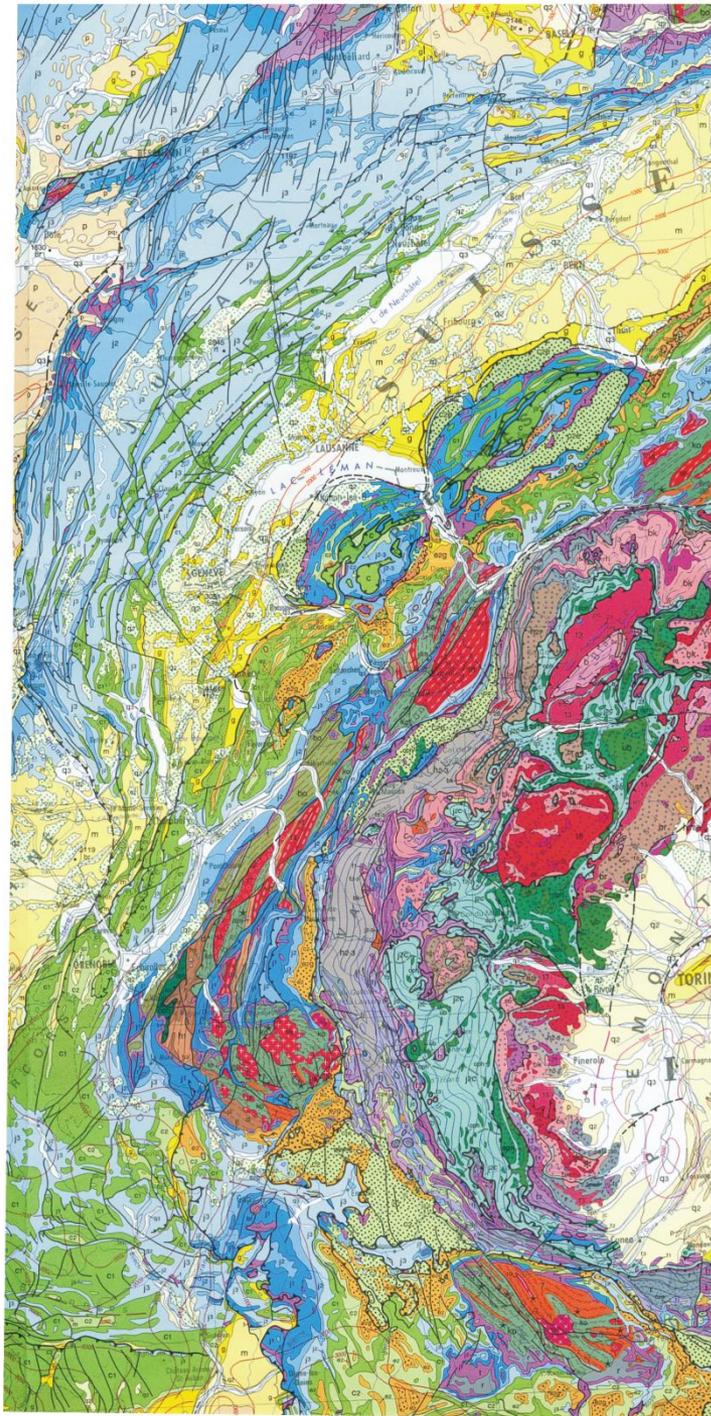
Le domaine dauphinois
et les chaînes de l'avant-pays alpin :
Un « prisme d'accrétion » oligo-miocène



Prisme orogénique

Bassin d'avant-pays



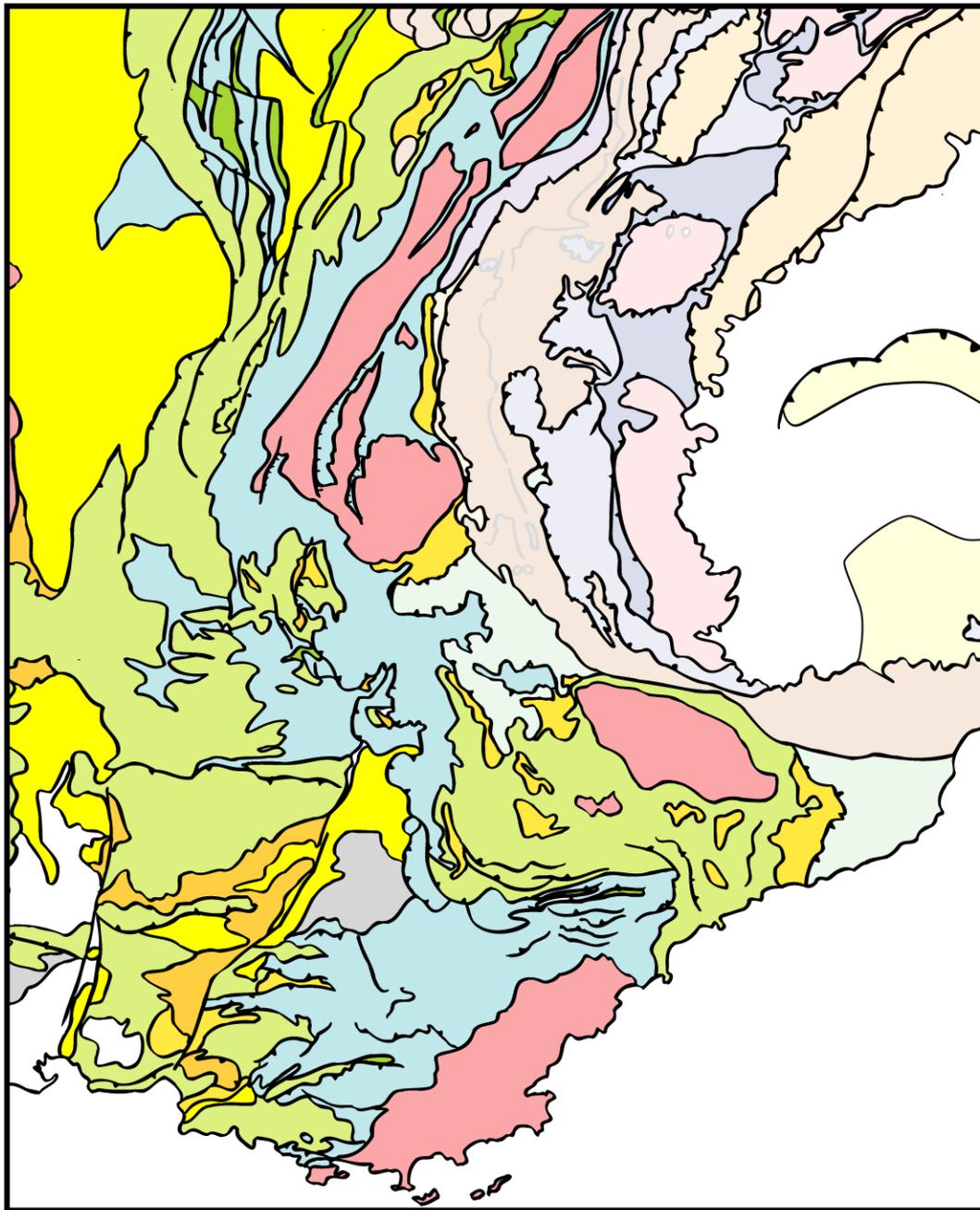


Esquisse structurale des Alpes occidentales, des Préalpes à l'Apennin septentrional.

1. Bassins tertiaires et quaternaires péri-alpins ; 2. Couverture sédimentaire mésozoïque et cénozoïque de la zone externe ; 3. Unités parautochtones orientales majeures de la zone externe ; 4. Massifs cristallins externes et leur tégument permo-carbonifère ; 5. Nappes ultrahelvétiques (Préalpes inférieures) ; 6. Zone valaisanne (et nappe du Niesen des Préalpes) ; 7. Zone subbriançonnaise (et Préalpes médianes "plastiques") ; 8. Zone briangonnaise (et Préalpes médianes "rigides") ; 9. Unités prépiémontaises (et nappe de la Brèche des Préalpes) ; 10. Zone piémontaise ("Pays des Schistes lustrés") ; 11. Massifs cristallins internes sous la zone piémontaise ; 12. Flyschs allochtones et nappes ligures de l'Apennin ; 13. Unités ? austroalpines ? ; 14. Zone du Canavese ; 15. Cristallin insubrien (sud-alpin) ; 16. Chevauchement majeur ; 17. Limite d'unité tectonique ; 18. Frontière franco-italienne et franco-suisse ;

Ba. Barcelonnette (fenêtre de) ; Br. Briançon ; C.T. Col de Tende (unité parautochtone du) ; F. Furfande (klippe de Nisch de) ; P. Parpaillon (massif du) ;

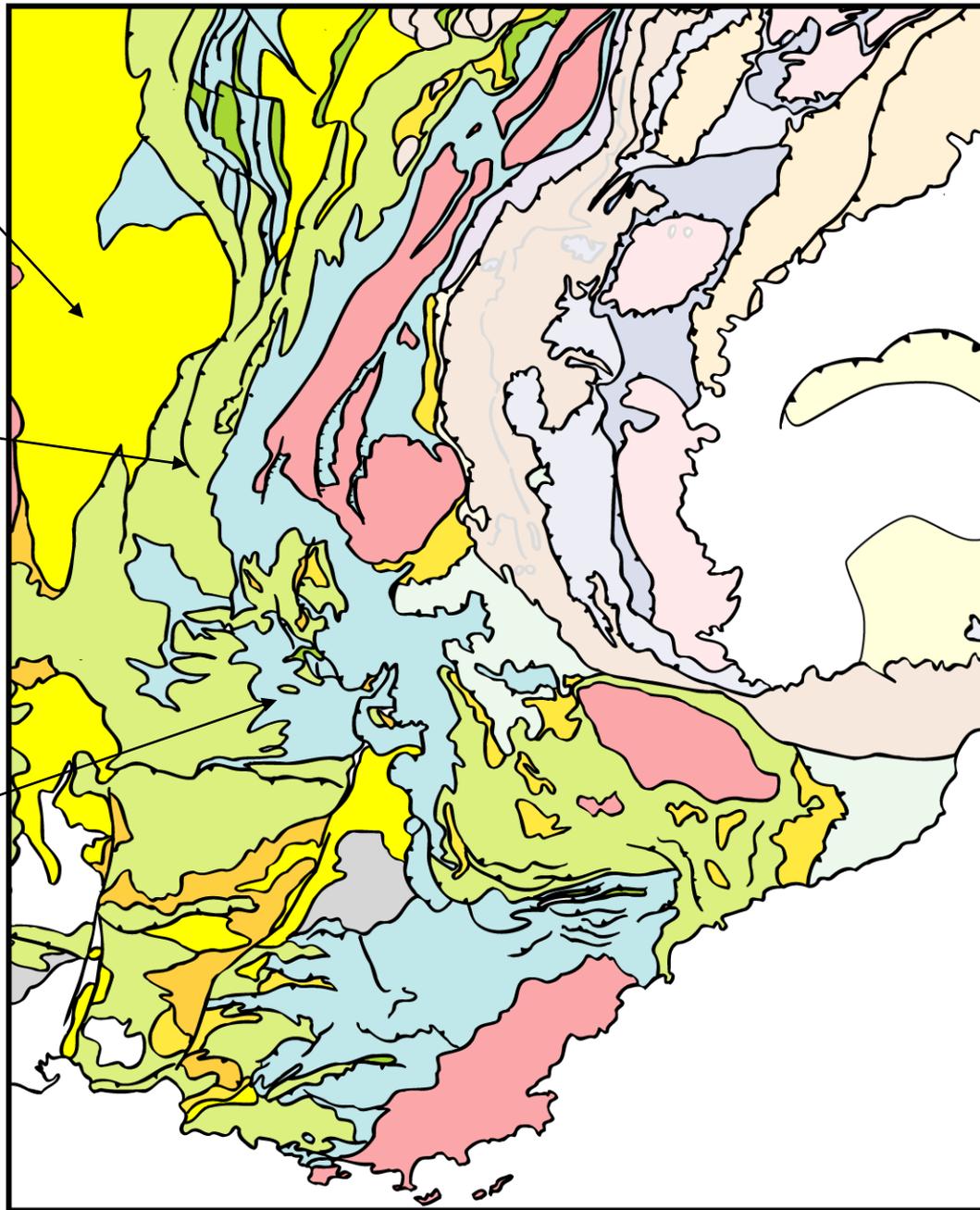
Le domaine Dauphinois

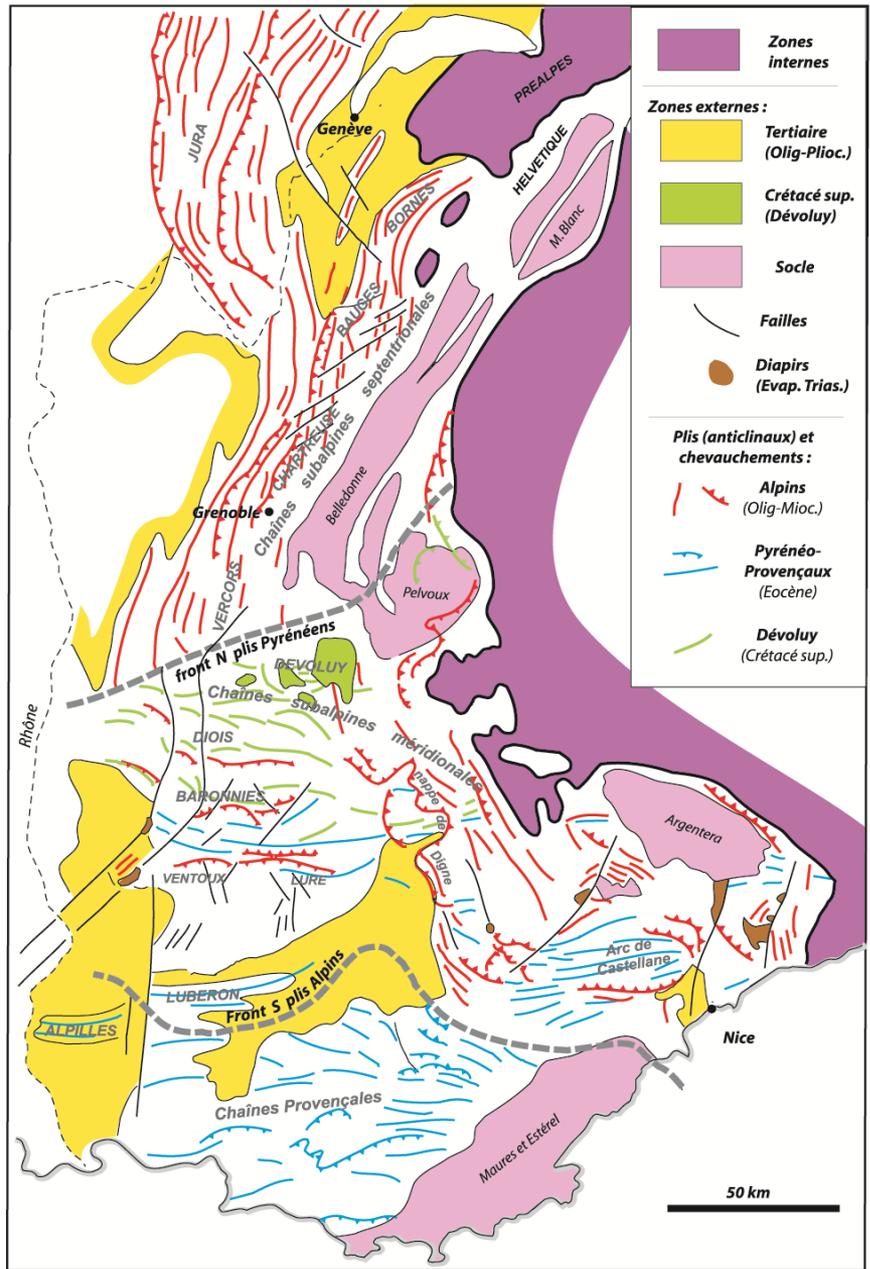


Bassin
d'avant-pays de
Valence

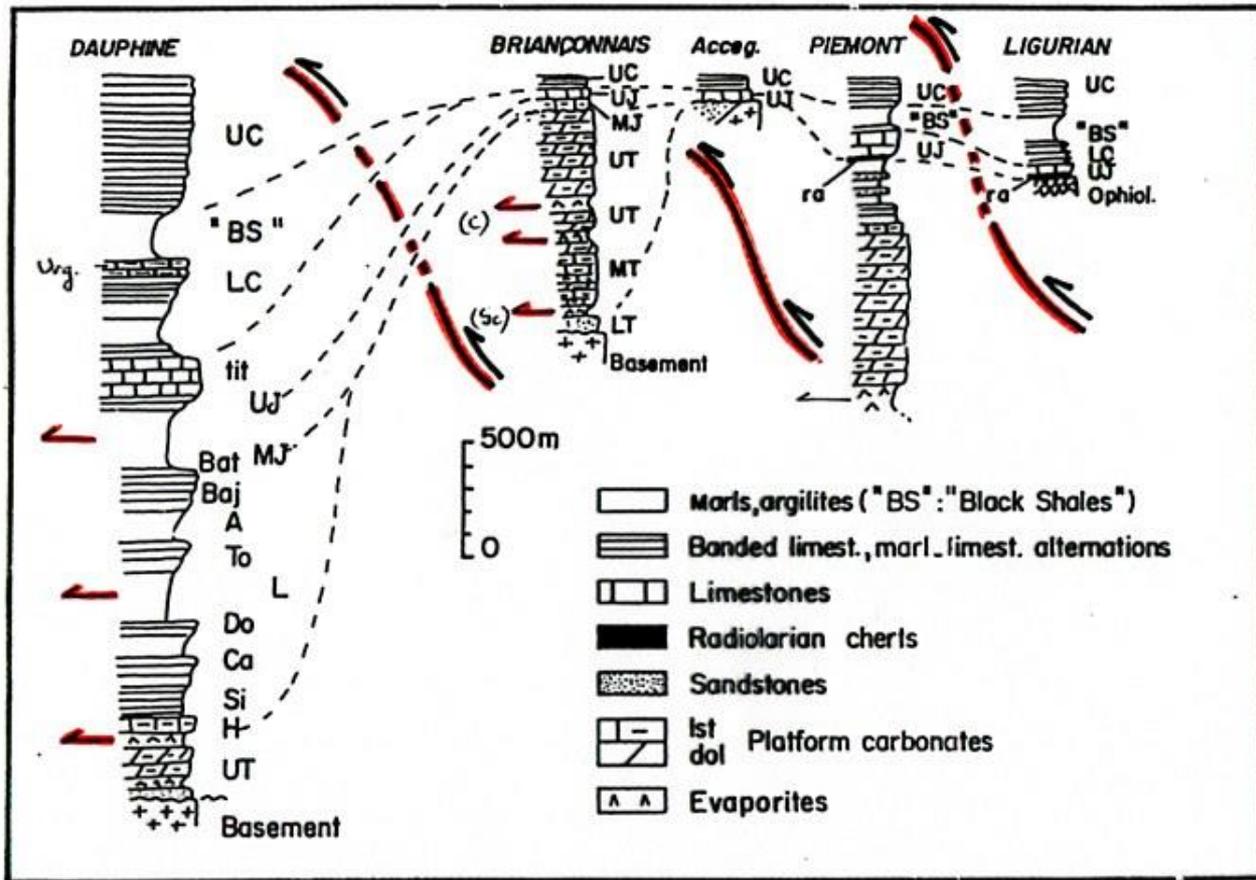
Chaînes
Subalpines
Septentrionales
(Vercors)

Chaînes
Subalpines
Méridionales
(Diois)





(Agard et Lemoine, 2003)

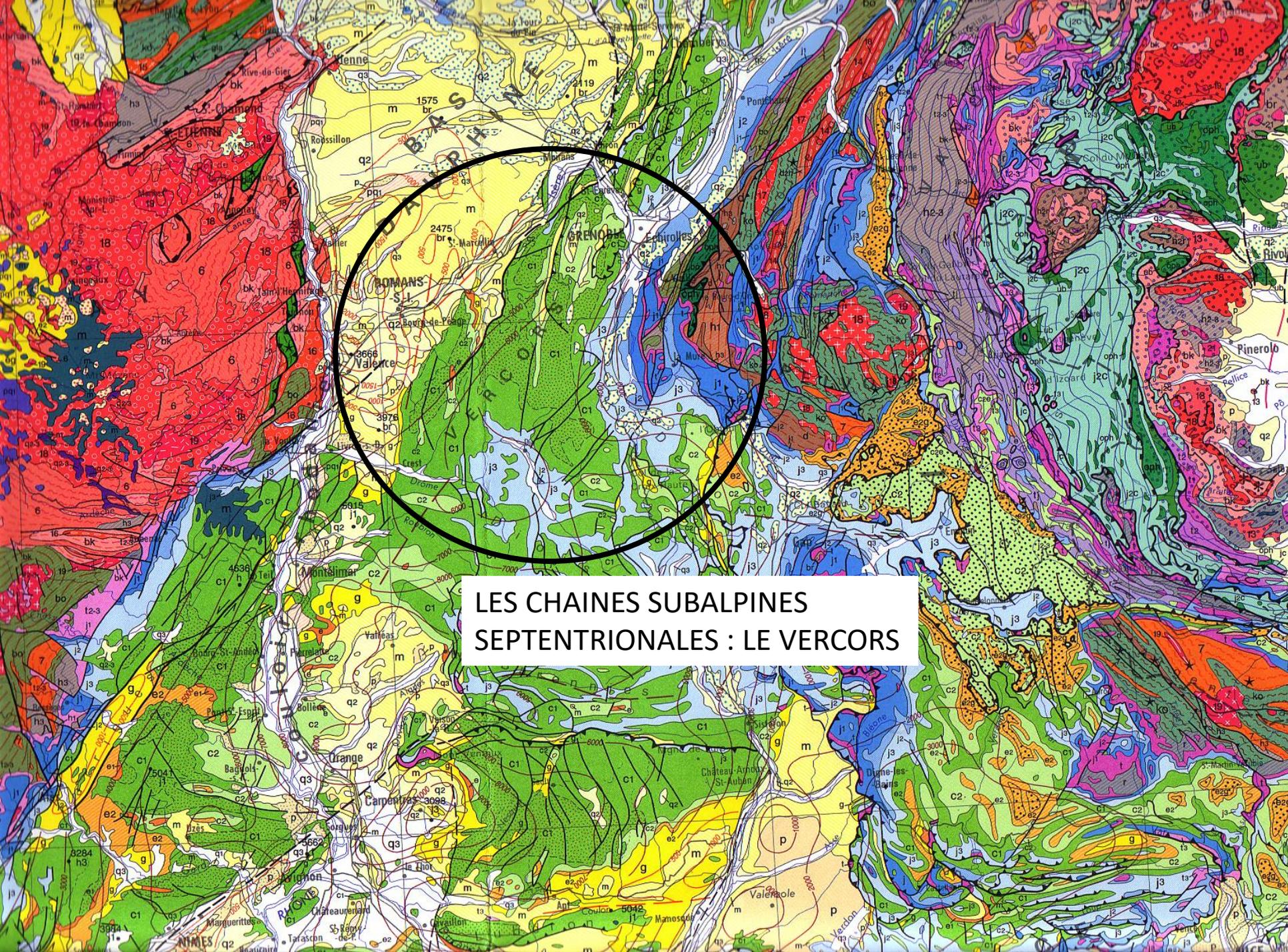


Simplified stratigraphic columns of the main types of sedimentary series in the Western Alps.

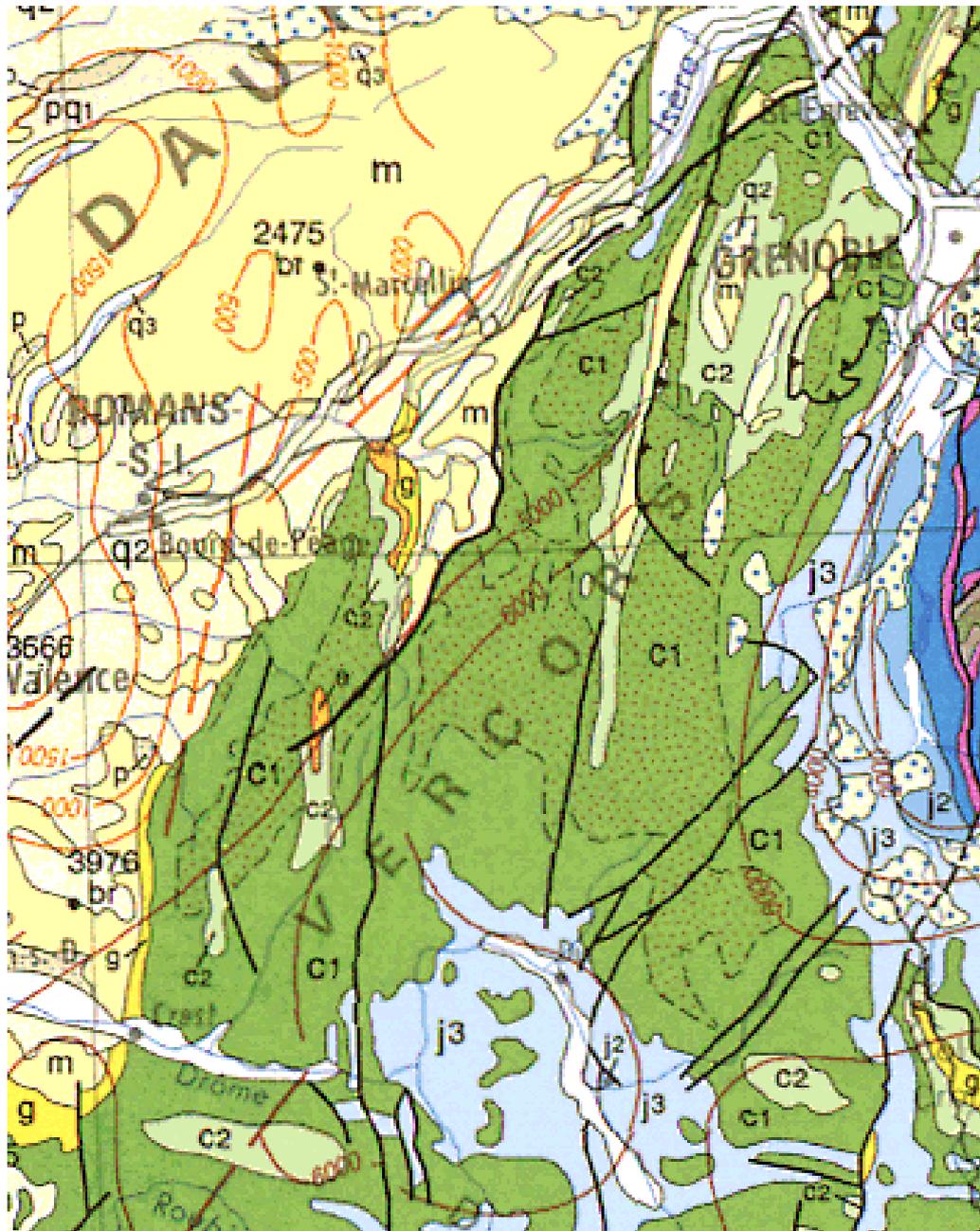
= Méozoïque

(Lemoine et al., 2006)

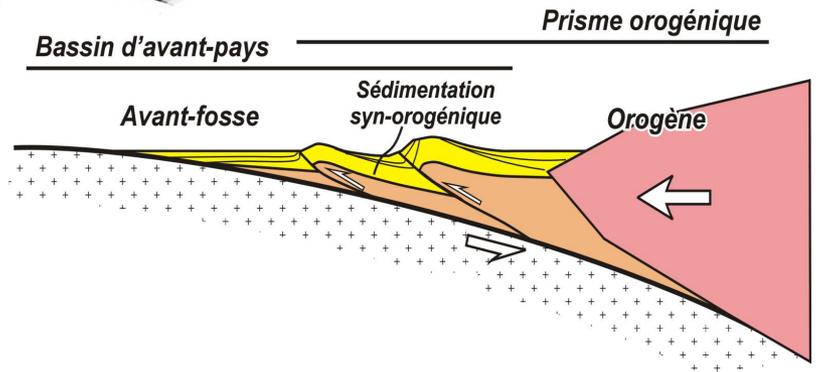
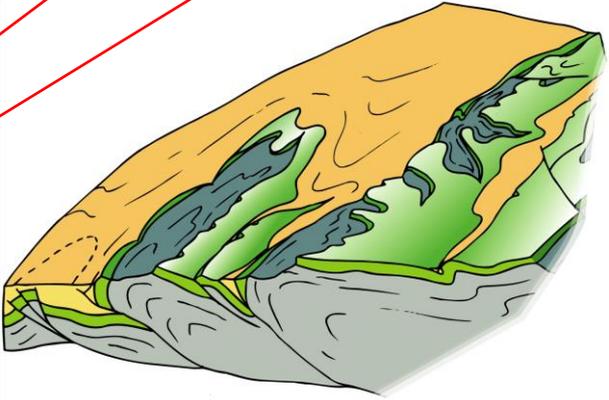
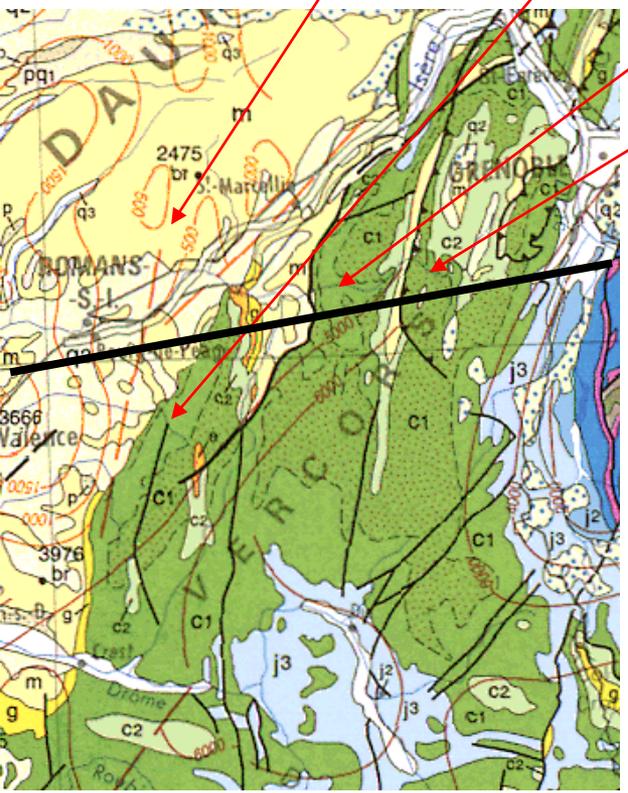
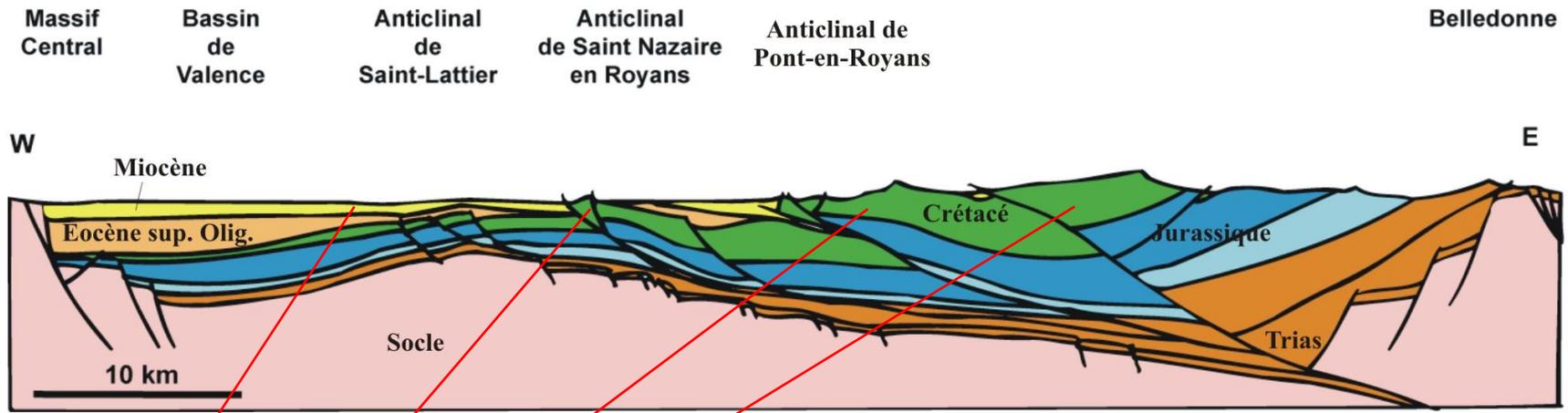
Un exemple de chaîne subalpine :
La chaîne plissée d'avant-pays du Vercors



LES CHAINES SUBALPINES
SEPTENTRIONALES : LE VERCORS

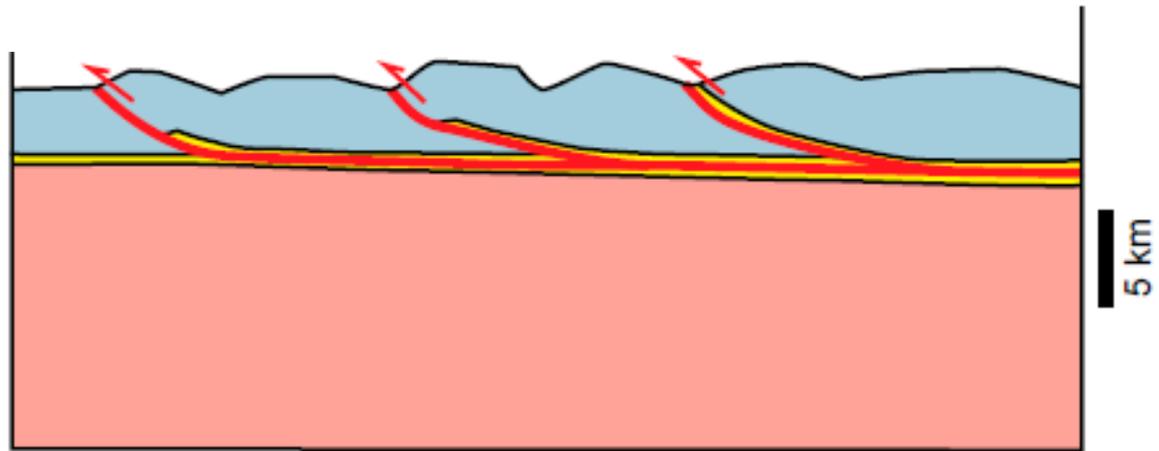


VERCORS

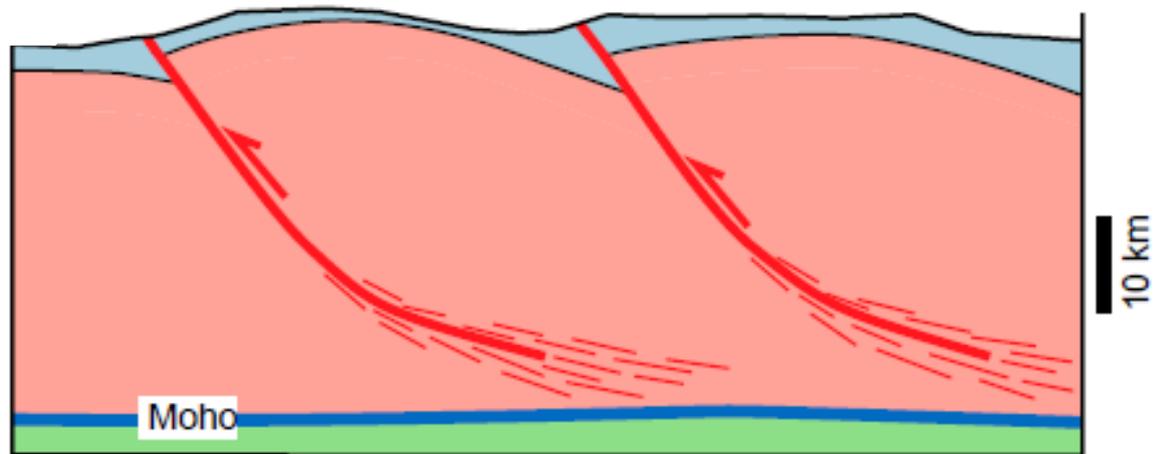


(Pfiffner, 2017)

Thin-skinned style

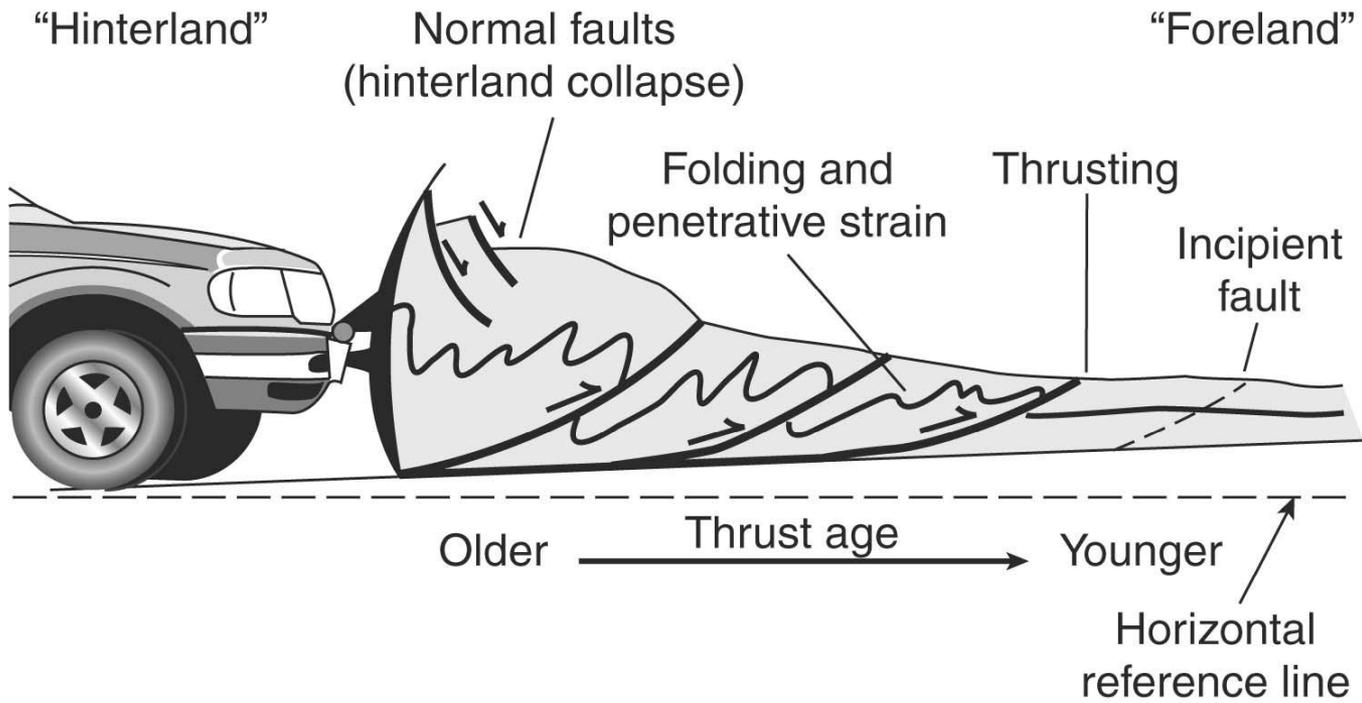


Thick-skinned style

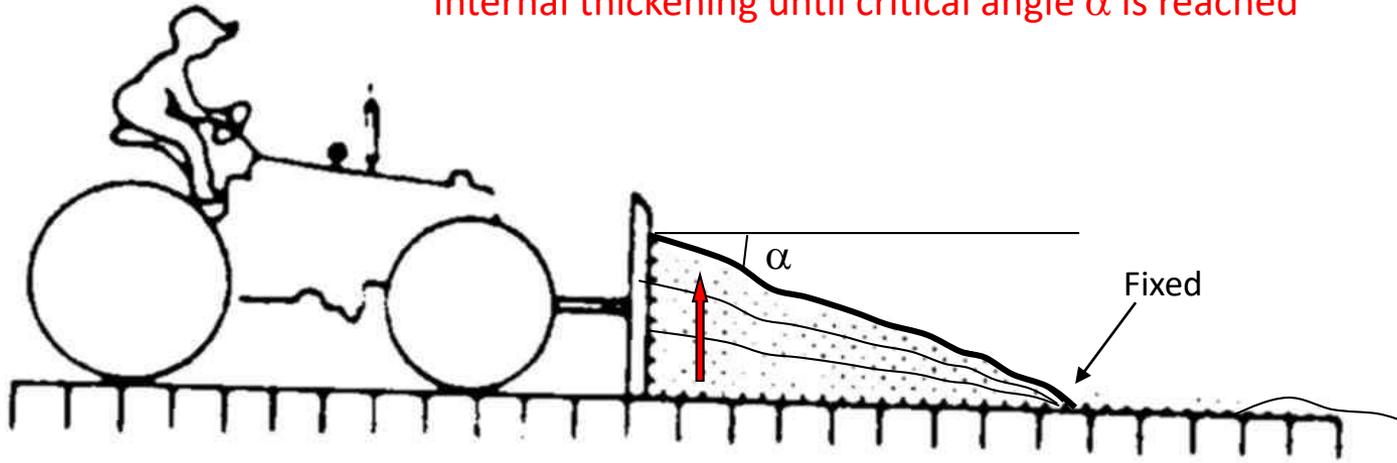


Le Vercors :
une chaîne de couverture Mio-Pliocène
décollée au niveau du Lias...

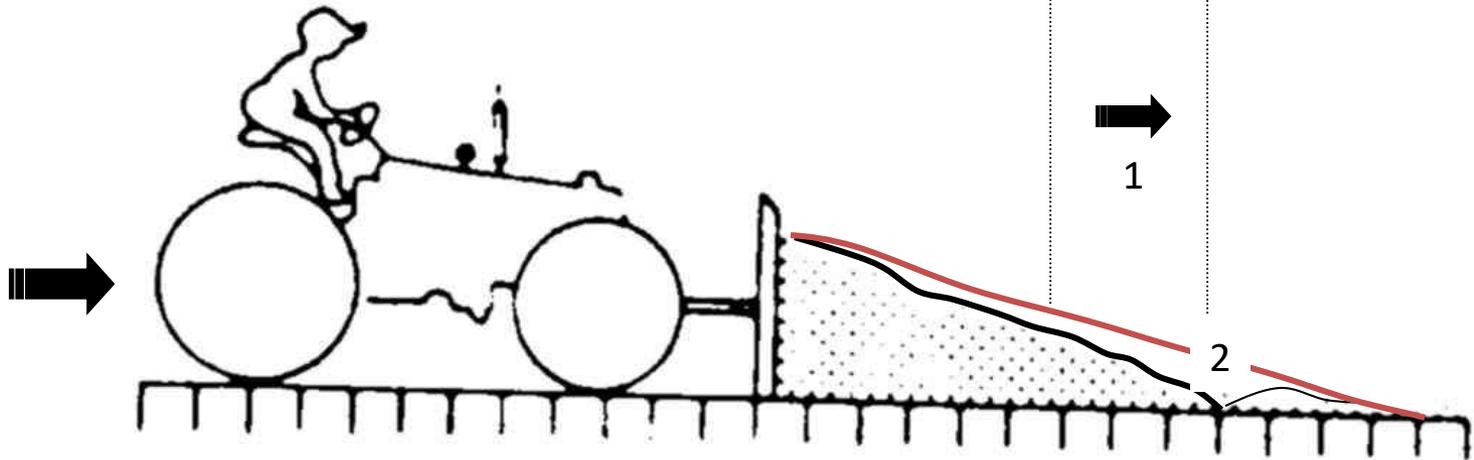
... analogue à un prisme d'accrétion
sédimentaire des zones de subduction ...



Internal thickening until critical angle α is reached



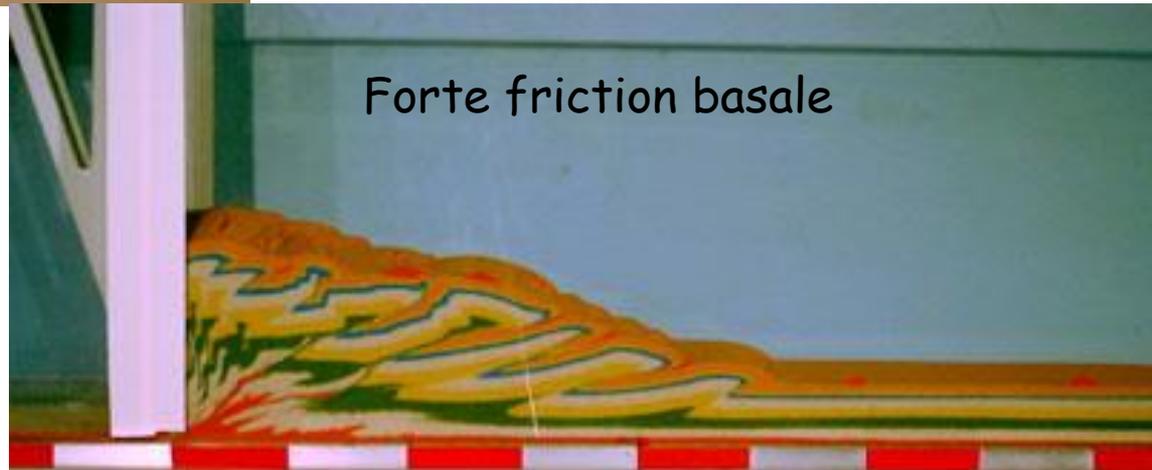
1. Basal sliding without internal thickening, then
2. New snow is incorporated in the wedge, α is lowered, then
3. The wedge will deform internally until α is reached again, and so on



Faible friction basale



Forte friction basale





| B

| A

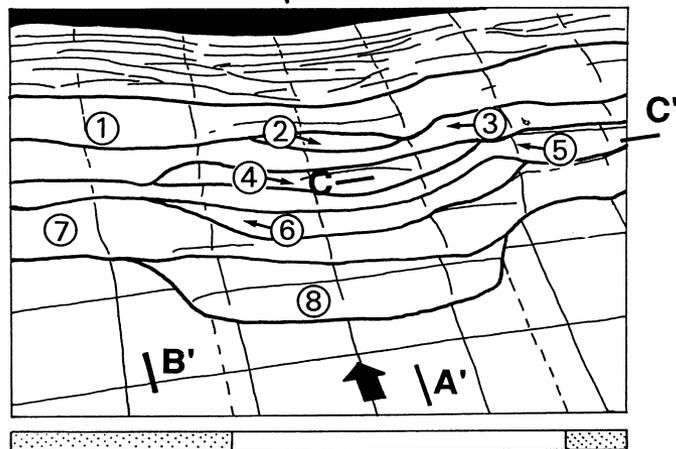
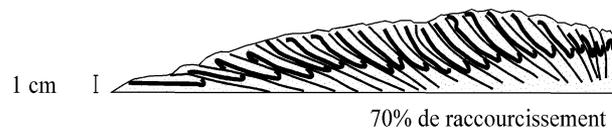
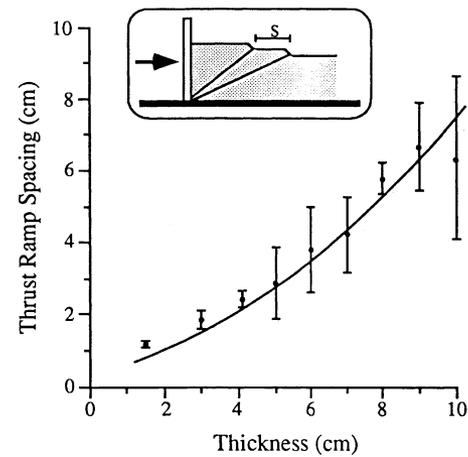
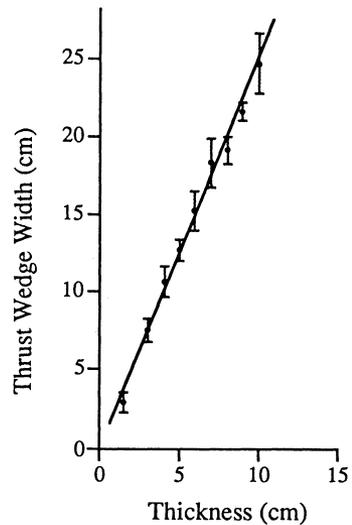
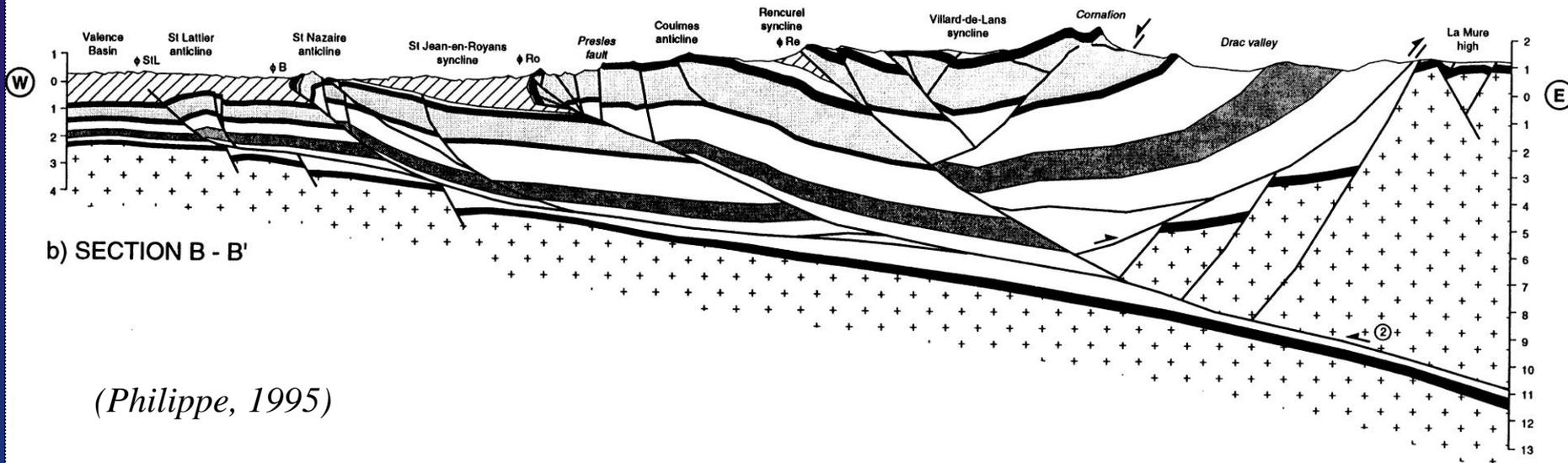
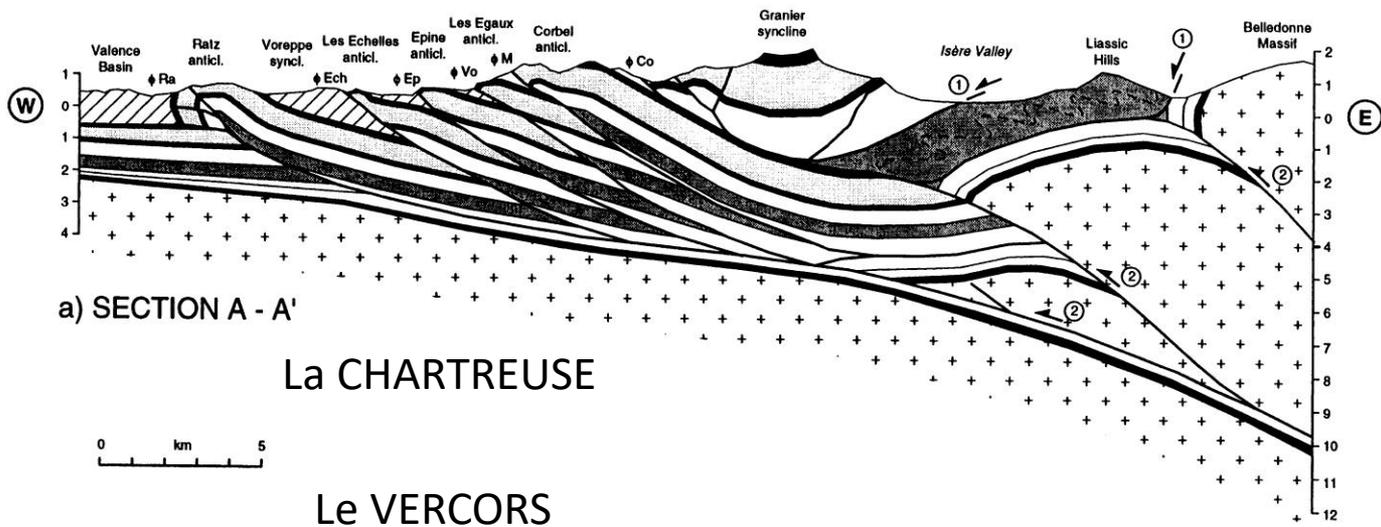
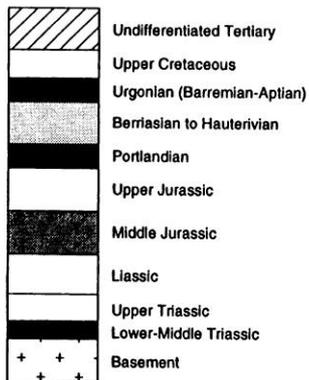


Fig. 12. The kinematics of thrust propagation during the final stage of shortening.

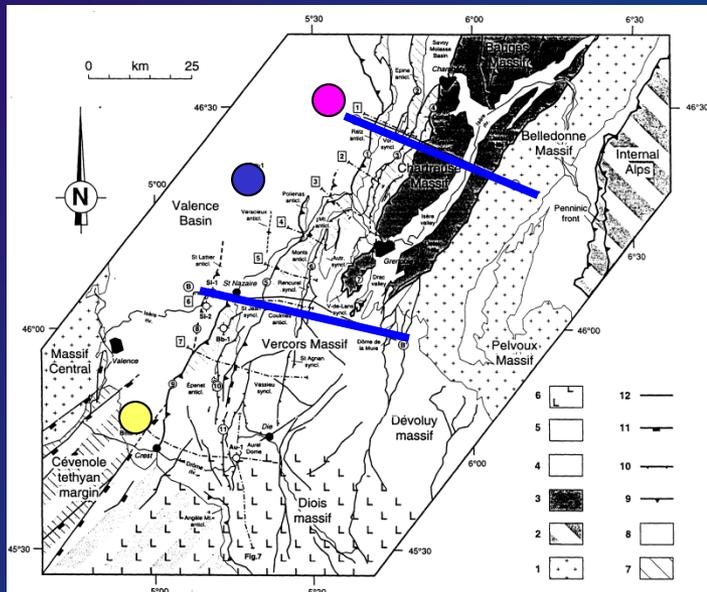


3 cm |

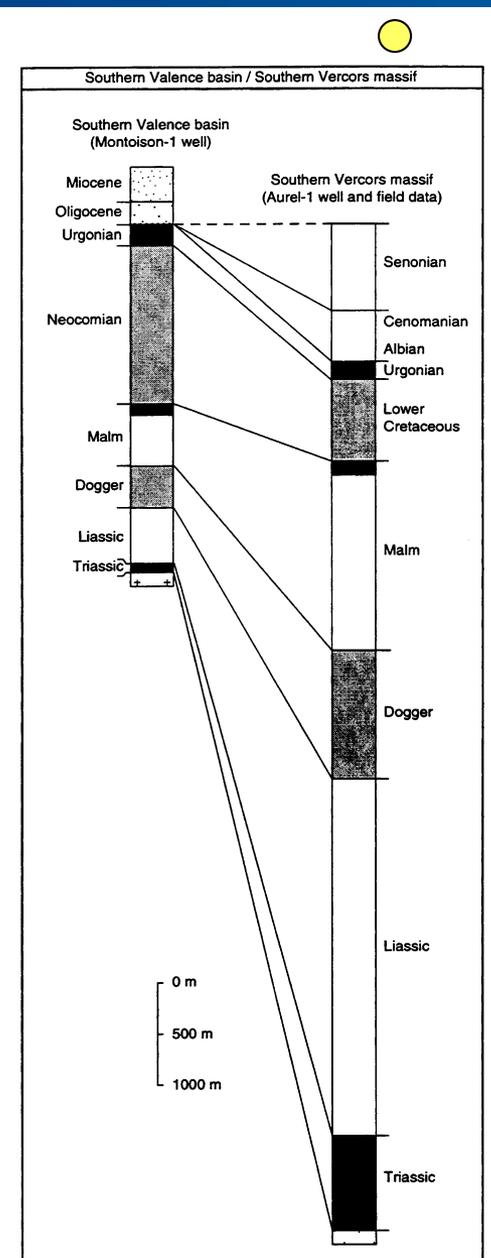
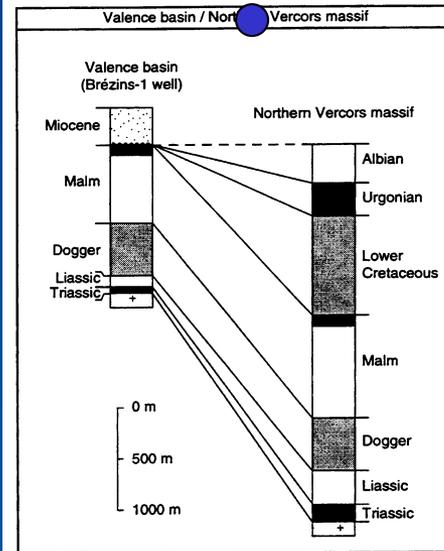
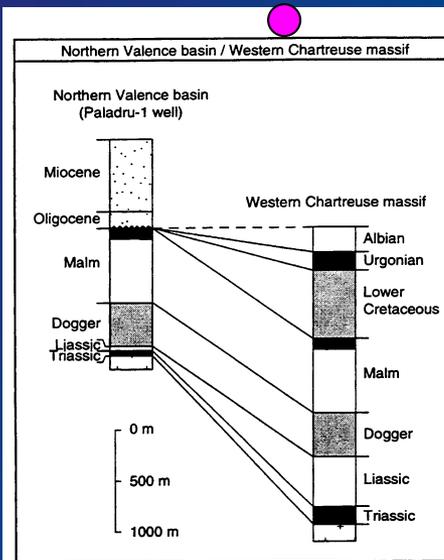




Epaisseur de la couverture sédimentaire de la Chartreuse au Vercors



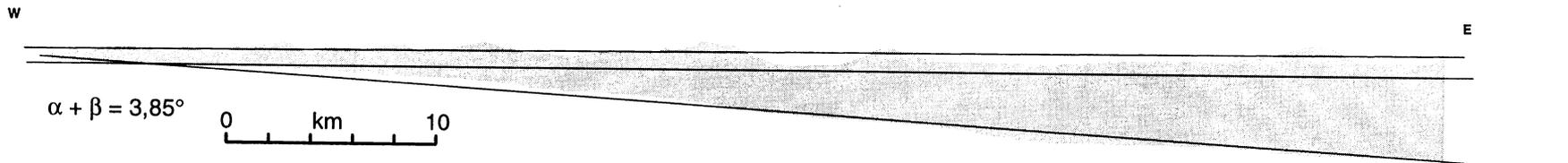
(Philippe, 1995)



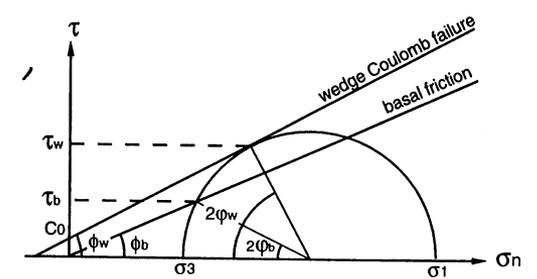
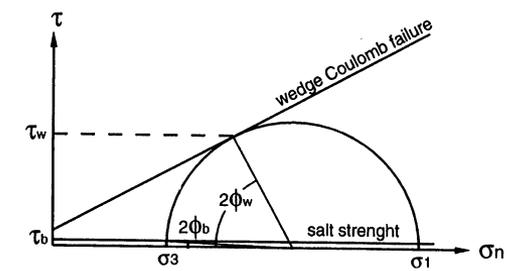
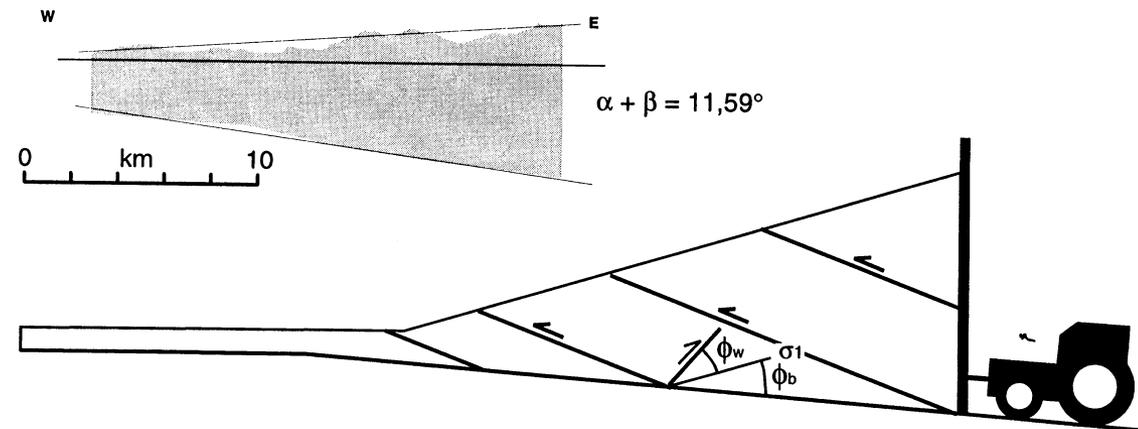
Interprétation Jura (ou Vercors)/Chartreuse en termes de prisme critique (rôle de la friction basale)

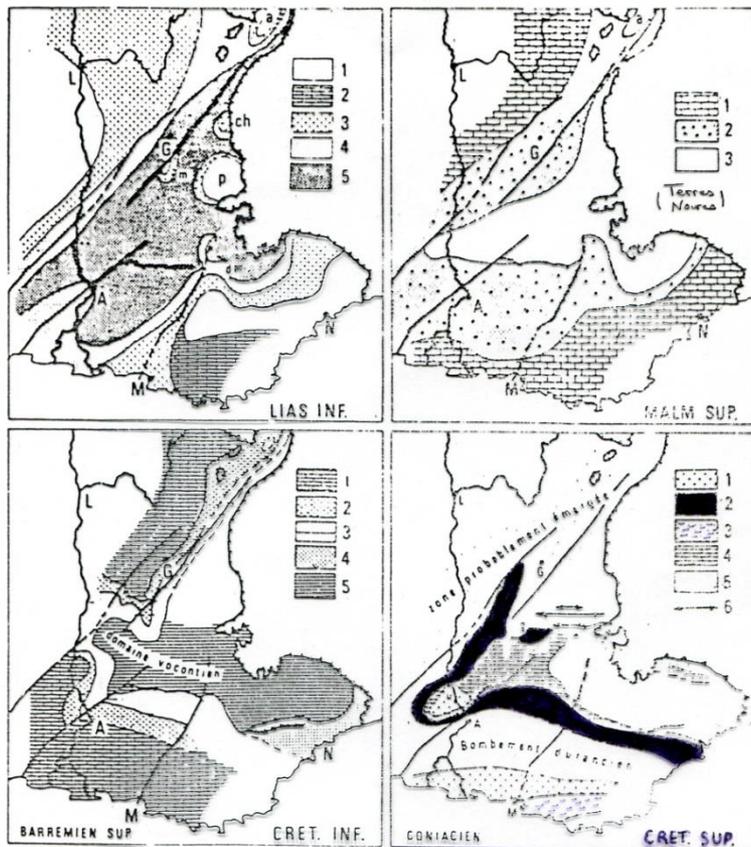
(a) Jura fold-and-thrust belt and Molasse Basin: / Vercors

(Philippe, 1995)



(b) Chartreuse fold-and-thrust belt:





Cartes paléogéographiques simplifiées au Sud-Est de la France.

Sur toutes les cartes, on a indiqué un certain nombre de grandes failles qui ont commandé la paléogéographie pendant tout le Mésozoïque et ont, localement au moins, rejoué au moment du plissement alpin. Ce sont, du NW au SE, la faille d'Alès-Marsanne, la faille de la Cléry et du synclinal médian de Belledonne, la faille de Nîmes, et la faille de la Basse-Durance (ou d'Aix-en-Provence).

En outre ont été indiqués, à titre de repère topographique et parce qu'ils raccourcissent l'aire paléogéographique, les chevauchements de Ventoux-Lure (à gauche) et de Castellane (à droite).

A : Avignon, G : Grenoble, L : Lyon, M : Marseille, N : Nice.

Lias inférieur : 1. Zones émergées; 2. Dolomies intertidales à supratidales; 3. Faciès zongènes peu épais; 4. Faciès calcaréo-marneux à Céphalopodes et Gryphées (Digne); épaisseur moyenne à faible; 5. Faciès calcaréo-marneux à Céphalopodes; épaisseur forte.

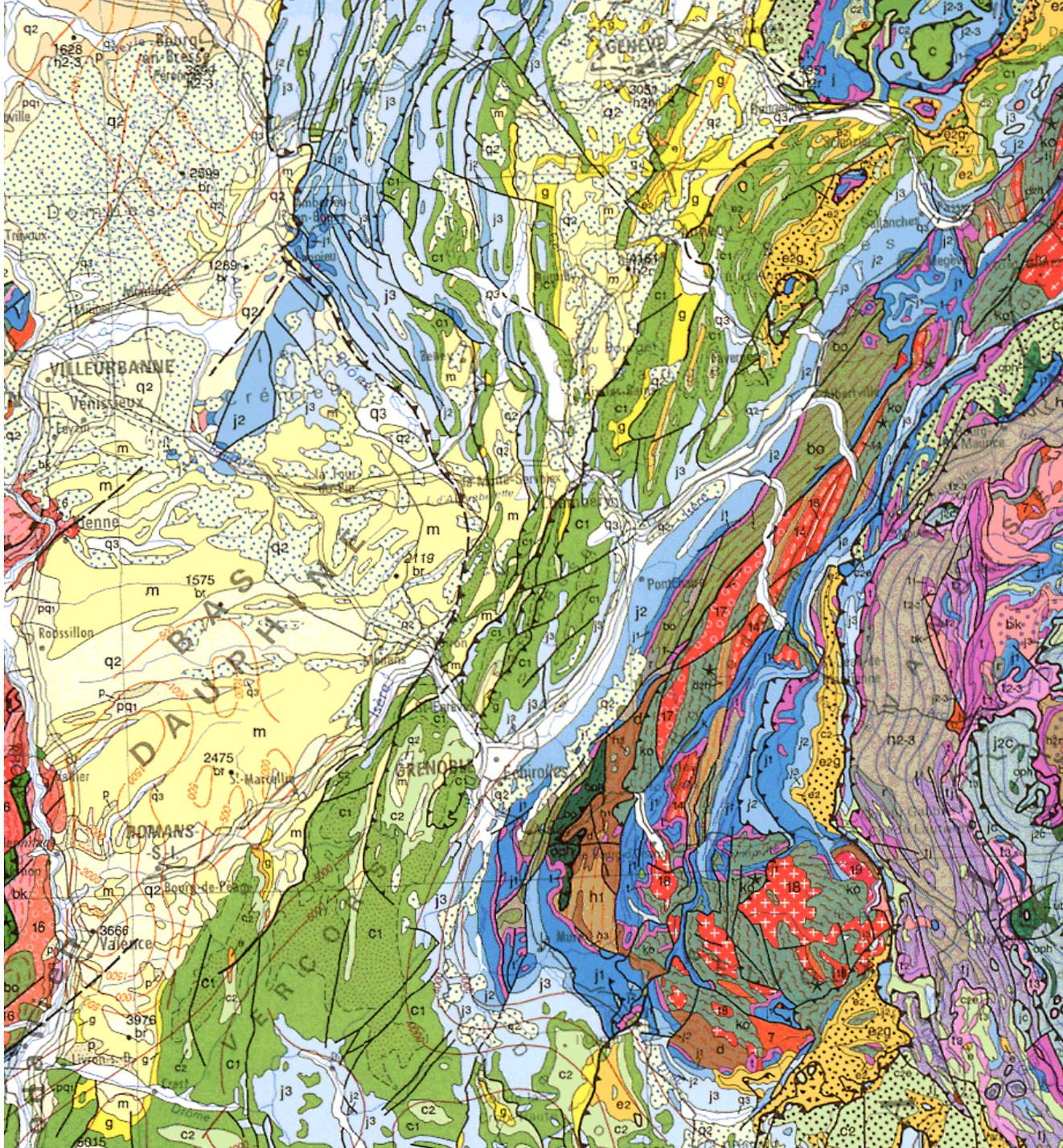
Malm supérieur : 1. Portlandien récifal, souvent dolomitisé; 2. Tithonique pélagique; 3. Id. mais faciès plus profond.

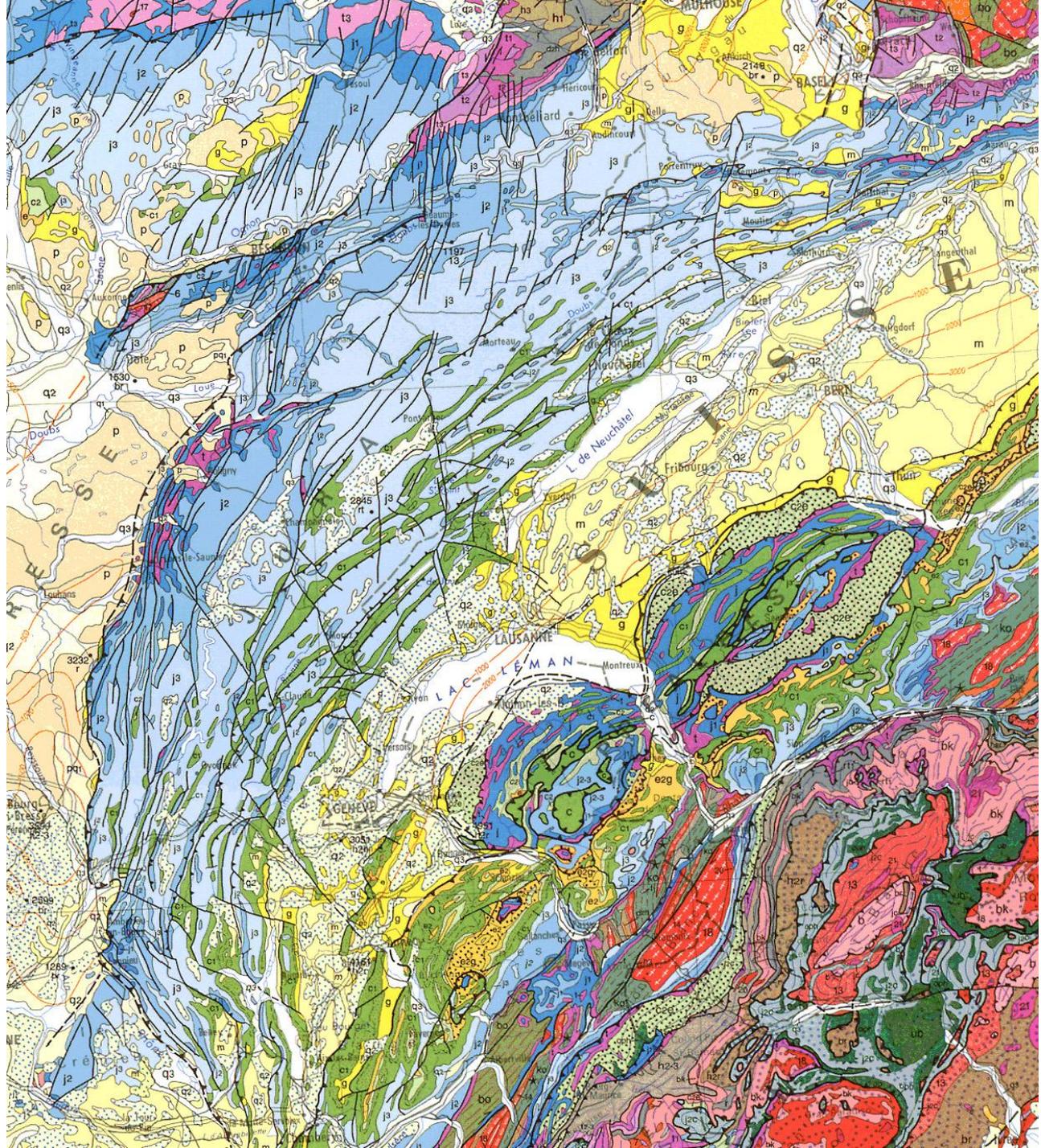
Crétacé inférieur (Barremien supérieur) : 1, 2. Calcaires à Rudistes; 2. Calcaires à débris; 3. marnes et calcaires à spicules de Spongiaires; 4. séries minces : calcaires micritiques à Céphalopodes, glauconie, galets phosphatés et niveaux de condensation; 5. Calcaires et marnes à ammonites (faciès vocontien s.str.).

Crétacé supérieur (Coniacien) : 1. Calcaires à Rudistes (u. Uchaux); 2. Sables glauconieux souvent rubéfiés, et conglomérats (g. congl. des Cds, près Châtillon-en-Diois); 3. marnes gréseuses à brèches sédimentaires du sillon provençal; 4. Calcaires gréseux; 5. Calcaires pélagiques à Foraminifères, Céphalopodes et Inocérames; 6. Plis (Diois, Devoluy).

Le Lias d'après R. Mouterde; le Malm d'après Baudrimont et Dubois; le Crétacé inférieur d'après H. Arnaud; le crétacé supérieur d'après H. Arnaud, J. Philip et B. Porthault.

Le Jura







Jura externe =
Jura des Plateaux

Jura interne = Jura plisse

LAC LÉMAN

GENÈVE

LAUSANNE

Montreux

BASEL

BERN

DOUBES

SAVOIE

EVIAN

YVERDON

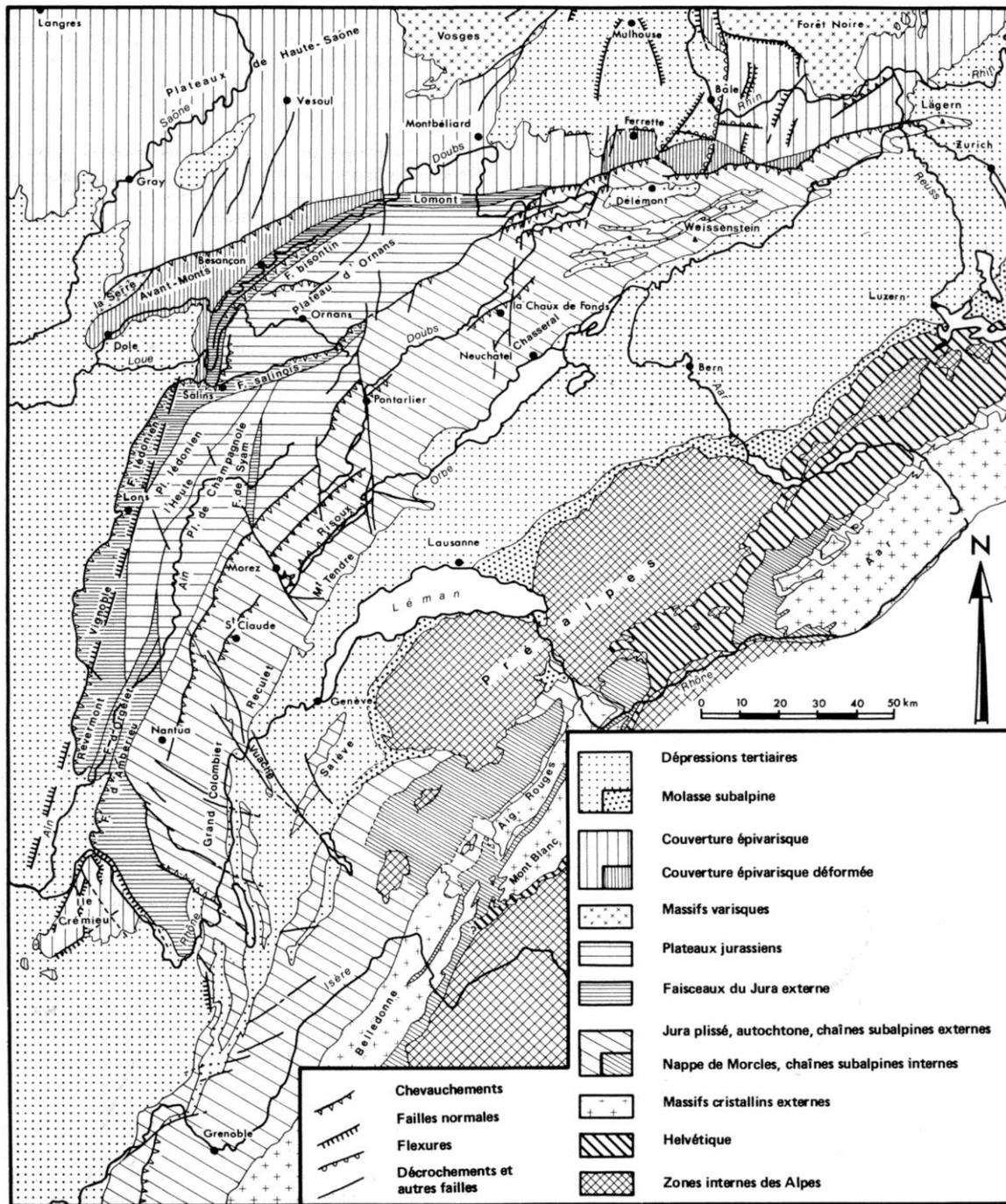
CHAM

NEUCHÂTEL

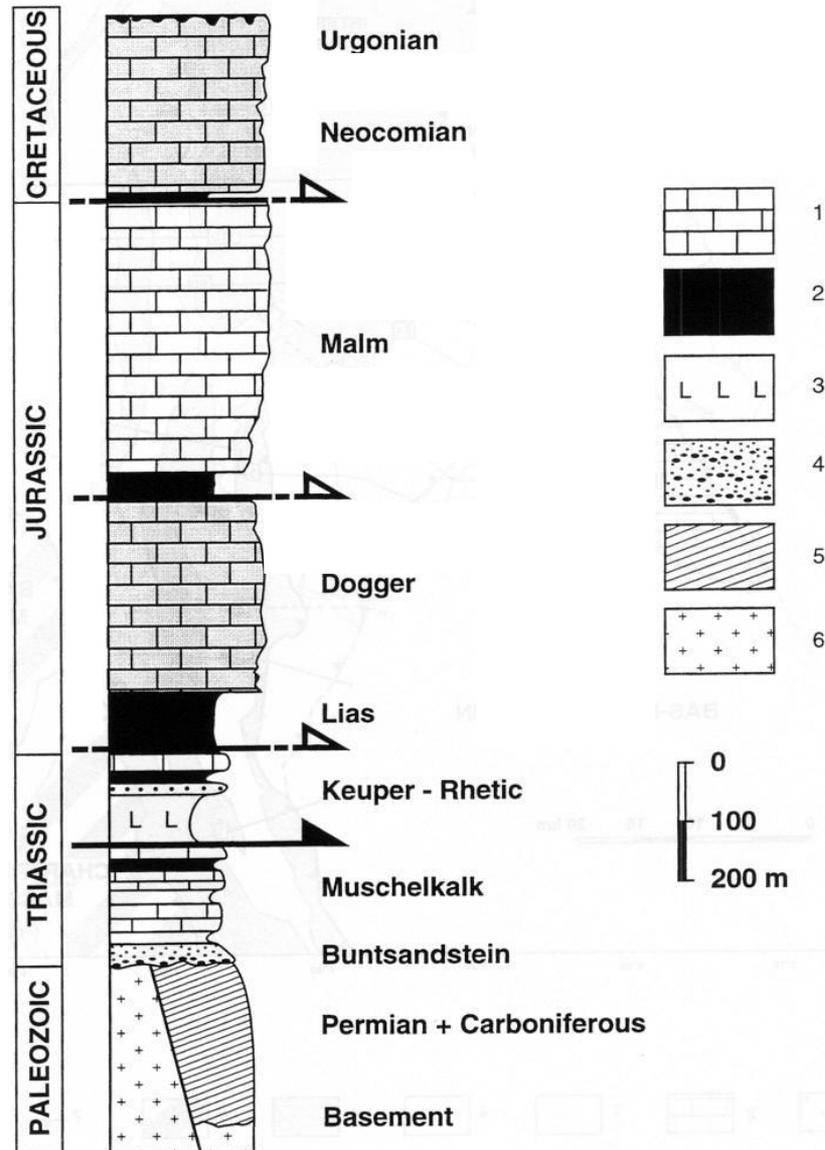
VAUD

NEUCHÂTEL

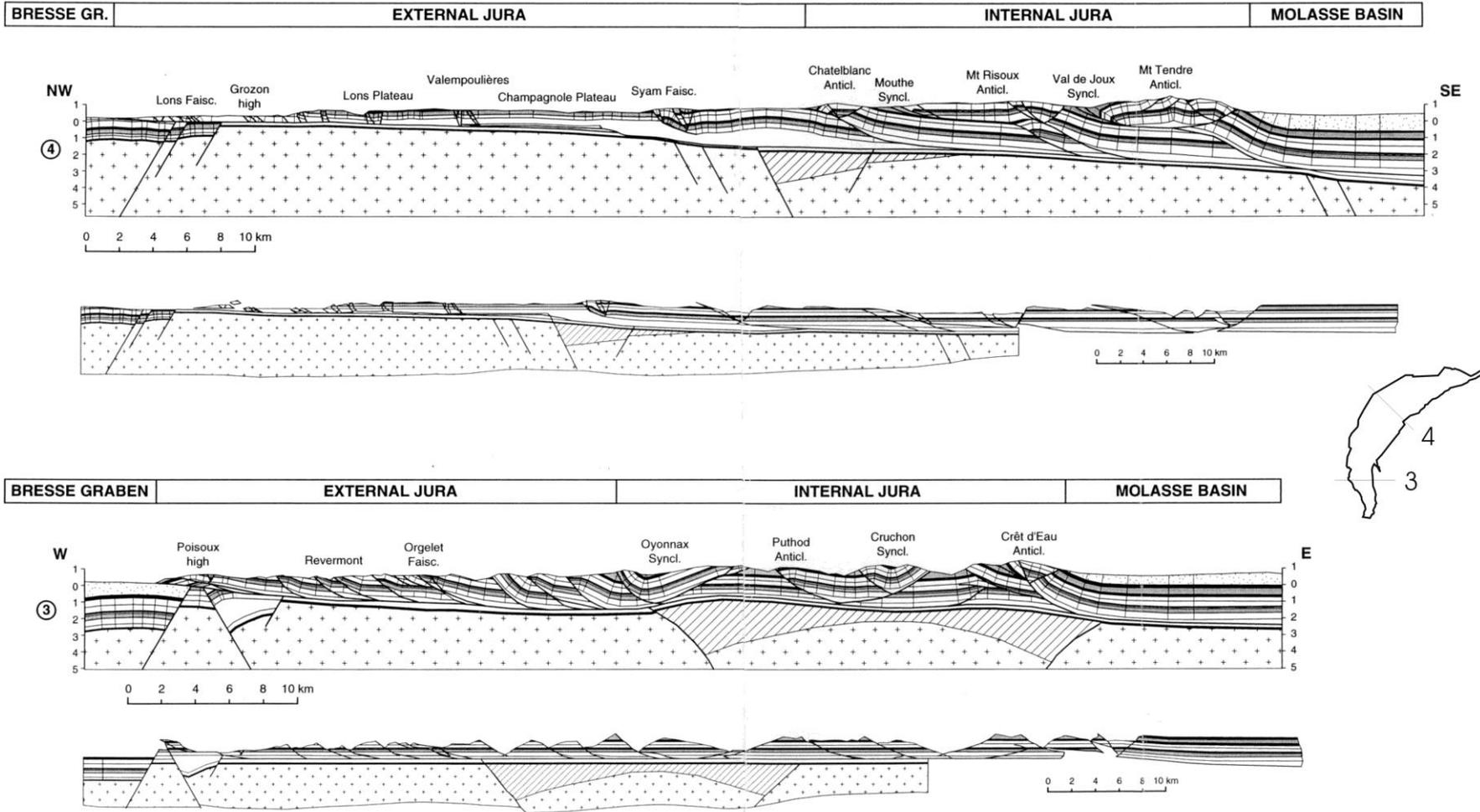
VAUD

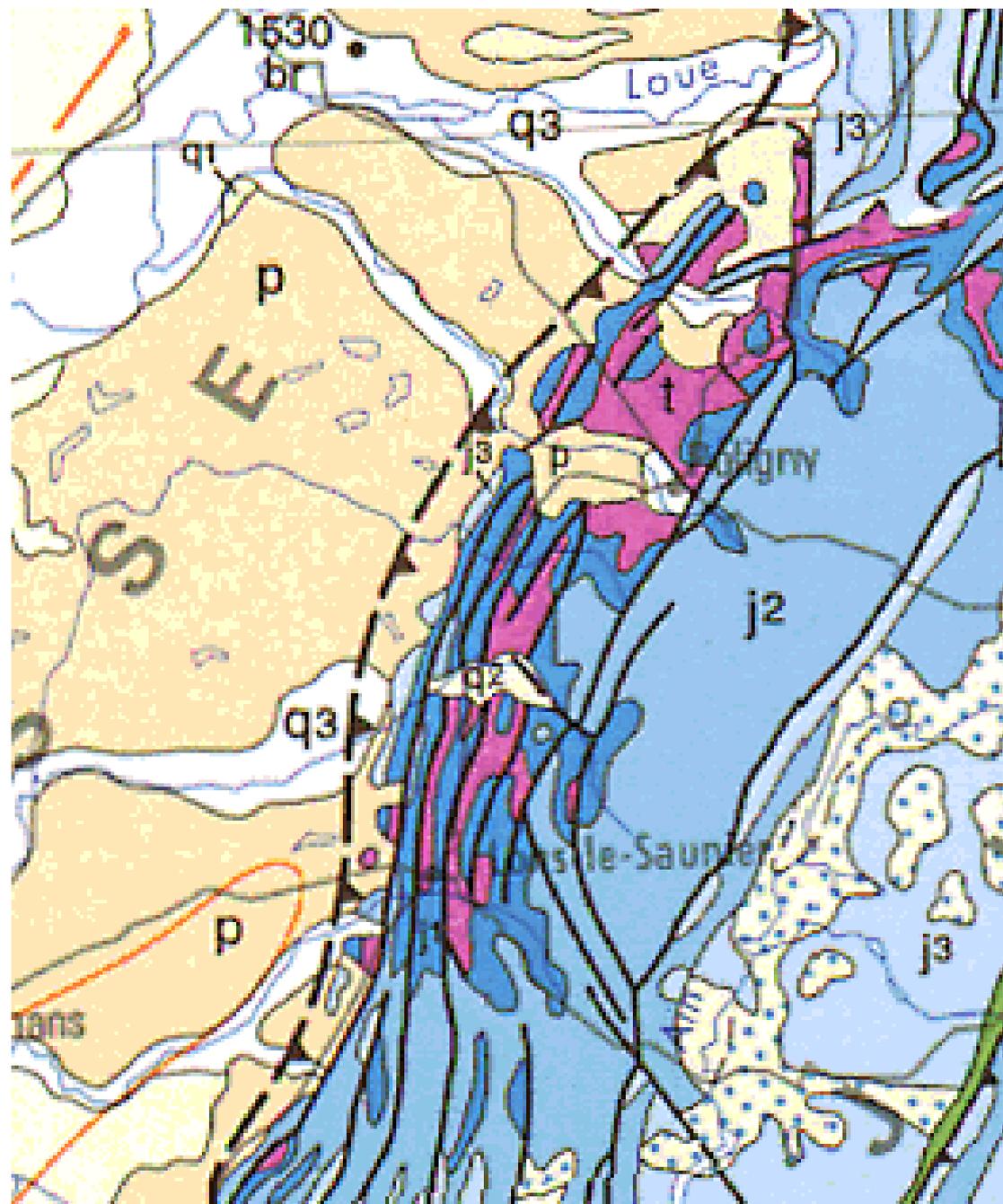


**Décollement majeur
dans le Trias**

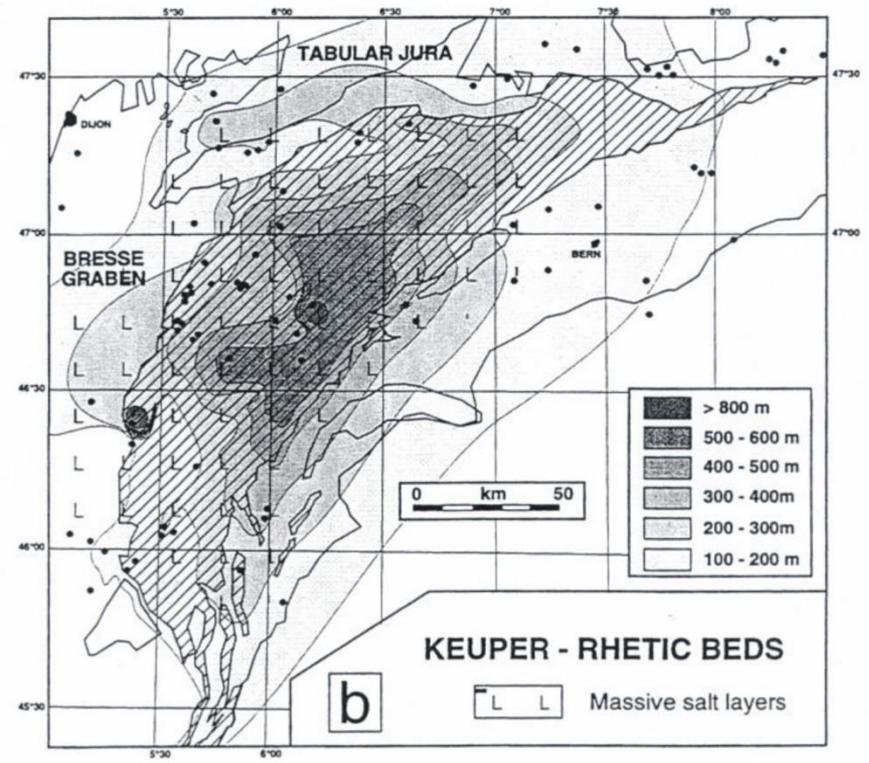
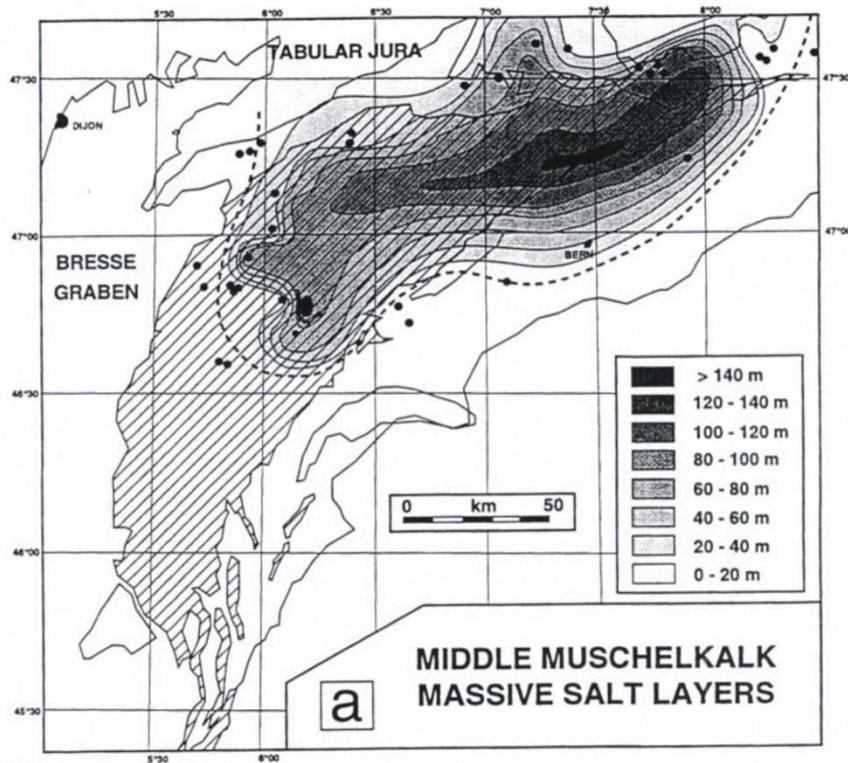


(Philippe, 1995)



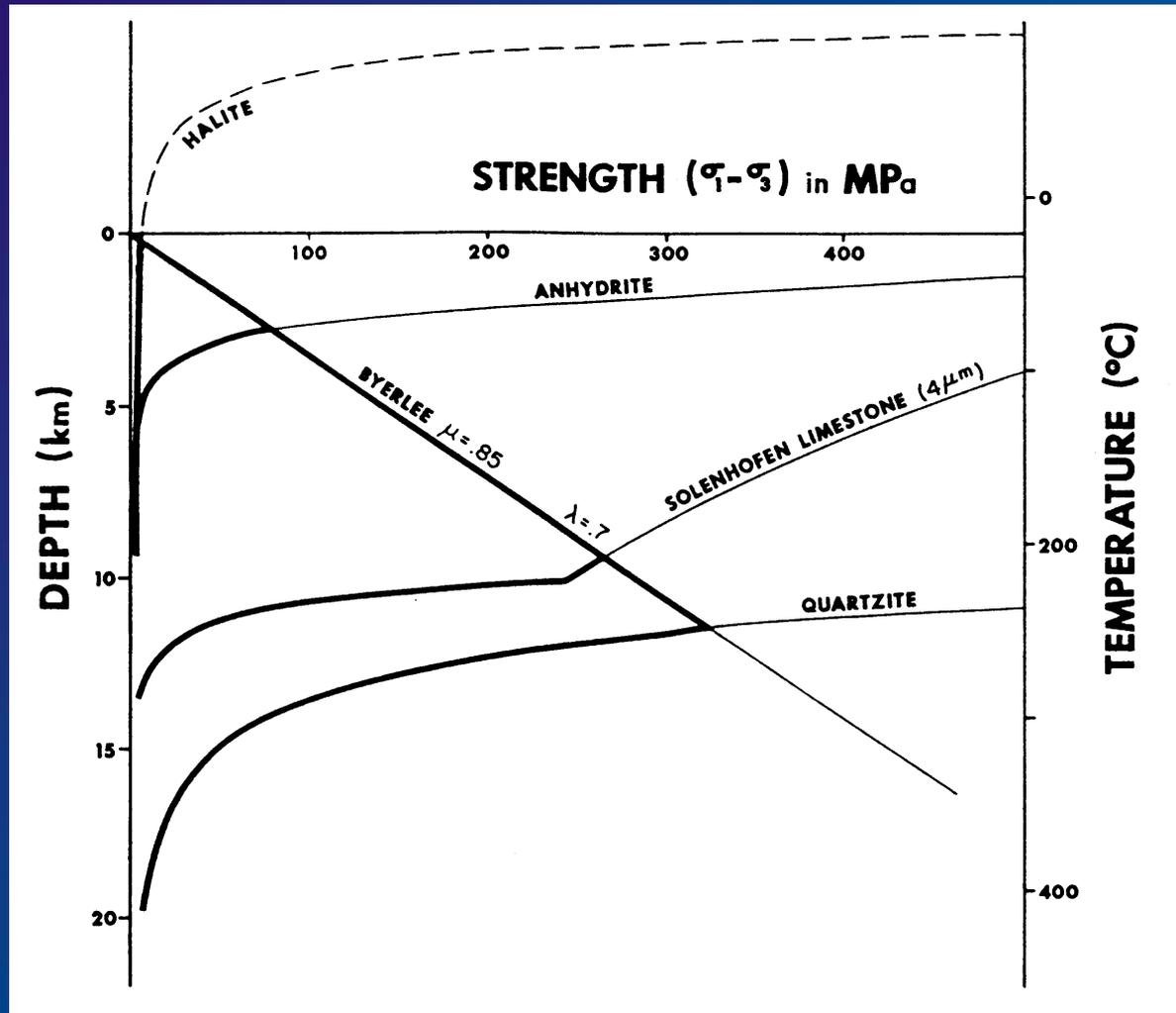


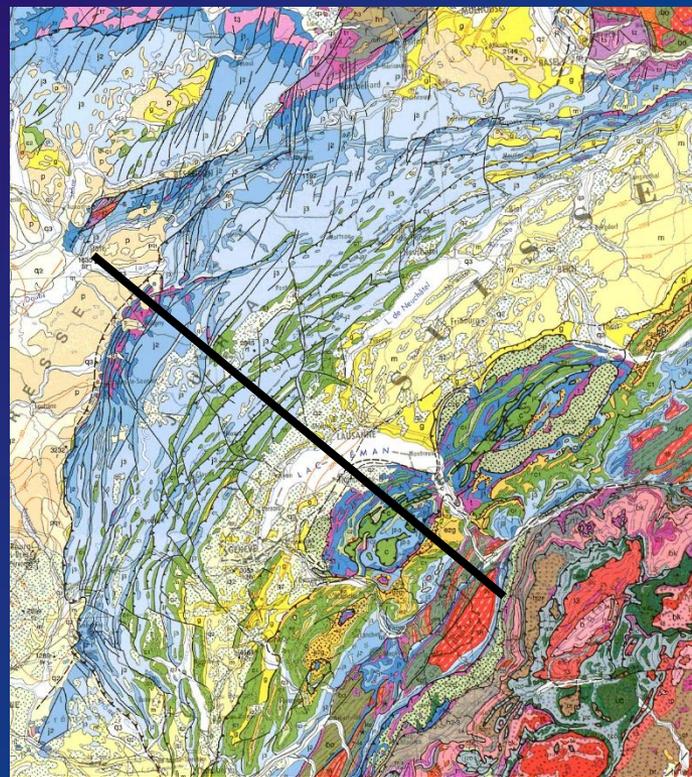
Répartition des évaporites du Trias sous le Jura



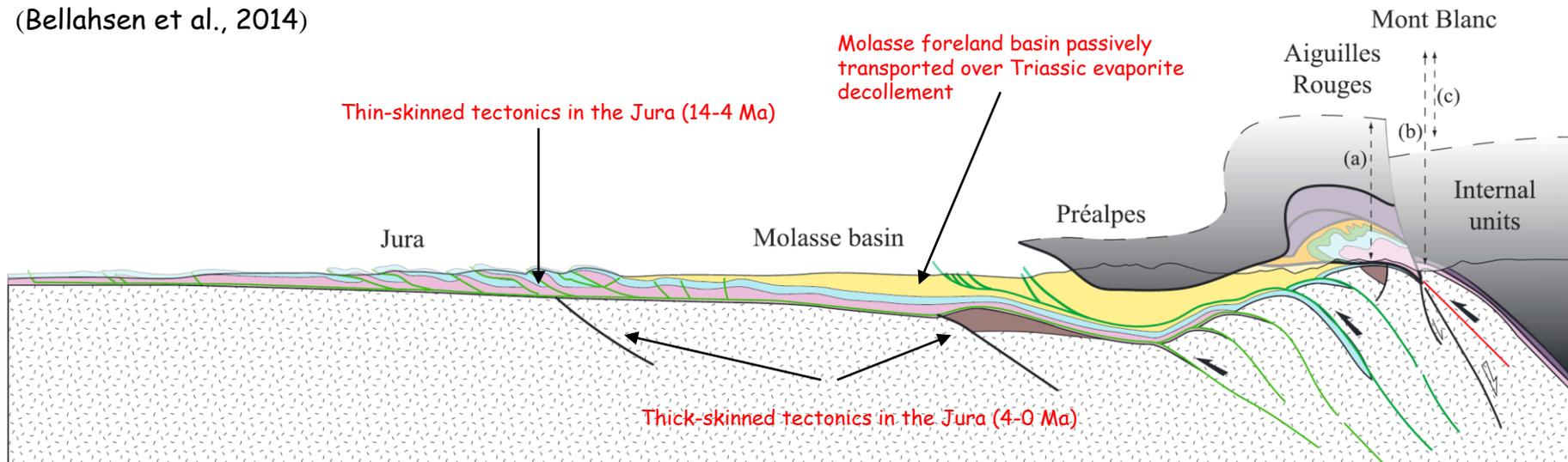
(Lienhard, 1984)

Comportement mécanique des évaporites du Trias



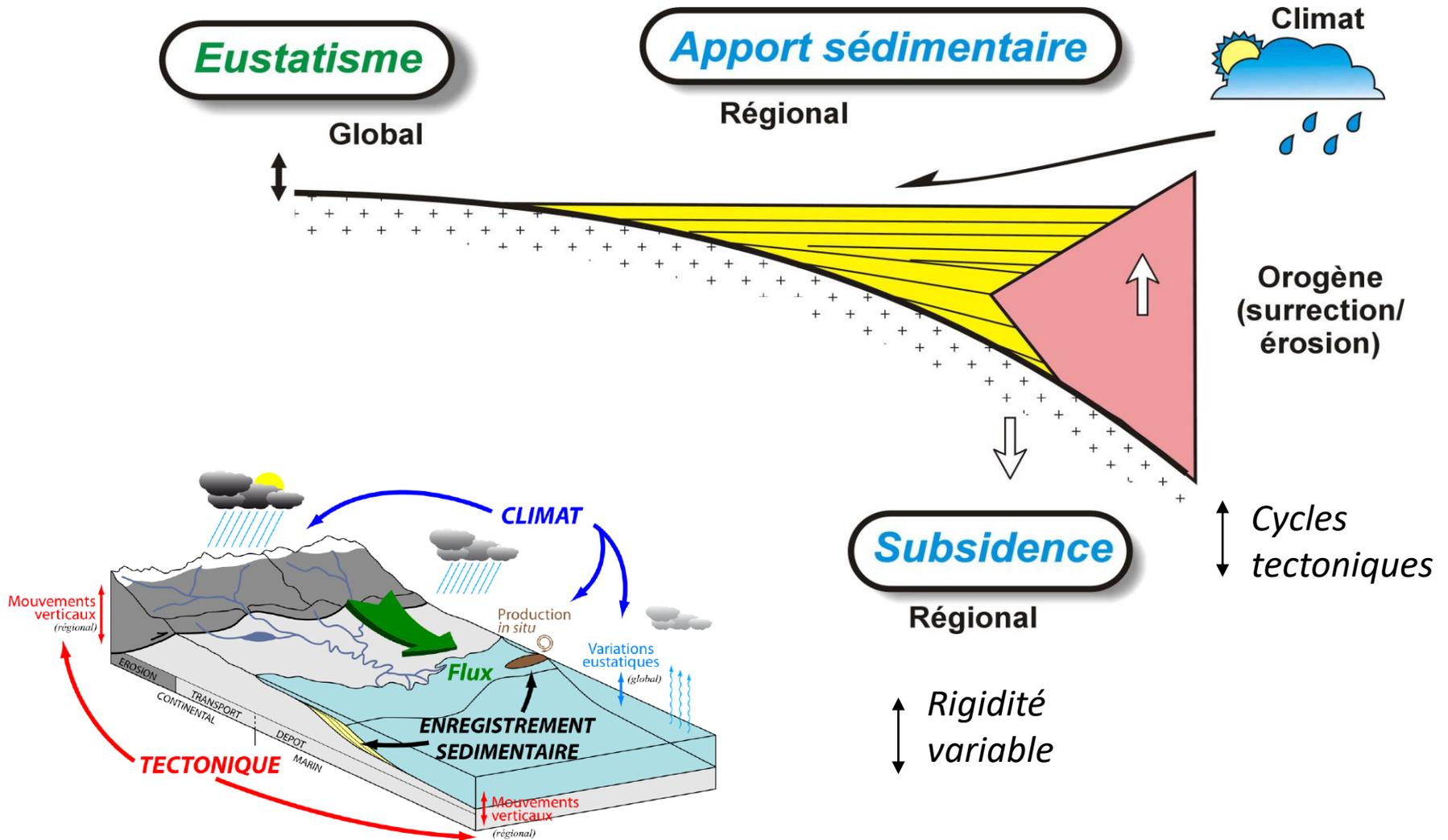


(Bellahsen et al., 2014)



Le bassin d'avant-pays

L'enregistrement sédimentaire est le résultat de l'interaction de facteurs tectoniques et eustatiques

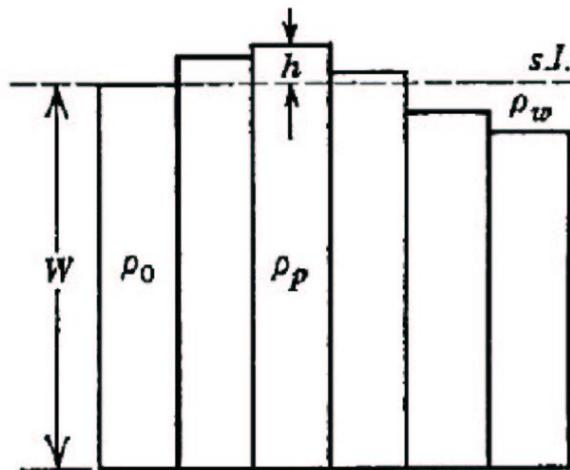


Isostasie



Pratt (1854)

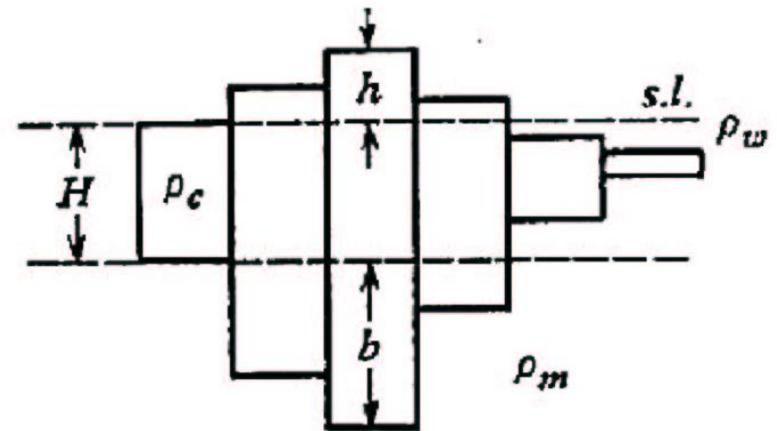
- ρ diminue si h augmente
- profondeur de compensation constante



Exemple: dorsales océaniques

Airy (1855)

- ρ constant
- profondeur de compensation augmente si h augmente

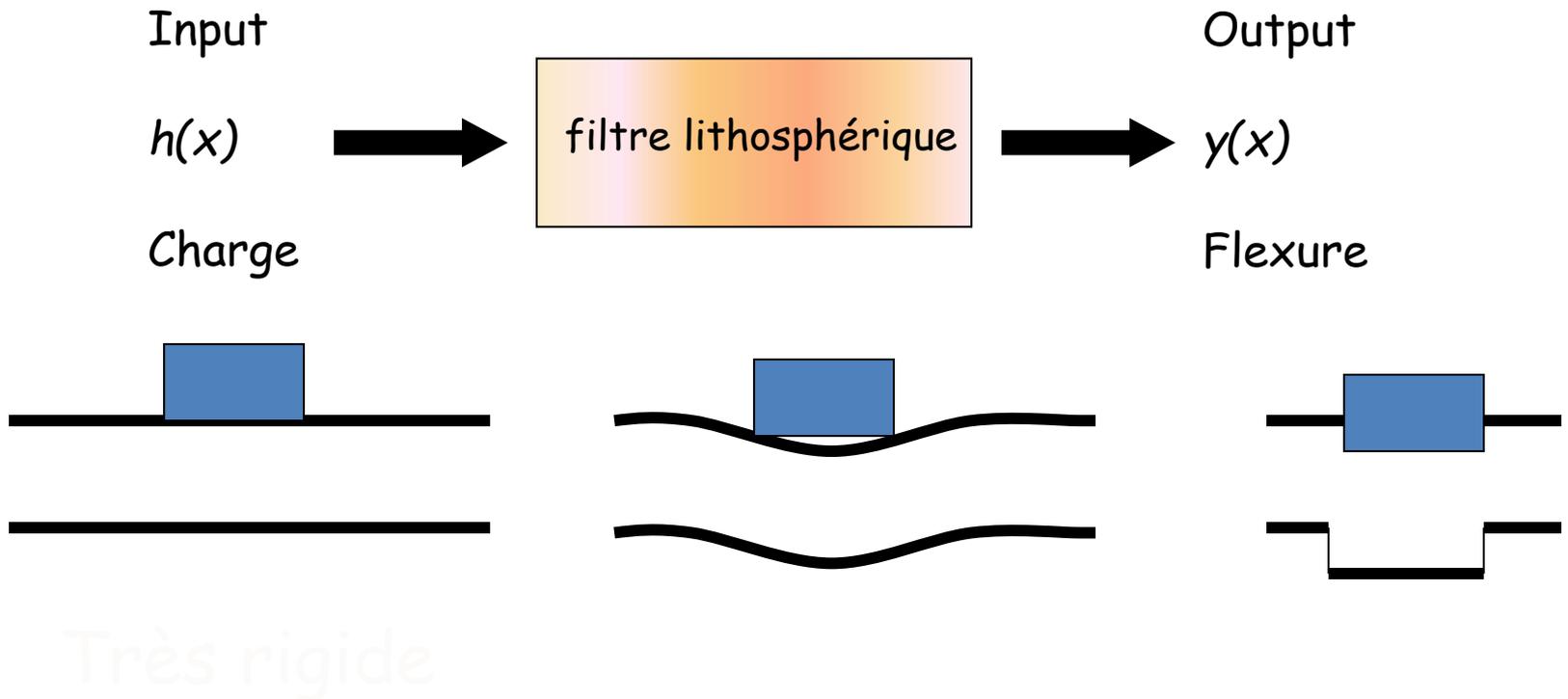


Exemple: Chaînes de montagnes

Isostasie

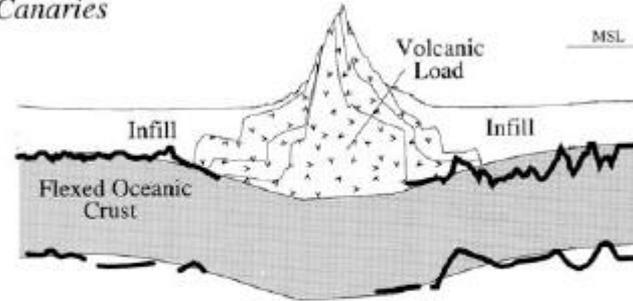
- Isostasie régionale

- Dépend de la rigidité de la lithosphère
- En étudiant le signal gravimétrique, on détermine le comportement mécanique de la lithosphère

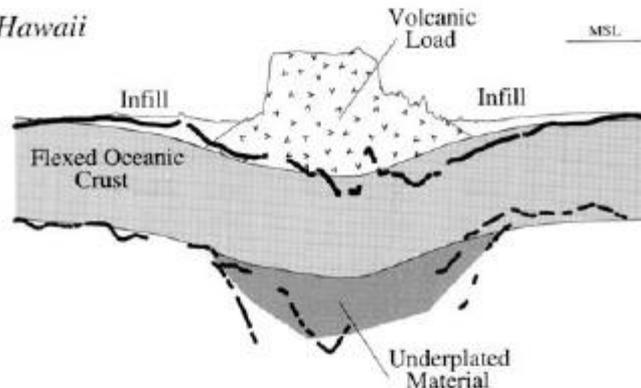


4.3 Seamounts and Oceanic Islands

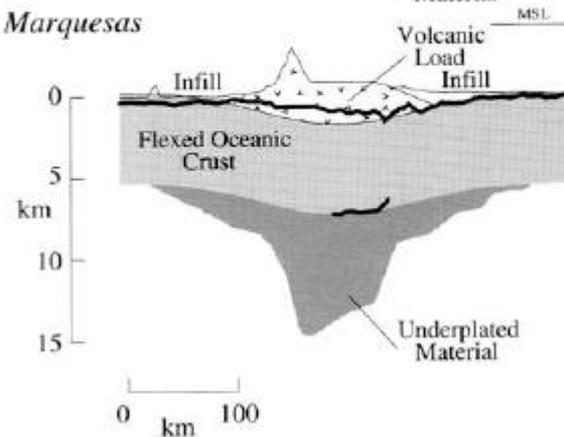
Canaries



Hawaii



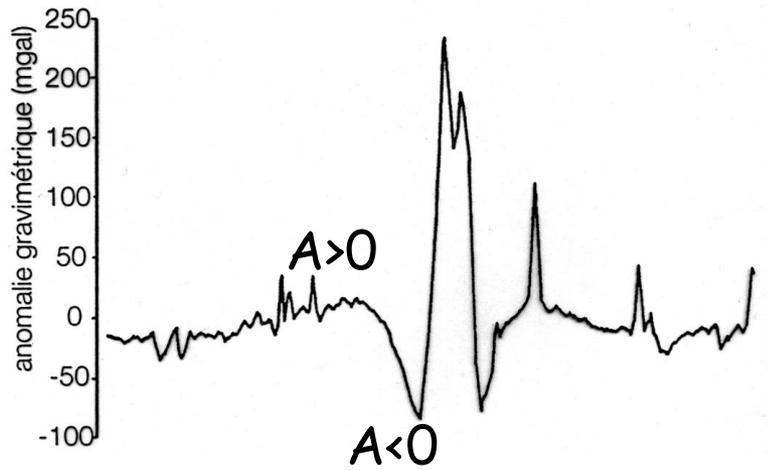
Marquesas



Plaque continue

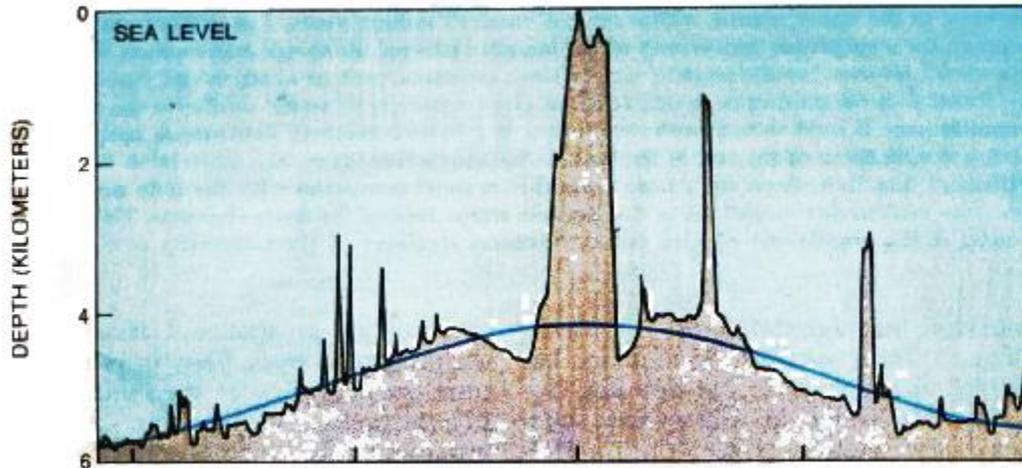
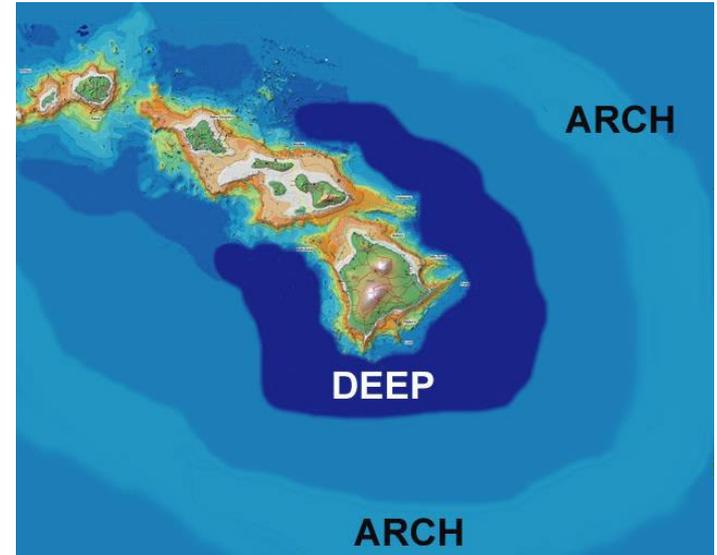
Les « Seamounts »

(D'après Watts)



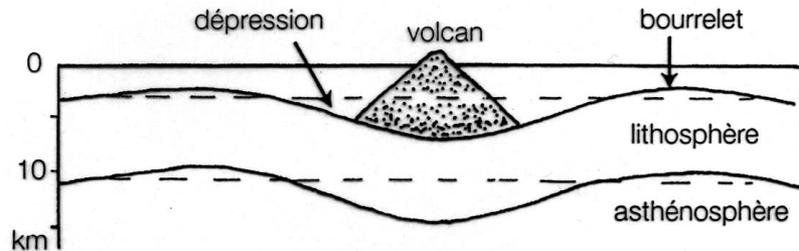
$A > 0$ excès de masse

$A < 0$ défaut de masse

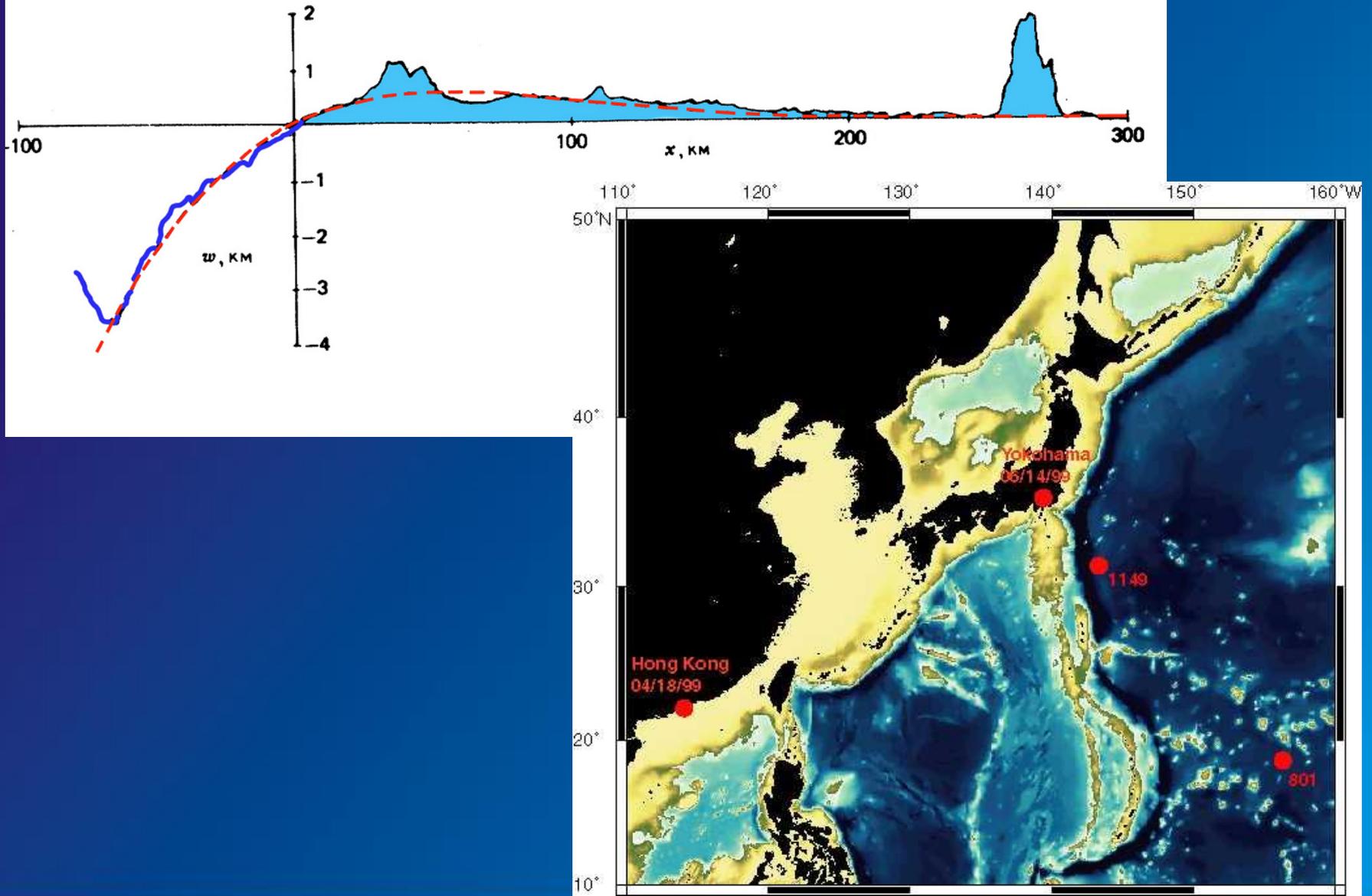


Flexure de la lithosphère

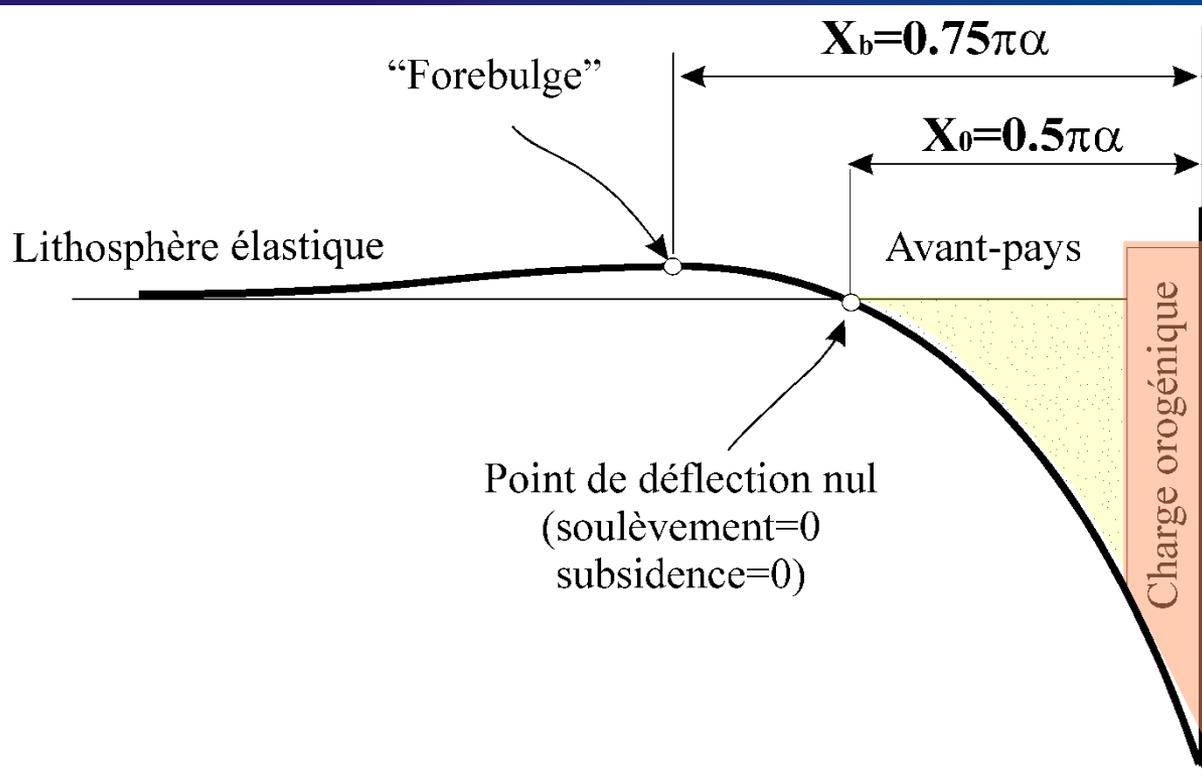
Compensation régionale



Mariana Trench



Déflexion d'une lithosphère élastique (continentale ou océanique)



Rigidité et épaisseur
élastique équivalente
d'une lithosphère

Paramètre flexural

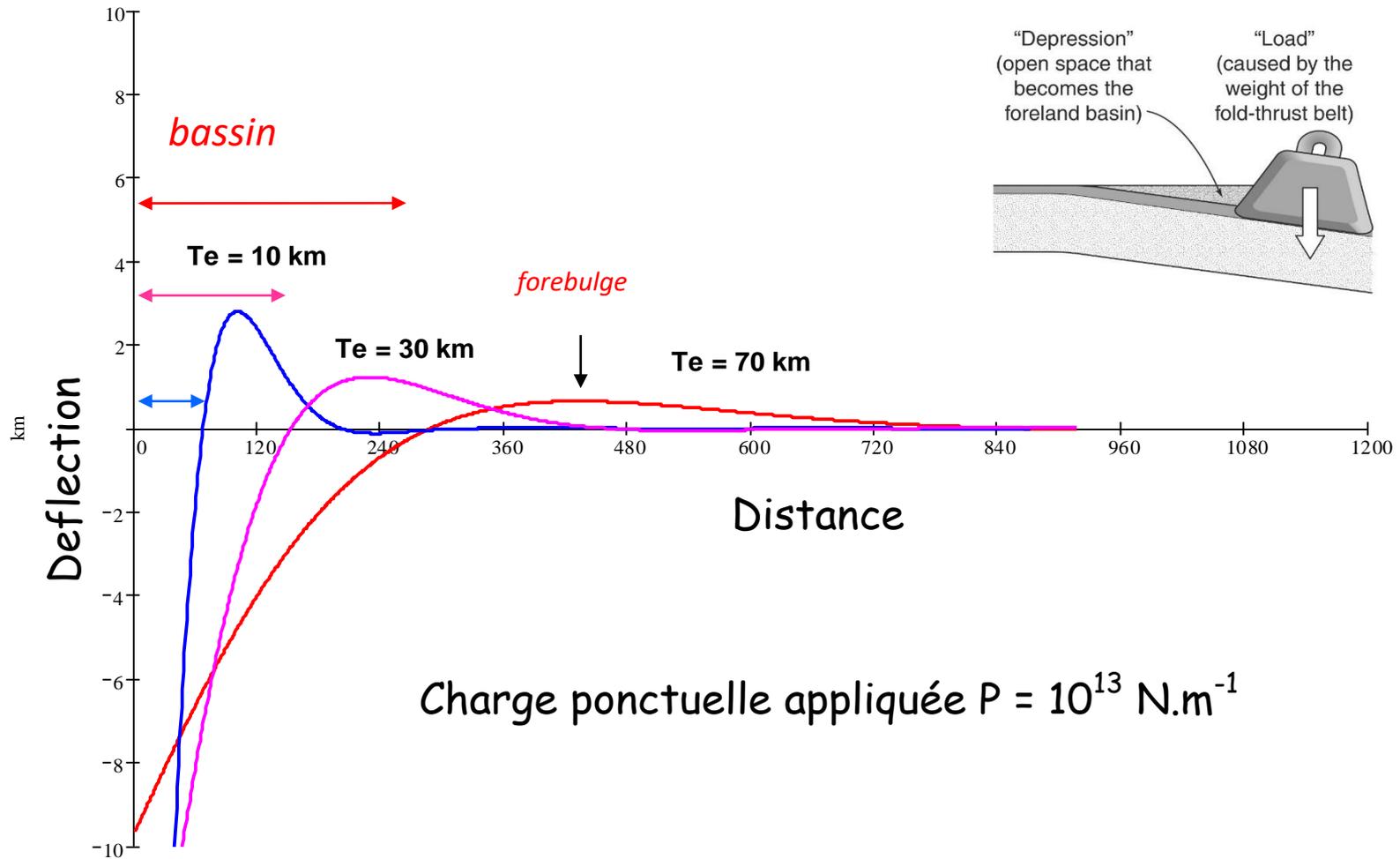
$$\alpha = \left(\frac{4D}{g(\rho_m - \rho_{w/sed})} \right)^{1/4}$$

$$D = \frac{ET_e^3}{12(1-\nu^2)}$$

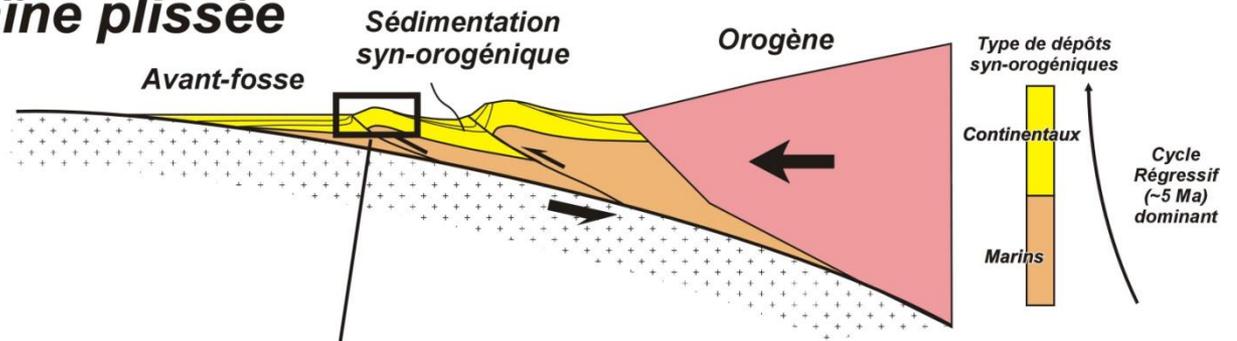
Te (km)
D (Nm)

La subsidence est liée à la compensation isostatique régionale (flexurale)
et non locale (Airy) de la surcharge tectonique et sédimentaire

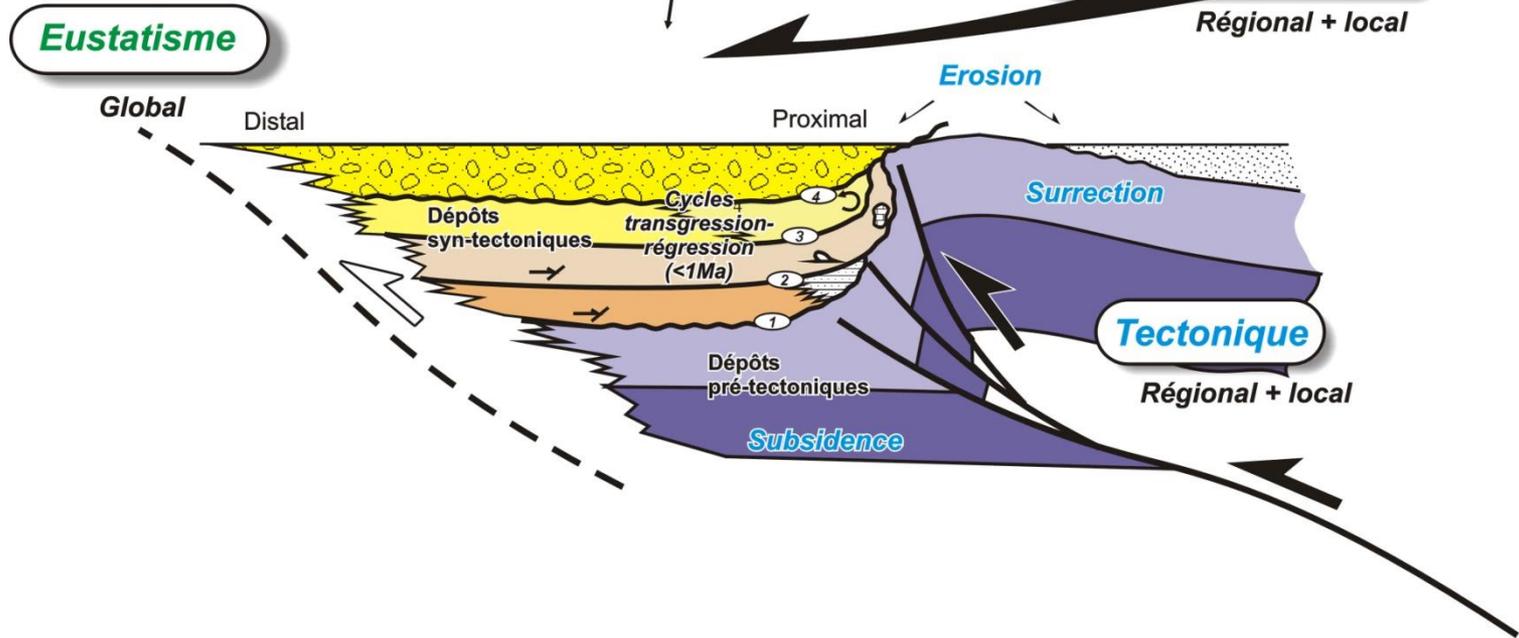
Plaque cassée

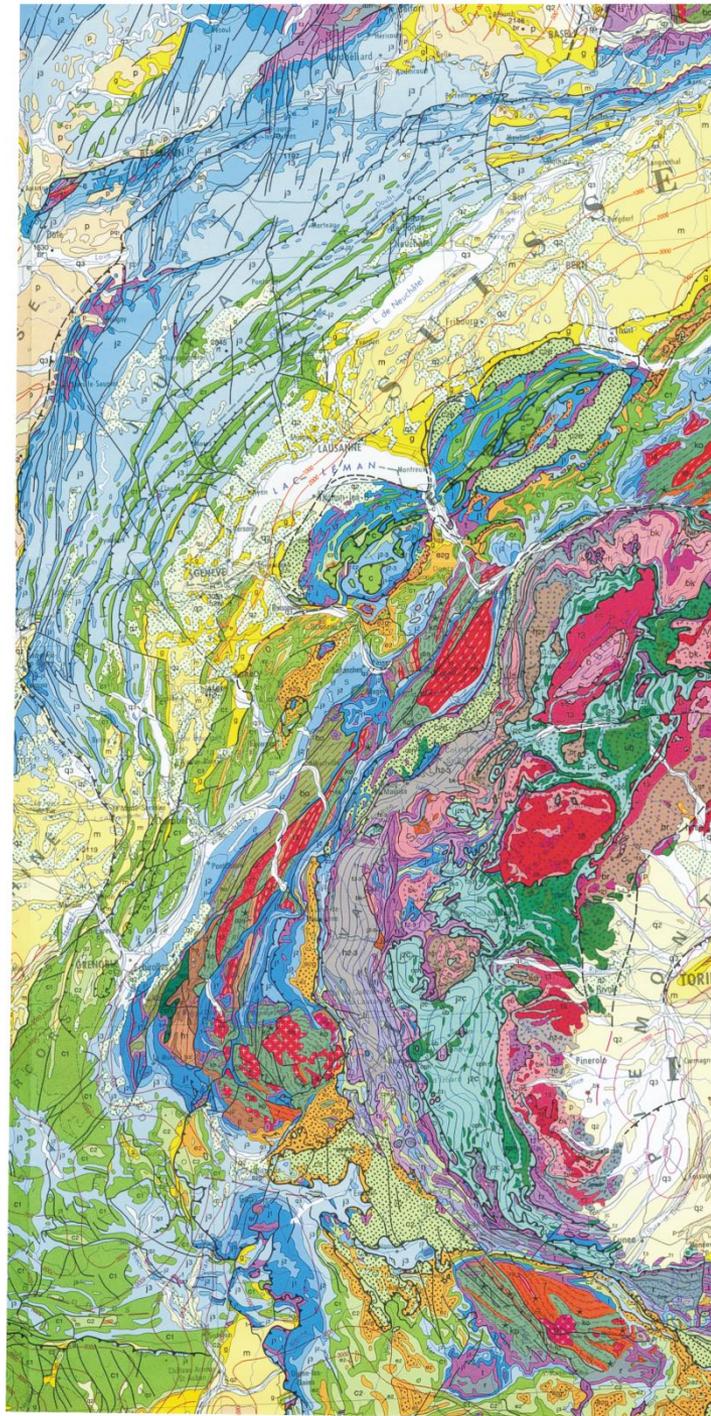


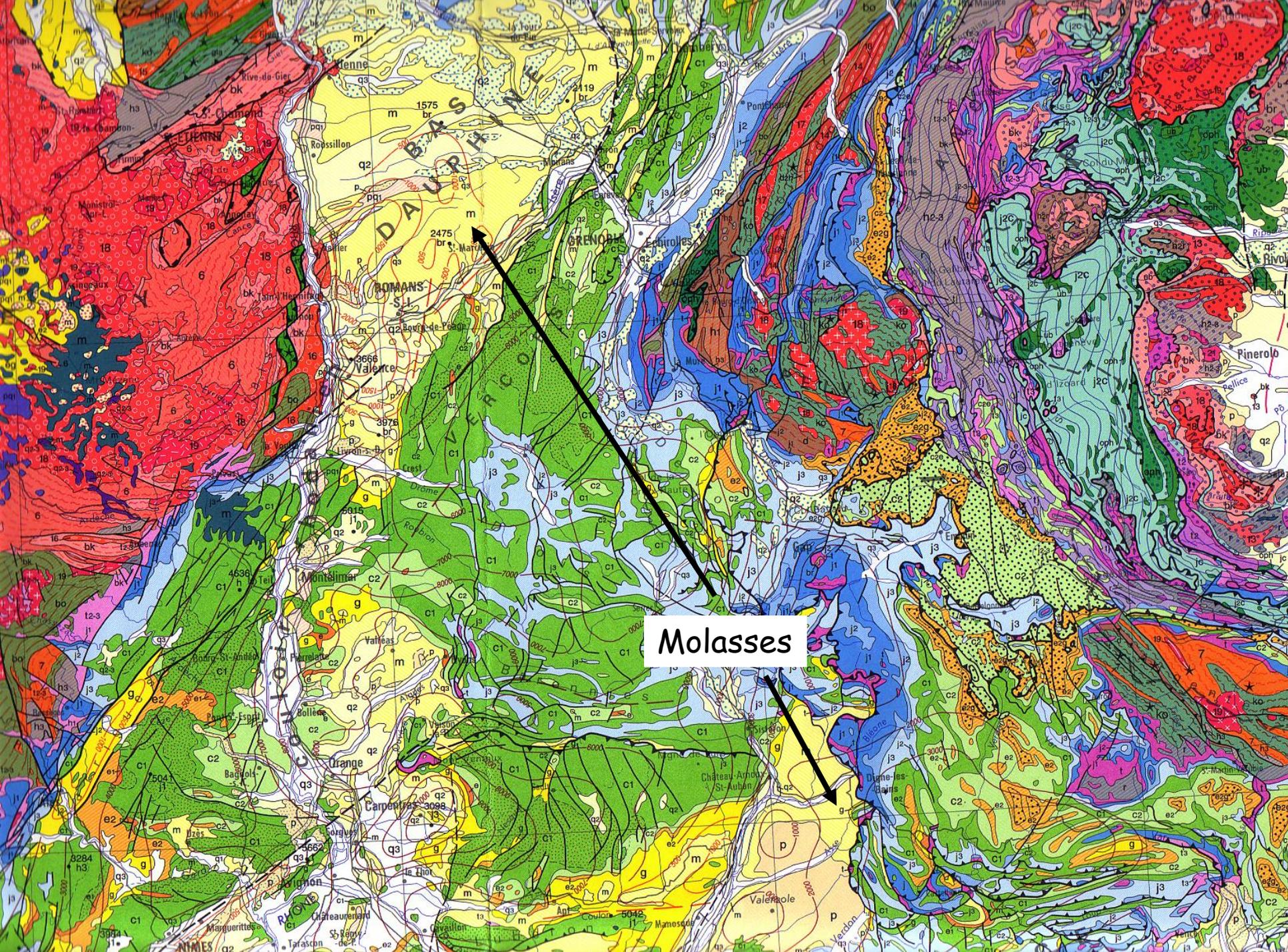
La chaîne plissée



L'unité chevauchante







DAUPHINÉ

ROMANS

GRENOBLE

Montlamar

Orange

Carpenas

Molasses

Valevole

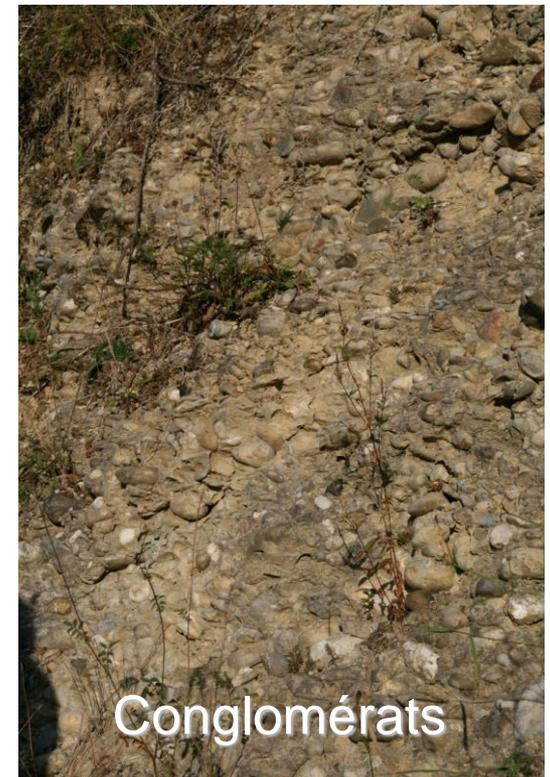
Pinerolo

Molasse Alpine

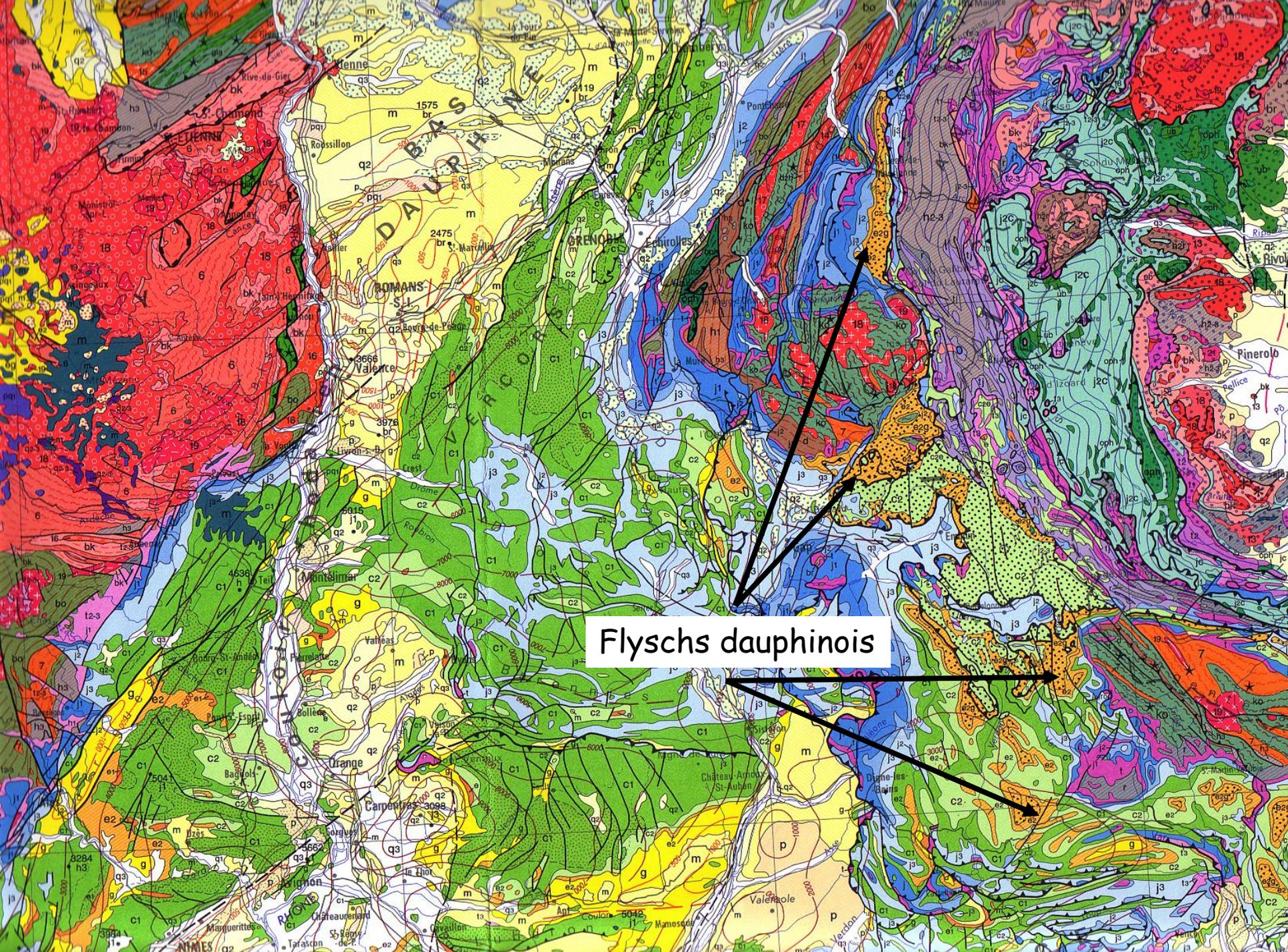
Dépôts fluvio-marins miocènes
contemporains de la croissance de la chaîne



Dépôts d'avant-pays proximaux (source d'apports proche)







Flyschs dauphinois



Grès turbiditiques du Champsaur
(Eo-Oligocène)

Marnes bleues

Calcaires

« *Flyschs* » éocènes dauphinois : les grès d'Annot



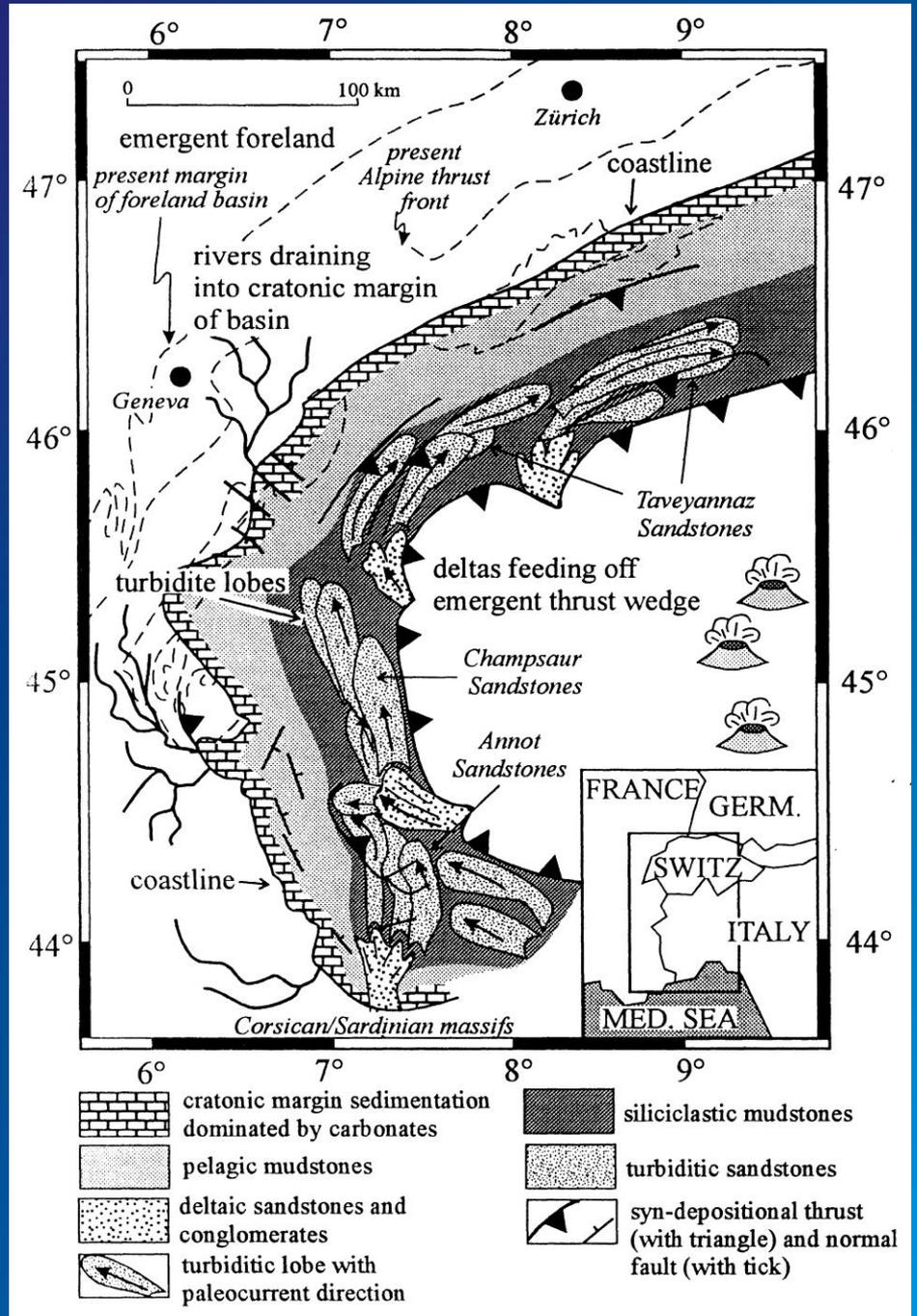
Dépôts marins profonds
turbiditiques d'âge Eocène
sup (Priabonien)

Soulignent l'initiation du
bassin flexural

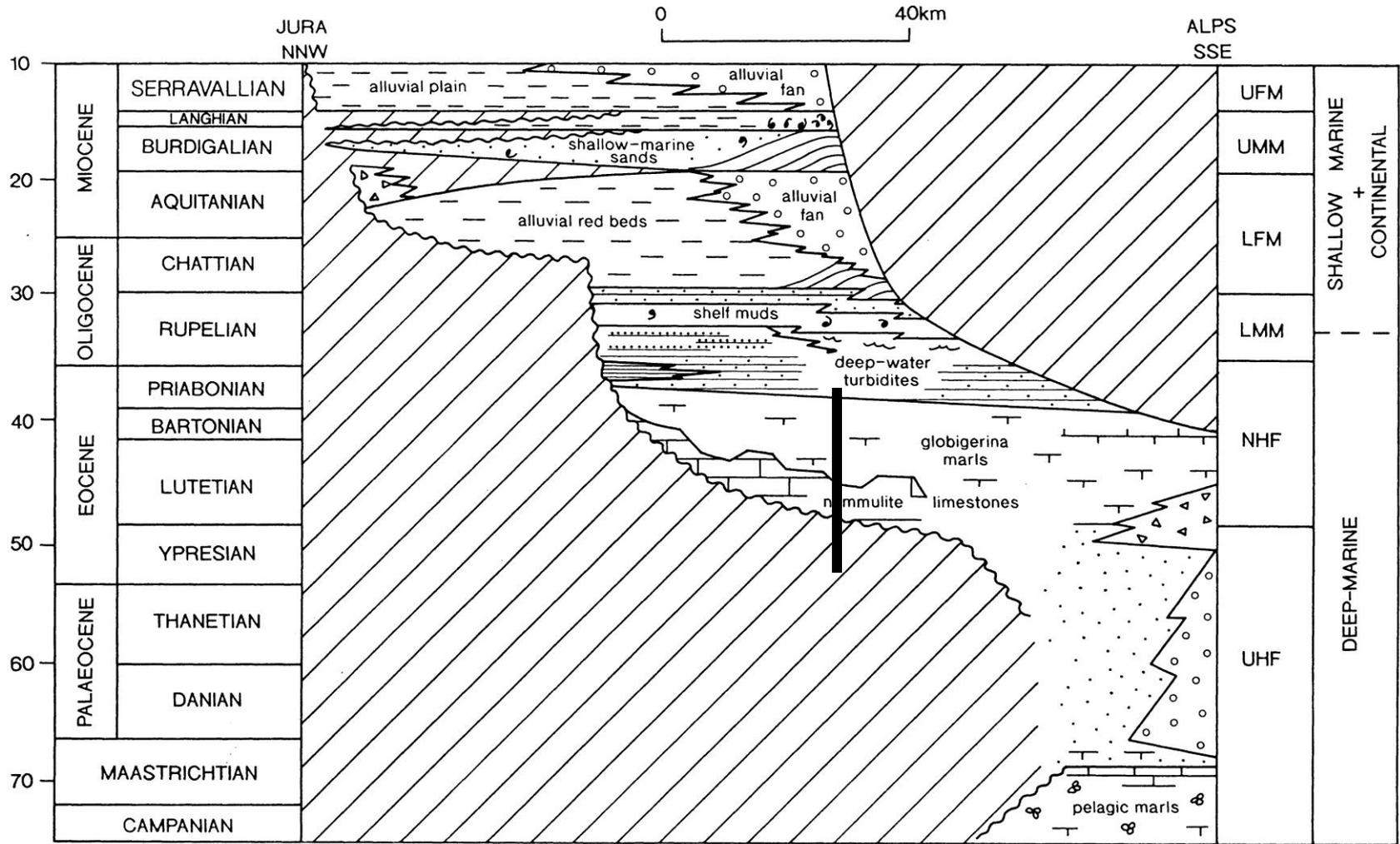


L'avant-pays alpin à l'Eocène

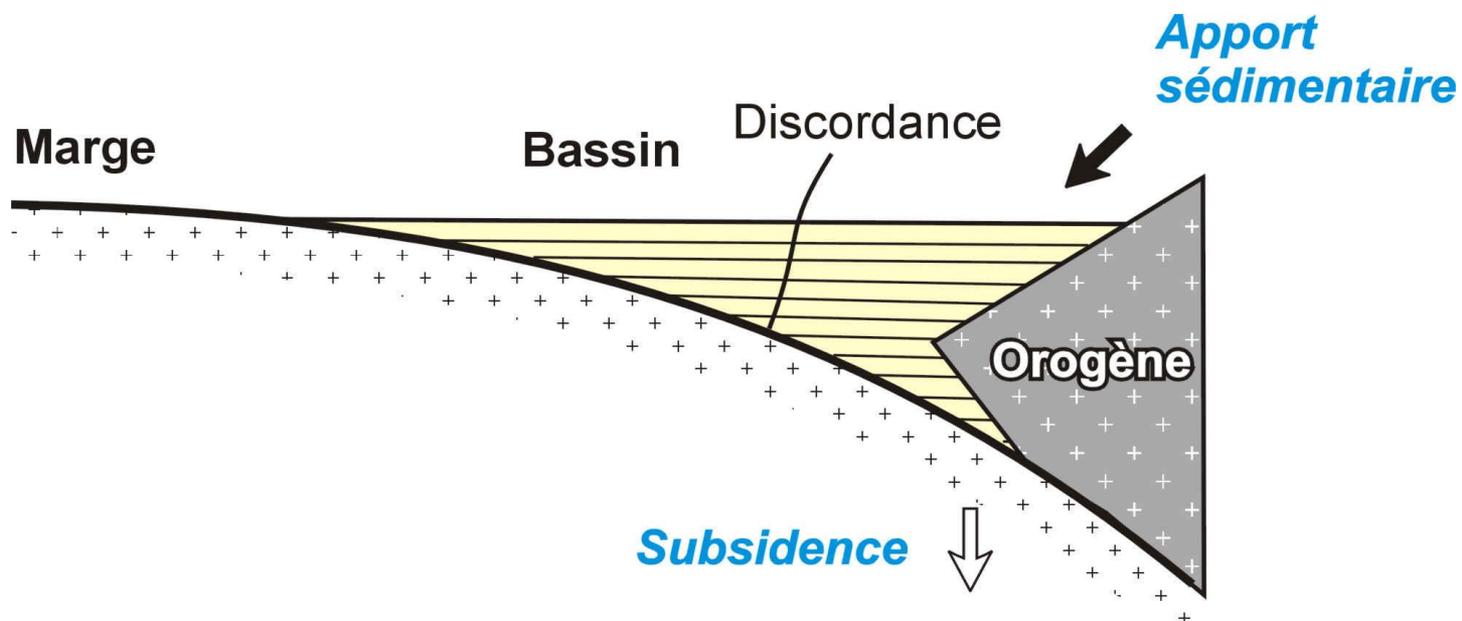
La trilogie calcaire/
marnes/flyschs
souligne la géométrie
initiale du bassin



Coupe stratigraphique reconstituée du bassin flexural alpin



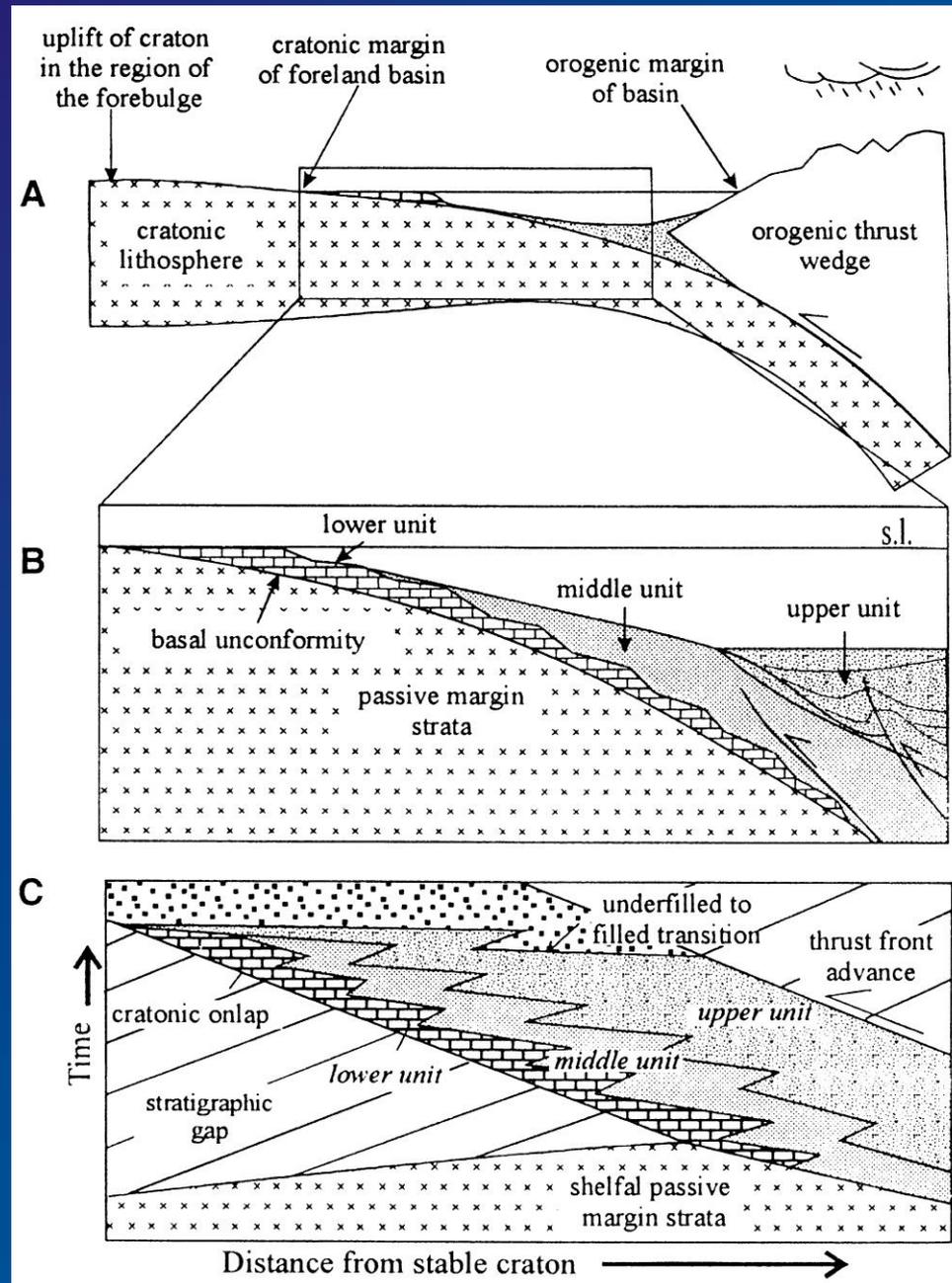
Remplissage sédimentaire discordant en onlaps sur la marge



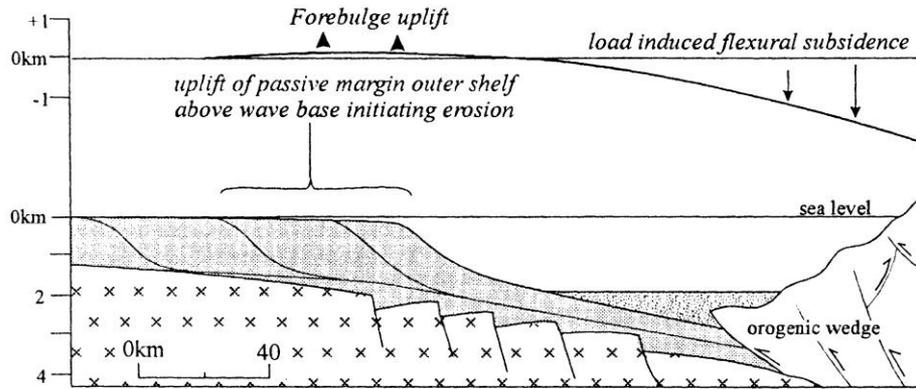
*Début du développement
du bassin et migration
sur la marge à l'Eocène*

*Reconstitution
du bassin
au Priabonien*

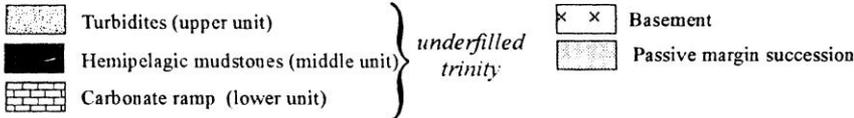
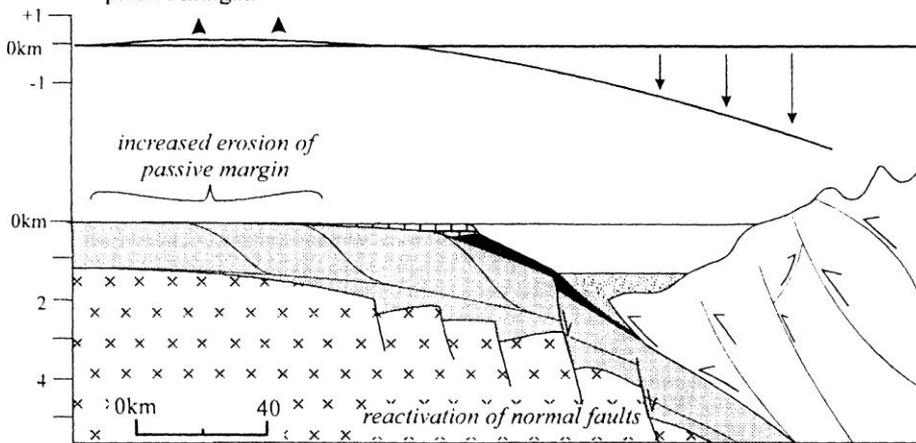
Stratigraphie



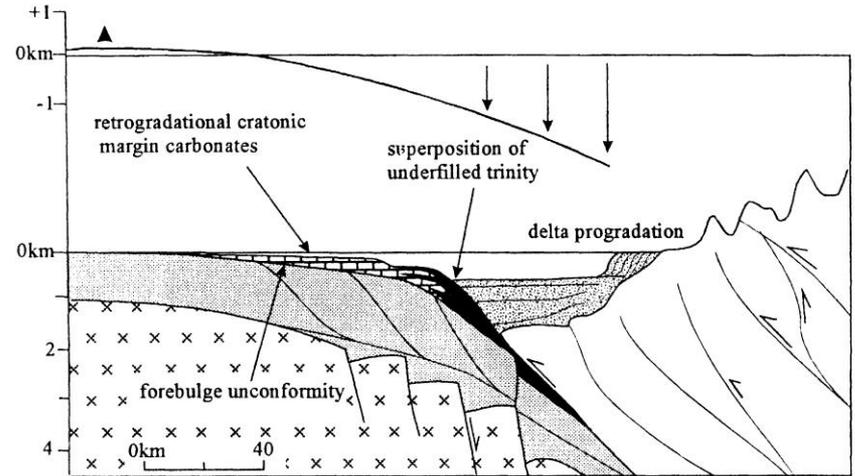
Stage 1. Initial loading of outer passive margin, eg., present day Taiwan, Timor and Papua New Guinea. Paleocene in the Alps.



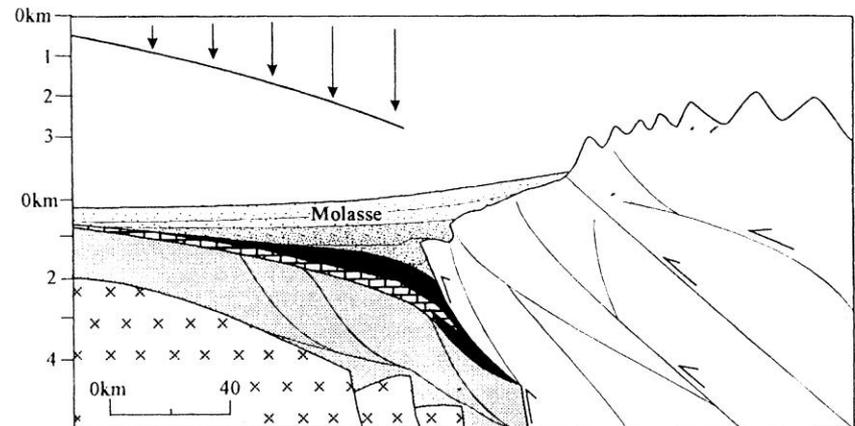
Stage 2. Development of underfilled trinity as flexural profile passes over passive margin.



Stage 3. Steady state migration of the underfilled trinity over the craton i.e., rate of thrust front advance equals rate of cratonic onlap



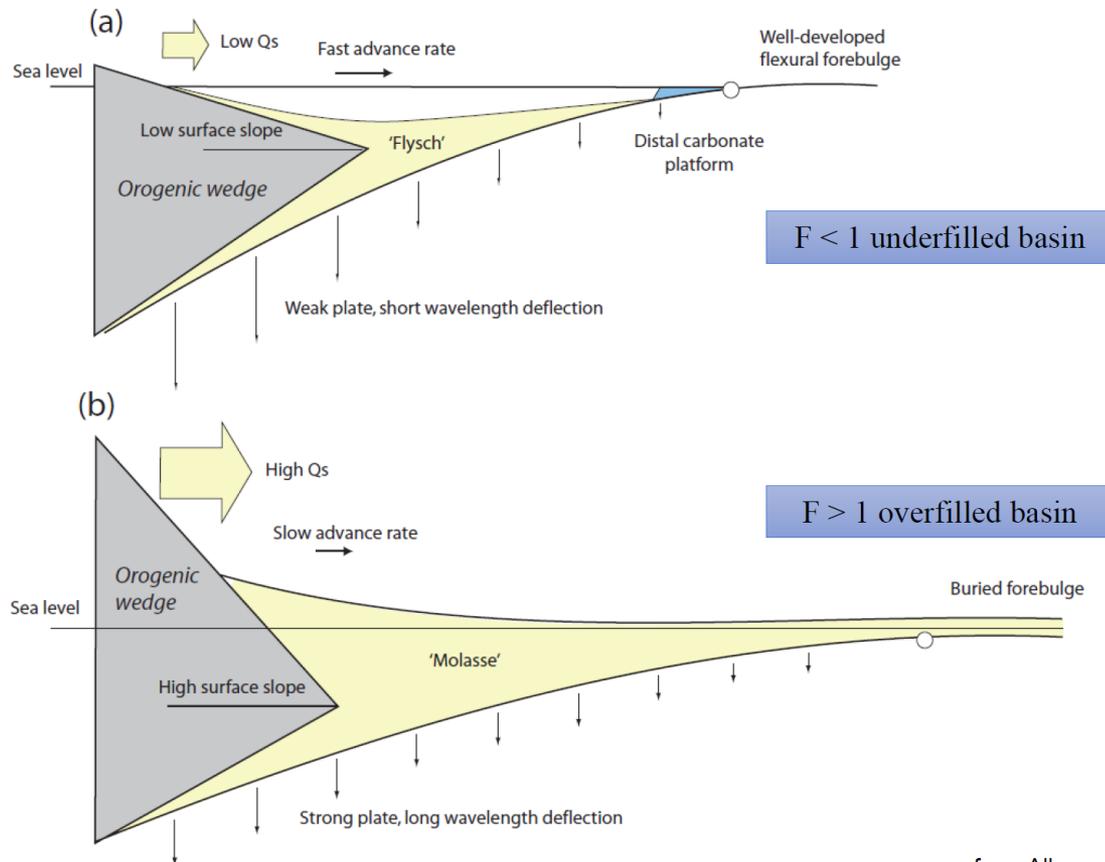
Stage 4. Transition of foreland basin from an underfilled to a filled depositional state. Siliciclastics from orogen fill the basin, smothering the underfilled stratigraphy.

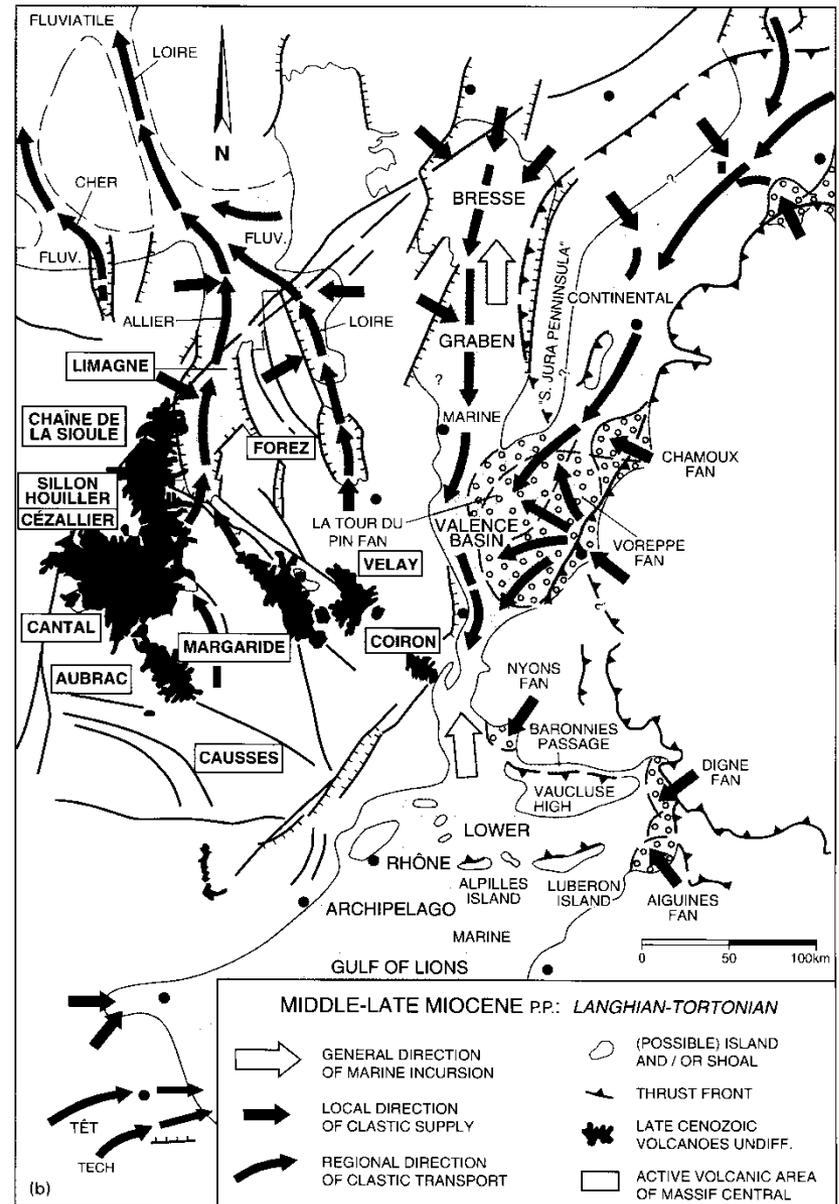
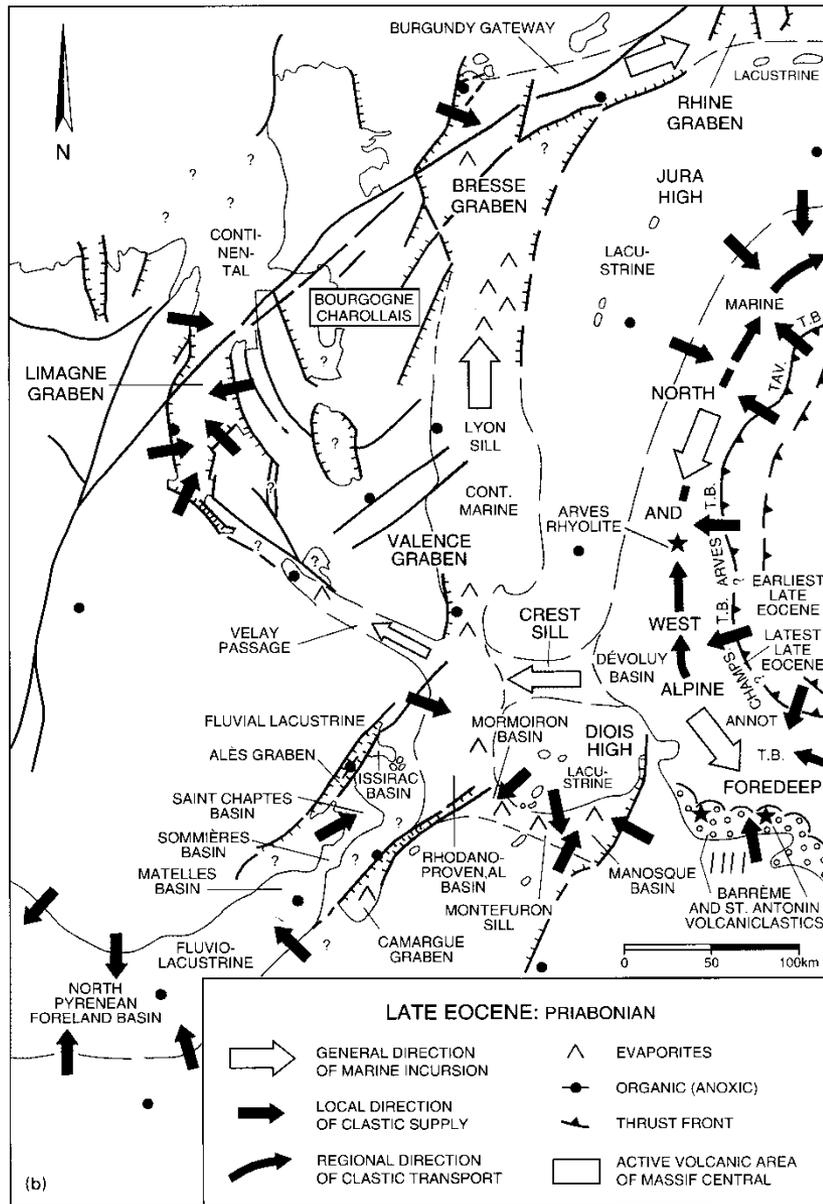




flysch *n*: a type of rock consisting of thinly bedded sandstone and shale, thought to be the result of the action of turbidity currents; a succession of turbidites originating in marine depositional basins, usually near the base of the continental slope. Flysch deposits are especially common in the Alpine region of Europe.

molasse *n*: a thick sequence of soft, ungraded, cross-bedded, fossiliferous marine and terrestrial conglomerates, sandstones, and shales derived from the erosion of growing mountain ranges.

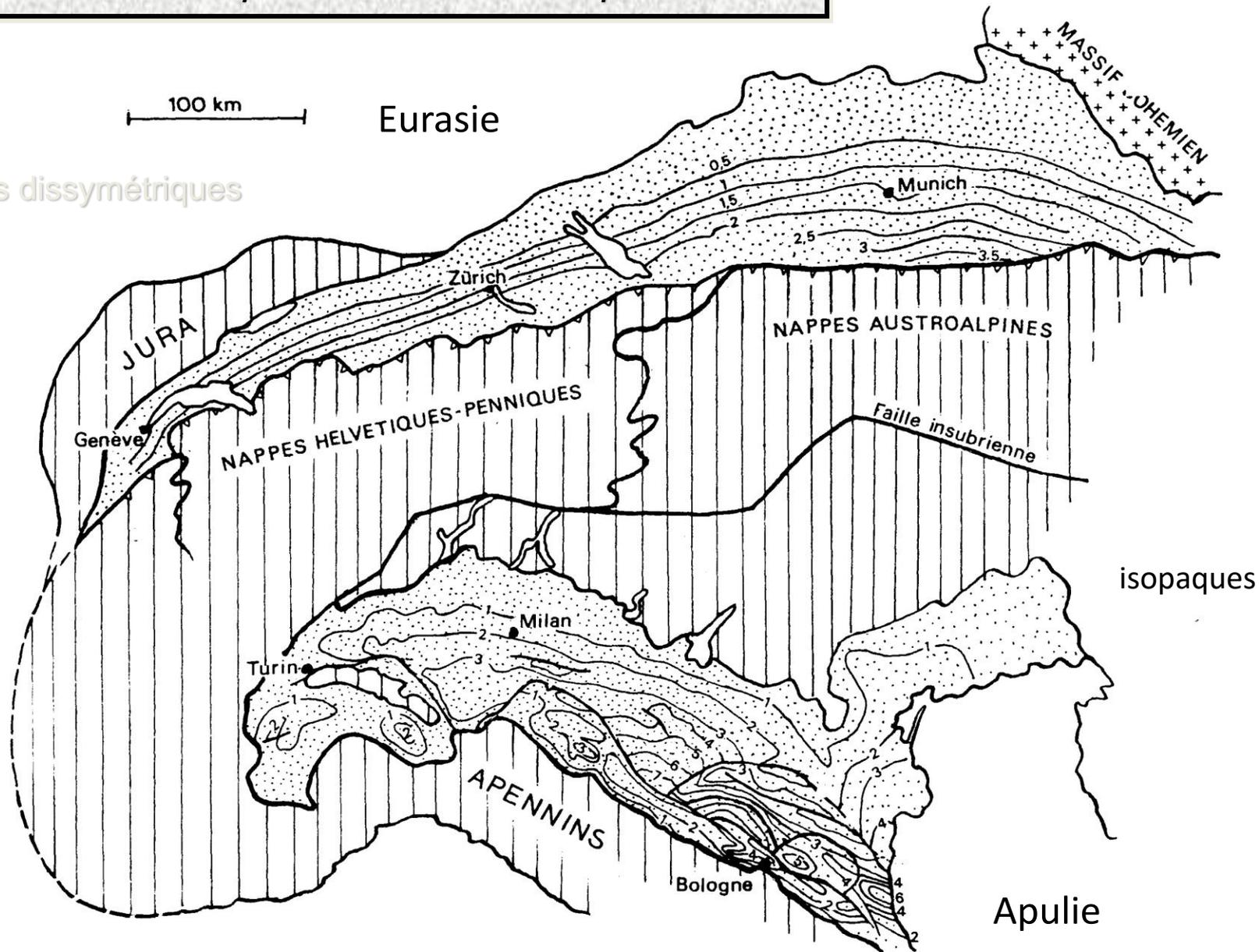




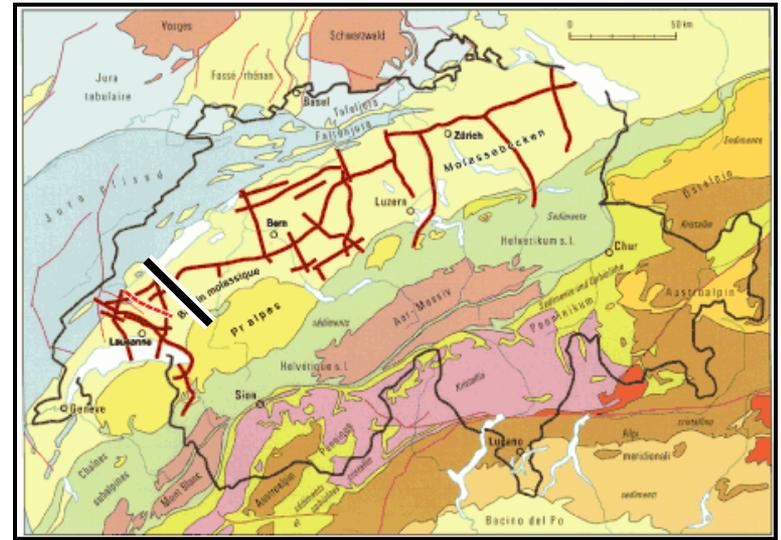
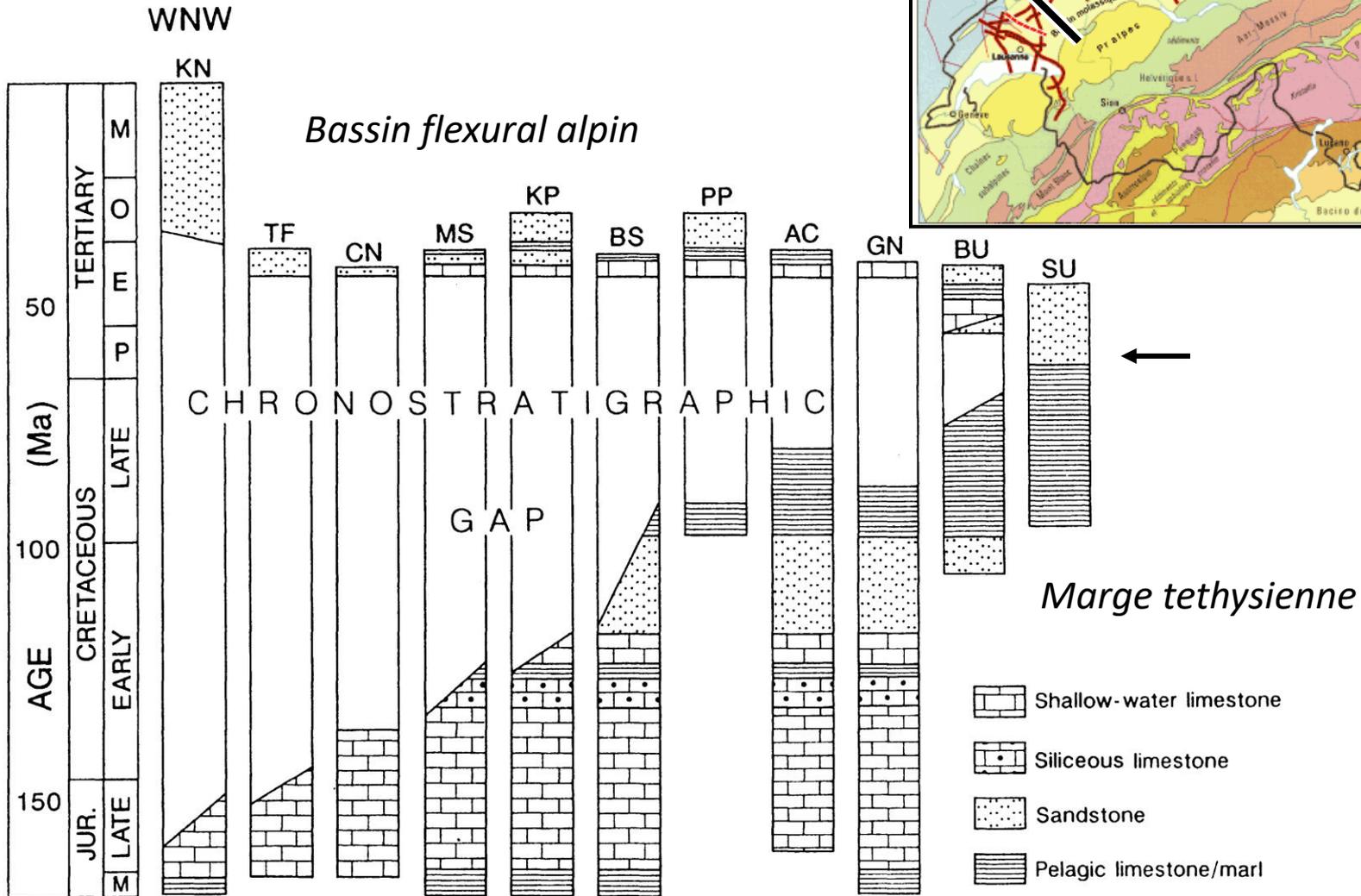
Paléogéographie de l'avant-pays alpin : des flyschs éocènes aux molasses oligo-miocènes : Sissingh, 1998

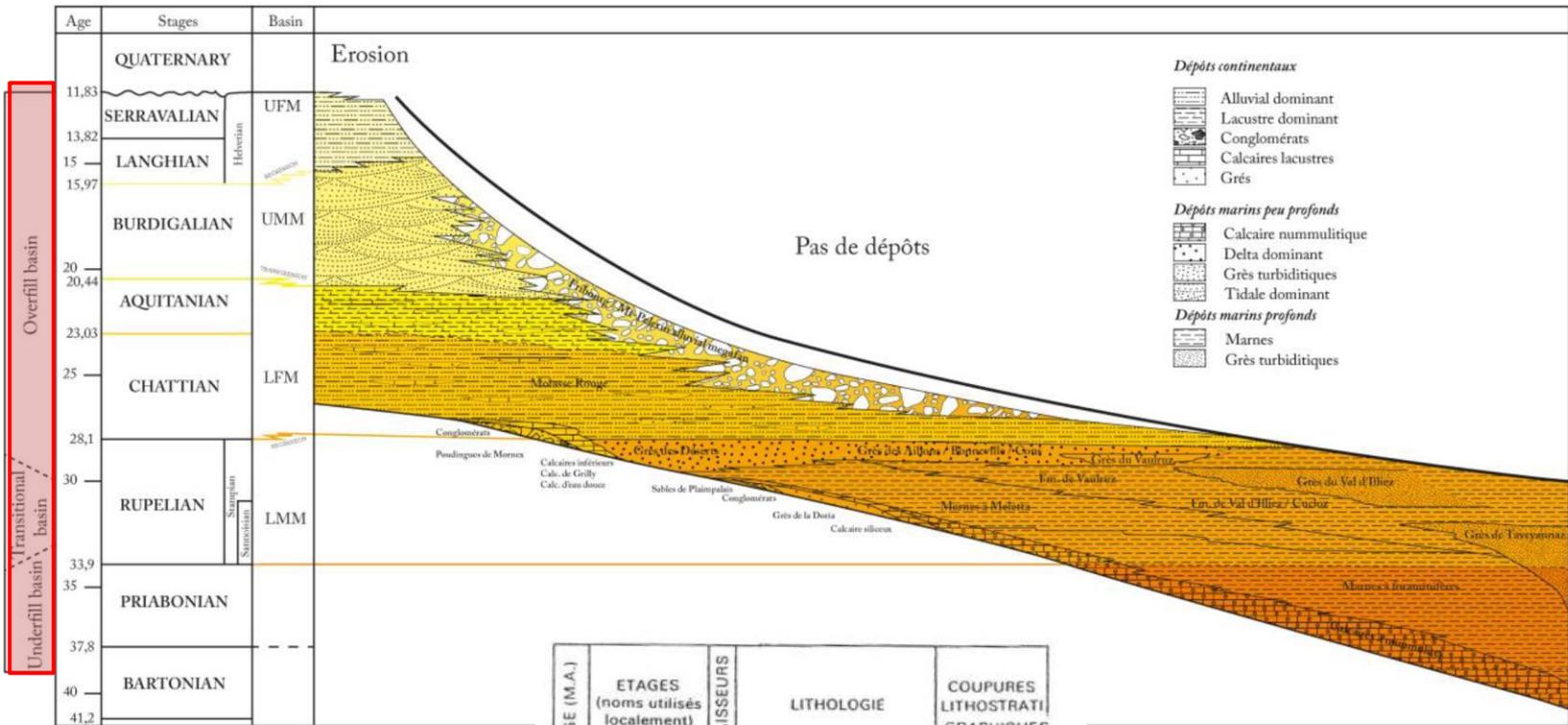
Bassin molassique suisse et bassin padan

Bassins dissymétriques



Stratigraphie et géométrie du bassin molassique

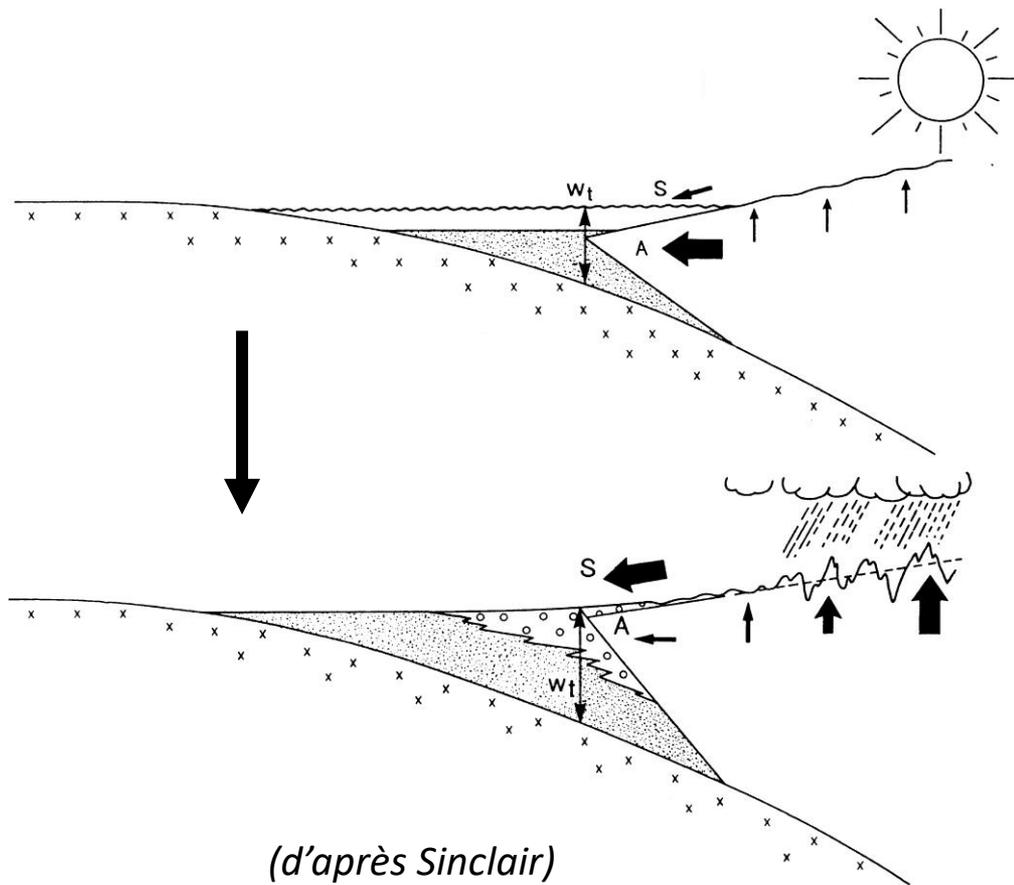




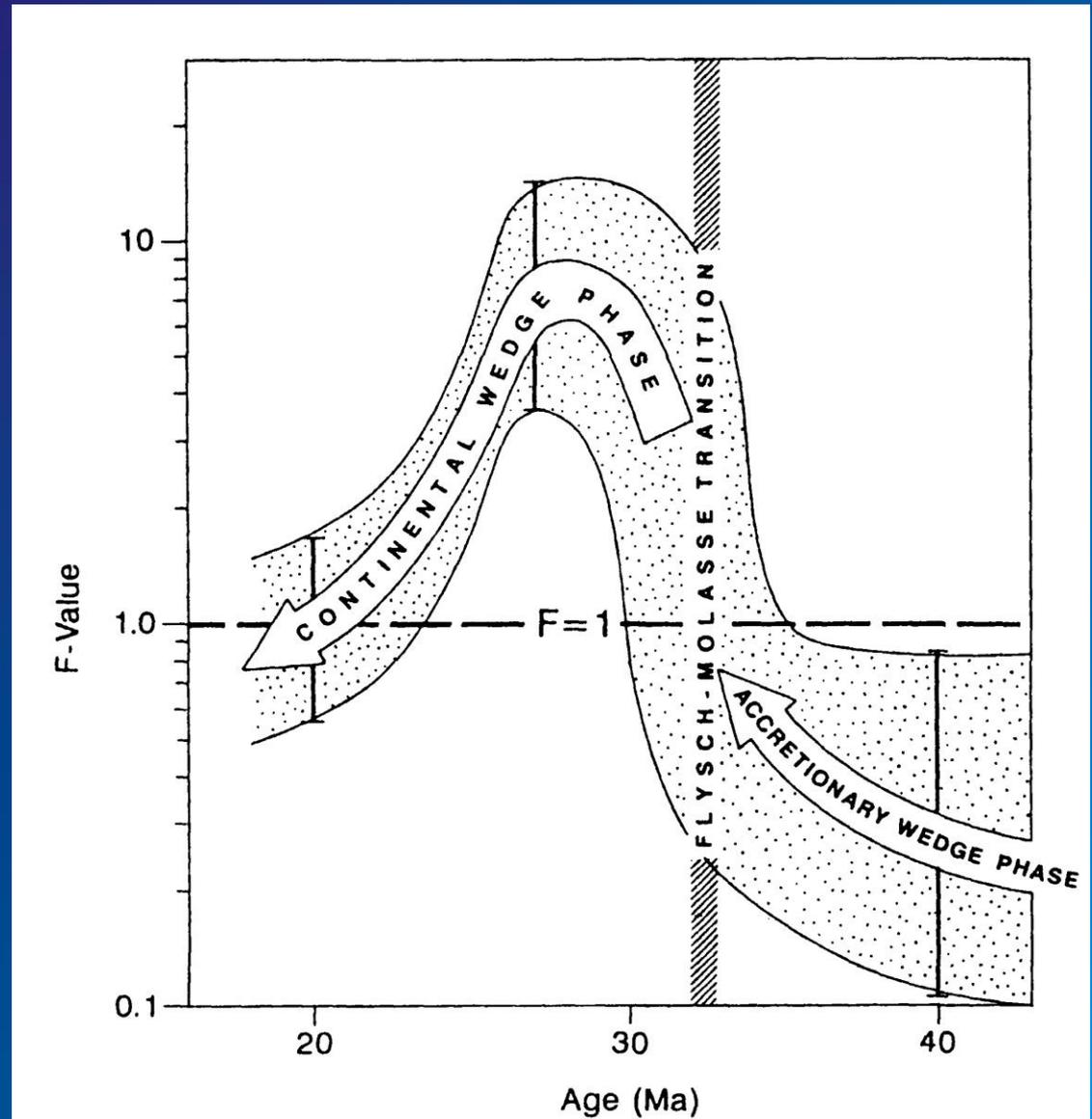
| AGE (M.A.) | ETAGES (noms utilisés localement) | EPAISSEURS | LITHOLOGIE | COUPURES LITHOSTRATIGRAPHIQUES |
|------------|-----------------------------------|------------|------------|--------------------------------|
| 15 | Oehningien | 0,7 km | | Molasse d'eau douce supérieure |
| | Tortonien | V | | |
| 20 | Helvétien | 1,3 km | | Molasse marine supérieure |
| | Burdigalien | V | | |
| 25 | Aquitainien | 3,4 km | | Molasse d'eau douce inférieure |
| | Chattien | V | | |
| 30 | Rupélien | 1,5 km | | Molasse marine inférieure |
| | Latdorfien | 0 | | |

Apports sédim. <
création d'espace
disponible
Bassin sous-alimenté
Dépôt = Flysch

Apports sédim. >
création d'espace
disponible
Bassin sur-alimenté
(comblement)
Dépôt = Molasse



Modèle d'accommodation

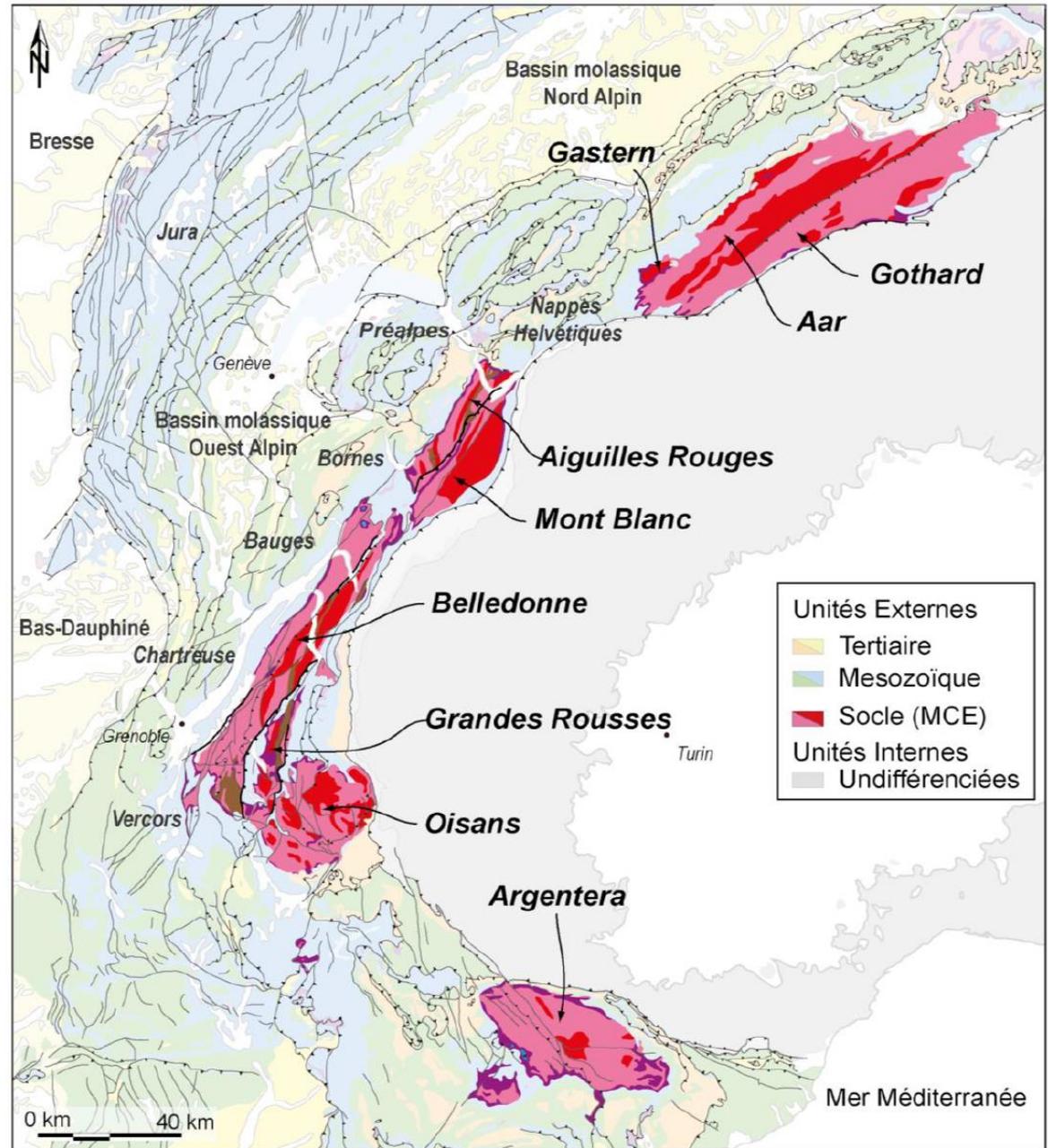


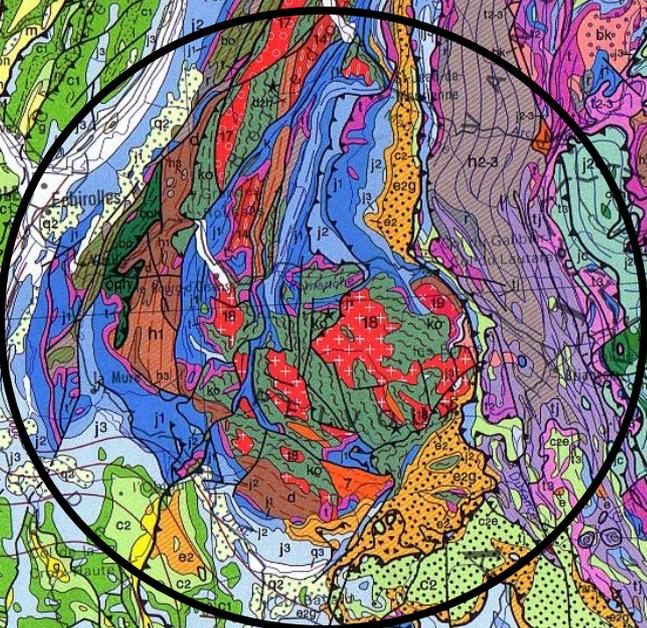
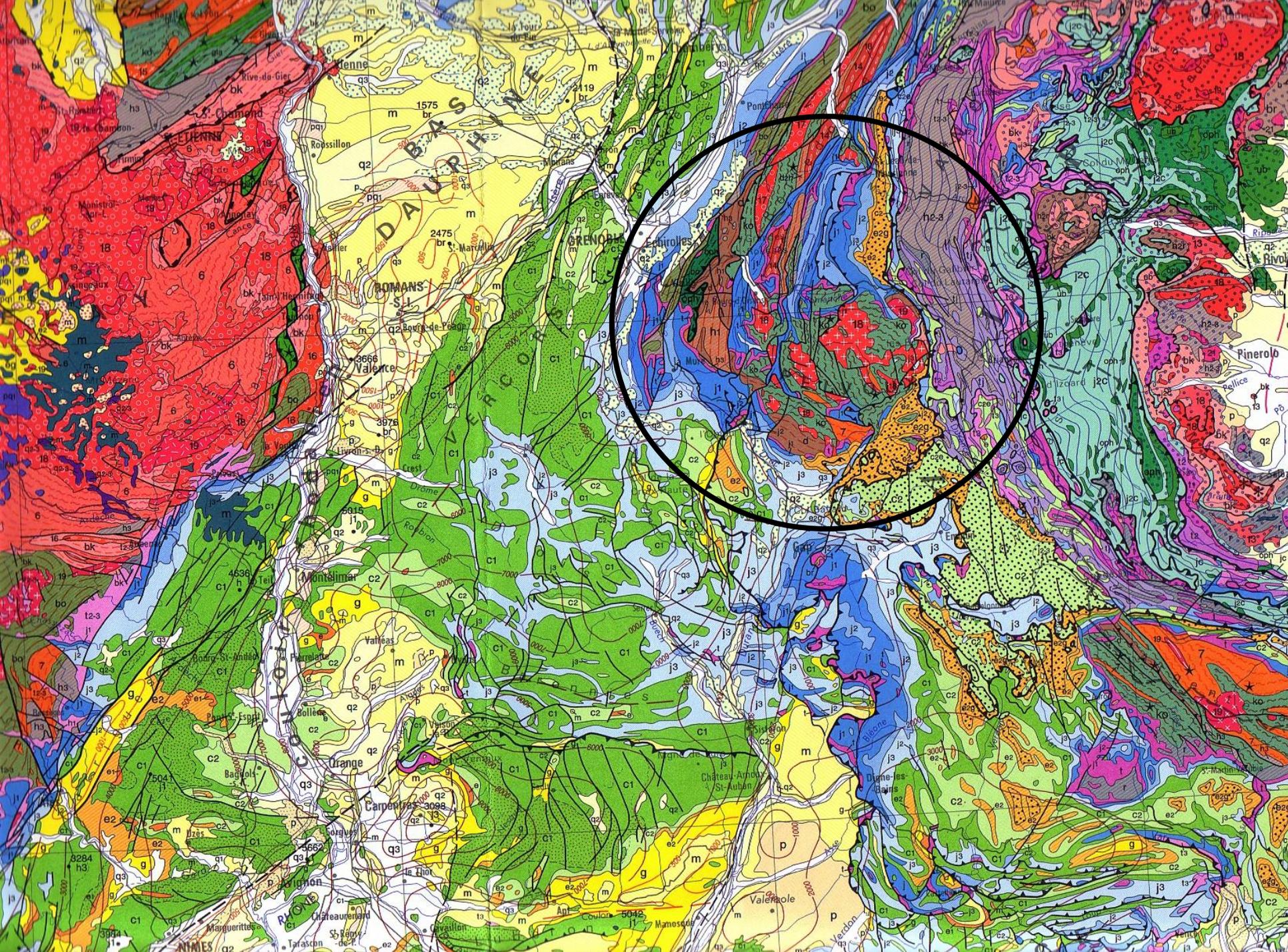
(d'après Sinclair)

Les Massifs Cristallins Externes

Le domaine Dauphinois

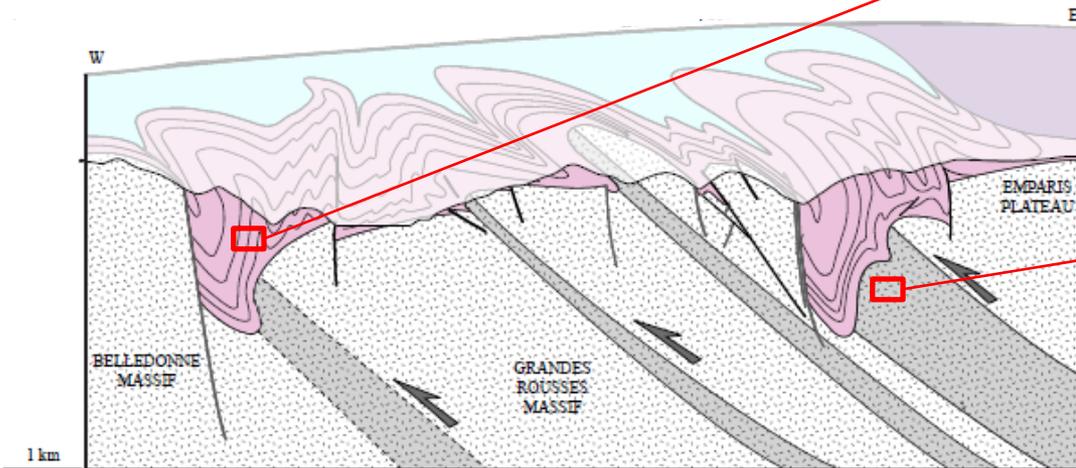
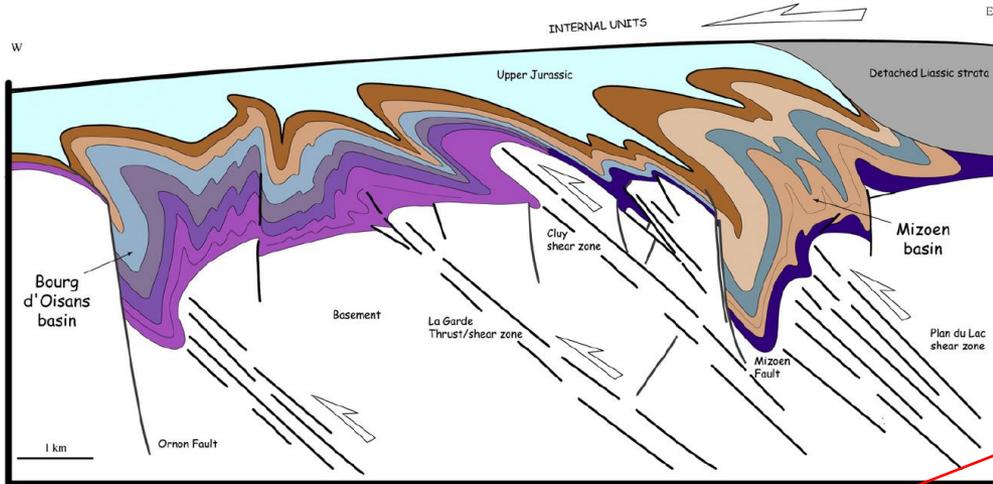
Les Massifs Cristallins Externes



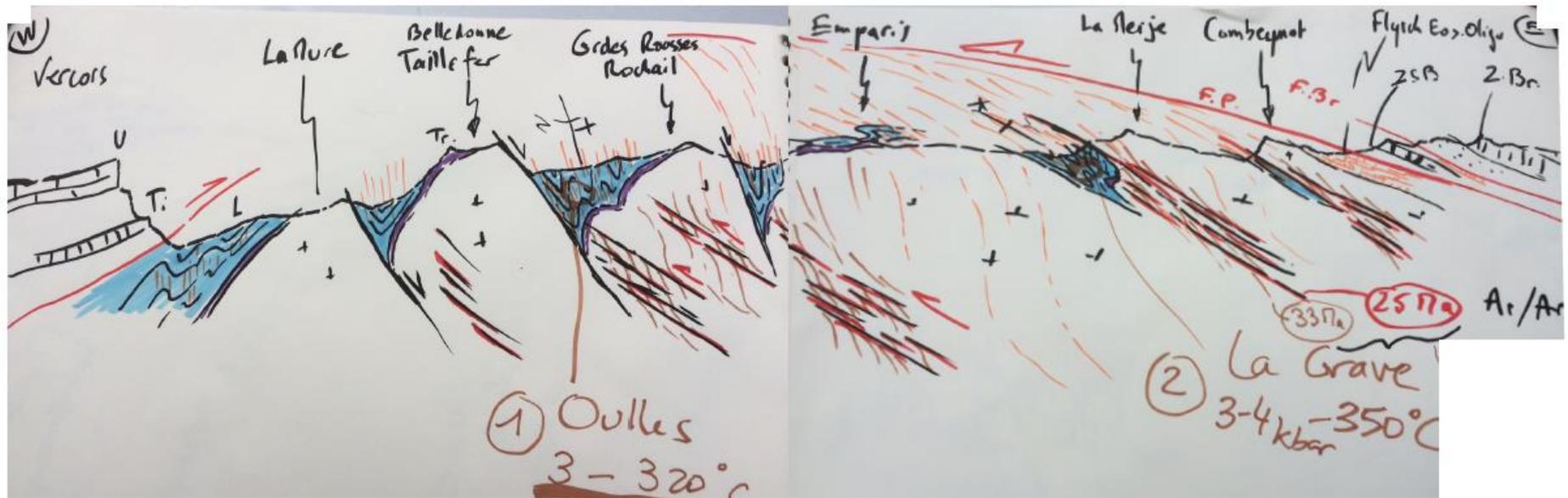




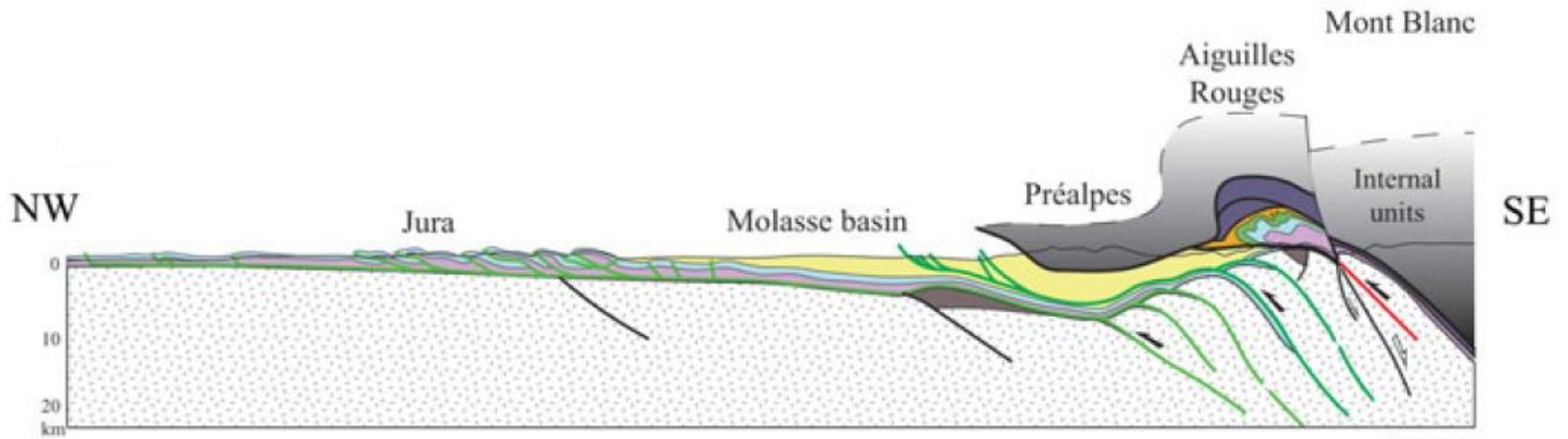
LA MEIJE
3983 m



Déformations dans les Massifs Cristallins Externes

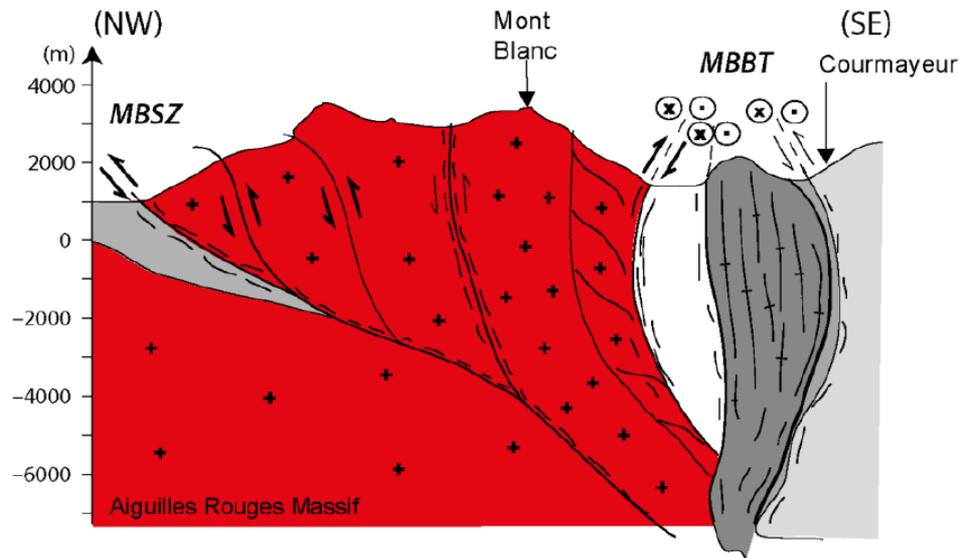


(Courtesy of L. Jolivet)



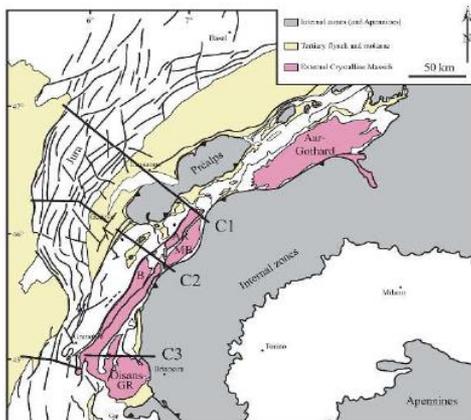
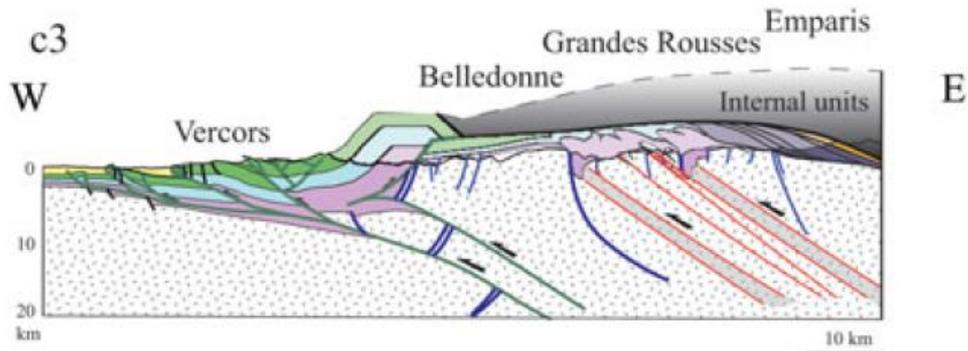
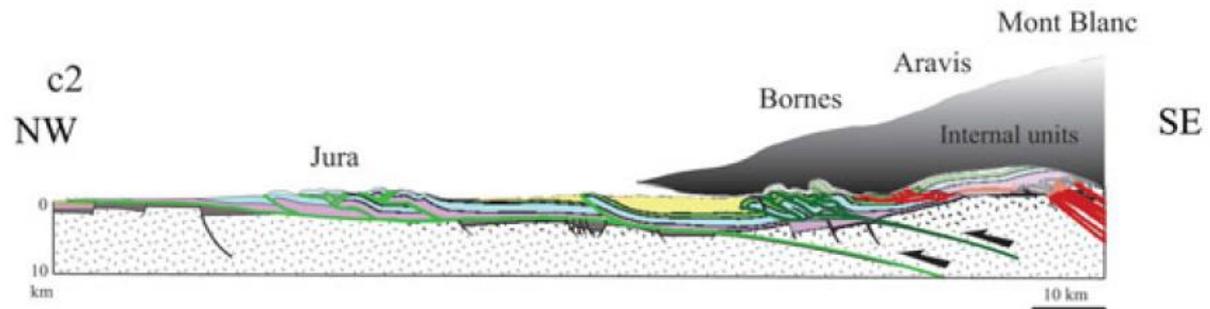
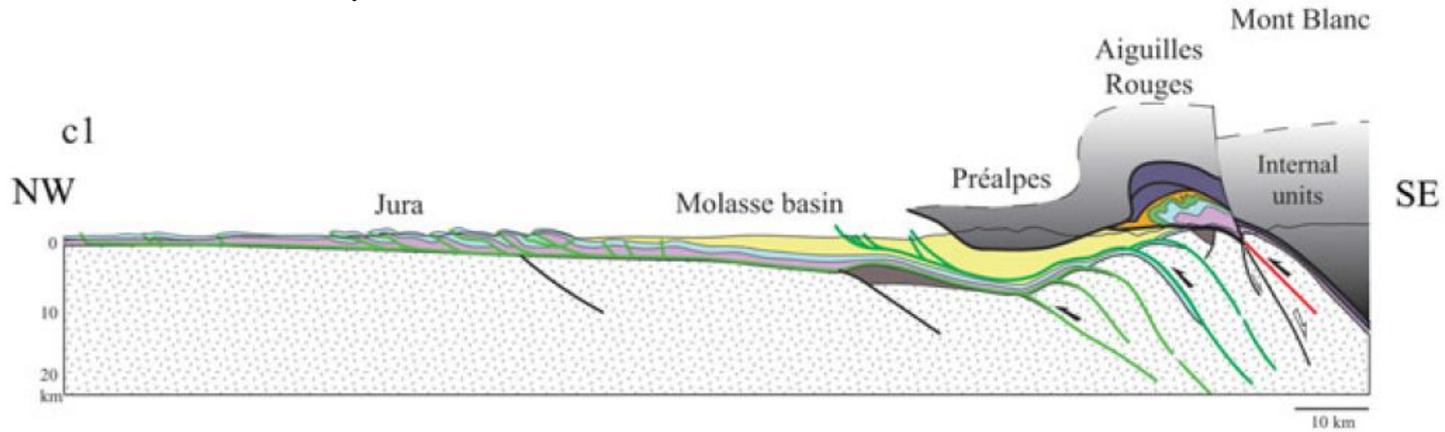
(Bellahsen et al., 2014)

Mont-Blanc «pop-up» structure

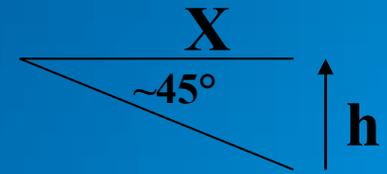
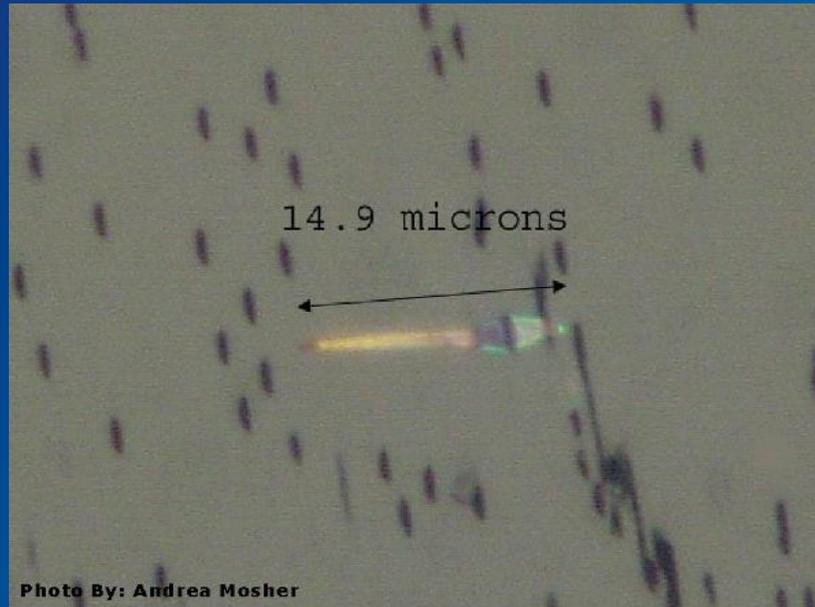
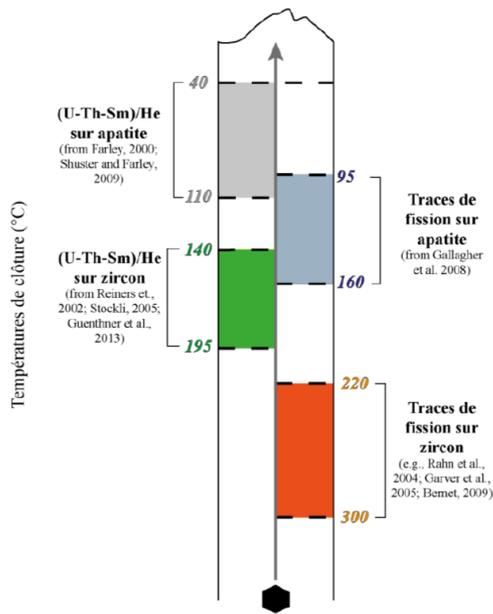
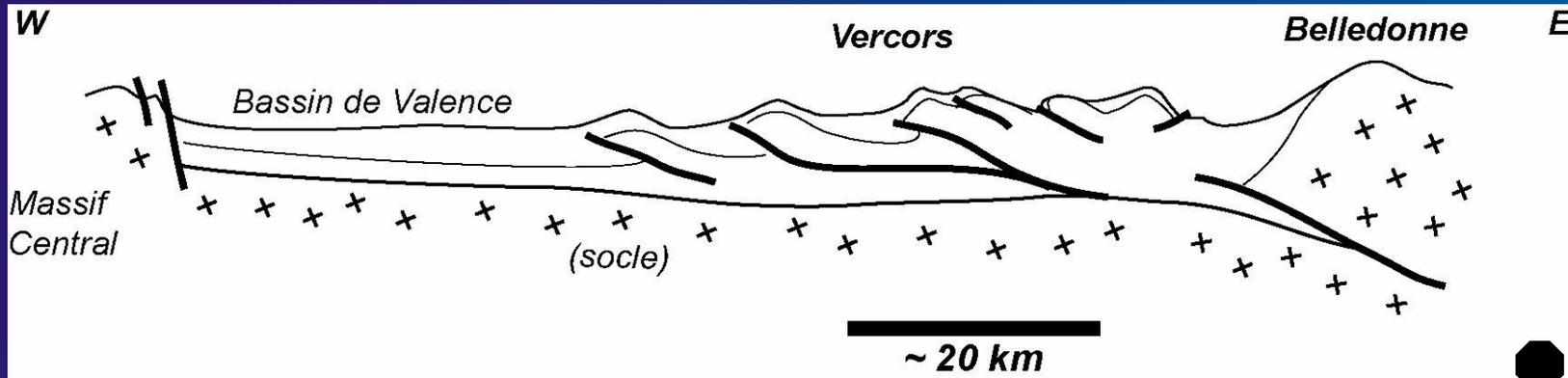


Cenki-Tok et al., 2013

(Bellahsen et al., 2014)

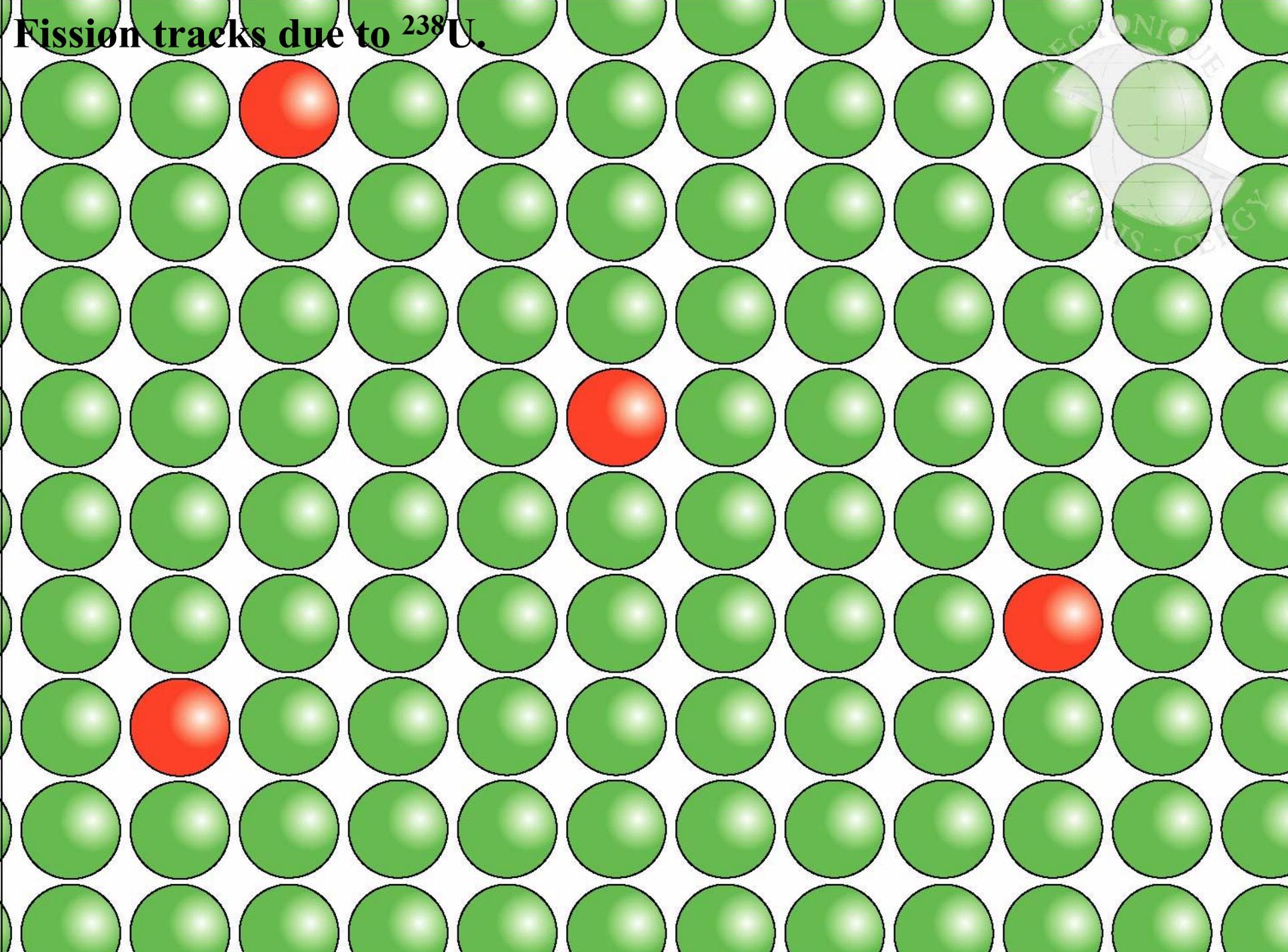


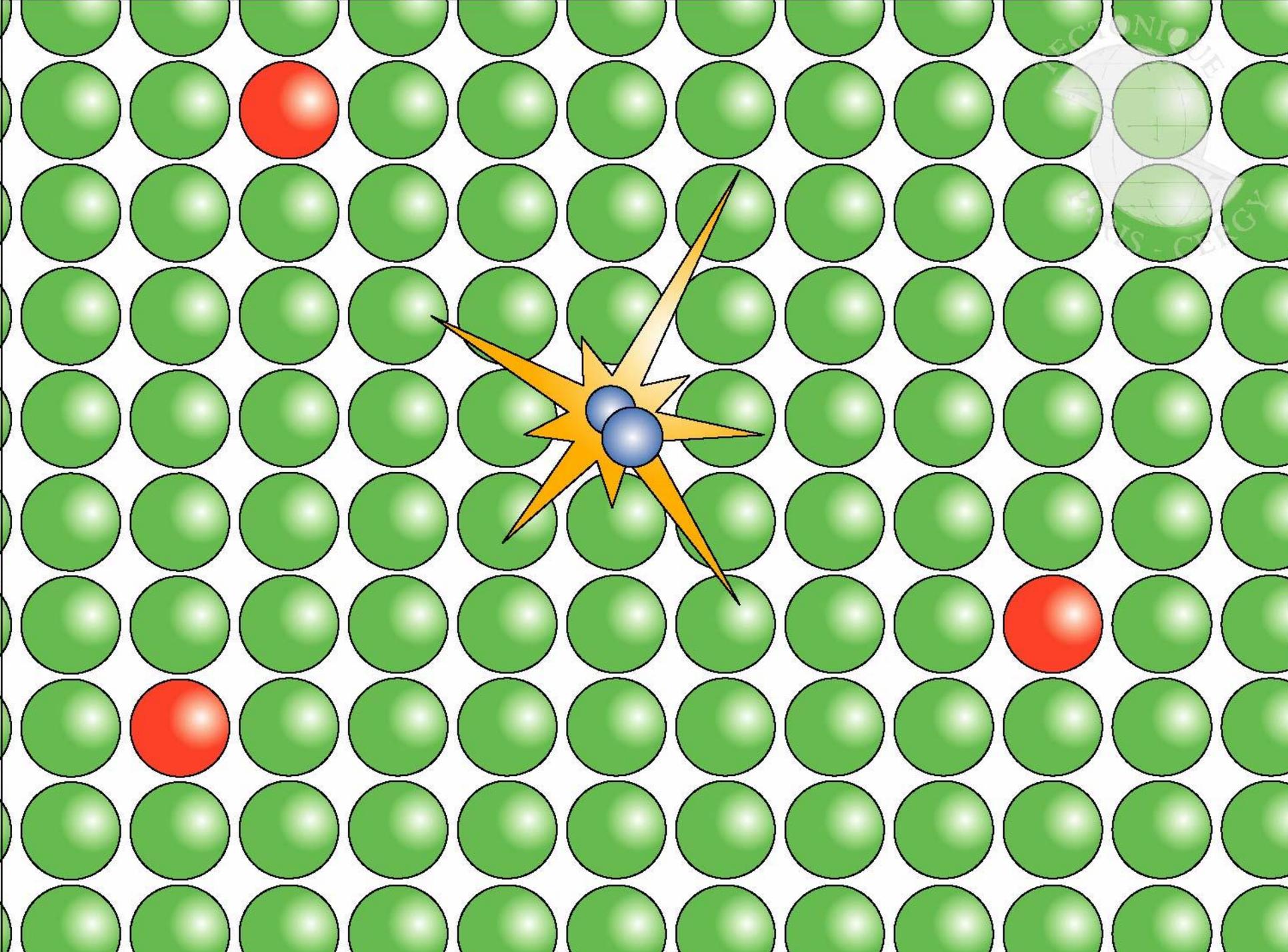
10 km of shortening in the cover since 10 Ma ~ 0 in the basement !...

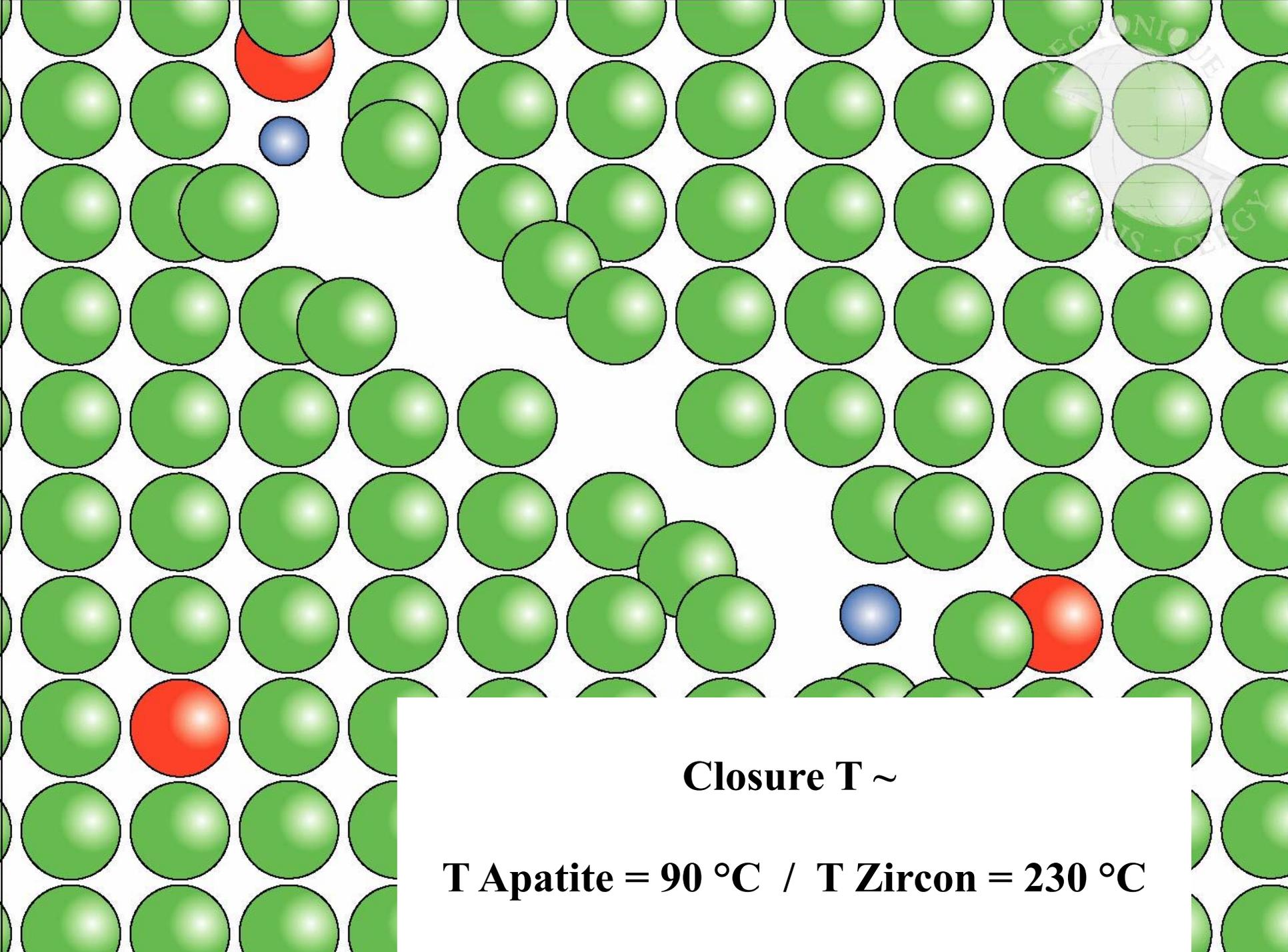


knowing h => X...

Fission tracks due to ^{238}U .



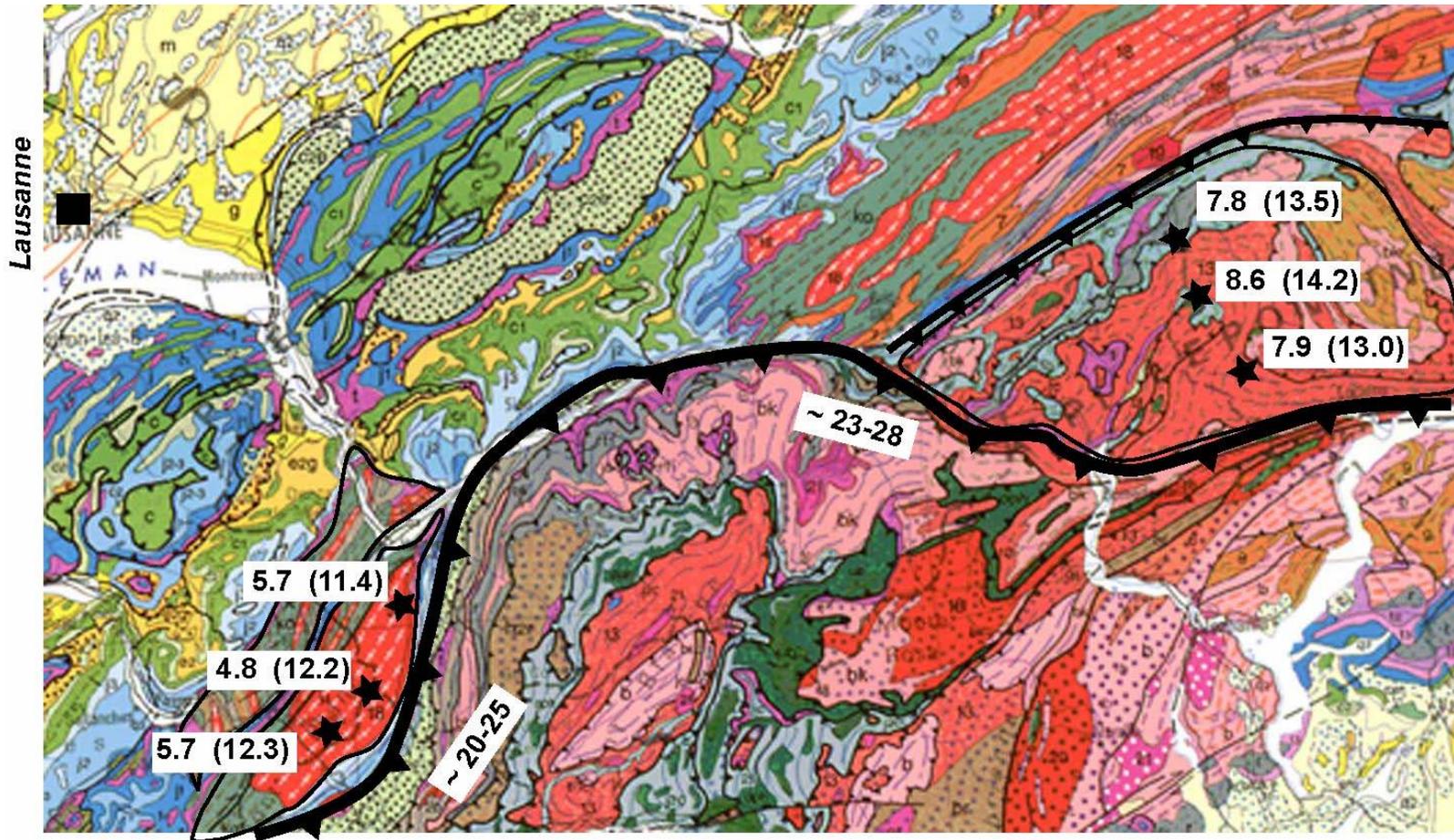




Closure T ~

T Apatite = 90 °C / T Zircon = 230 °C

FT ages : apatite (zircon), Ma

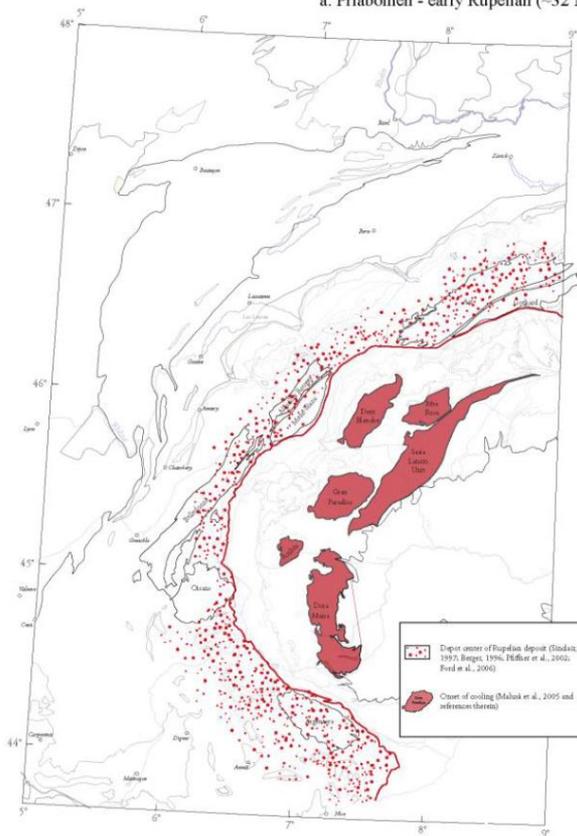


=> 140°C in 6 Ma, with a gradient of 25°C/km => ~1mm/yr

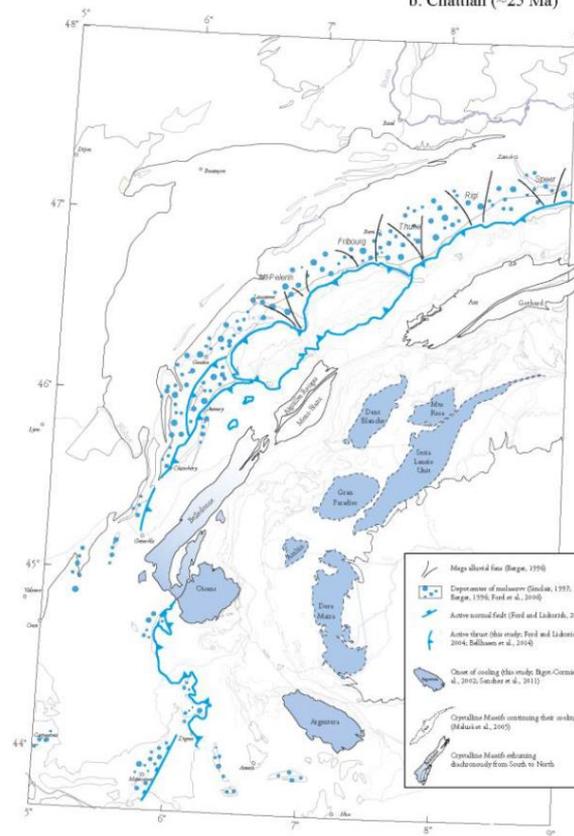
(D'après Girault, Thèse, 2020)

Corrélation entre exhumation des massifs de socle et remplissage sédimentaire dans le bassin d'avant-pays

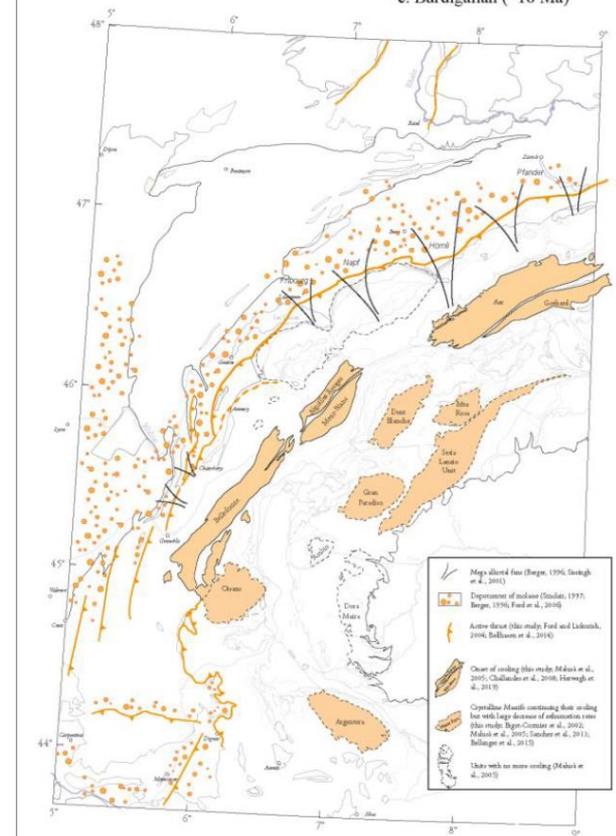
a. Priabonien - early Rupelian (~32 Ma)

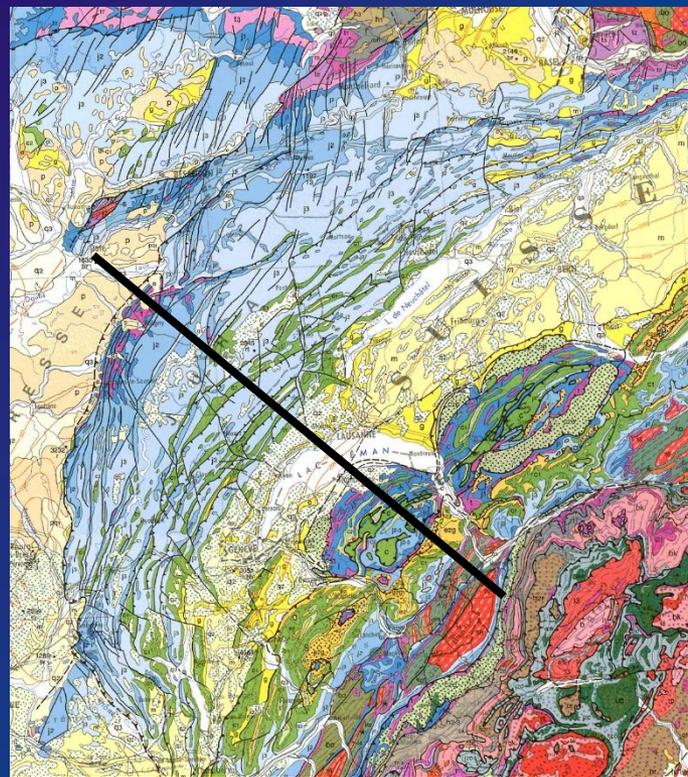


b. Chattian (~25 Ma)

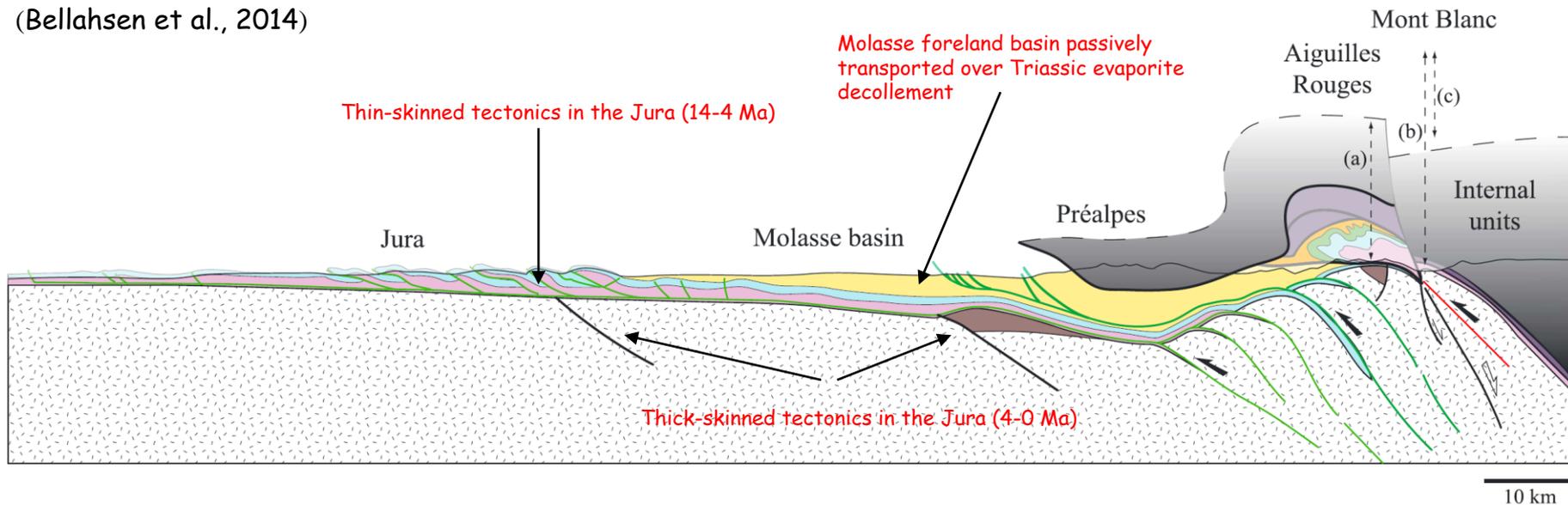


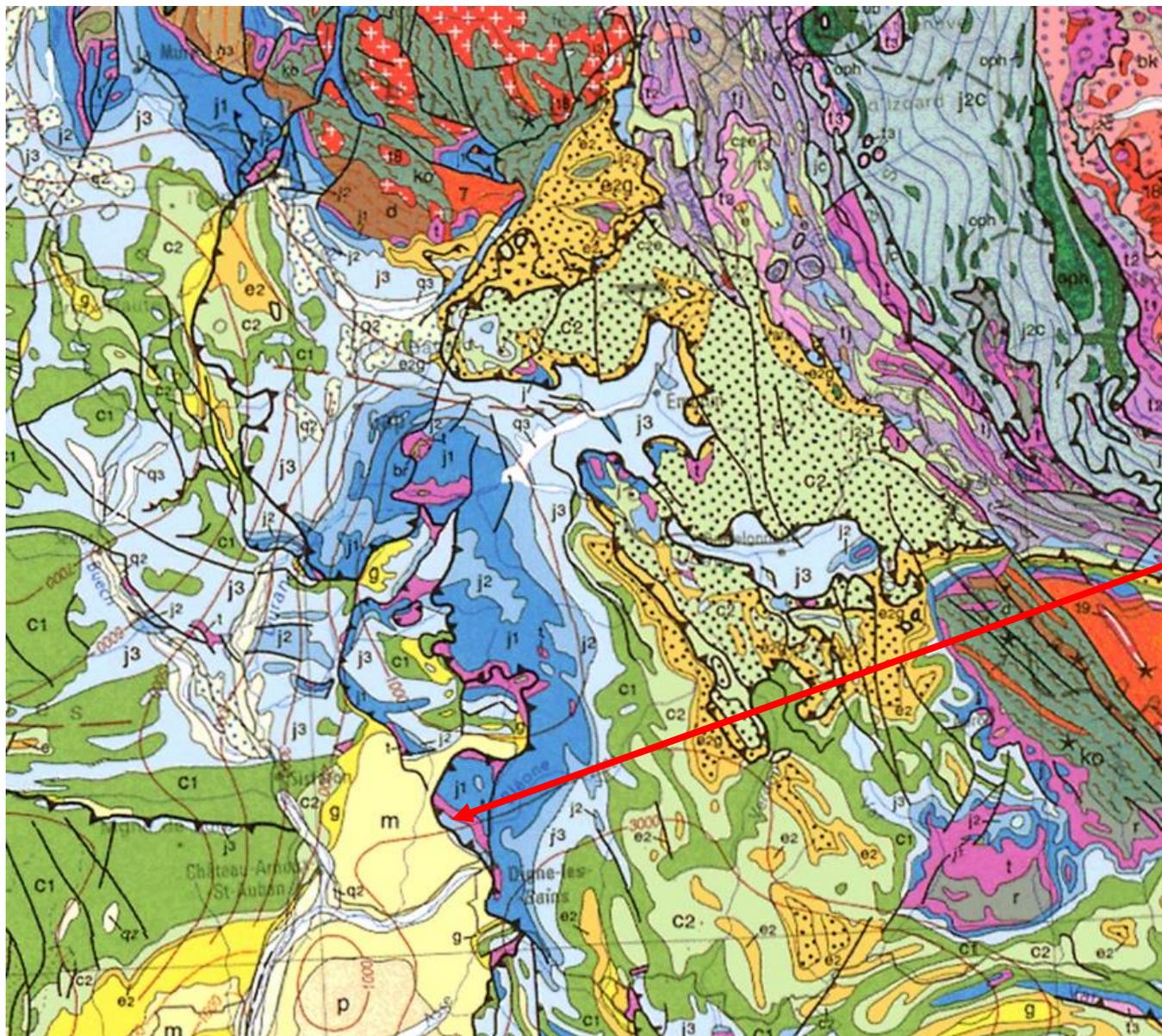
c. Burdigalian (~18 Ma)





(Bellahsen et al., 2014)





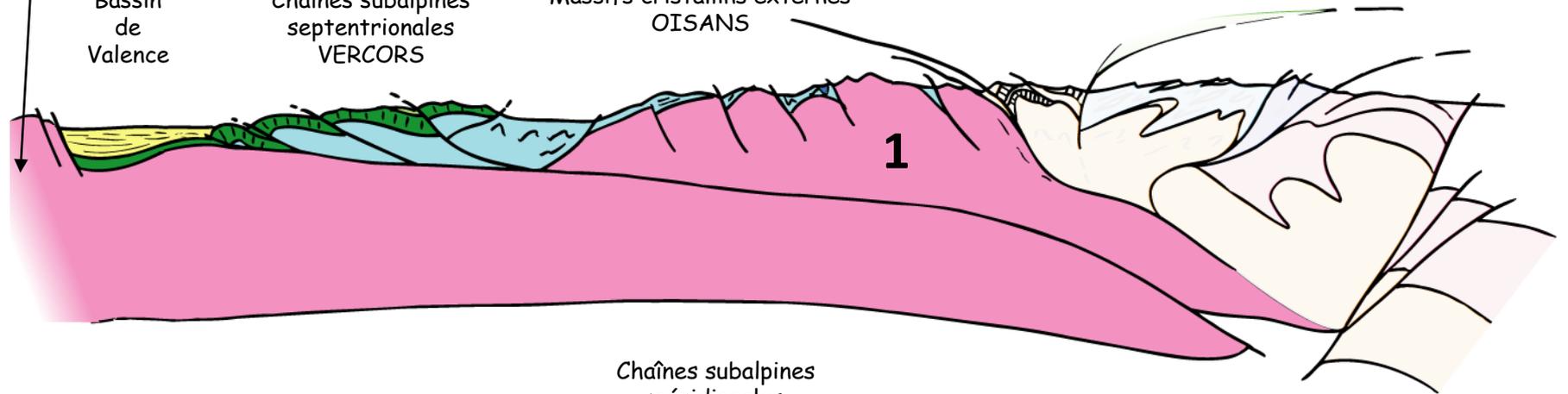
Chevauchement
du bassin molassique
miocène
par la nappe de Digne

Massif Central

Bassin de Valence

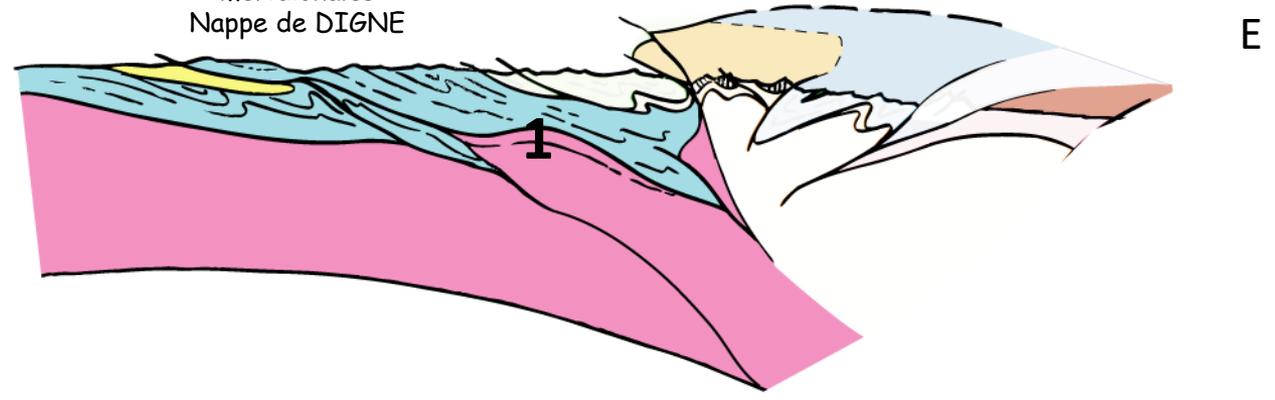
Chaînes subalpines septentrionales VERCORS

Massifs cristallins externes OISANS

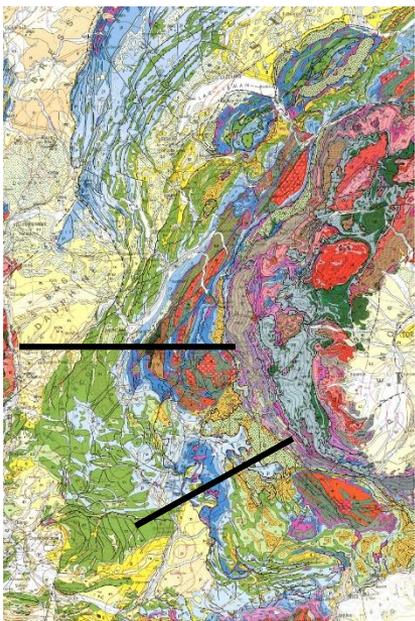


W

Chaînes subalpines méridionales Nappe de DIGNE



E

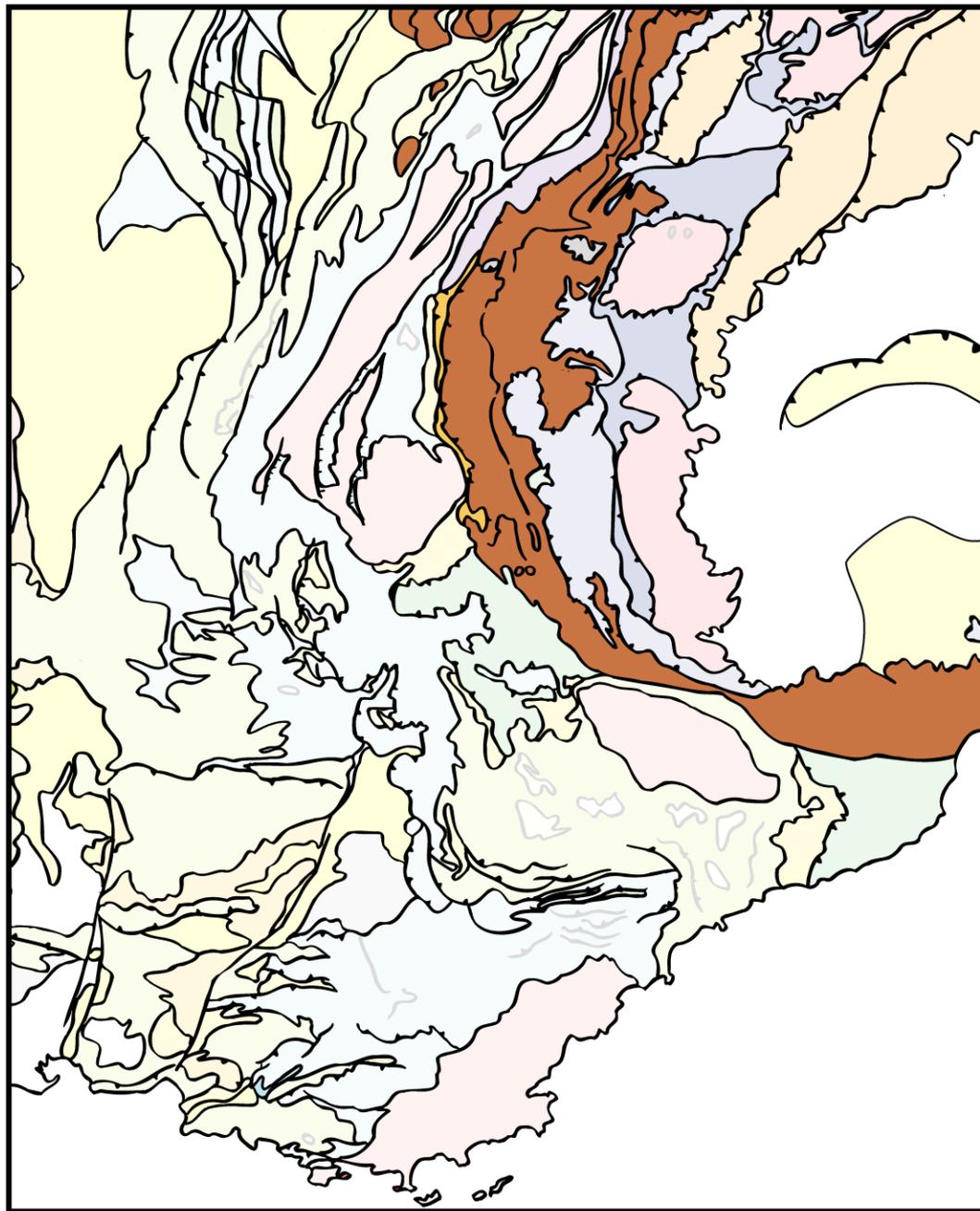


Le domaine Dauphinois

(D'après Jolivet)

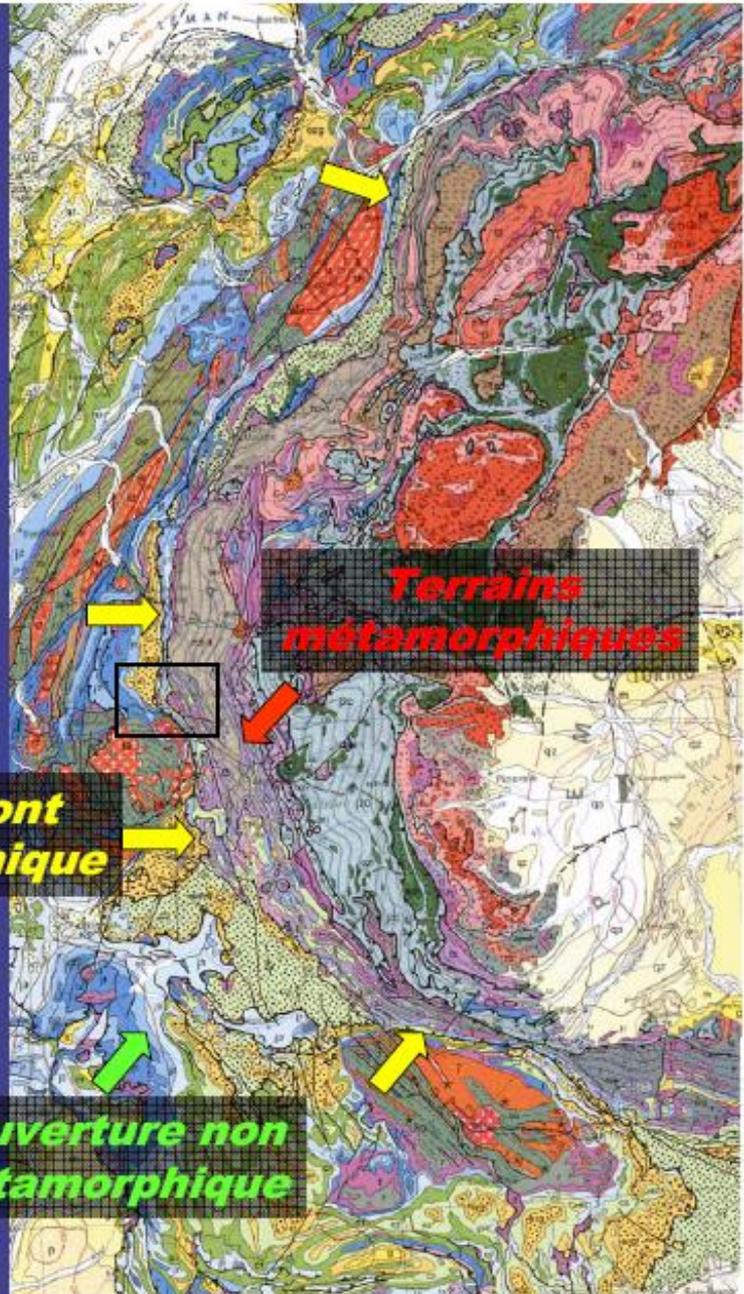
Les unités Briançonnaises et piémontaises :
Un « prisme d'accrétion » éocène

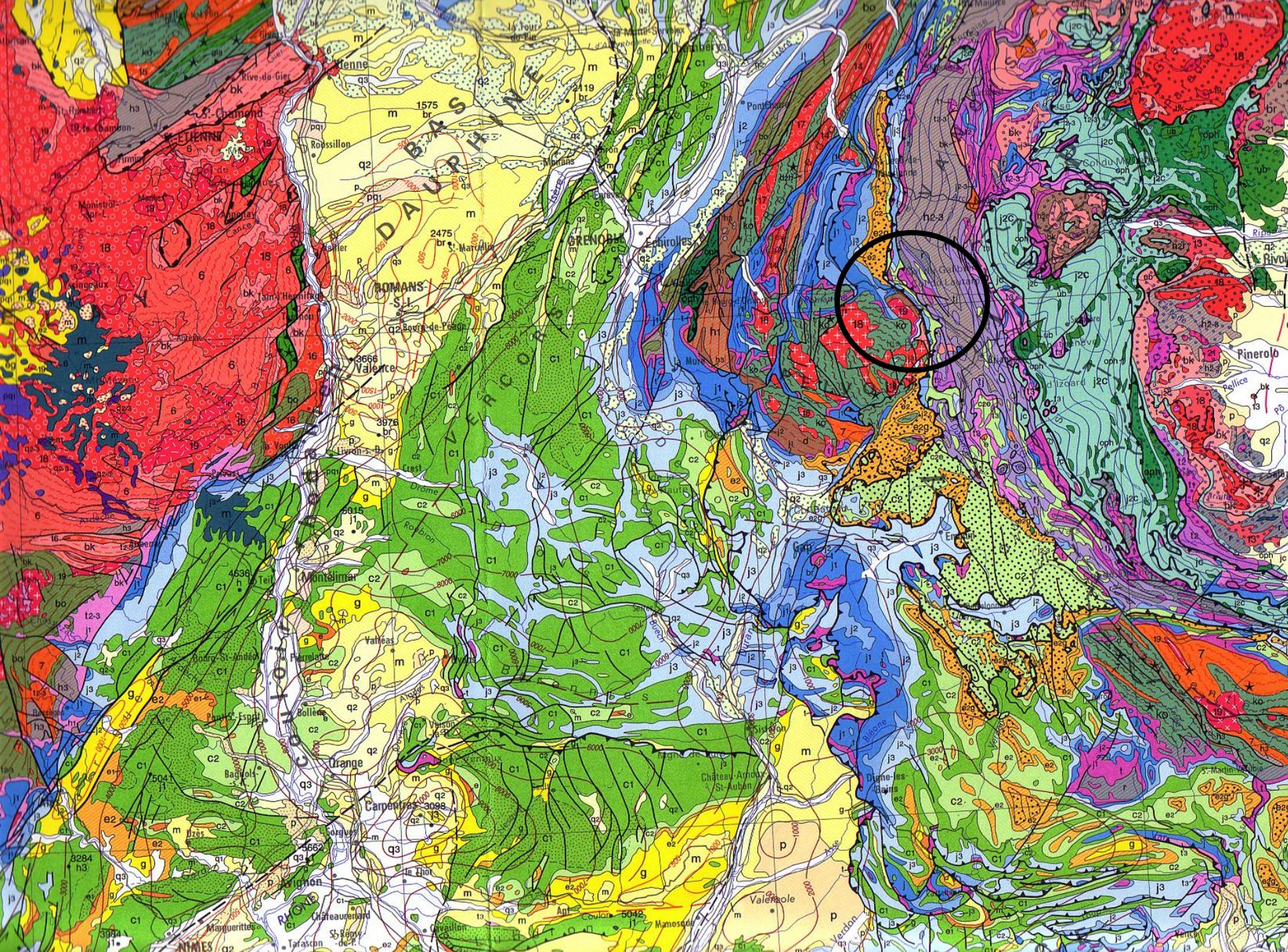
Le domaine Briançonnais

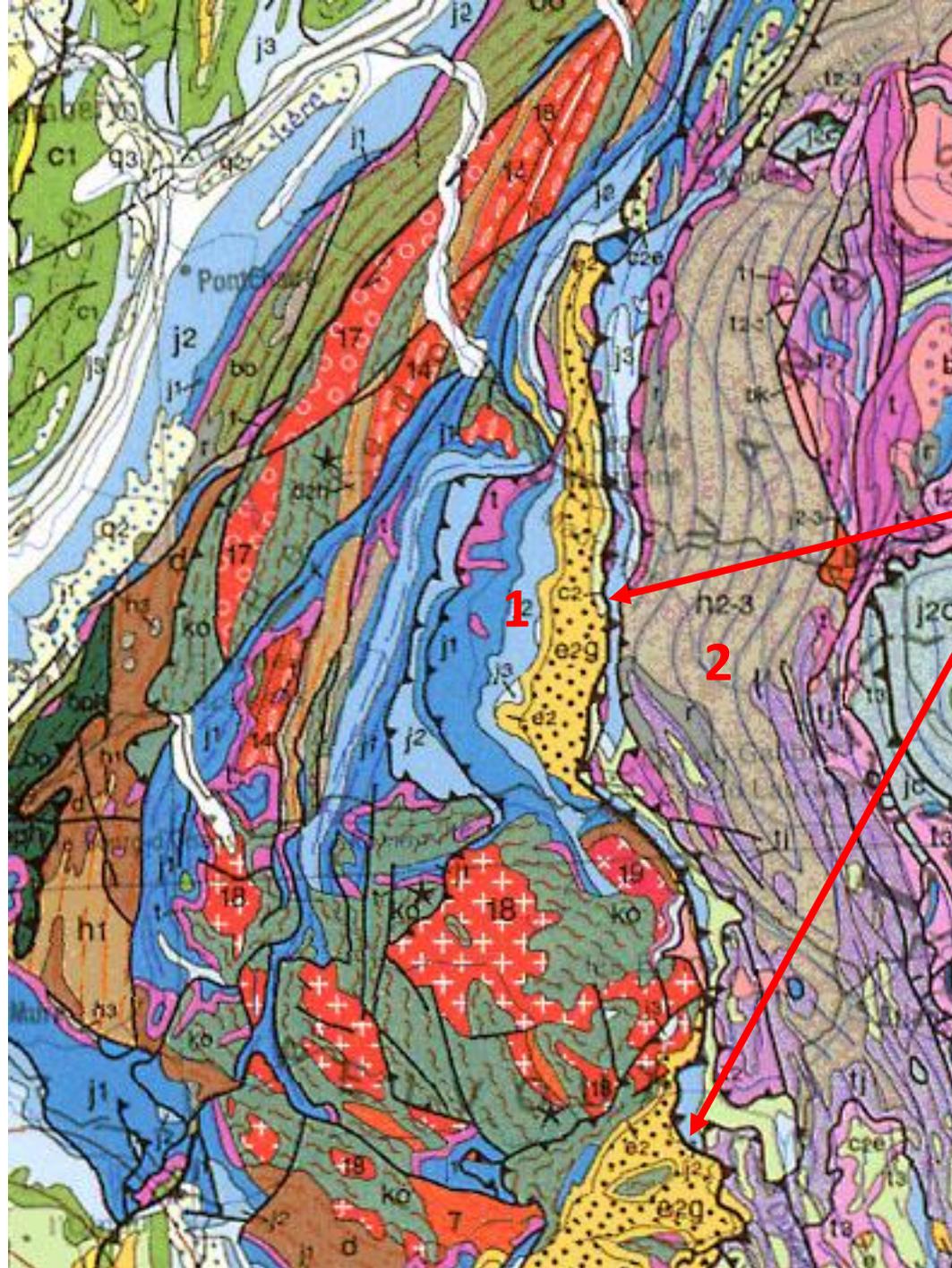


Front pennique
Structure majeure
à l'échelle de l'arc alpin

Limite tectonique:
chevauchement des zones
métamorphiques sur
l'avant-pays européen







Chevauchement
 du Briançonnais (2)
 sur le flysch Eo-
 Oligocène dauphinois
 (1)
 = Front Pennique ou
 Chevauchement
 Pennique Frontal

Panorama du Col du Lautaret



Panorama du Col du Lautaret

Unités externes

Unités internes

Flysch dauphinois

Sub-Briançonnais

Briançonnais

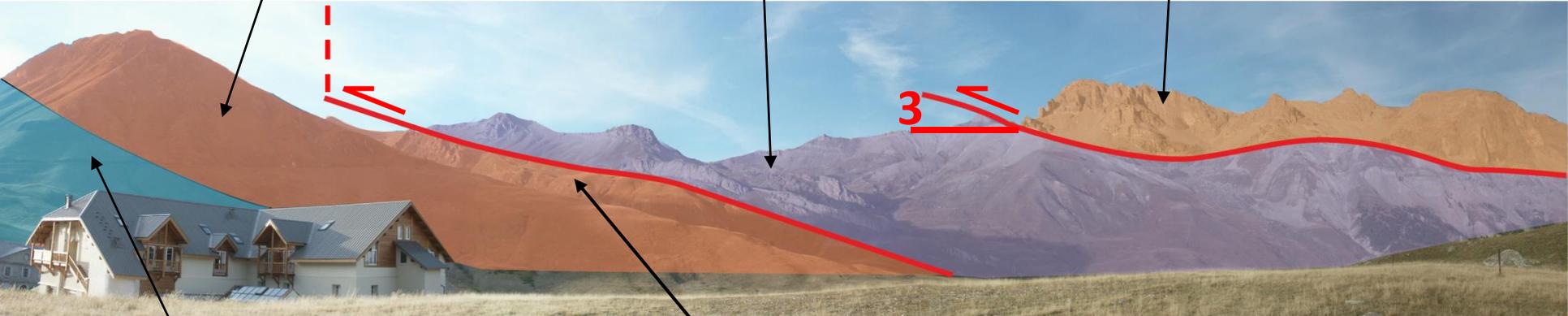
1

2

3

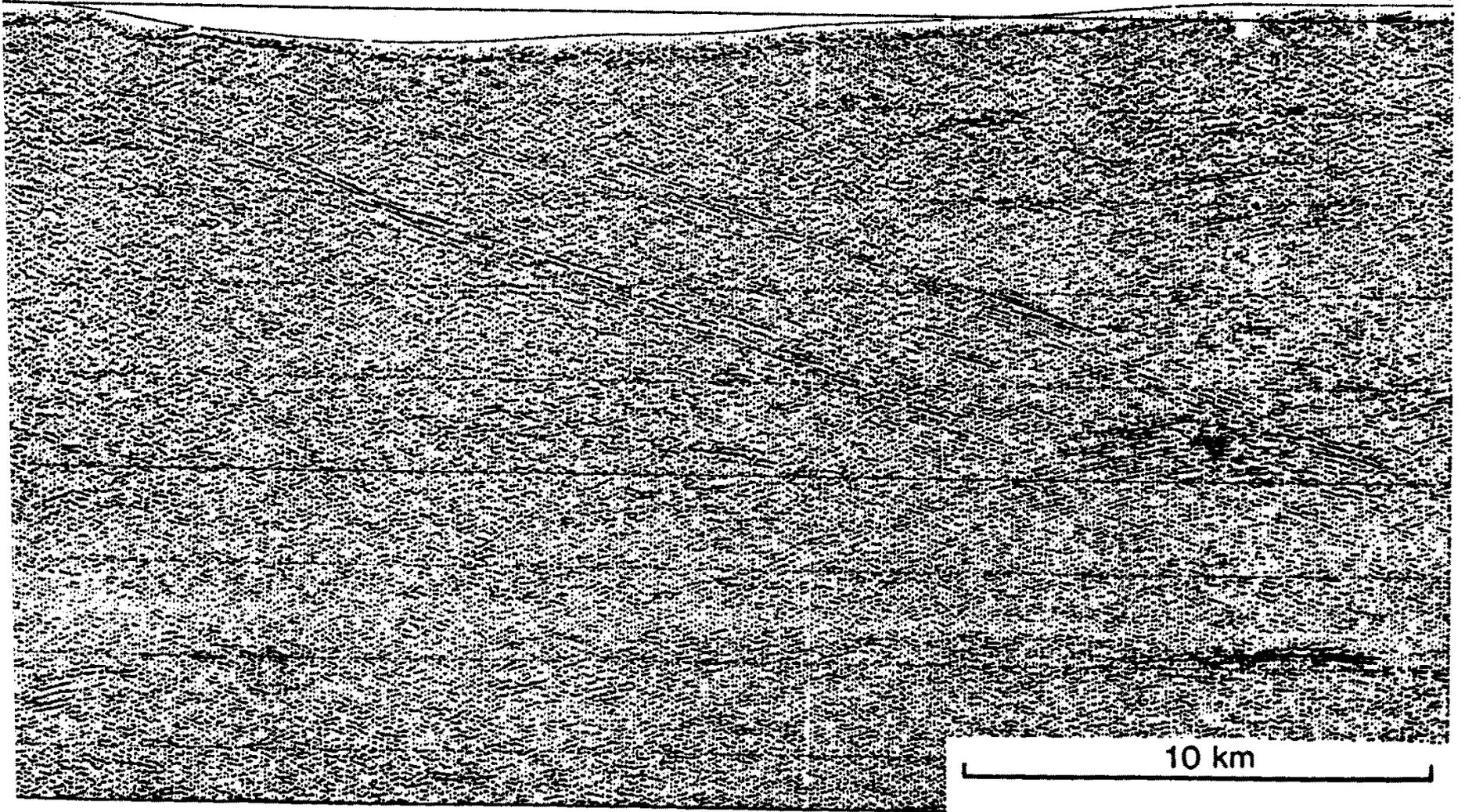
Lias dauphinois

CHEVAUCHEMENT PENNIQUE FRONTAL
OU FRONT PENNIQUE

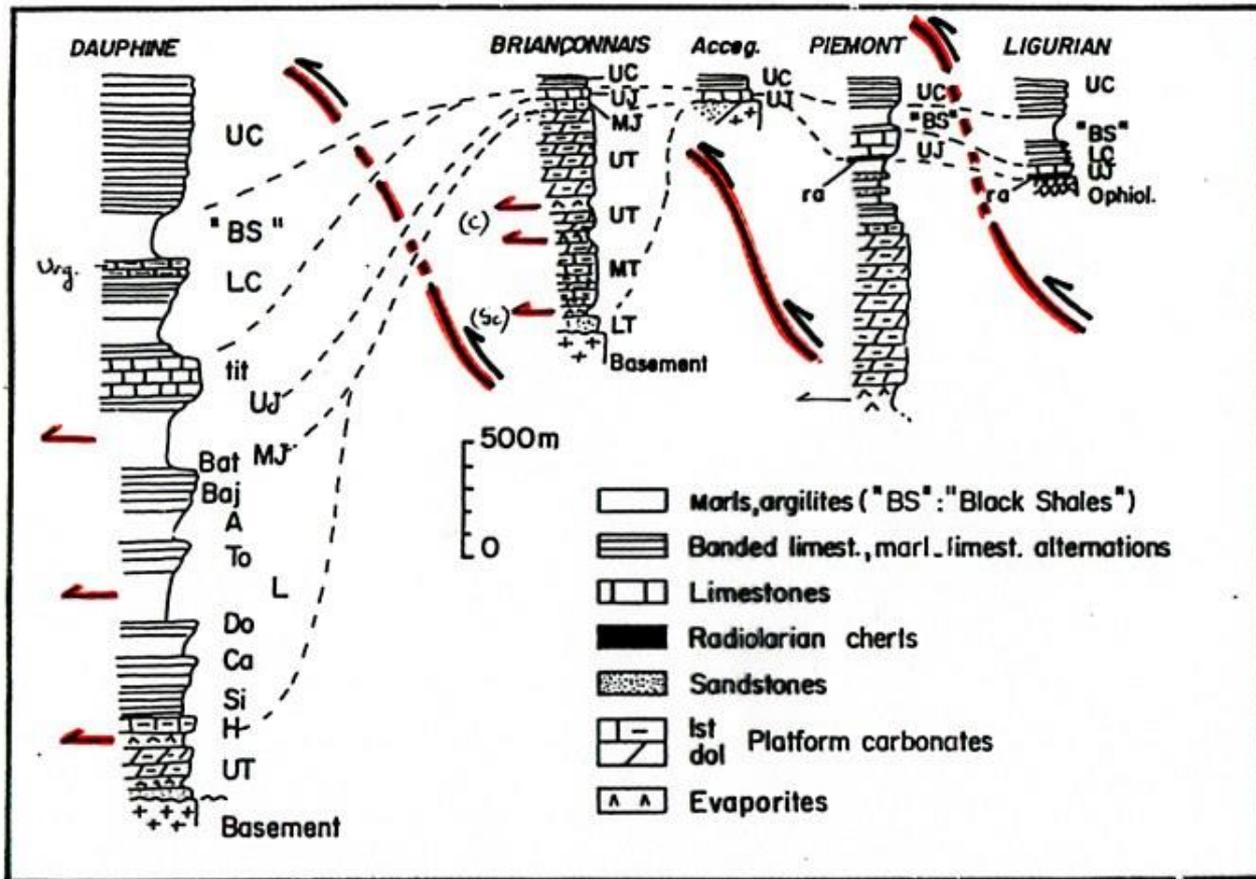


BOURG SAINT MAURICE

SE
VAL D'ISERE

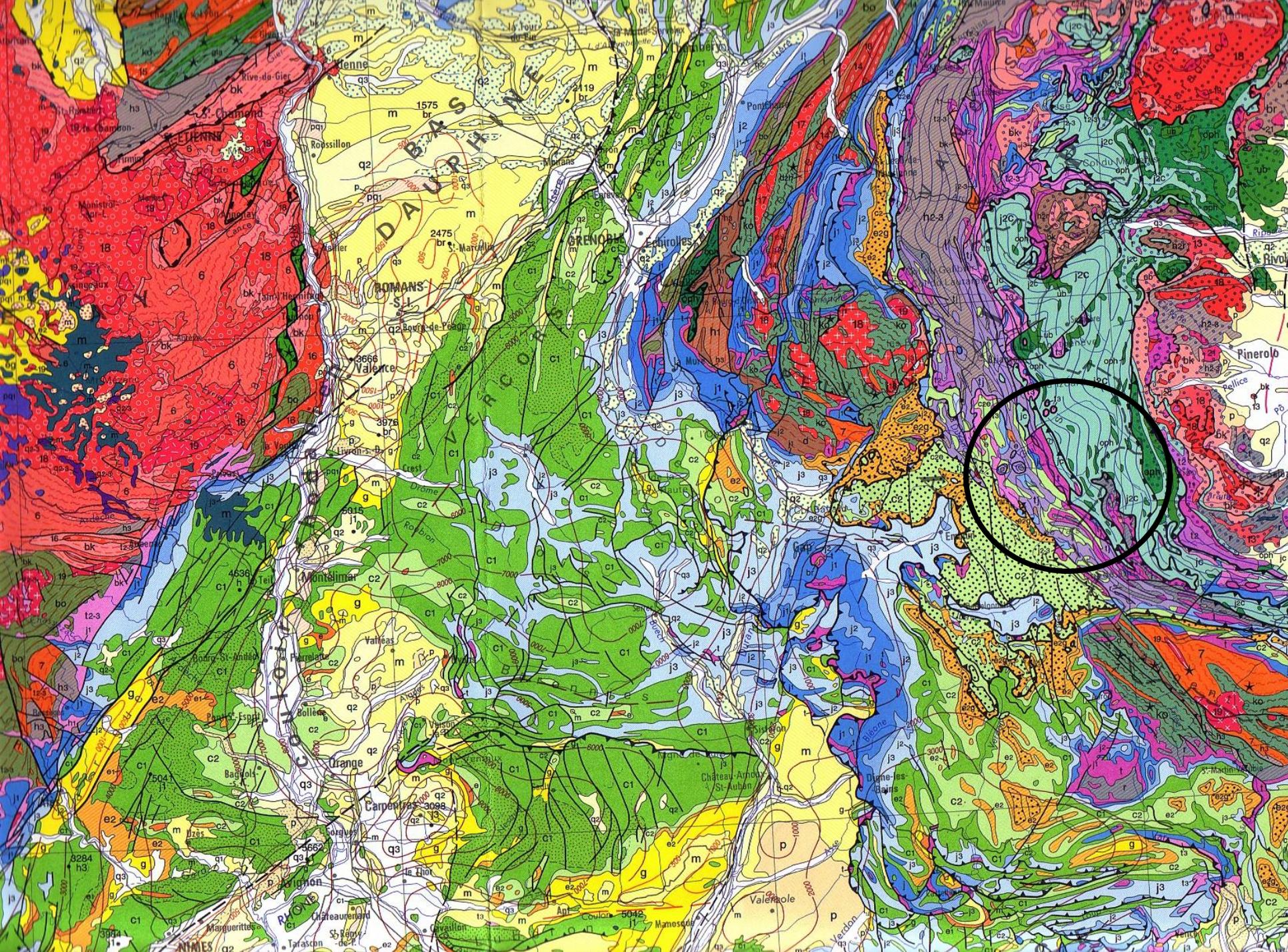


Réflecteur(s) du Front Pennique



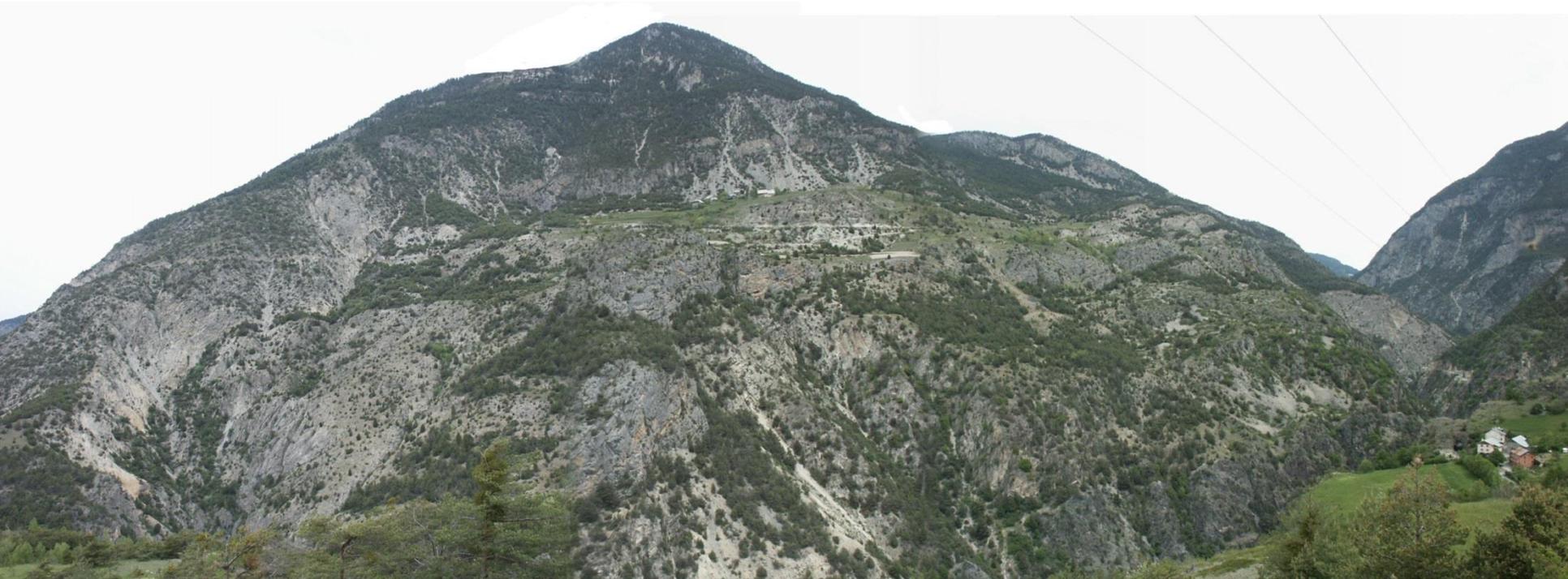
Simplified stratigraphic columns of the main types of sedimentary series in the Western Alps.

= Méozoïque

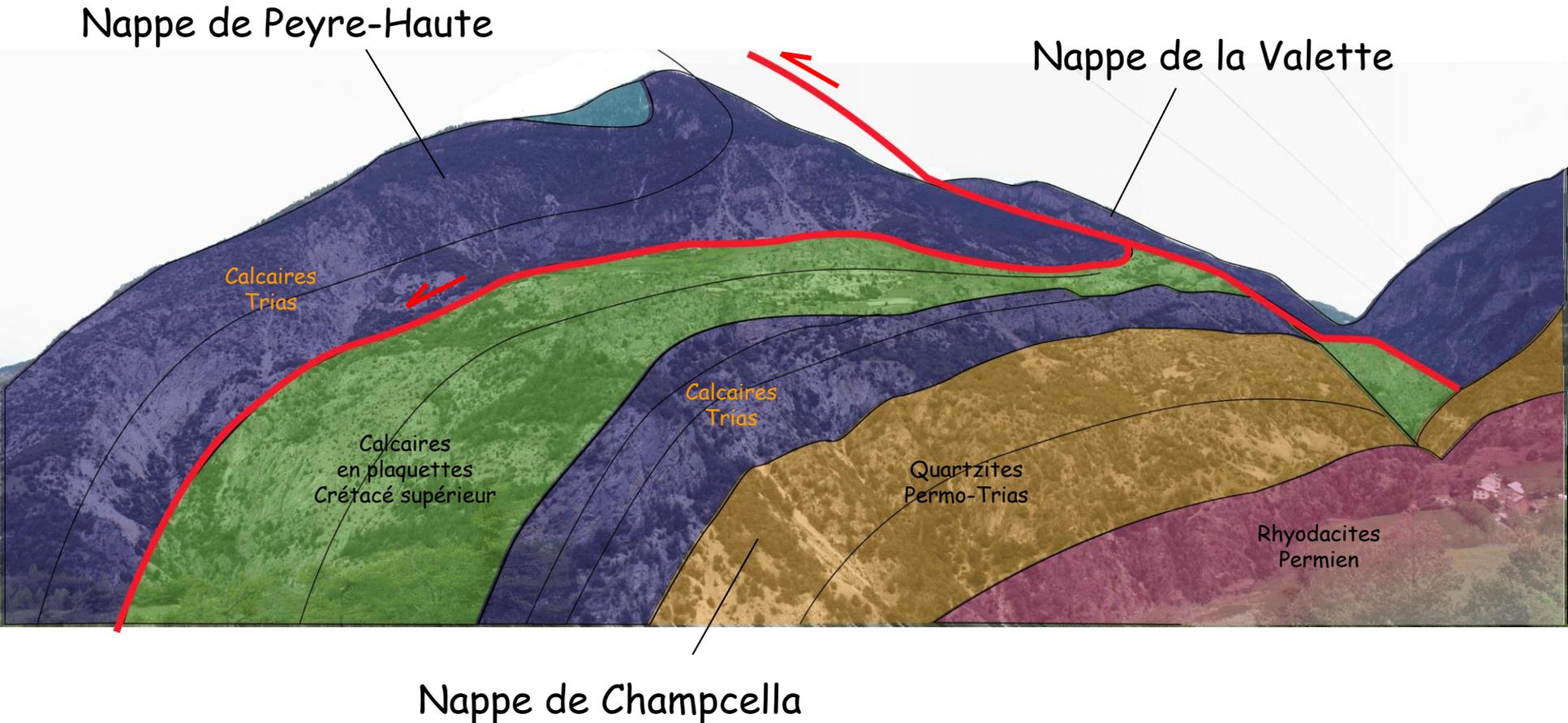




Panorama de la vallée du Guil



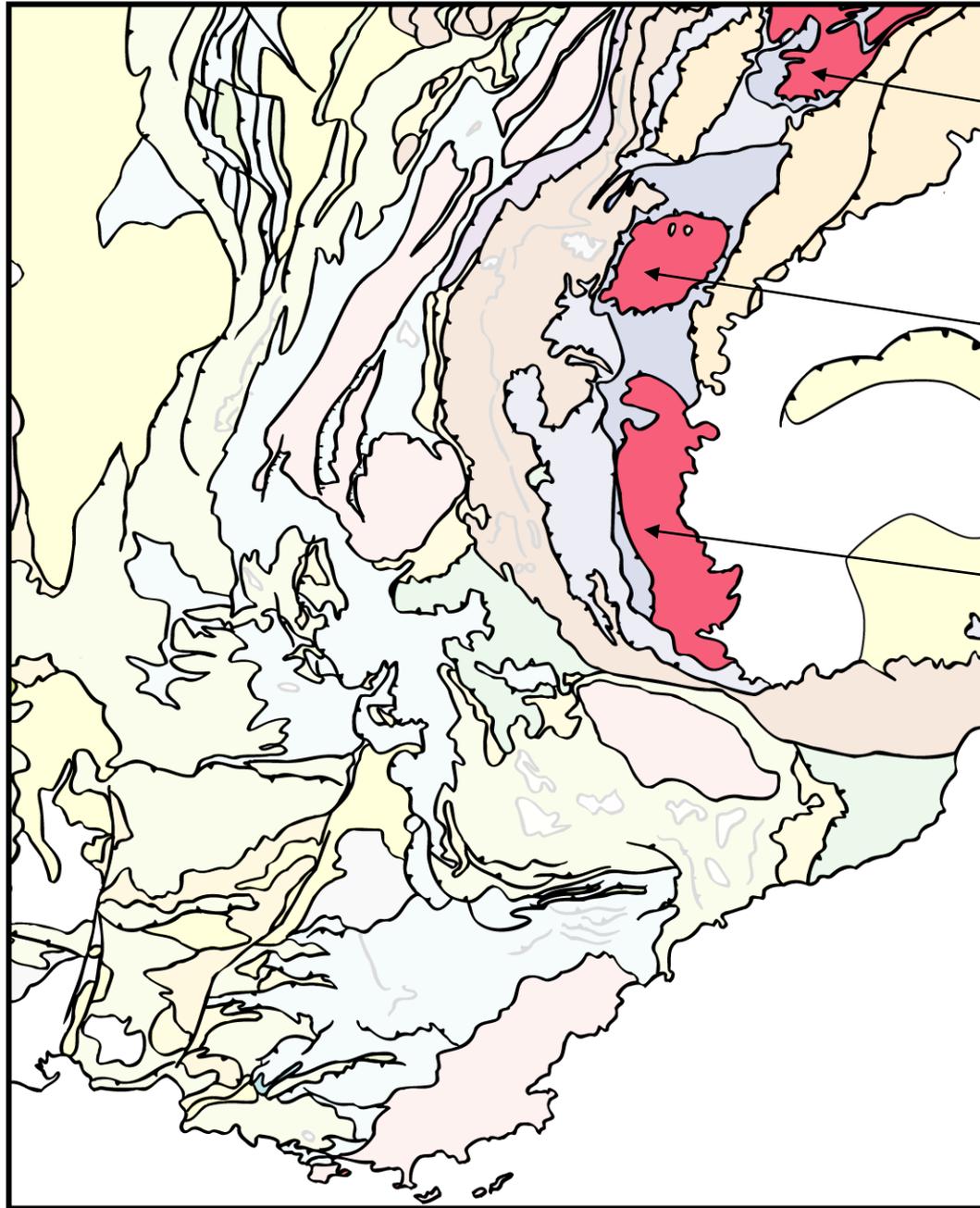
Panorama de la vallée du Guil



SUPERPOSITION DE NAPPES DE COUVERTURE BRIANÇONNAISE

Le domaine
Briançonnais

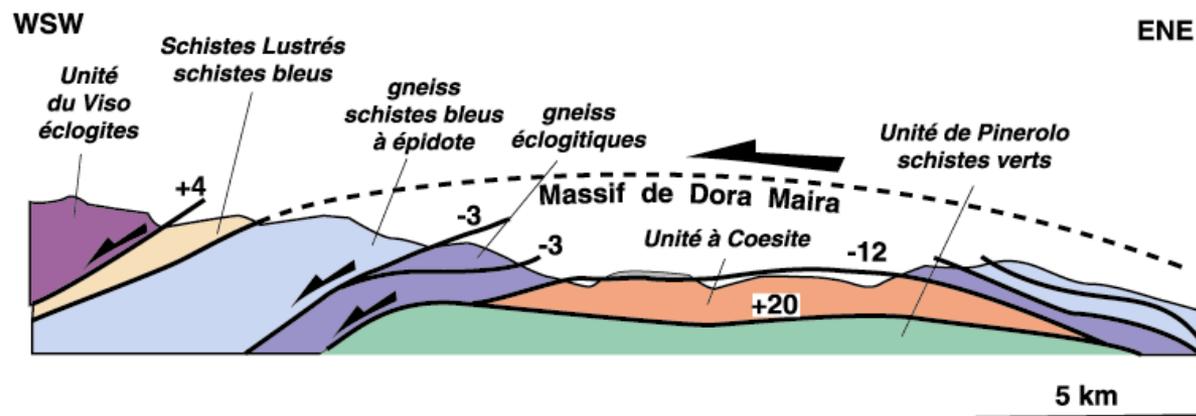
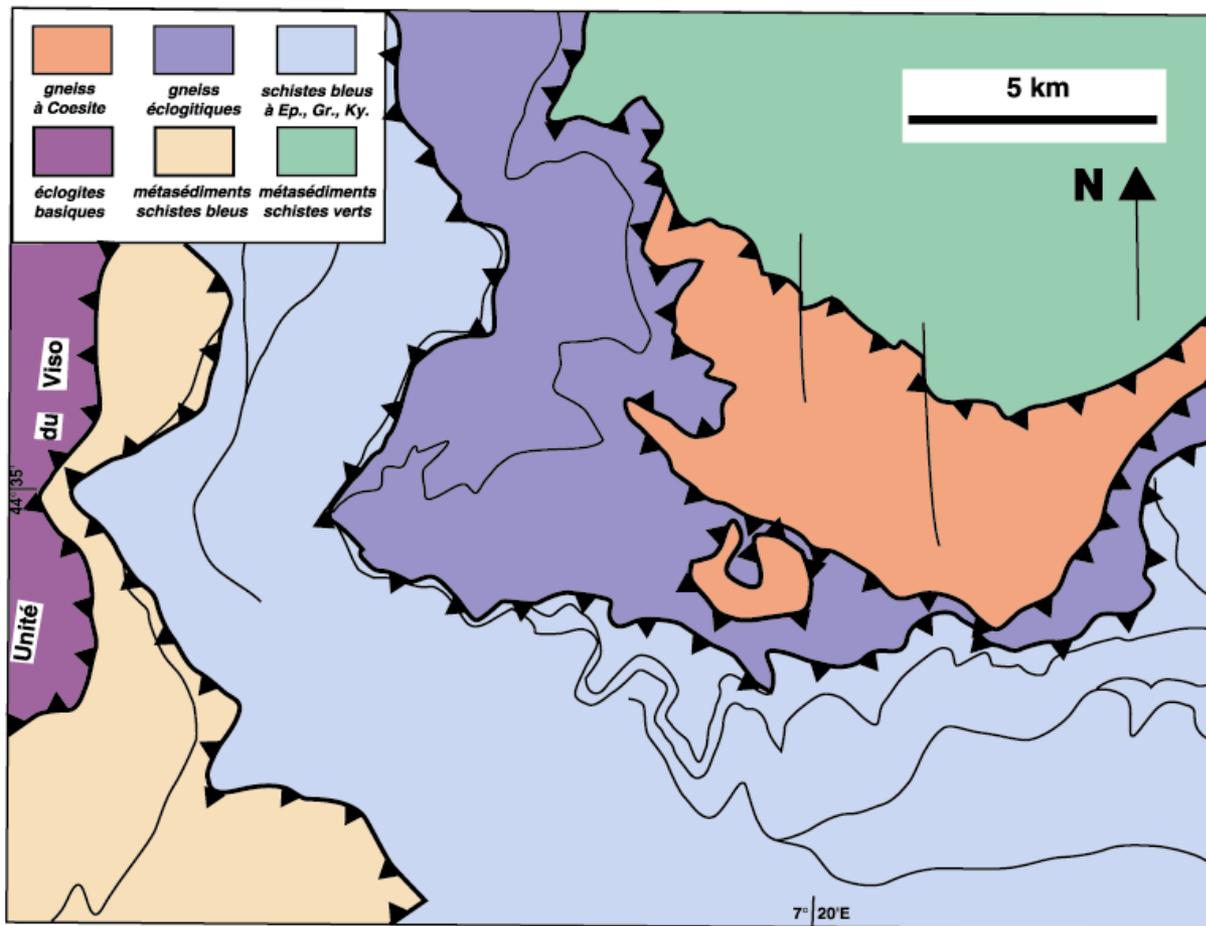
Les Massifs
Cristallins
Internes



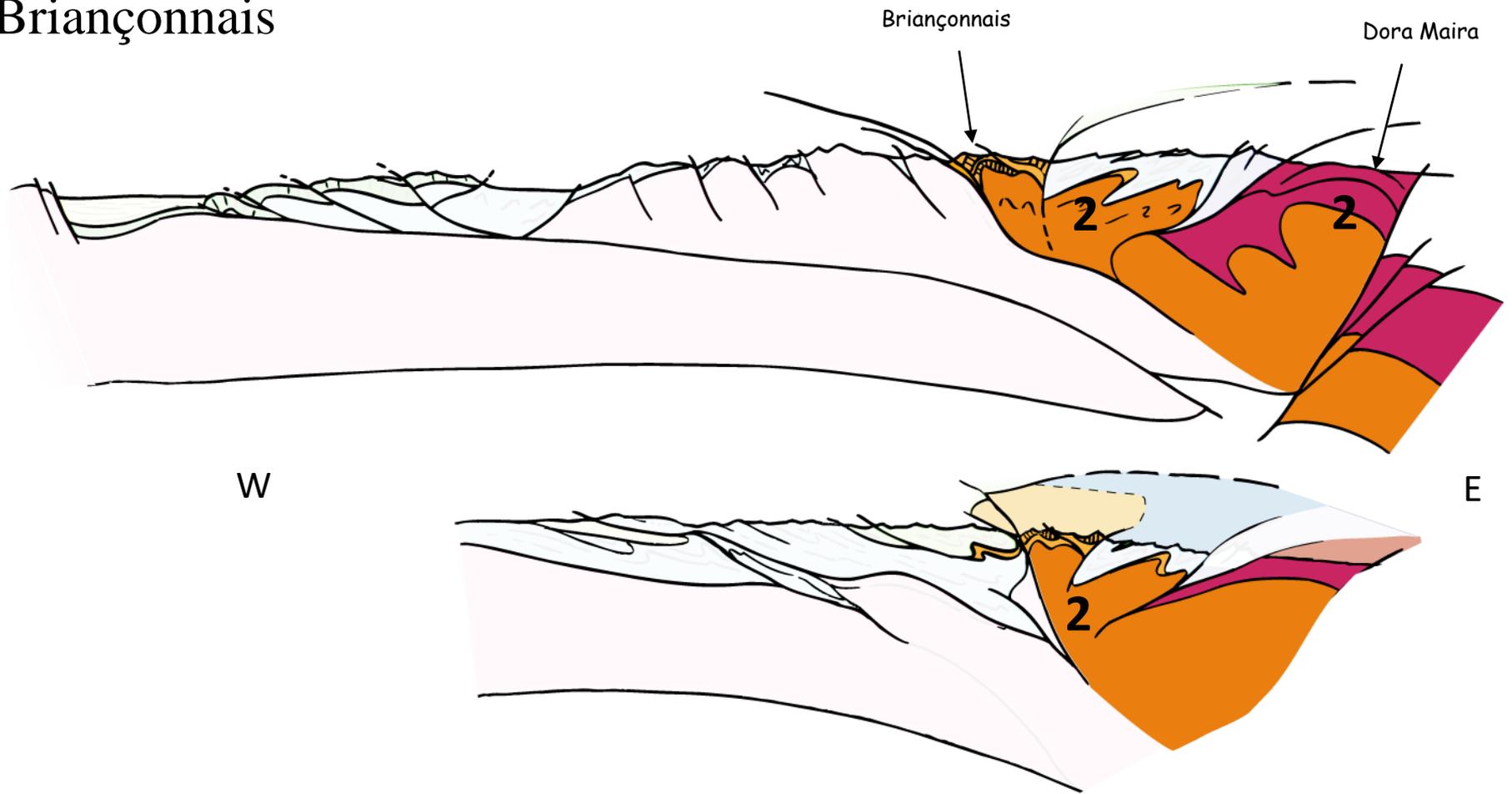
Mont Rose

Grand Paradis

Dora Maira



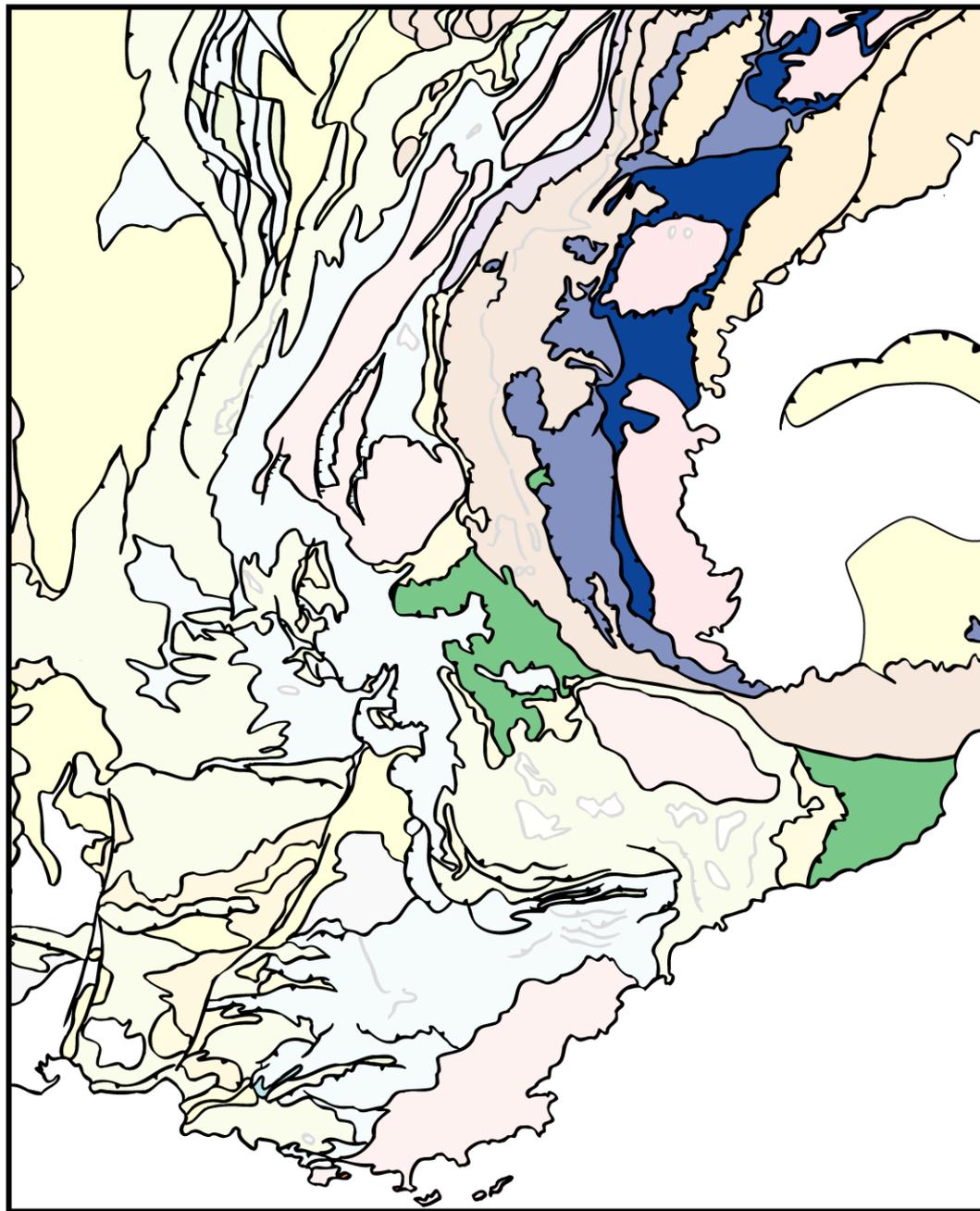
Le domaine Briançonnais



(D'après Jolivet)

Les unités liguro-piémontaises :
Un « prisme d'accrétion » crétacé sup.-paléocène

Le domaine
Ligure
ou
Liguro -
Piémontais

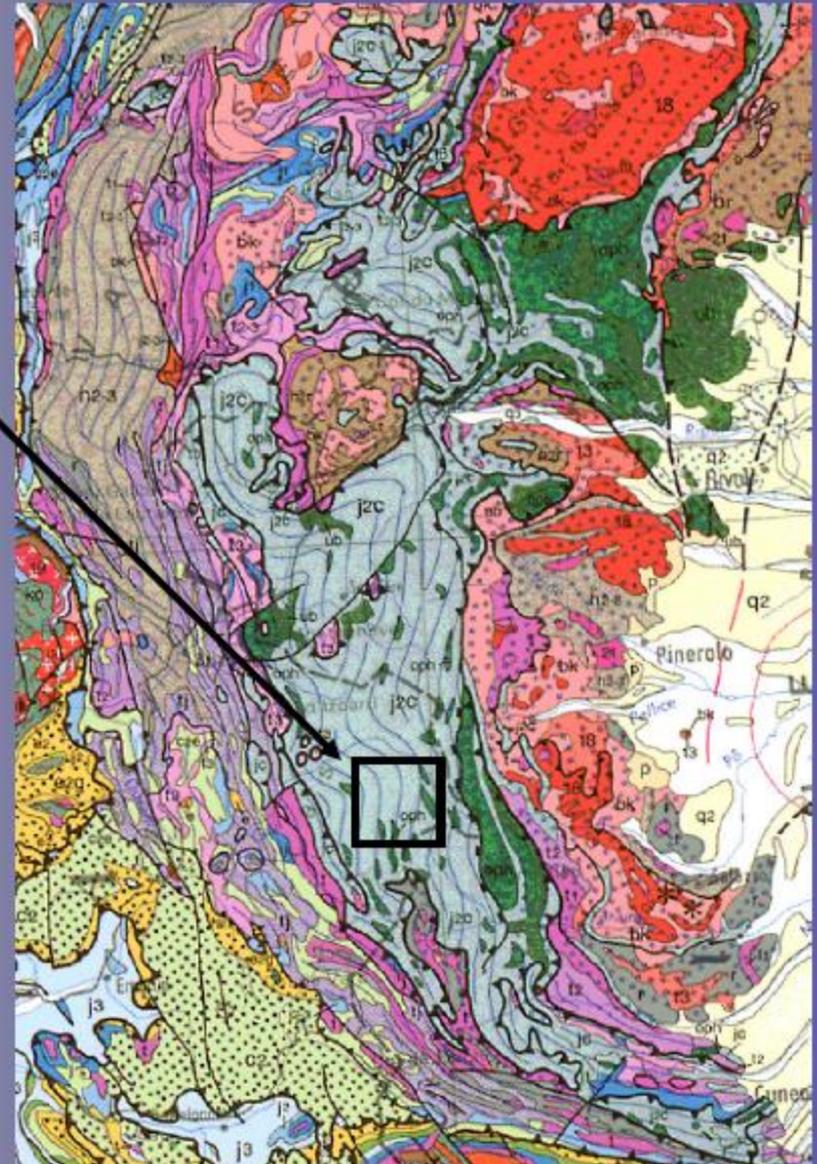


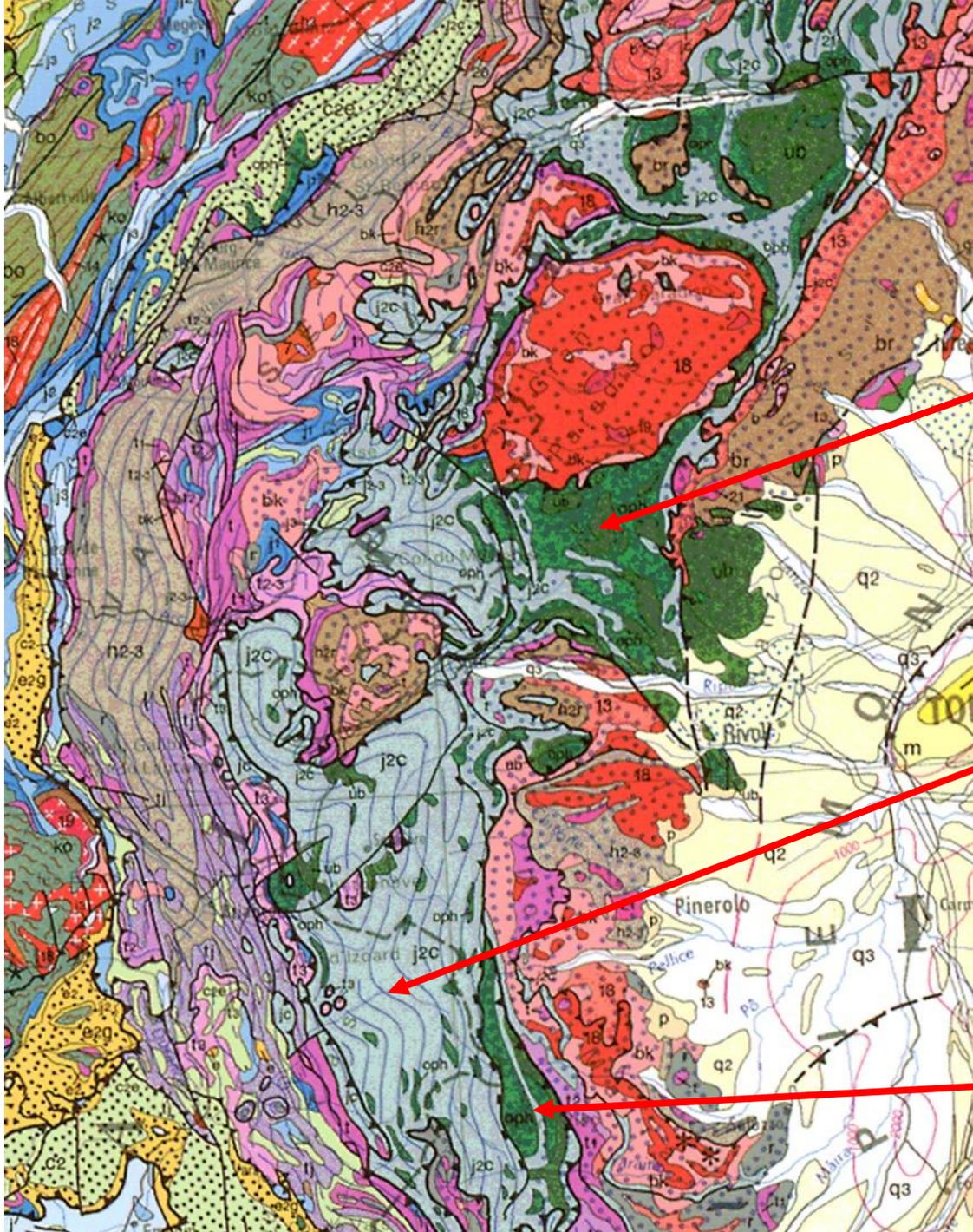


Association :

- sédiments**
- gabbros**
- basaltes**
- péridotites serpentinisées**

➔ Fragments de lithosphère océanique emballés dans des sédiments le tout métamorphisé

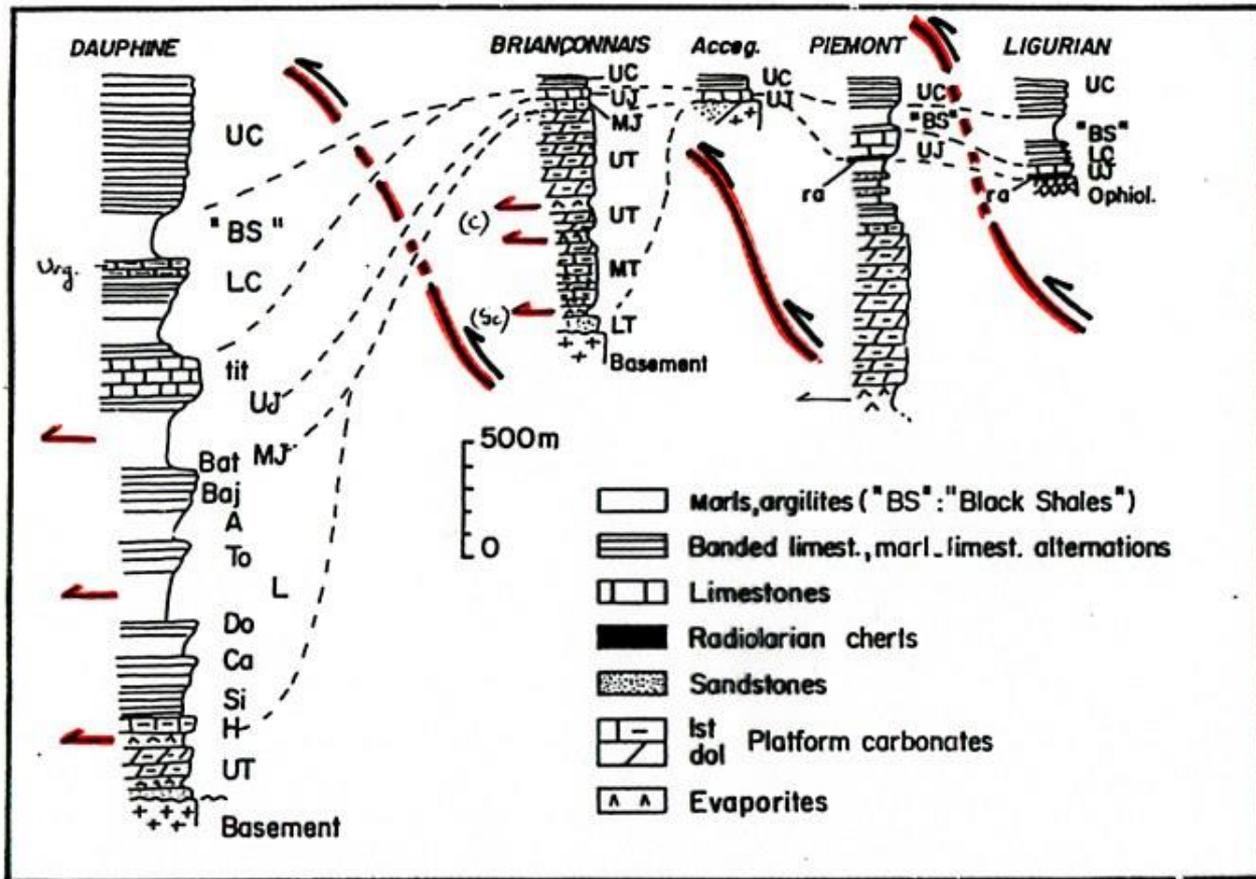




Fragments de lithosphère
océanique

Méta-sédiments océaniques
= Schistes Lustrés

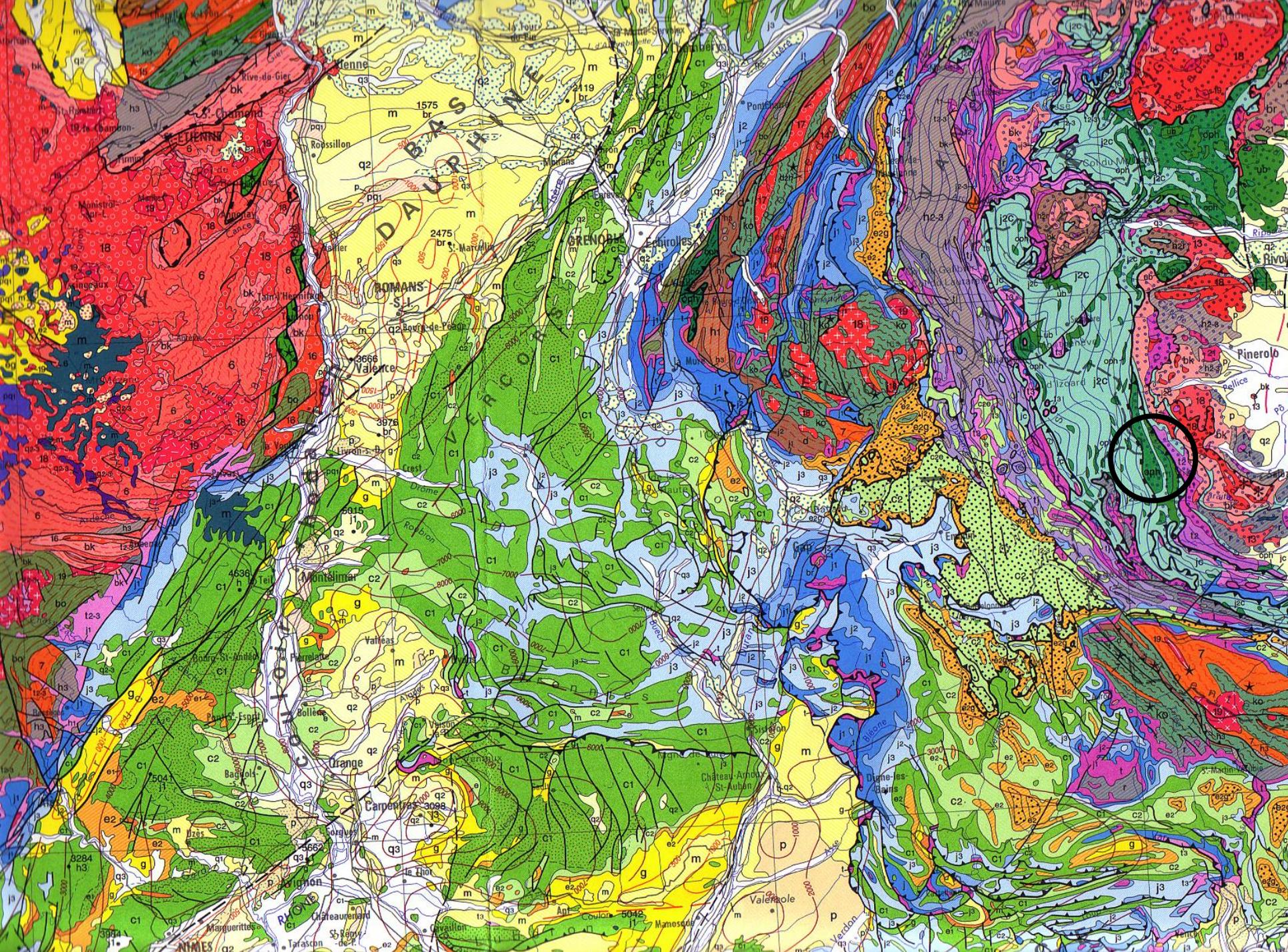
Fragments de lithosphère
océanique



Simplified stratigraphic columns of the main types of sedimentary series in the Western Alps.

= Mésozoïque





DAUPHINÉ

GRENOBLE

ROMANS

Valence

Orange

Carpenas

NÎMES

Pinerolo

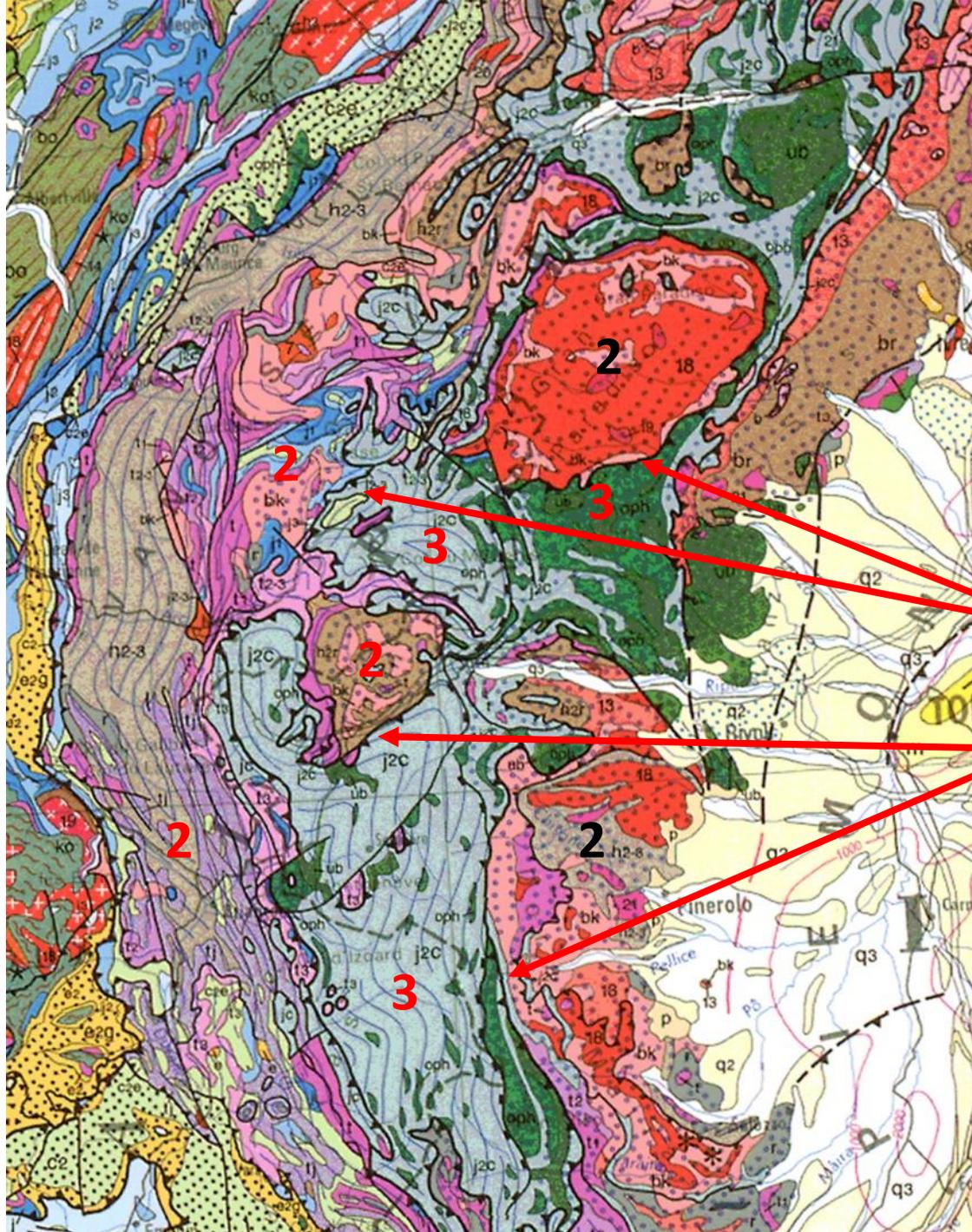


Le Mont Viso vu de la
plaine du Pô : du
matériel océanique à
~3800m d'altitude

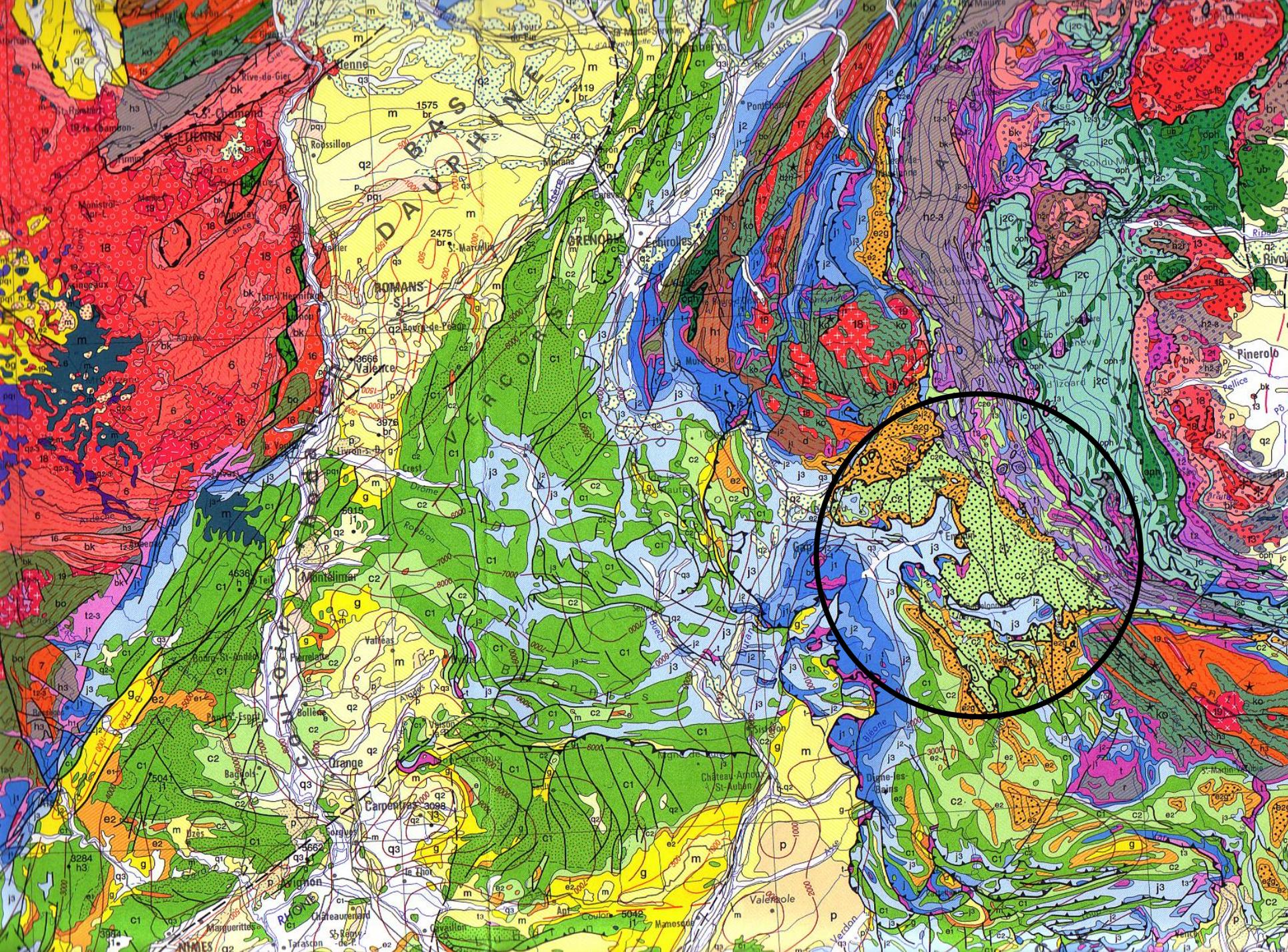


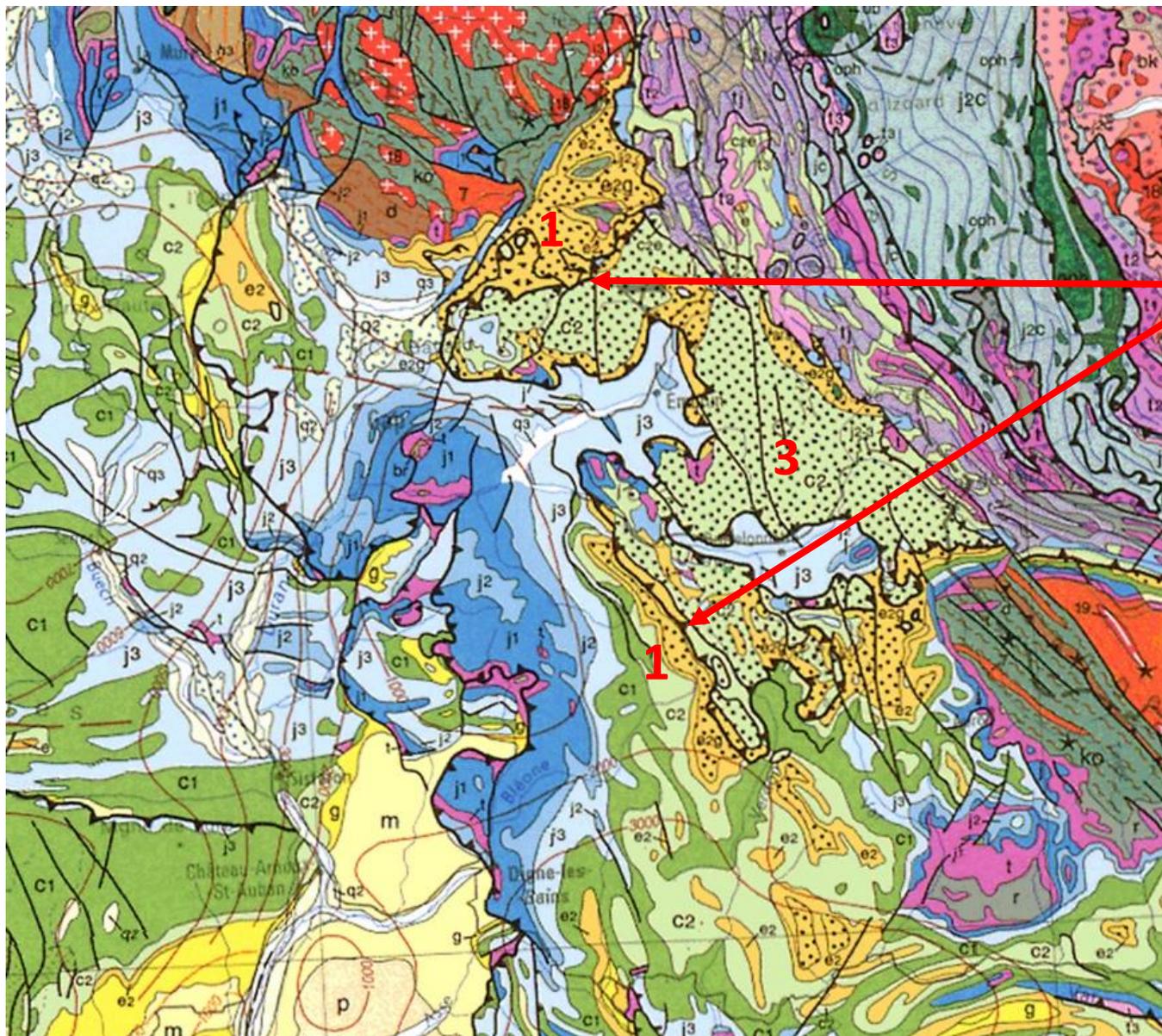
Le Viso





Chevauchement
de l'Unité des
Schistes Lustrés
d'origine océanique (3)
sur le Briançonnais
(continental) (2)

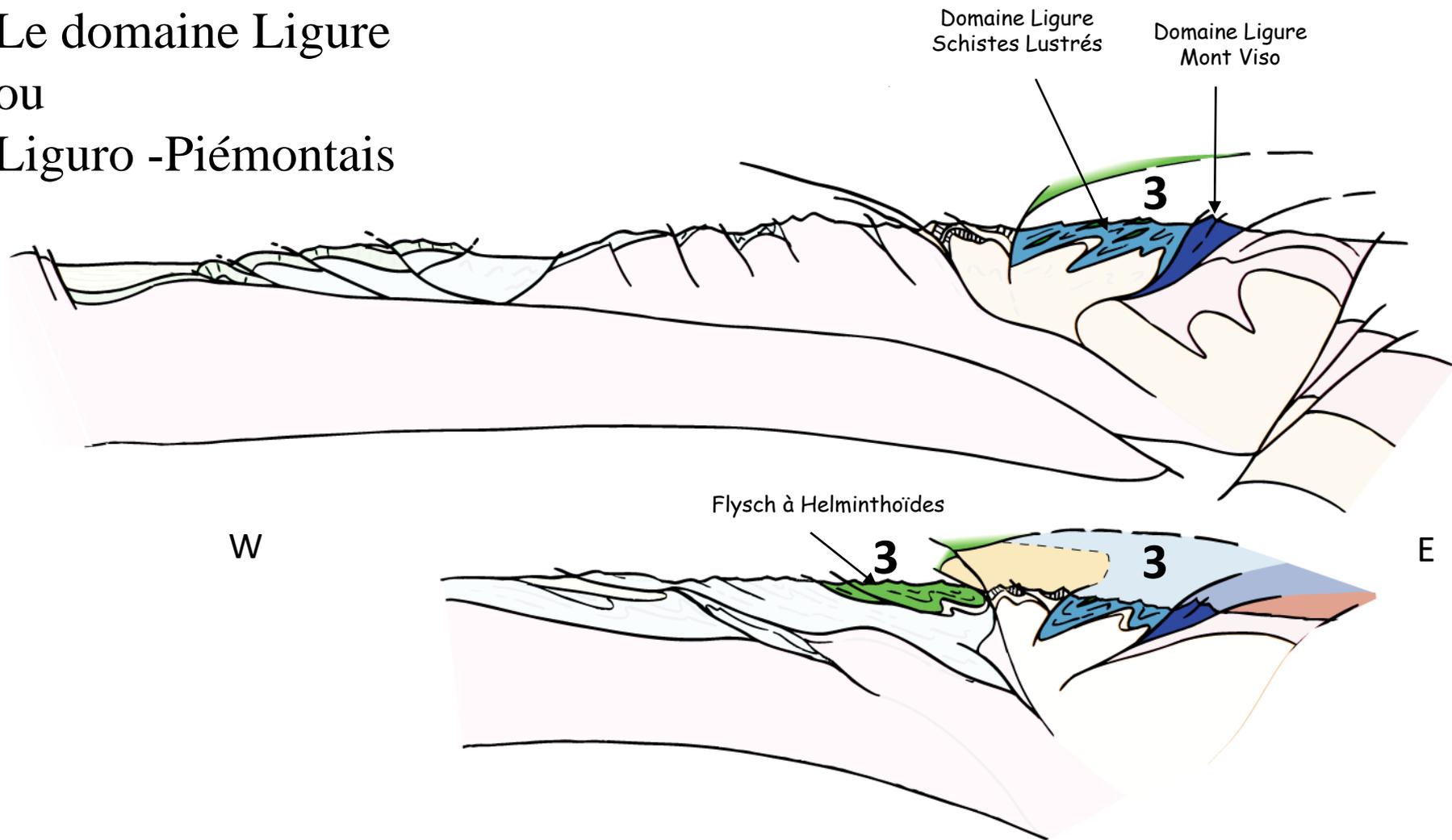




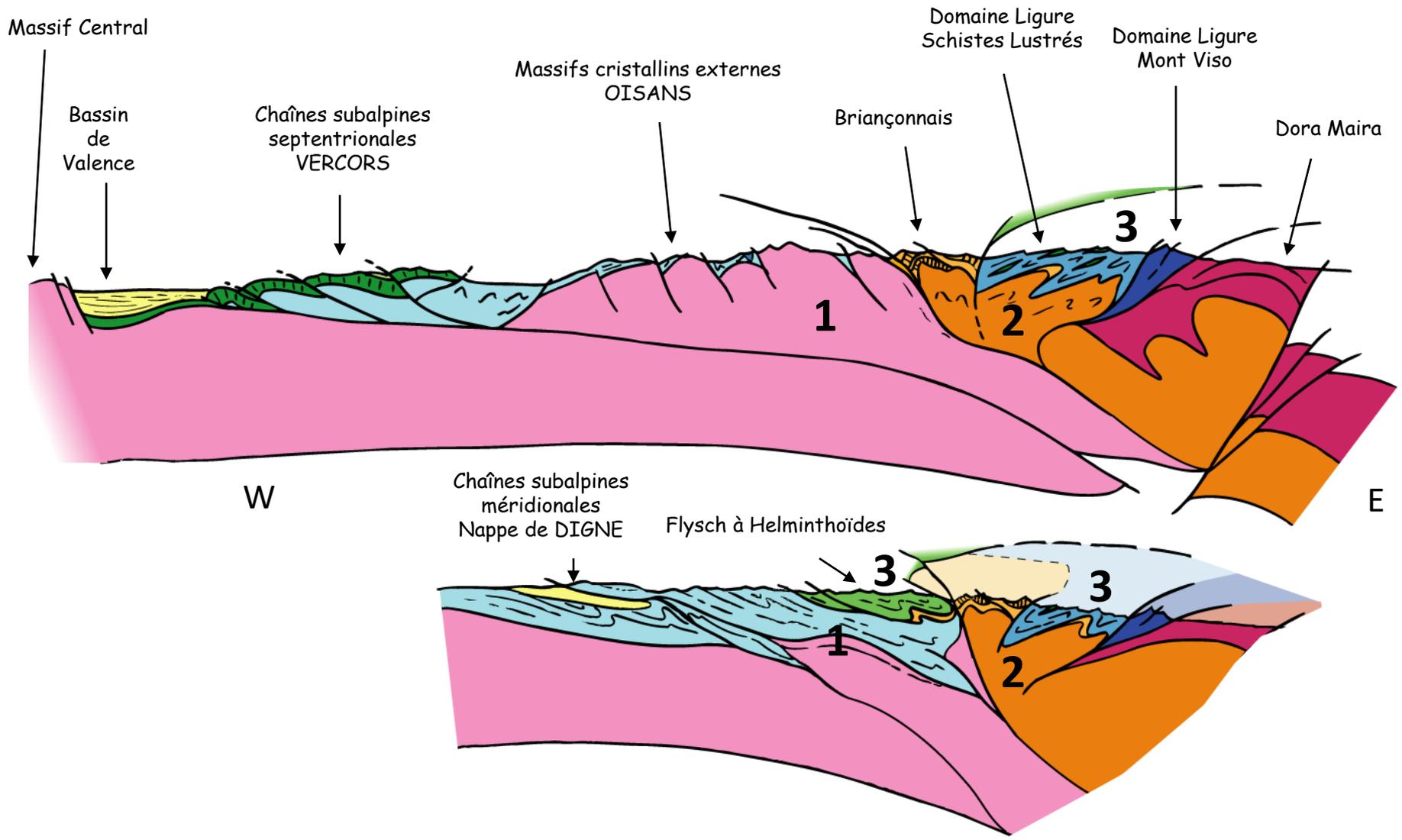
Chevauchement
du flysch dauphinois (1)
par la nappe
de flysch
à Helminthoïdes (3)



Le domaine Ligure ou Liguro -Piémontais



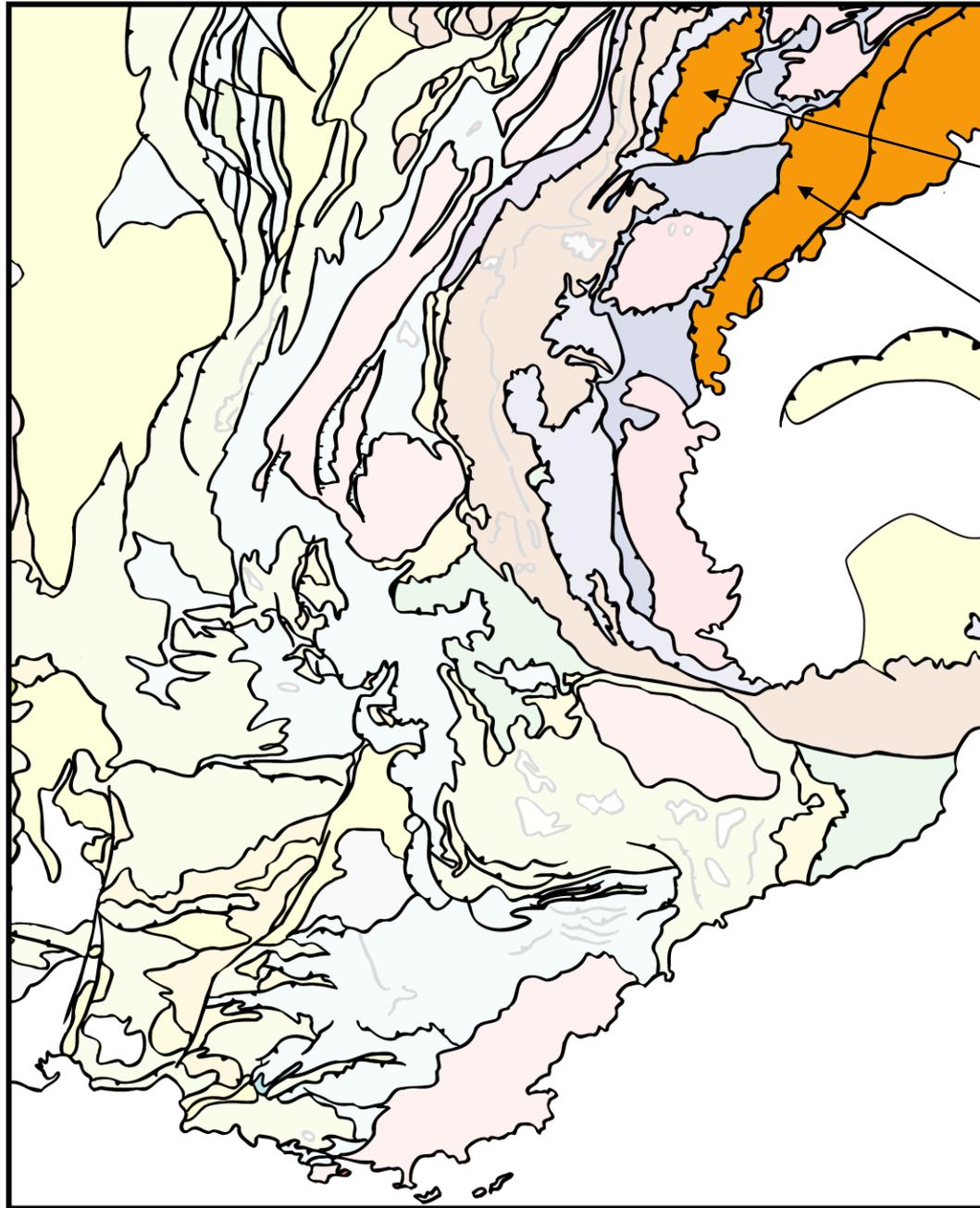
(D'après Jolivet)



(D'après Jolivet)

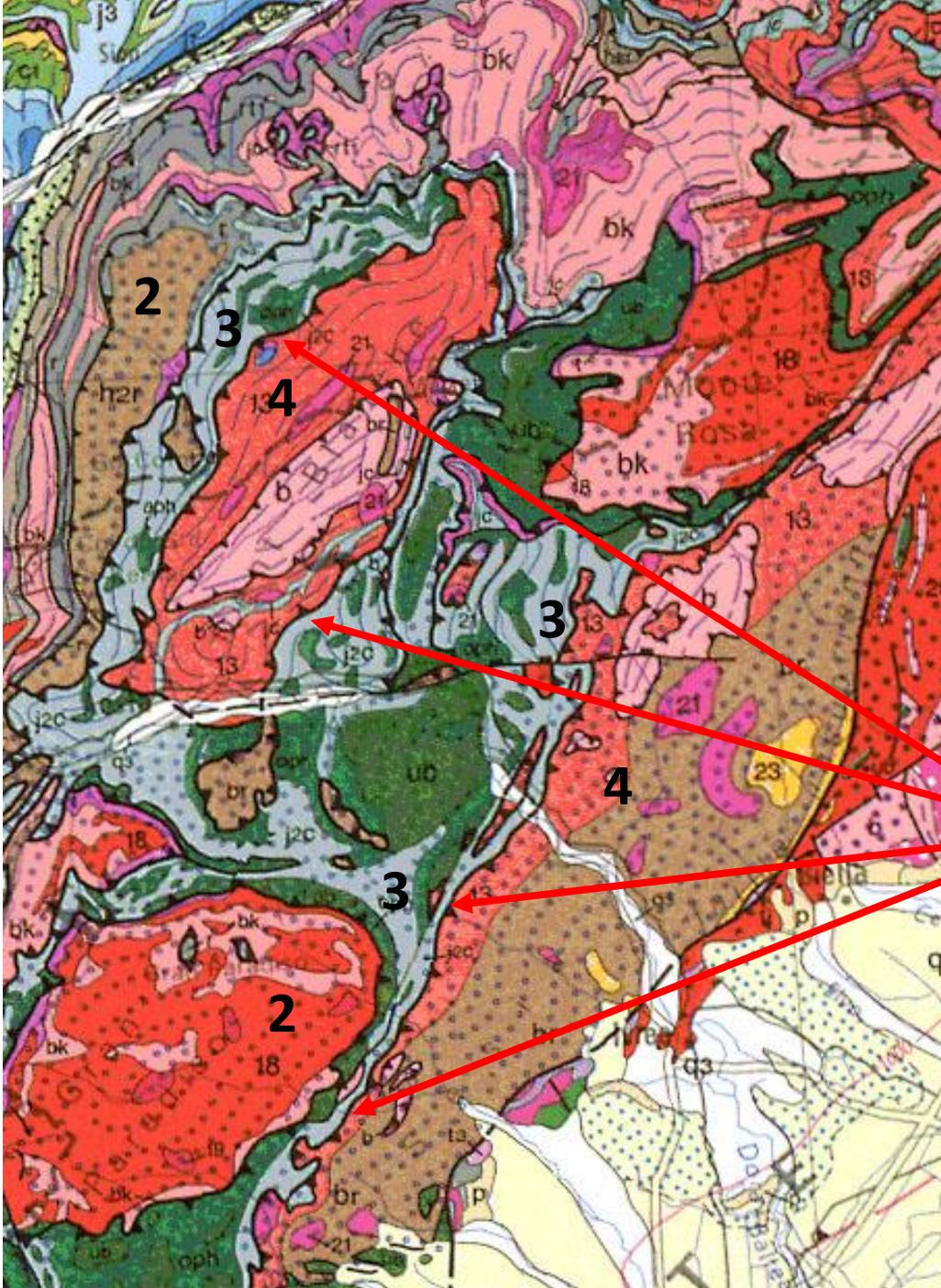
Les unités austro-alpines
= la plaque supérieure

Le domaine
Austro -
Alpin



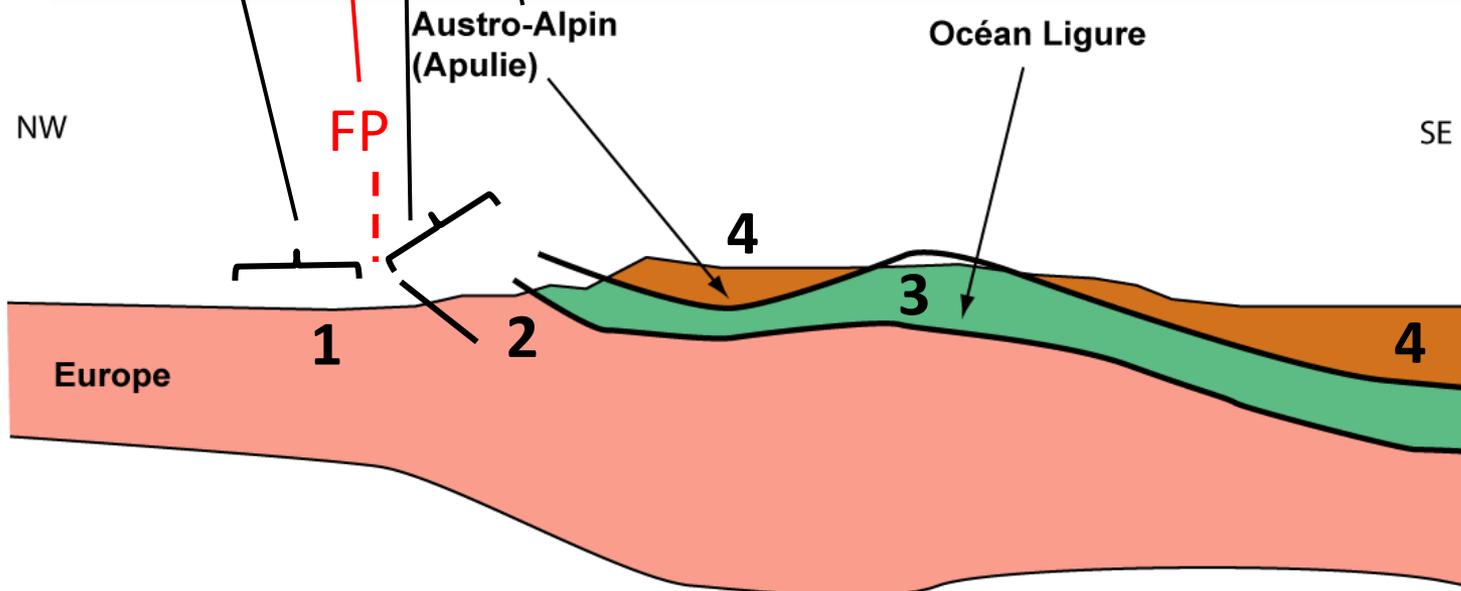
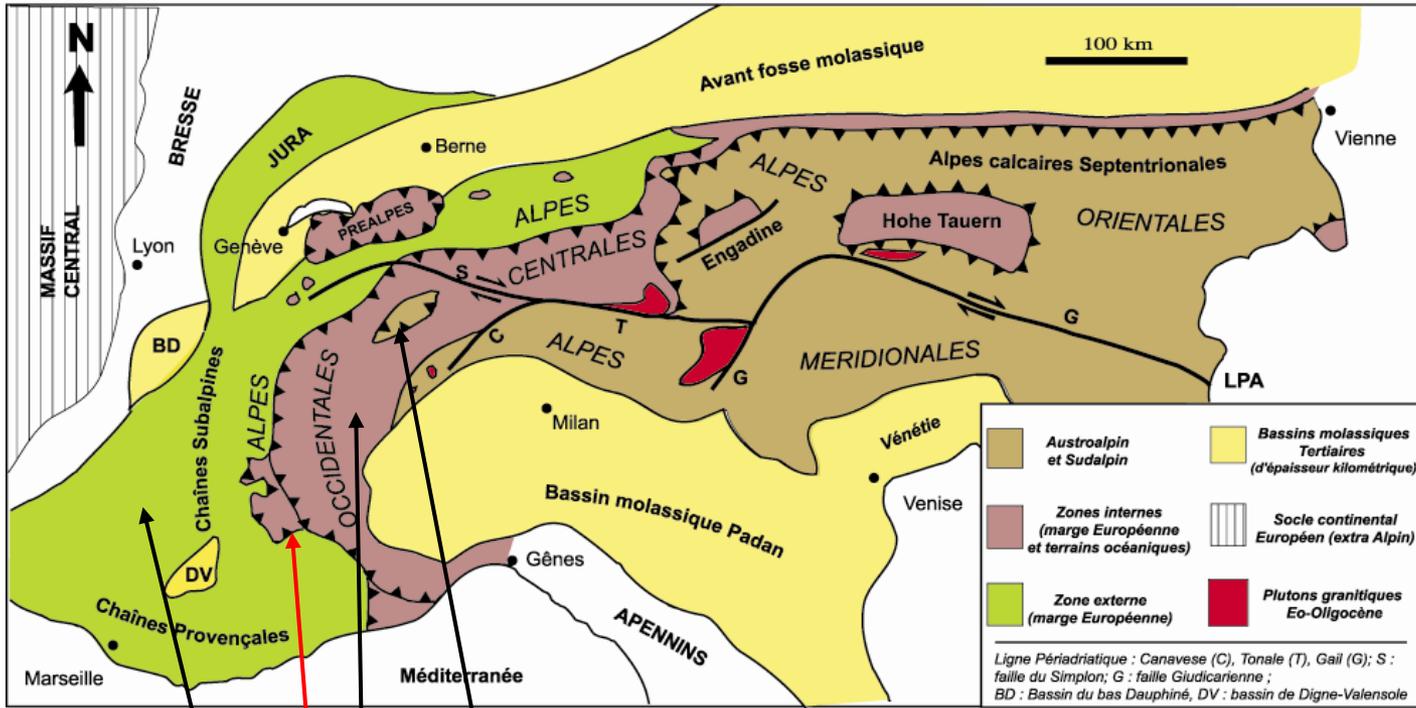
Dent Blanche

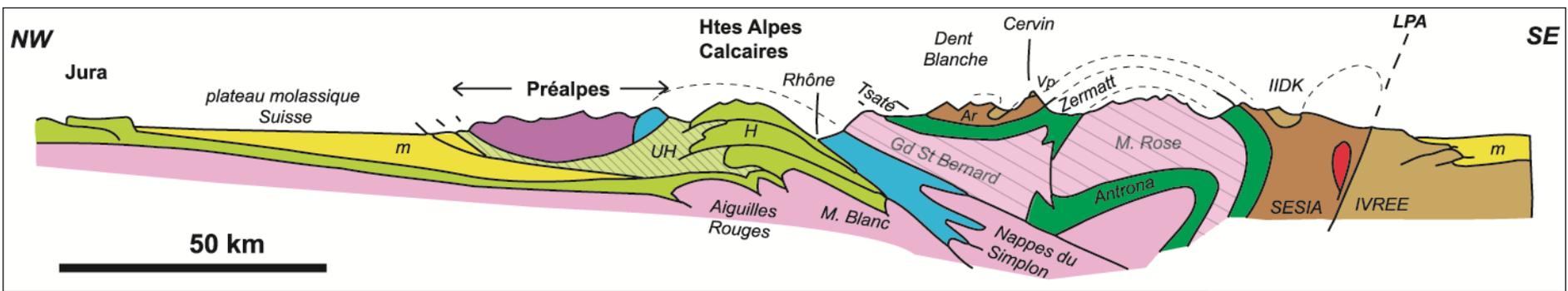
Sesia



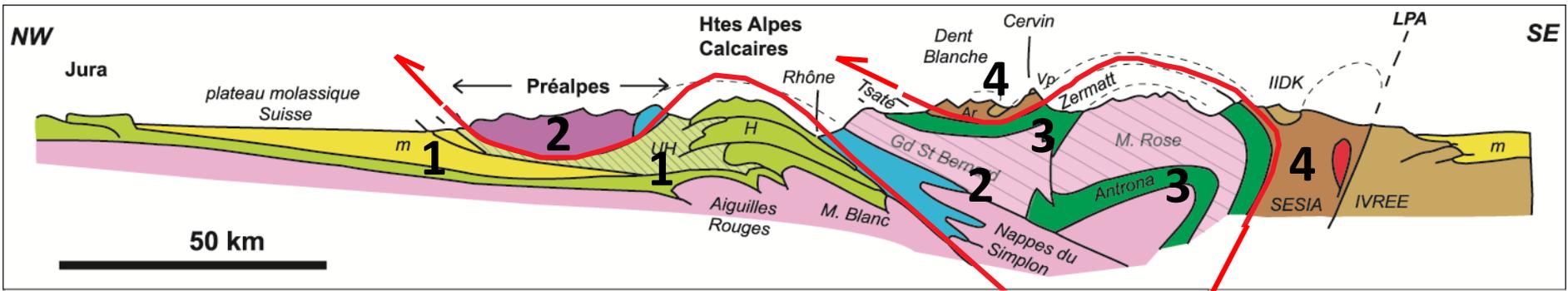
Chevauchement
de l'Unité austro-alpine (4)
sur l'Unité des
Schistes Lustrés (3)

Organisation d'ensemble

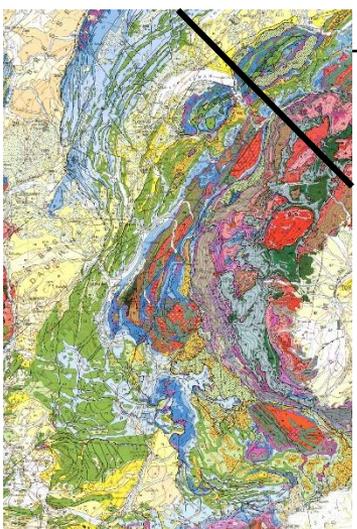




50 km



50 km



Zones externes (~Dauphinois)

1

Zones internes (Briançonnais sl + Liguro-Piémontais + Valaisan)

2+3

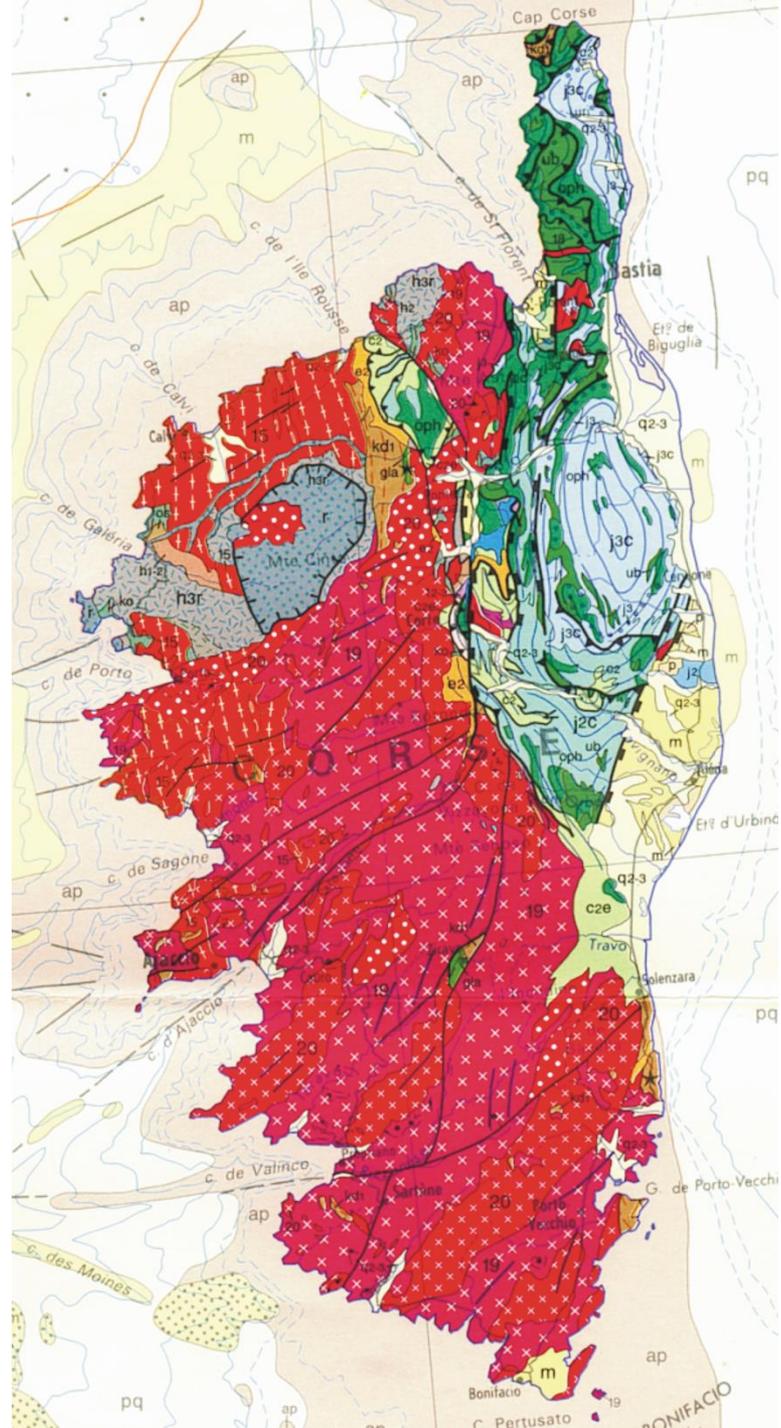
Austro-alpin (Apulie)

4

FP

(Agard et Lemoine, 2003)

La Corse alpine



Nappe de Balagne s.l.

1-3
Nappe des Schistes Lustrés

- Calcschistes
- Metagabbros et péridotites
- Orthogneiss
- Eclogites

Chev.

Chev. repris en dét.

FN ou dét.

10 km

Ecailles de Corte et Massif du Tendr.

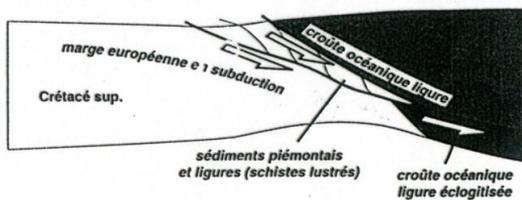
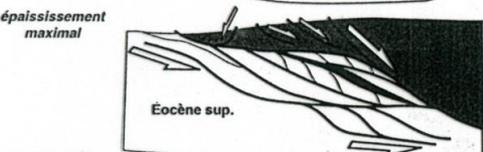
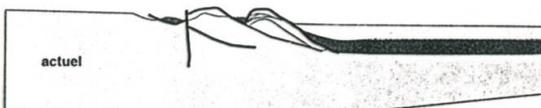
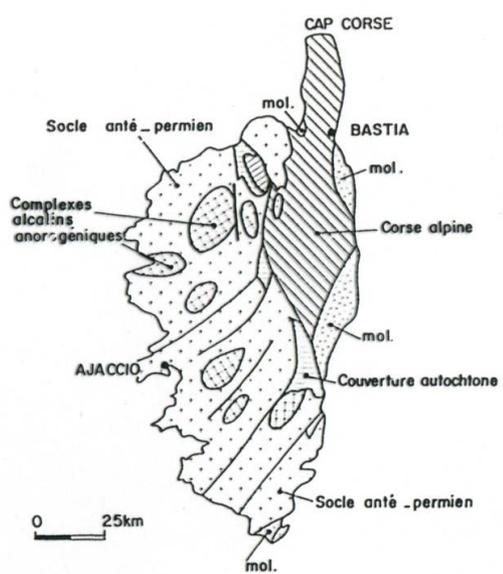
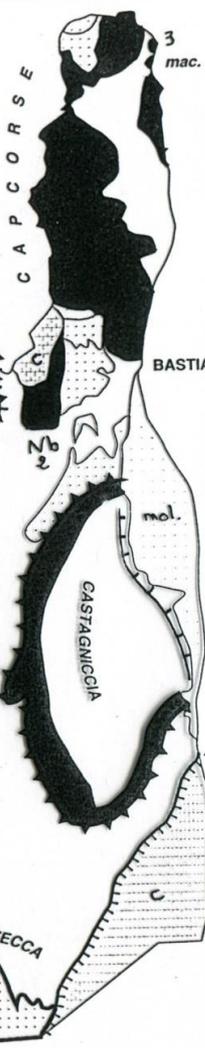
Socle et couverture

Corse occidentale
 socle granitique paléozoïque

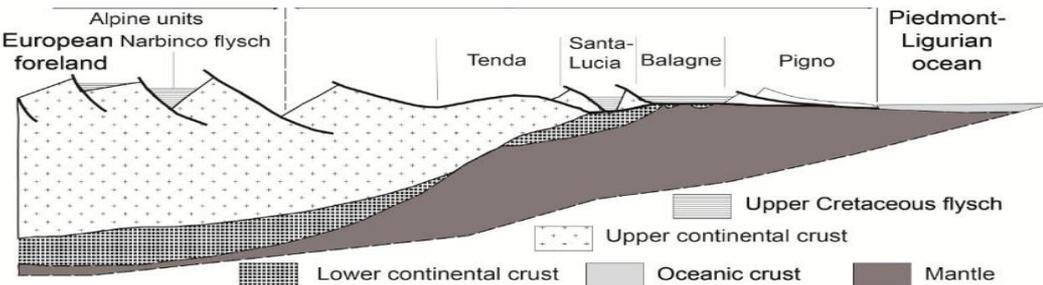
Bassins sédimentaires

Calcaires burdigalien

NW

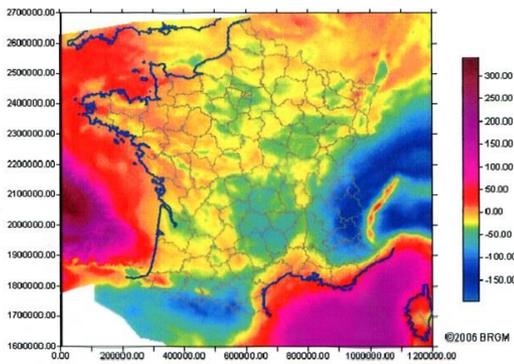


SE

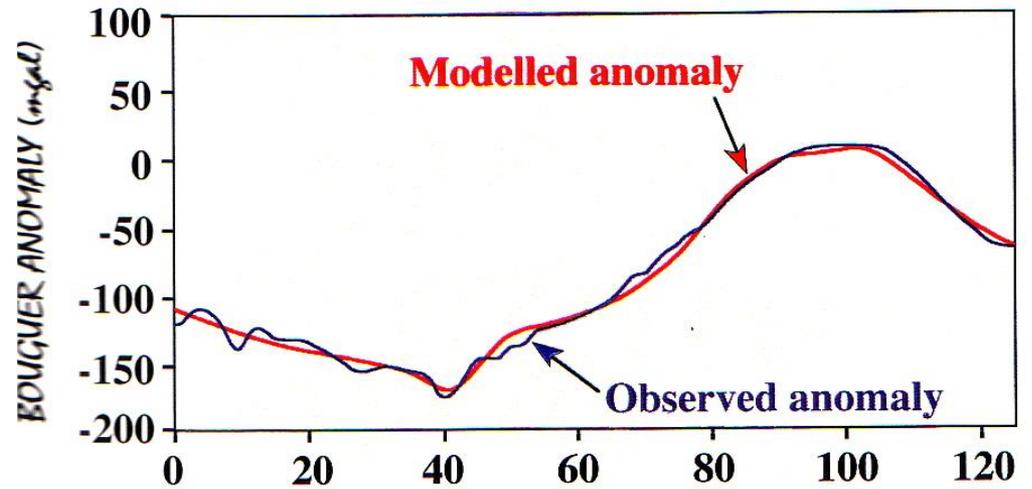


I. Les Alpes franco-italiennes :
une chaîne de subduction-collision

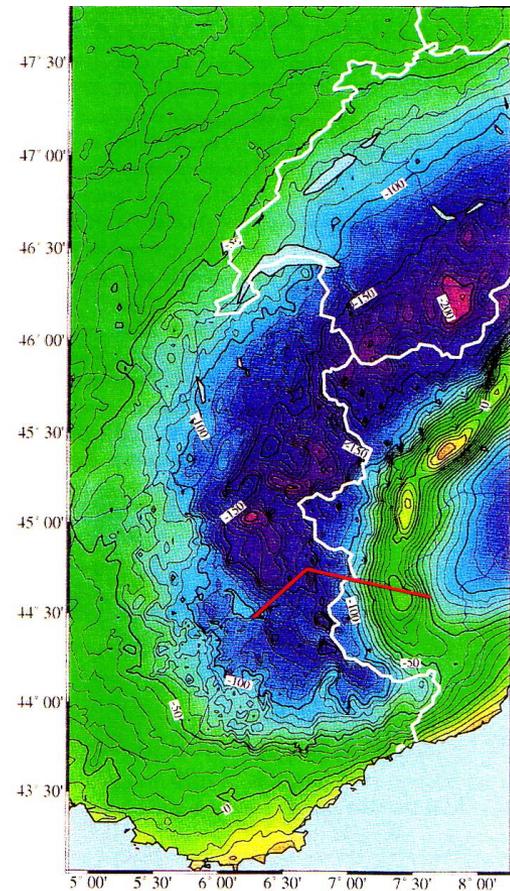
B. La structure profonde vue par la géophysique



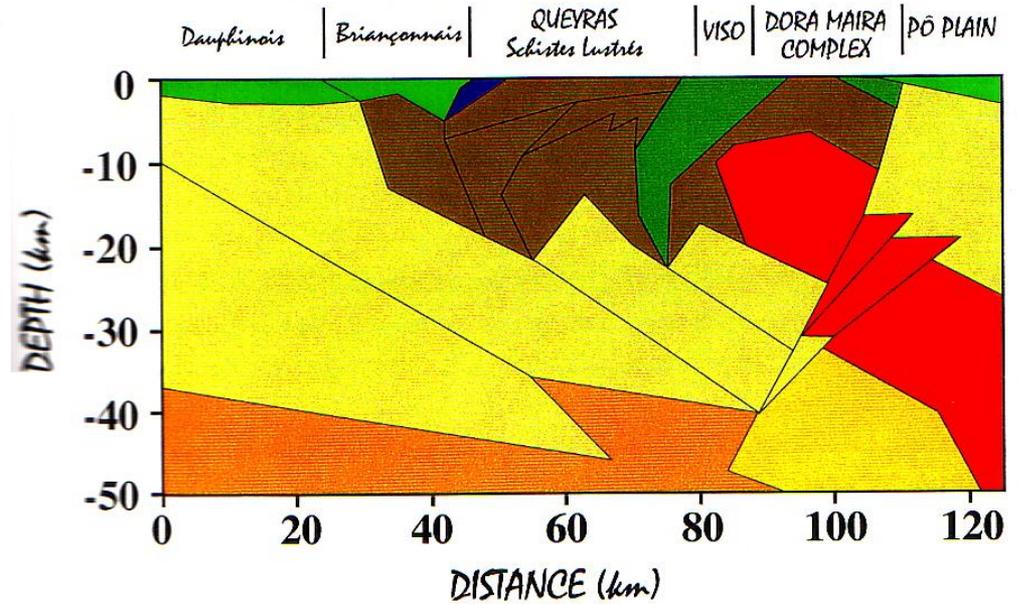
Anomalie de Bouguer (en 10^{-8} m/s²) cartographiée à partir d'une grille de maille 4 x 4 km.
(d'après Grandjean et al, 1998)

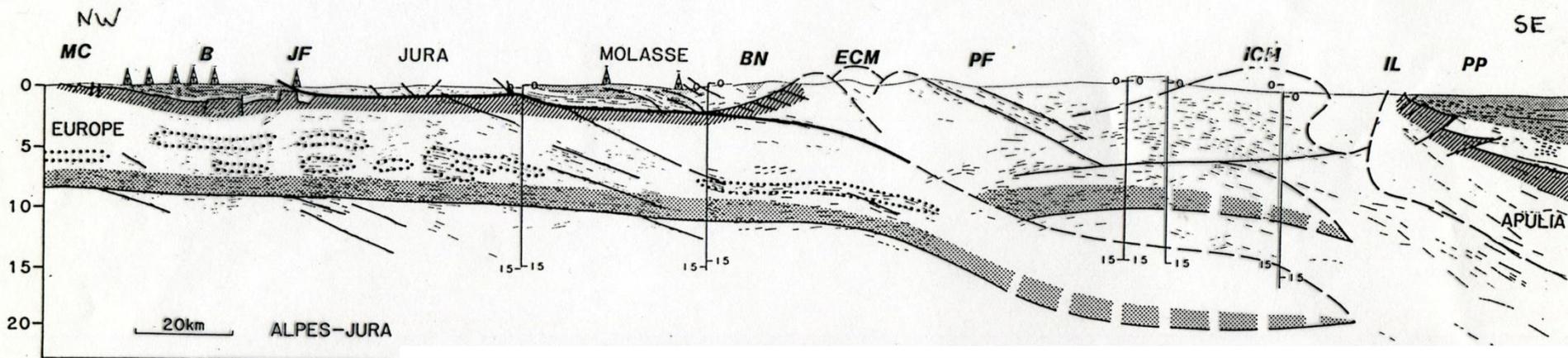
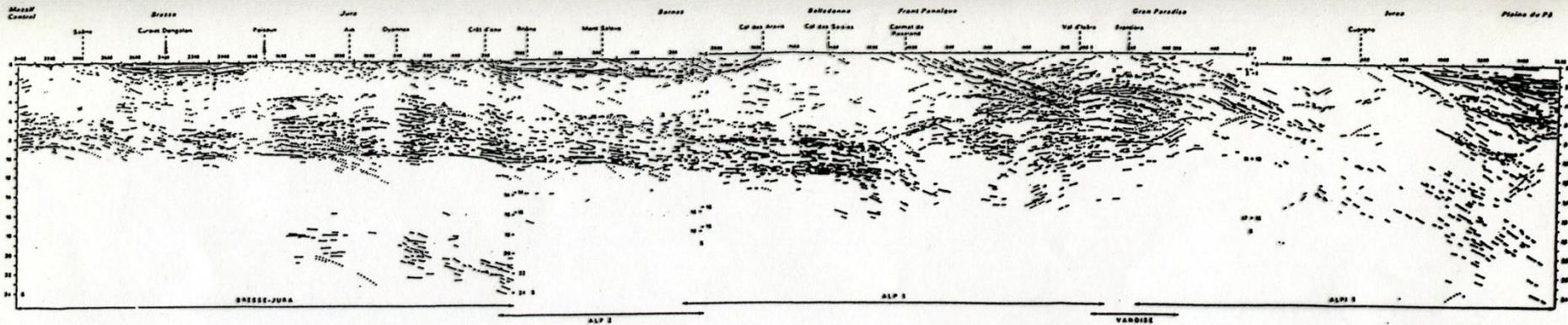


Gravimétrie

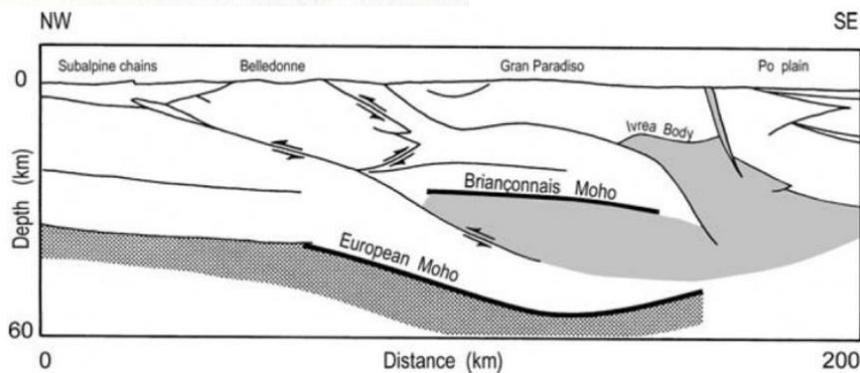


-220 -180 -140 -100 -60 -20 20 60 100
Anomalie de Bouguer en mgal





Temps-double



(D'après Thouvenot et al., 2007)

(D'après Bois et al.)

Mise en évidence de chevauchements d'échelle lithosphérique → épaissement
 → Moho à ~50 km sous la chaîne de montagnes
 = racine crustale

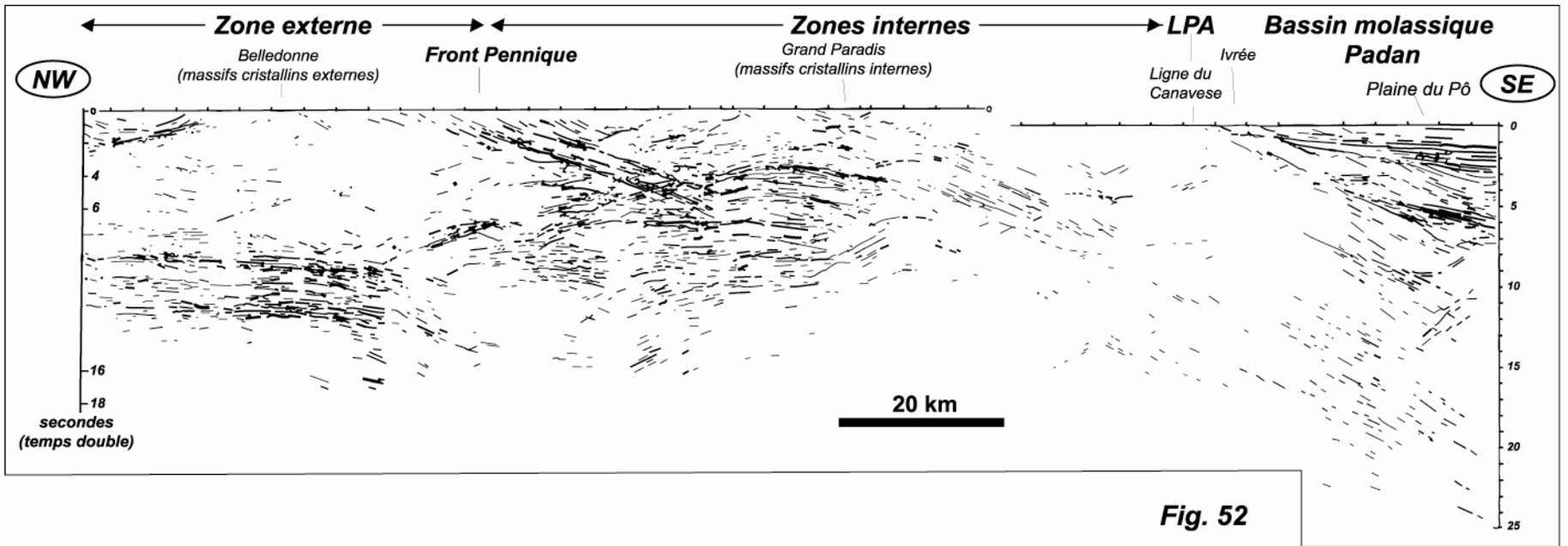
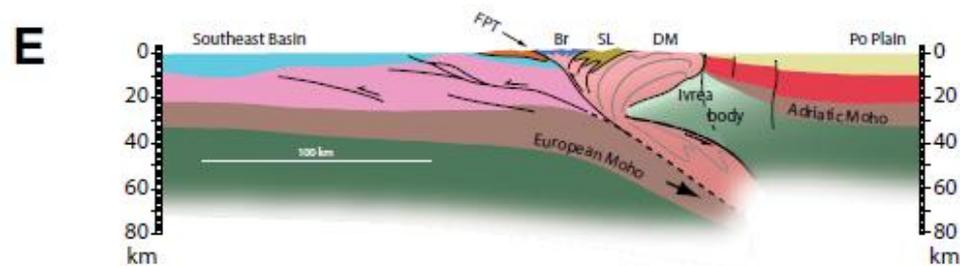
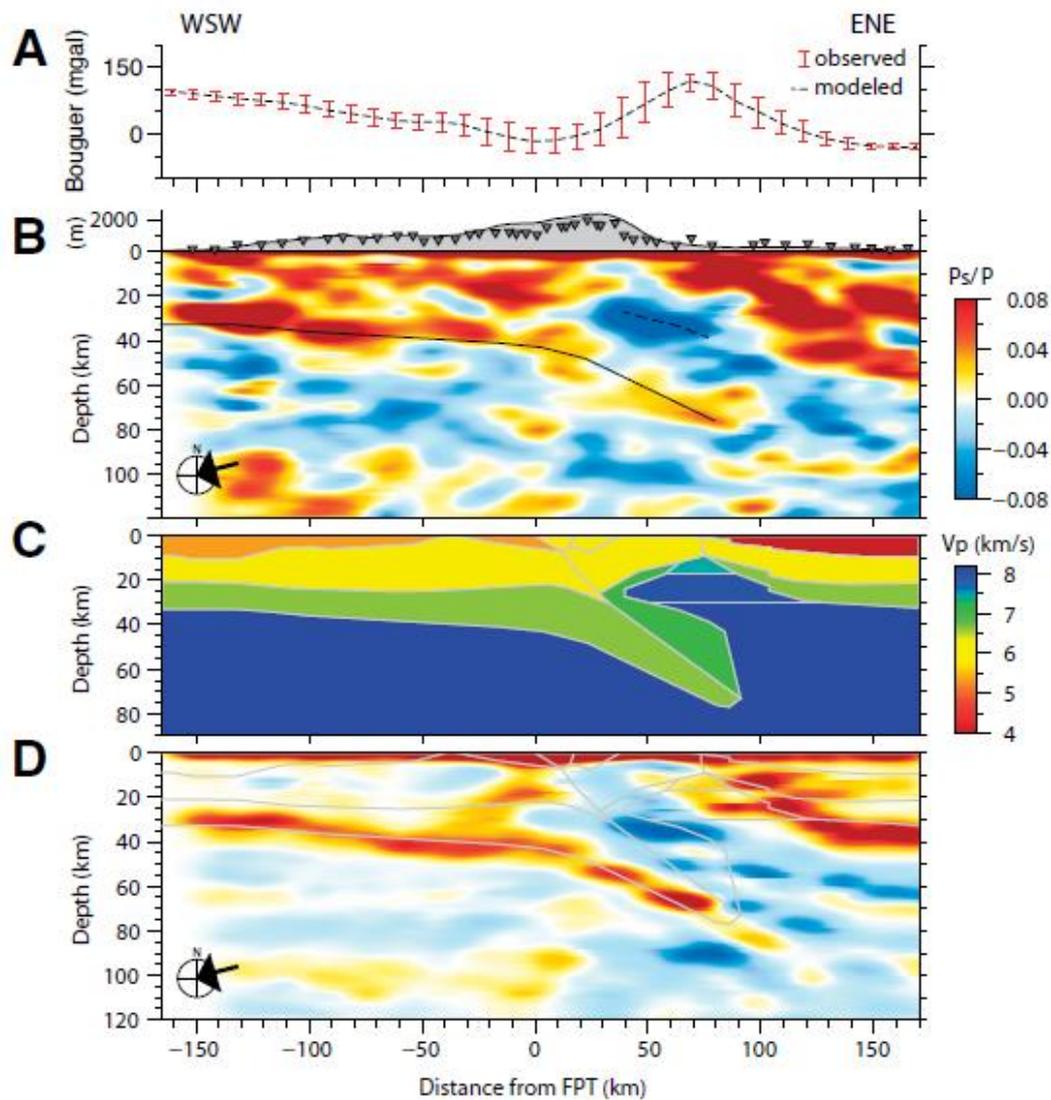
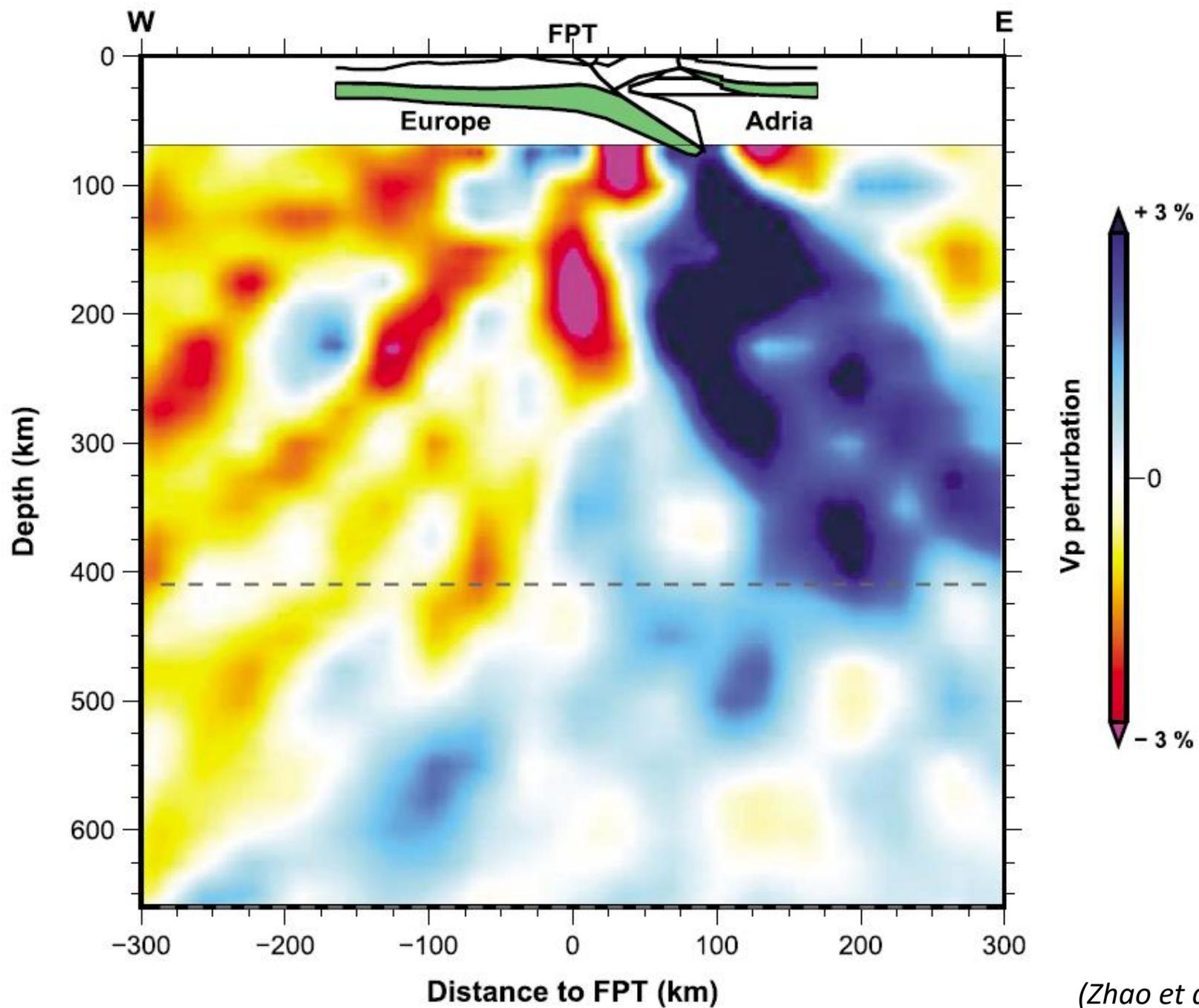


Fig. 52



La méthode dite des "fonctions récepteur" (*receiver function* en anglais) est basée sur l'étude des ondes P converties en S aux différentes interfaces sous une station sismologique. Elle permet notamment d'imager les interfaces majeures de la lithosphère et du manteau terrestre (Moho, discontinuités à 410 et 660km, ...). Pour la lithosphère, la méthode des fonctions récepteur permet de déterminer la profondeur du Moho et la valeur du rapport V_P/V_S .

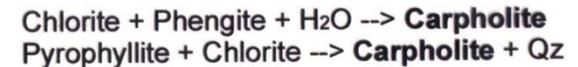
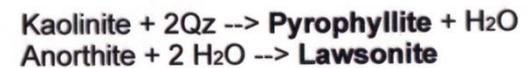
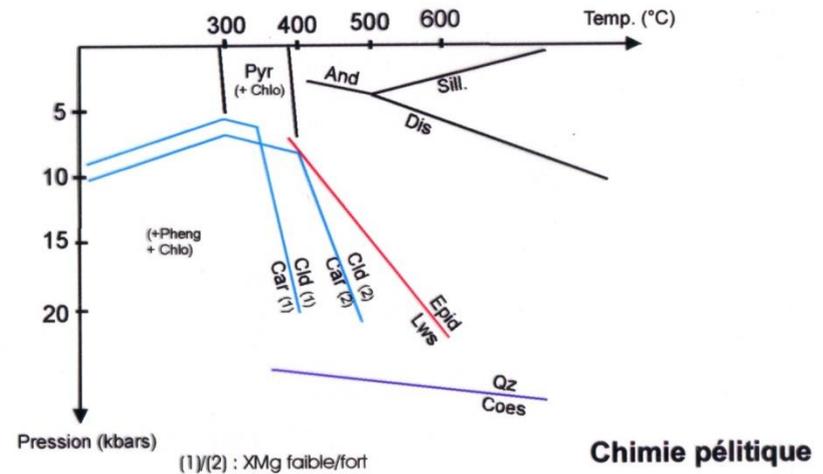
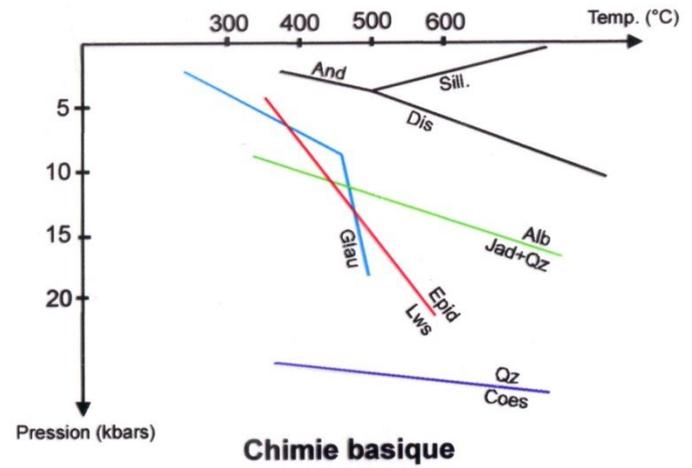
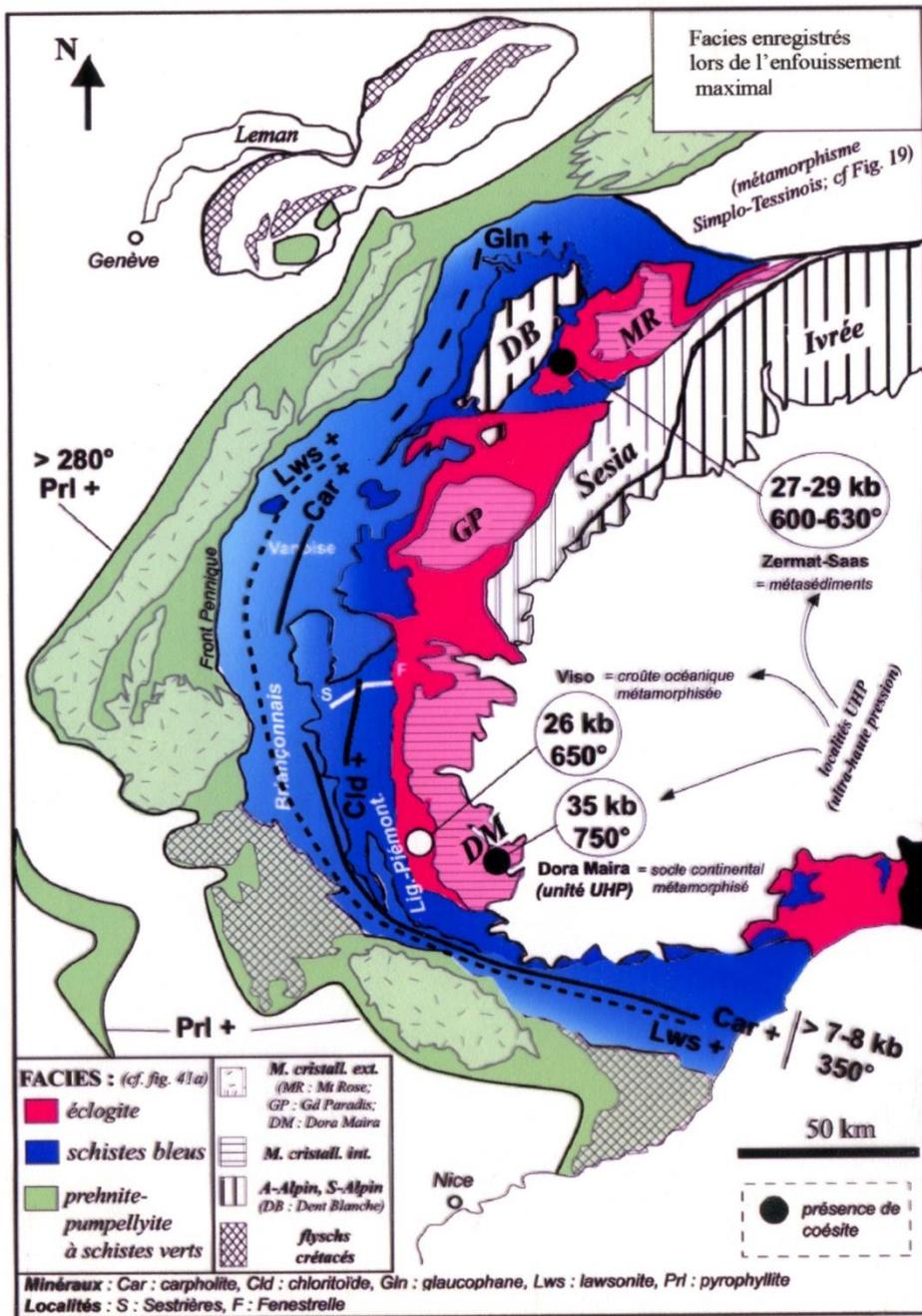
(Zhao et al., 2015)

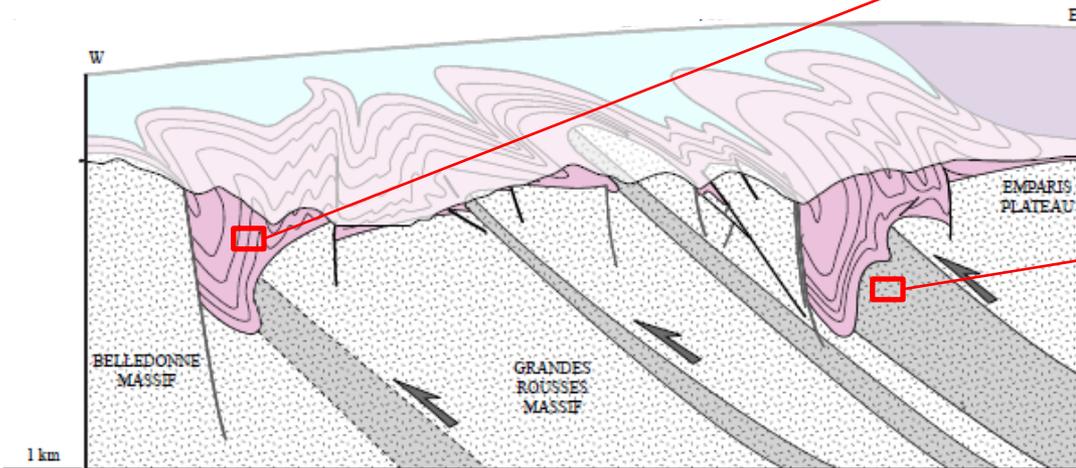
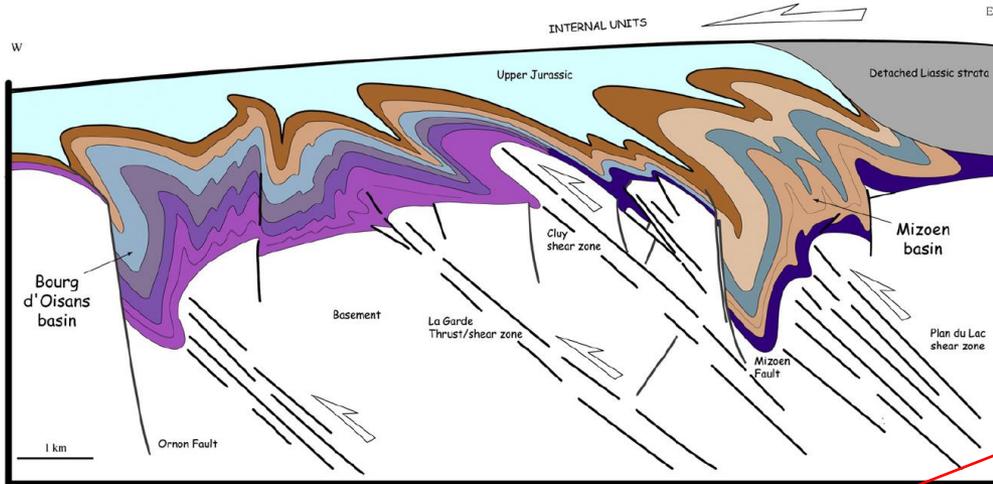


(Zhao et al., 2016)

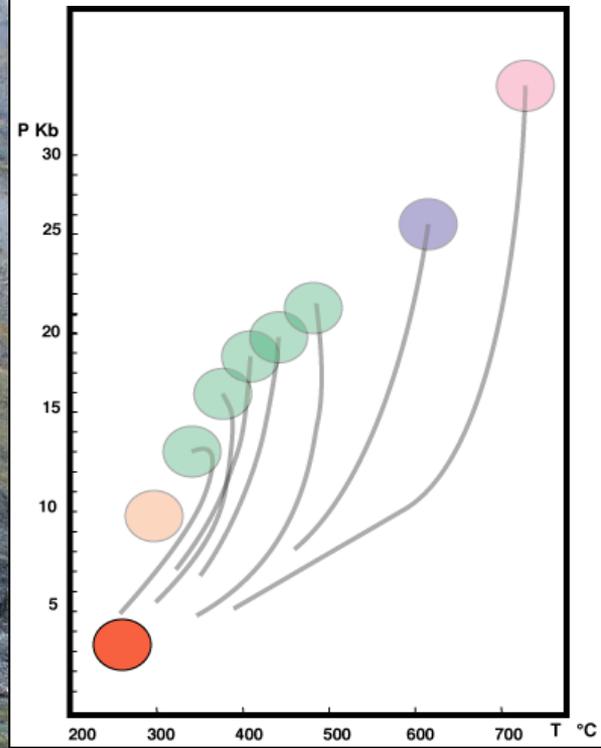
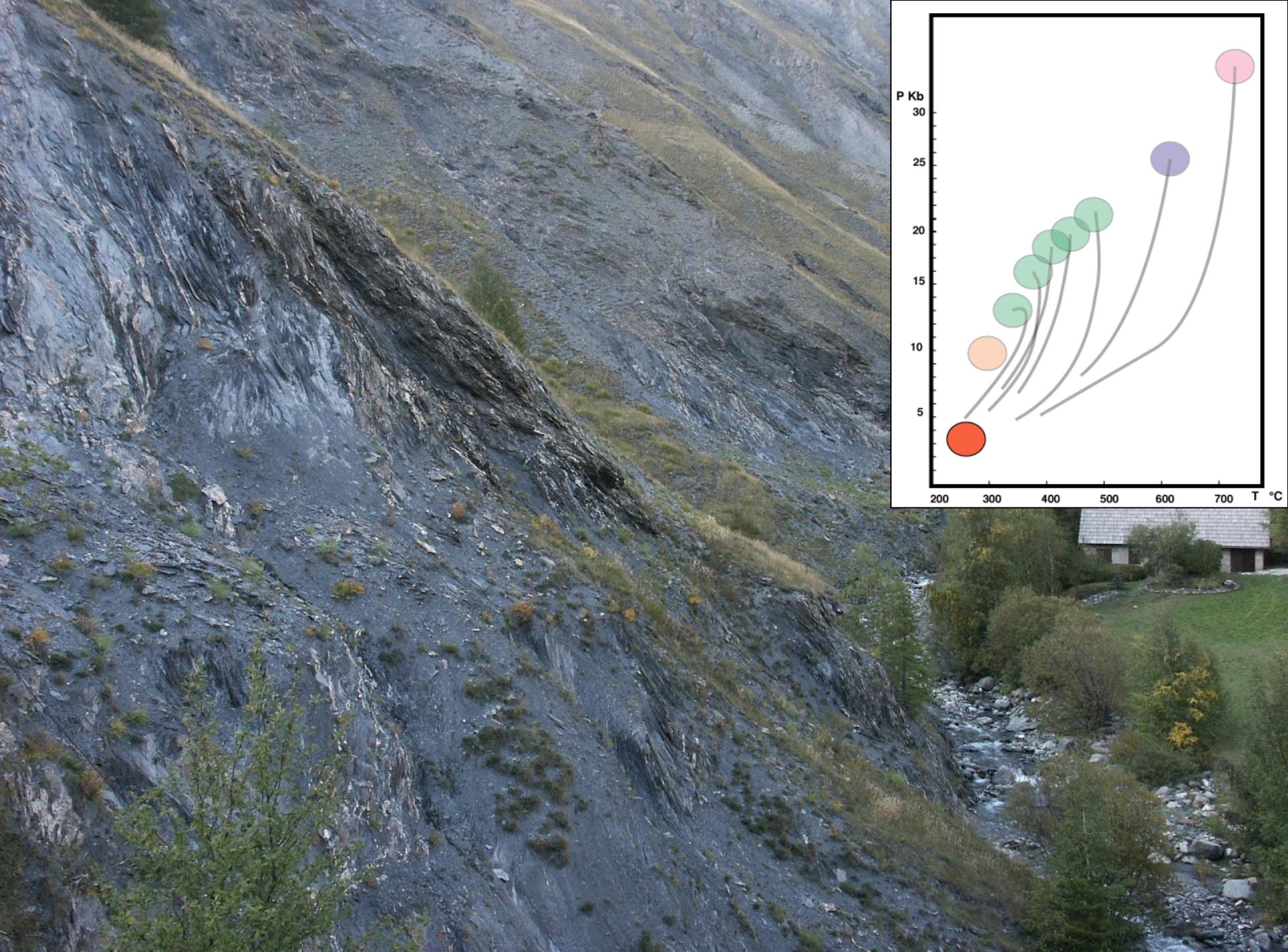
I. Les Alpes franco-italiennes : une chaîne de subduction-collision

C. Le métamorphisme alpin
et les contraintes thermo-barométriques
sur l'édification du prisme orogénique





Déformations dans les Massifs Cristallins Externes
(SV facies : 3-4 kb / 330-350°C, 25 Ma Ar-Ar)



MÉTAMORPHISME

Les caractères métamorphiques des terrains sont symbolisés par des figures dont la couleur indique l'âge de l'orogénèse, la forme indique le faciès du métamorphisme, et l'orientation correspond à la principale foliation régionale

Âge :

- cadomien
- méso-varisque
- néo-varisque
- alpin

— Métamorphisme permo-triasique de la marge sud-alpine

N. B. Dans les Alpes les faciès de haute pression sont privilégiés bien qu'ils soient généralement rétro-morphosés

Faciès
l'orogénèse néo-varisque
est prise comme exemple

de basse et
moyenne
pression

Faciès schiste vert
en domaine de nappes

Faciès amphibolite
(paragneiss, orthogneiss)

Zones anatectiques
(migmatites)

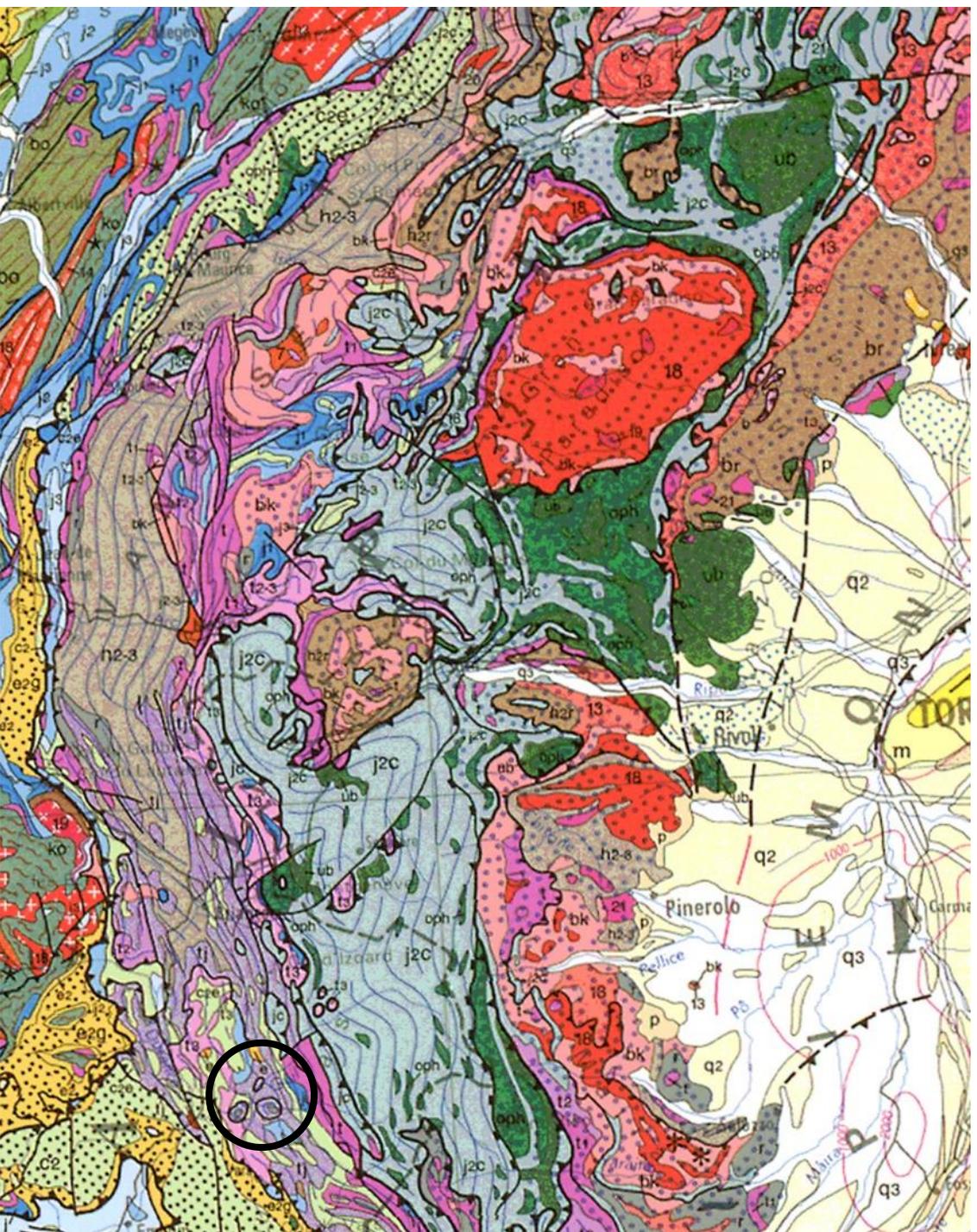
Faciès granulite
de basse pression

de haute
pression

Faciès schiste bleu
de basse température

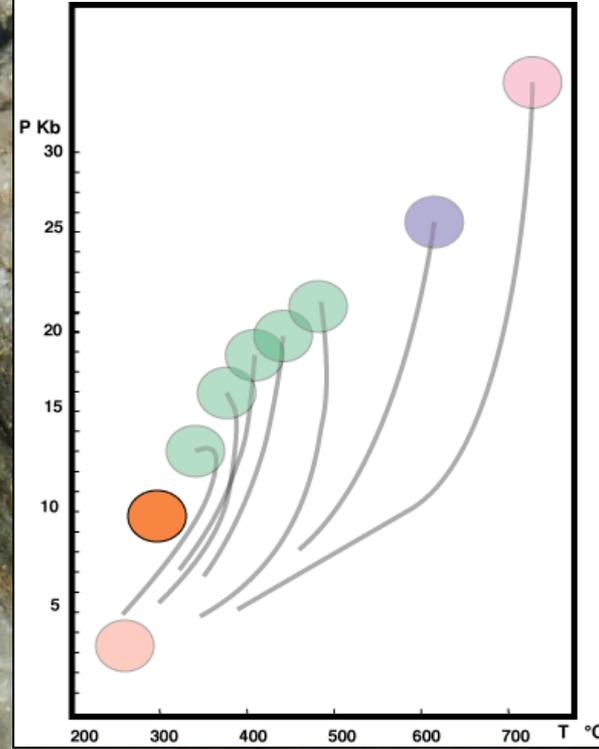
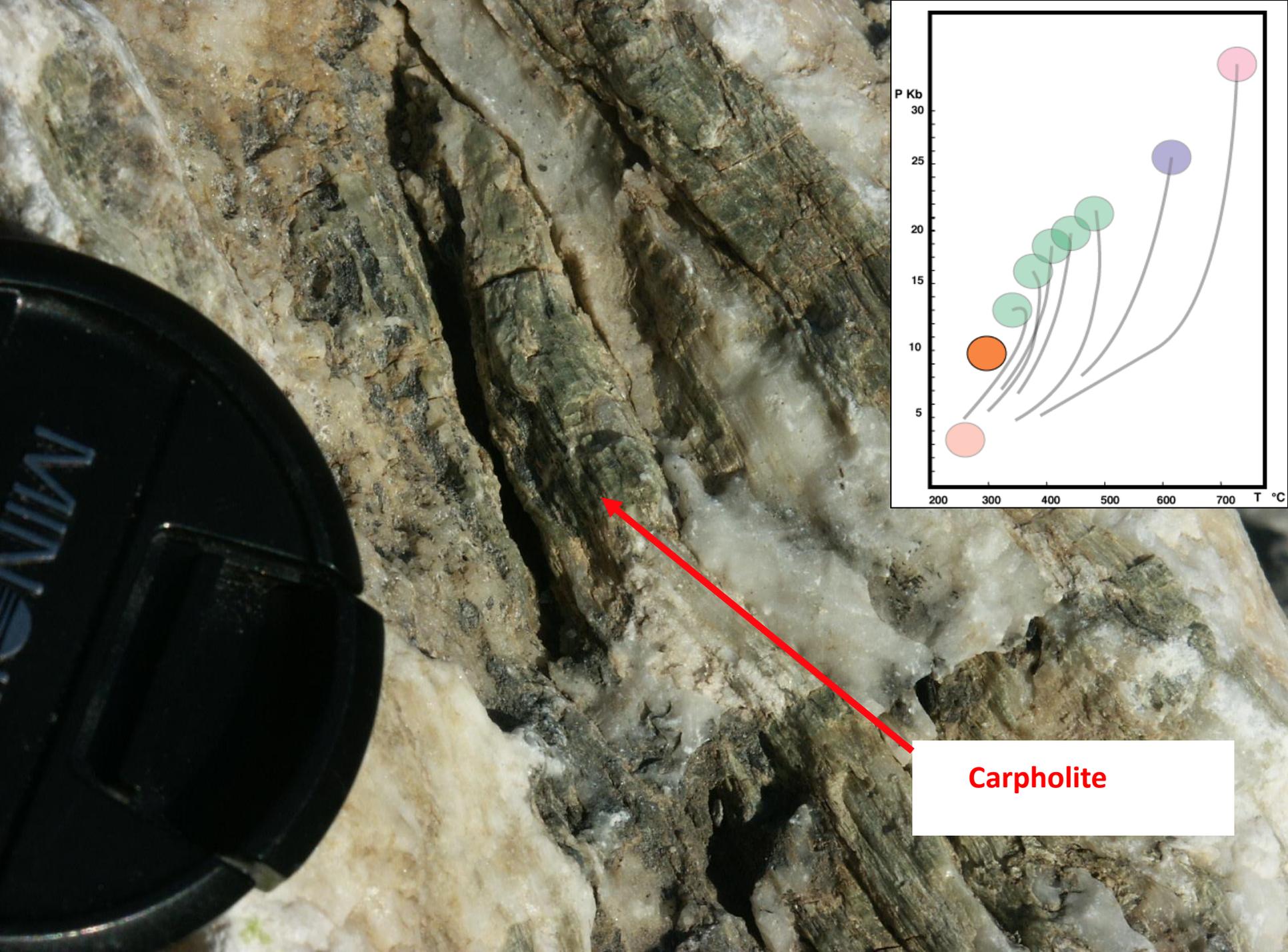
Faciès éclogite (et schiste
bleu de haute température)

1 : Relique éo-varisque
éclogitique
2 : Relique éo-alpine
à coarctée





Lawsonite



Carpholite

MÉTAMORPHISME

Les caractères métamorphiques des terrains sont symbolisés par des figures dont la couleur indique l'âge de l'orogénèse, la forme indique le faciès du métamorphisme, et l'orientation correspond à la principale foliation régionale

Age :

cadomien

méso-varisque

néo-varisque

alpin

Metamorphisme permo-triasique de la marge sud-alpine

Metamorphisme léponti, oligocène supérieur à miocène inférieur

N. B. Dans les Alpes les faciès de haute pression sont privilégiés bien qu'ils soient généralement rétro-morphosés

Faciès
l'orogénèse néo-varisque
est prise comme exemple

de haute
pression

Faciès schiste bleu
de basse température

Faciès eclogite (et schiste
bleu de haute température)

1 : Relique éo-varisque
éclogitique
2 : Relique éo-alpine
à coarcté

de basse et
moyenne
pression

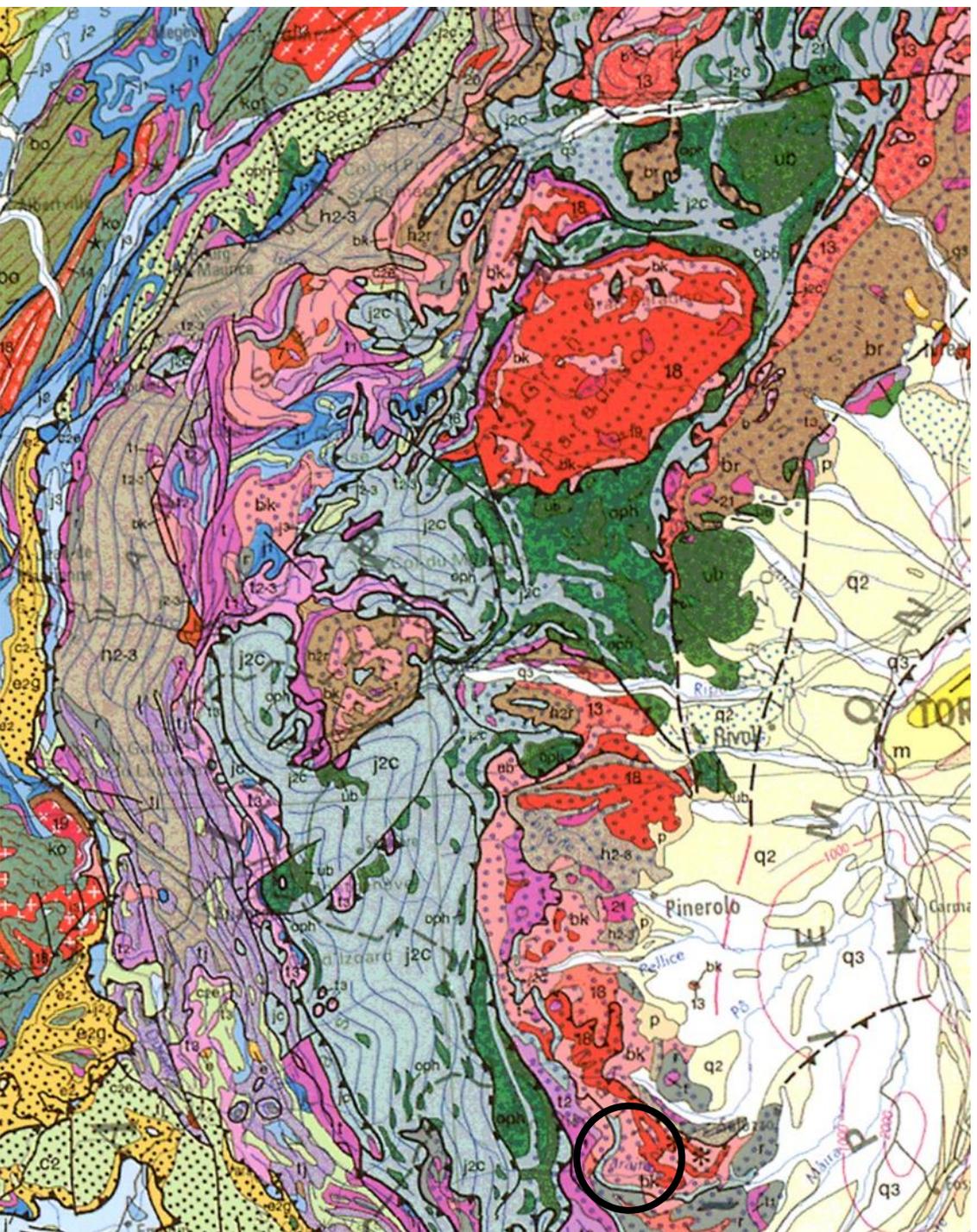
Faciès schiste vert
en domaine de nappes

Faciès amphibolite
(paragneiss, orthogneiss)

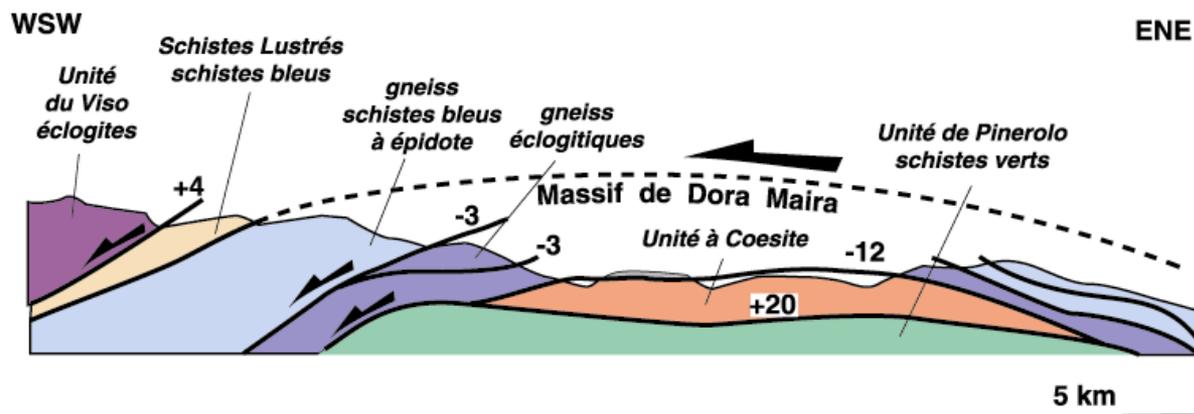
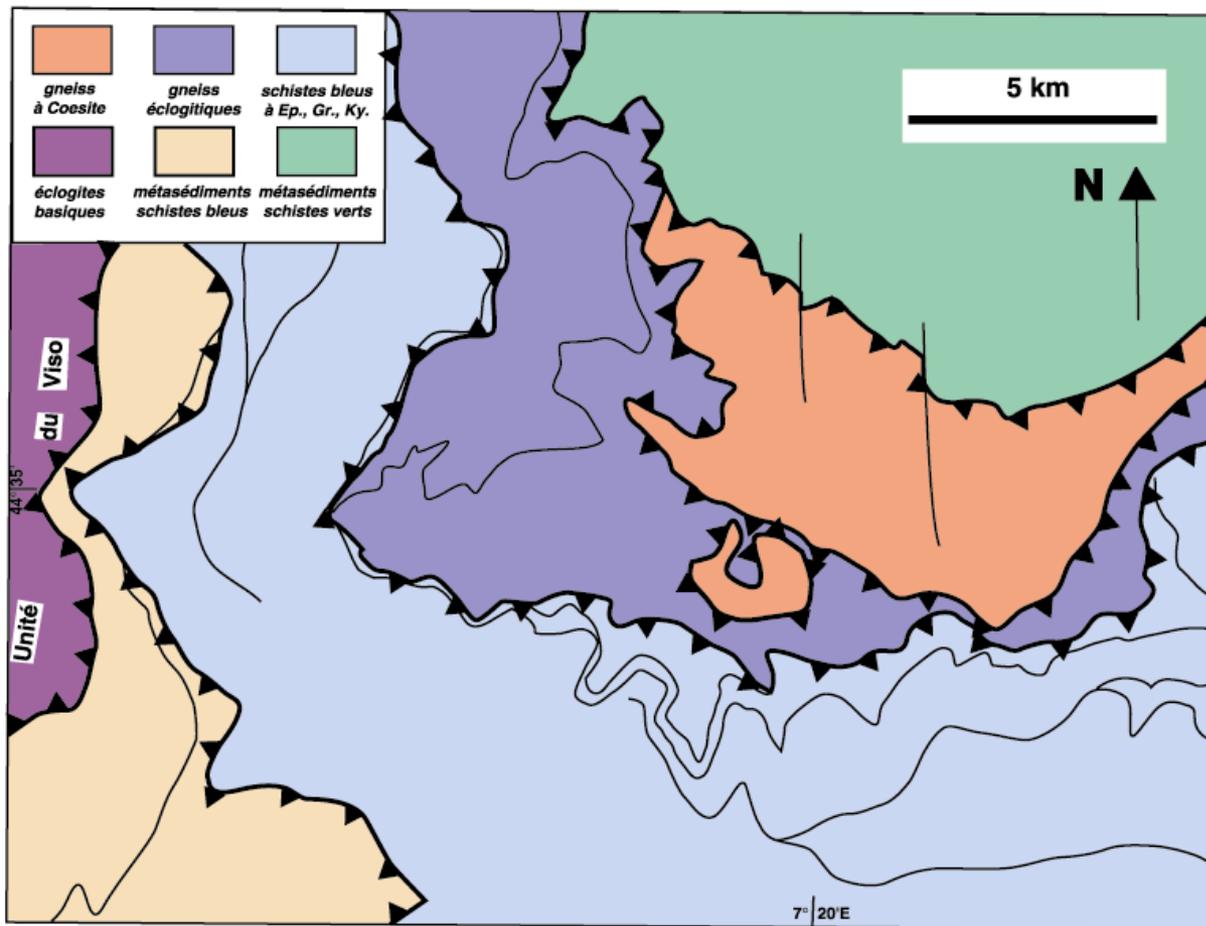
Faciès granulite
de basse pression

Zones anatectiques
(migmatites)

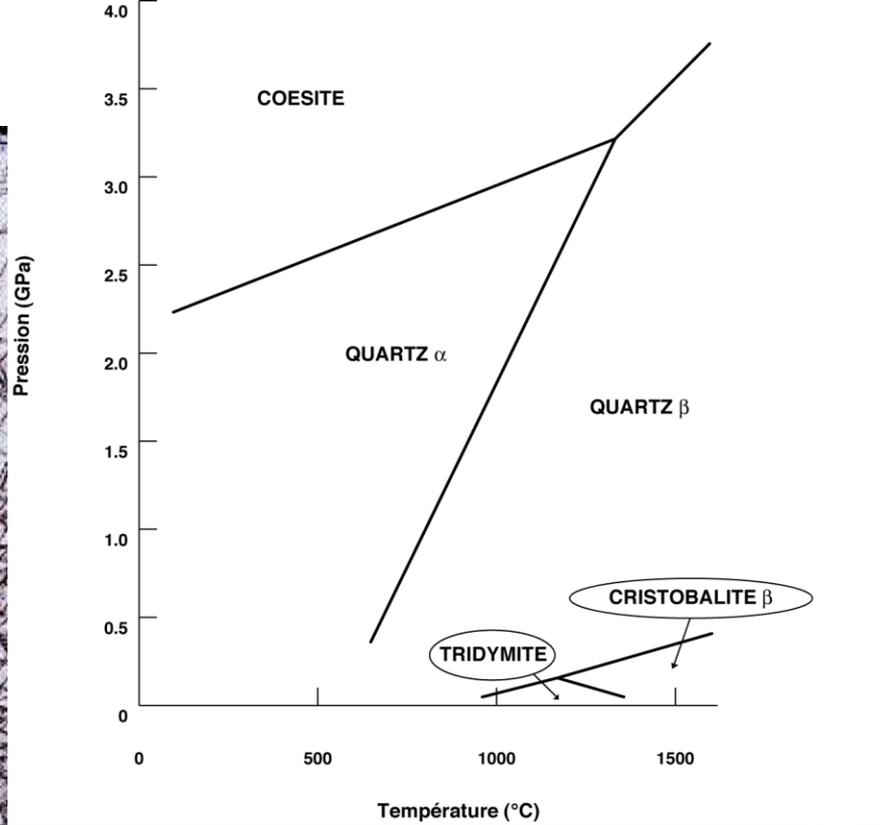
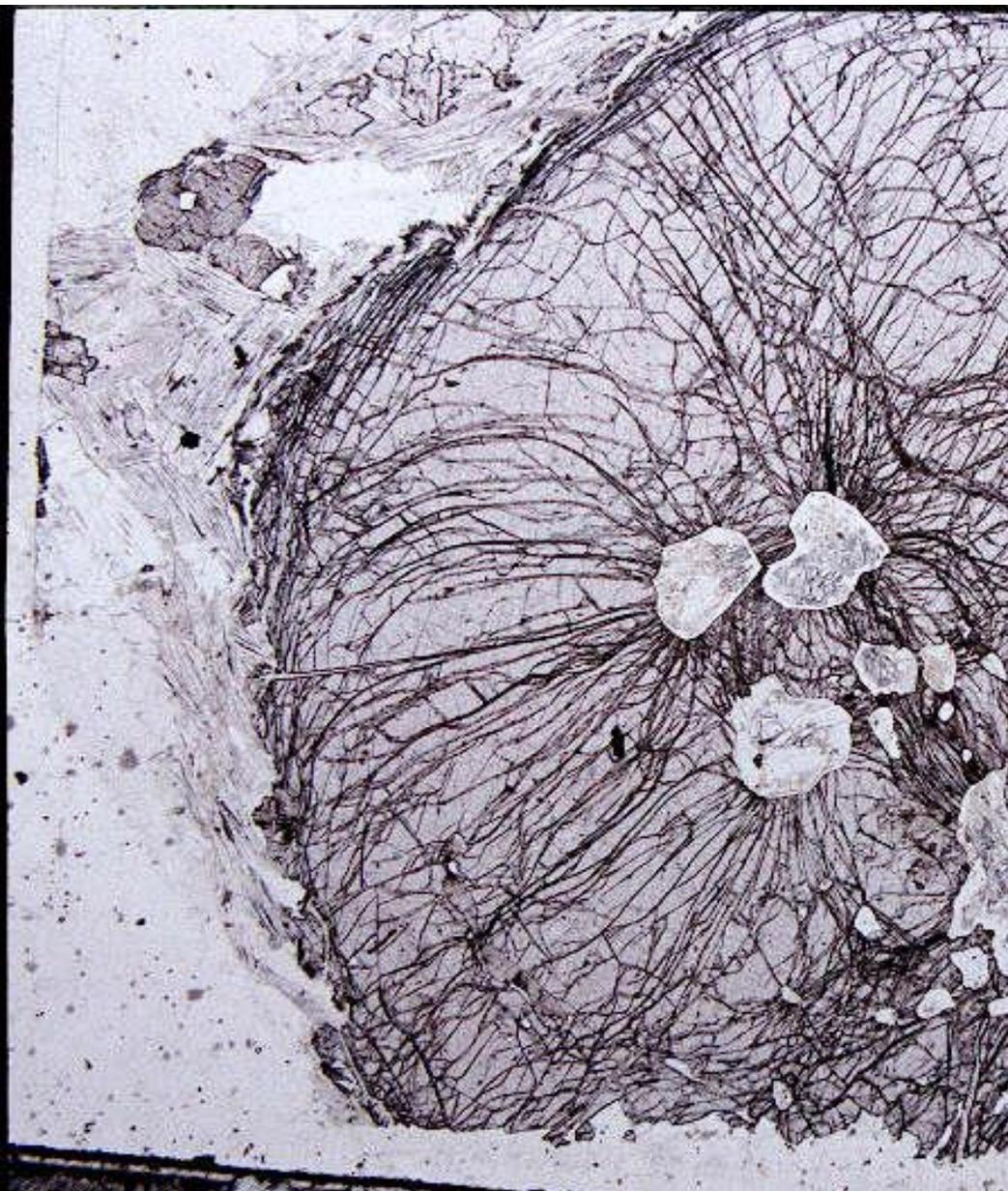
1 * 2

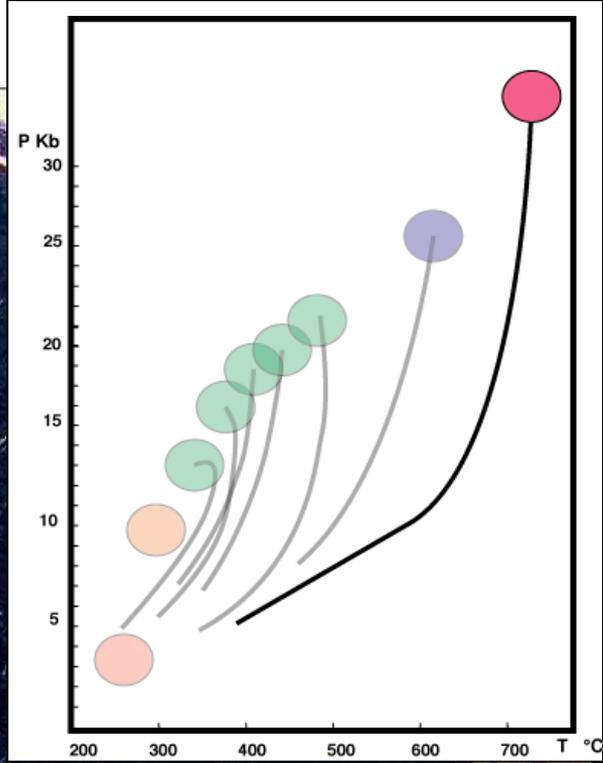
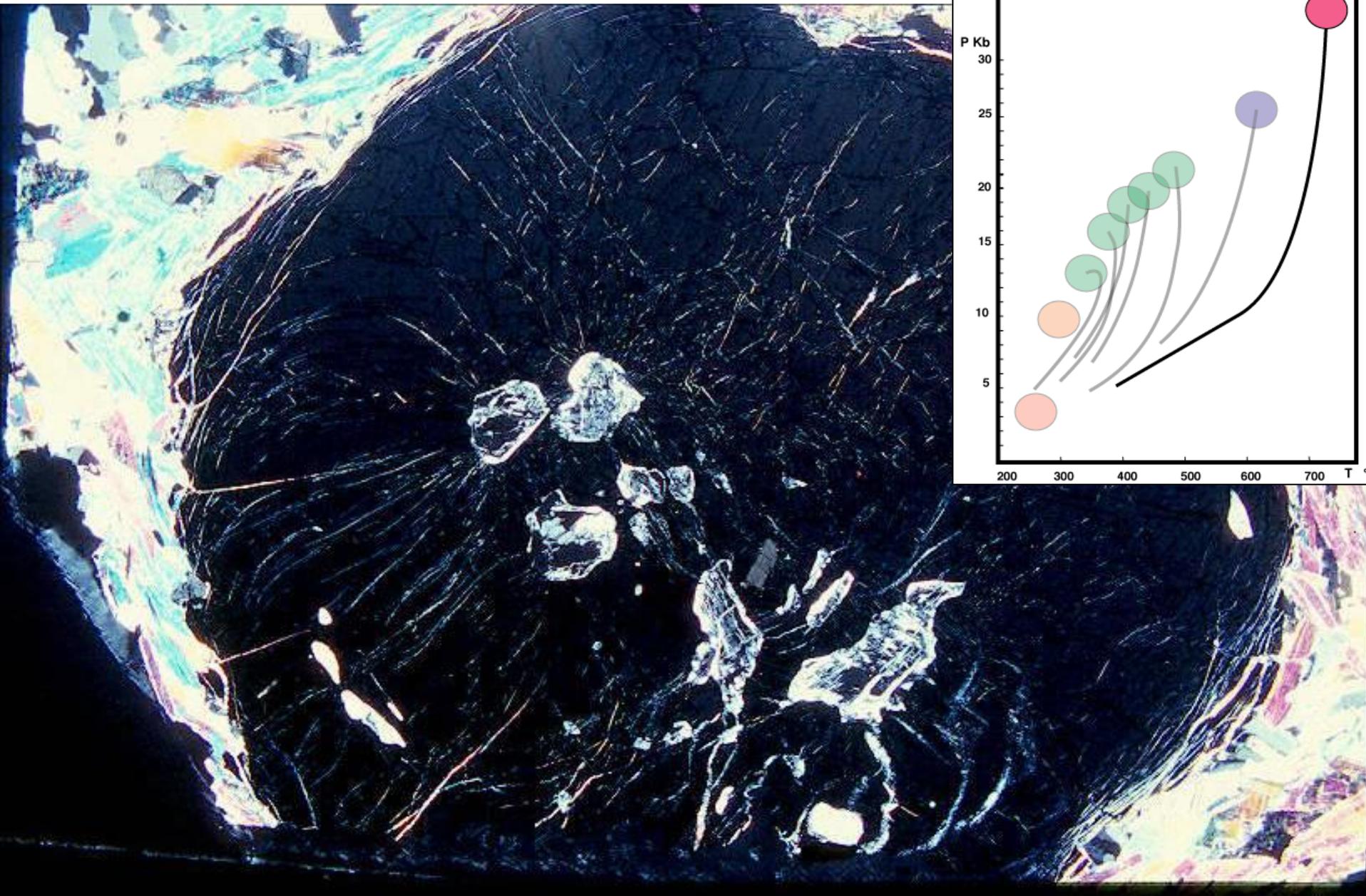












MÉTAMORPHISME

Les caractères métamorphiques des terrains sont symbolisés par des figures dont la couleur indique l'âge de l'orogénèse, la forme indique le faciès du métamorphisme, et l'orientation correspond à la principale foliation régionale

Age :

cadomien

méso-varisque

néo-varisque

alpin

Metamorphisme permo-triasique de la marge sud-alpine

Metamorphisme leptonit, oligocène supérieur à miocène inférieur

N. B. Dans les Alpes les faciès de haute pression sont privilégiés bien qu'ils soient généralement rétro-morphosés

Faciès
l'orogénèse néo-varisque
est prise comme exemple

de haute
pression

de basse et
moyenne
pression

Faciès schiste vert
en domaine de nappes

Faciès amphibolite
(paragneiss, orthogneiss)

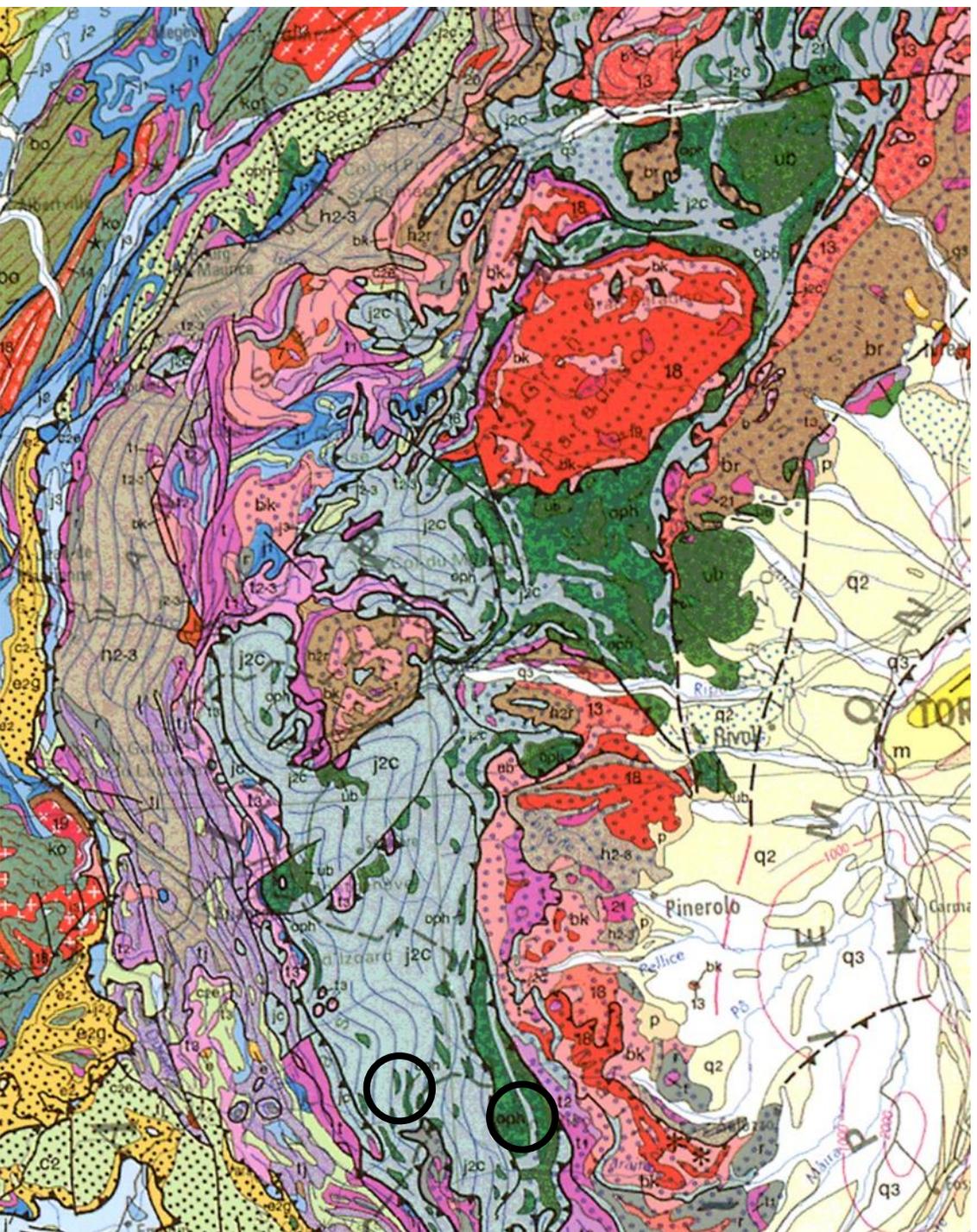
Zones anatectiques
(migmatites)

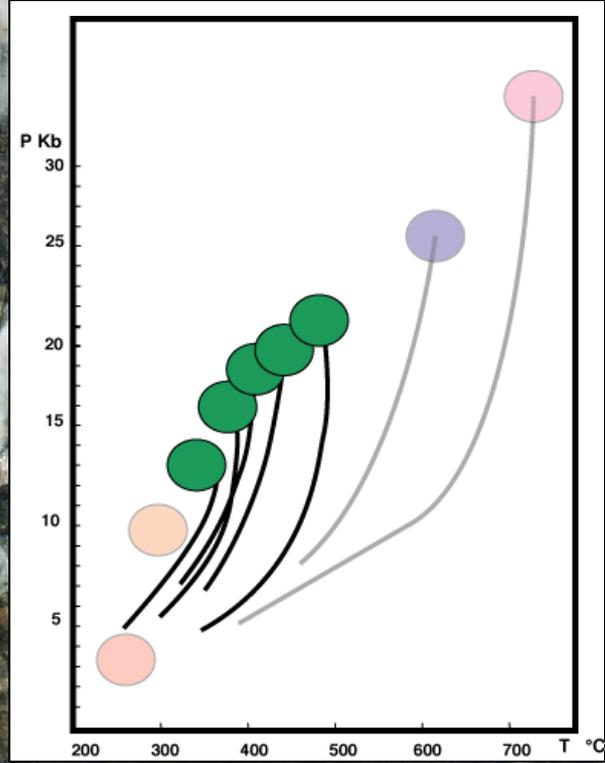
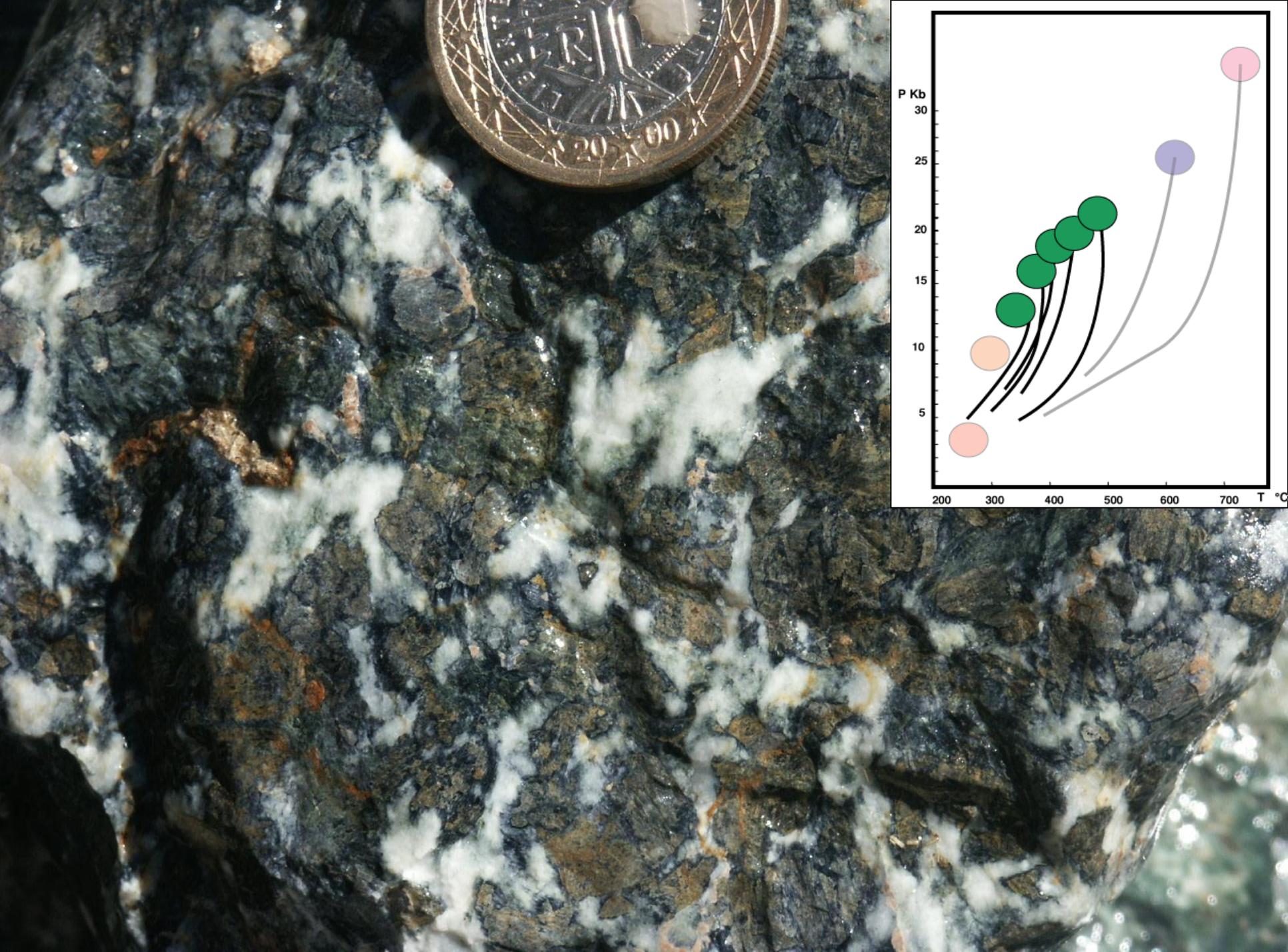
Faciès granulite
de basse pression

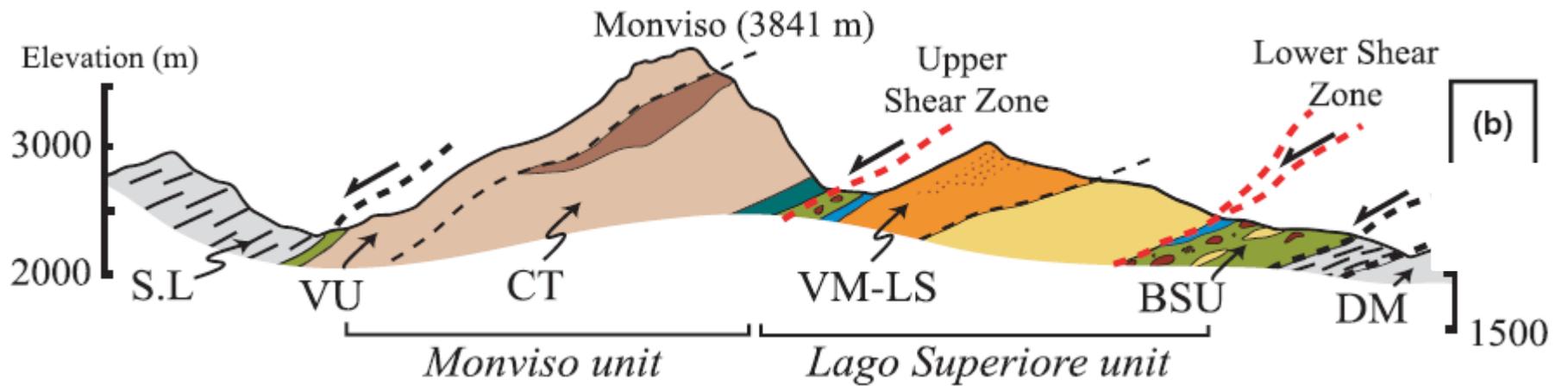
Faciès schiste bleu
de basse température

Faciès éclogite (et schiste
bleu de haute température)

1 : Relique éo-varisque
éclogitique
2 : Relique éo-alpine
à coarctée

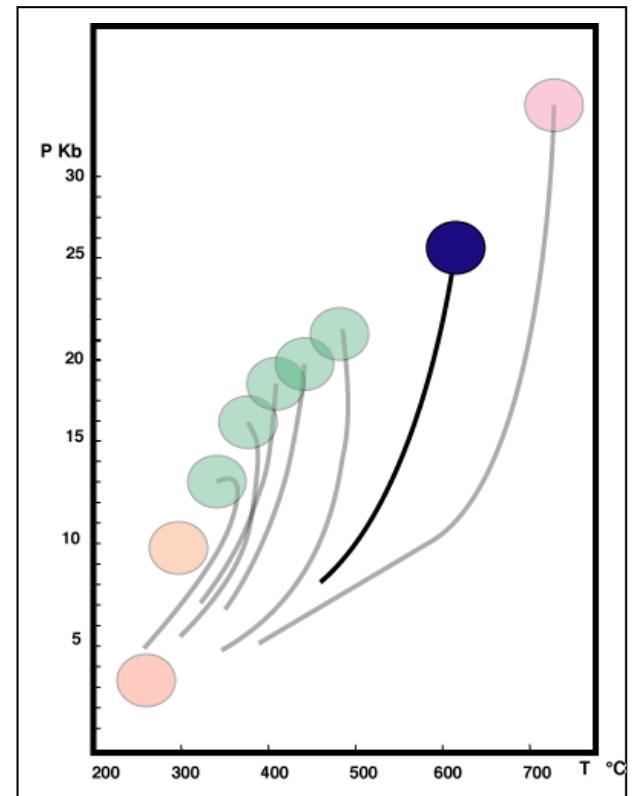
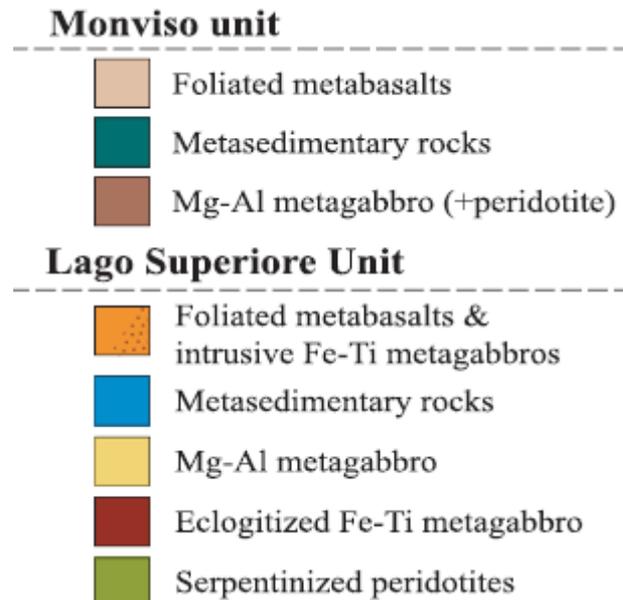






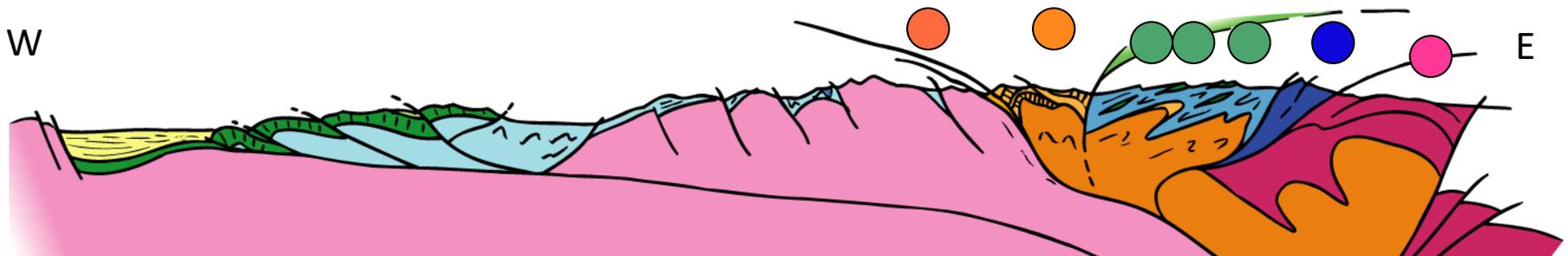
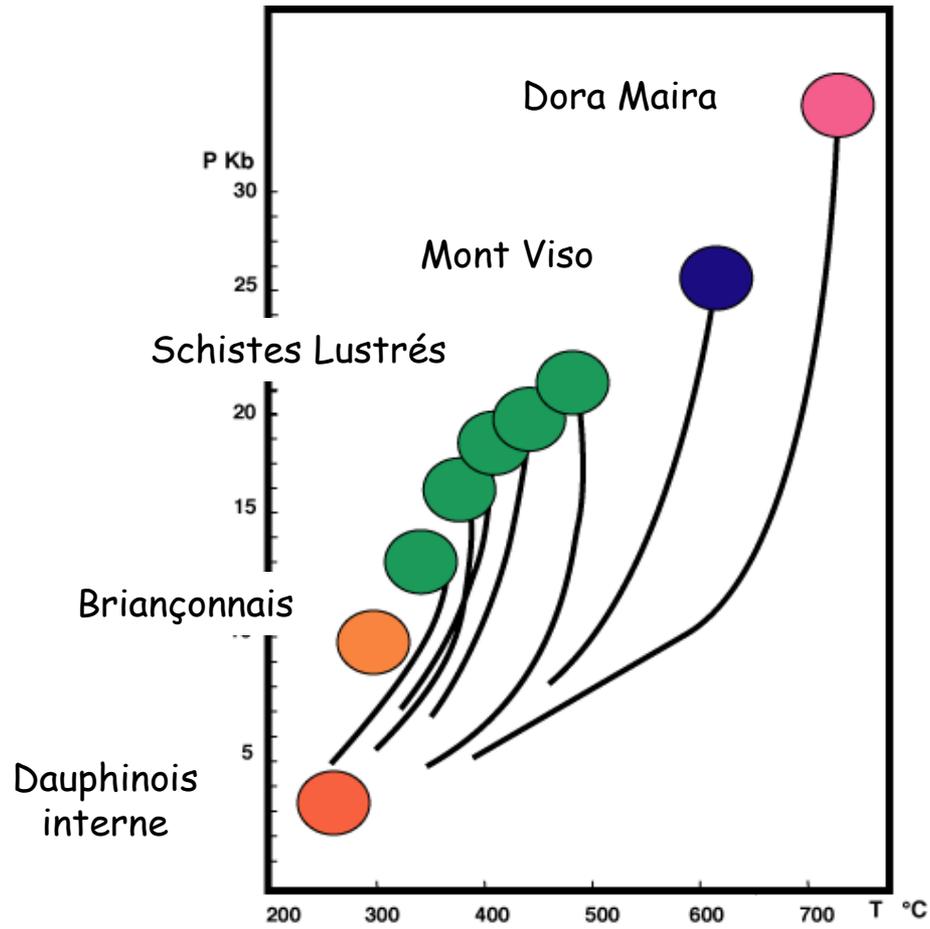
VU (Vallanta Unit), CT (Costa Ticino unit), VM-LS (Viso Mozzo, Lago Superiore units), BSU (Basal Serpentinite Unit) and DM (Dora Maira)

(Angiboust et al., 2011)

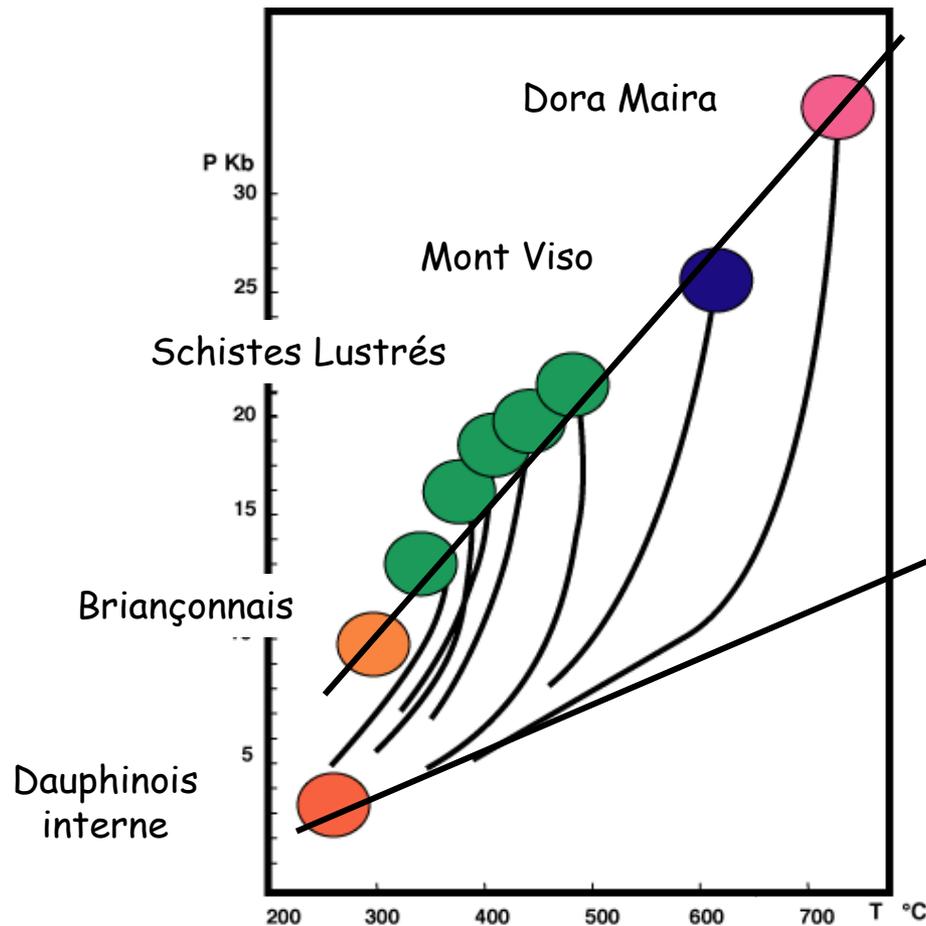




Évolution des conditions P-T sur une coupe

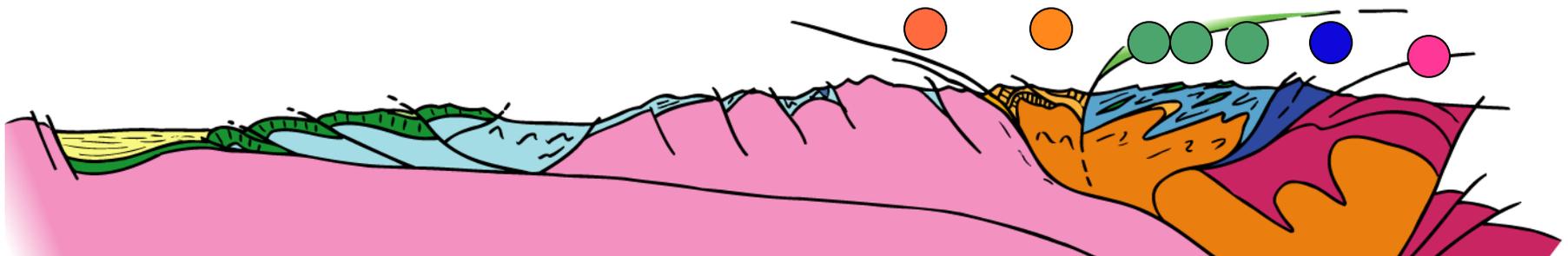


Évolution des conditions P-T sur une coupe

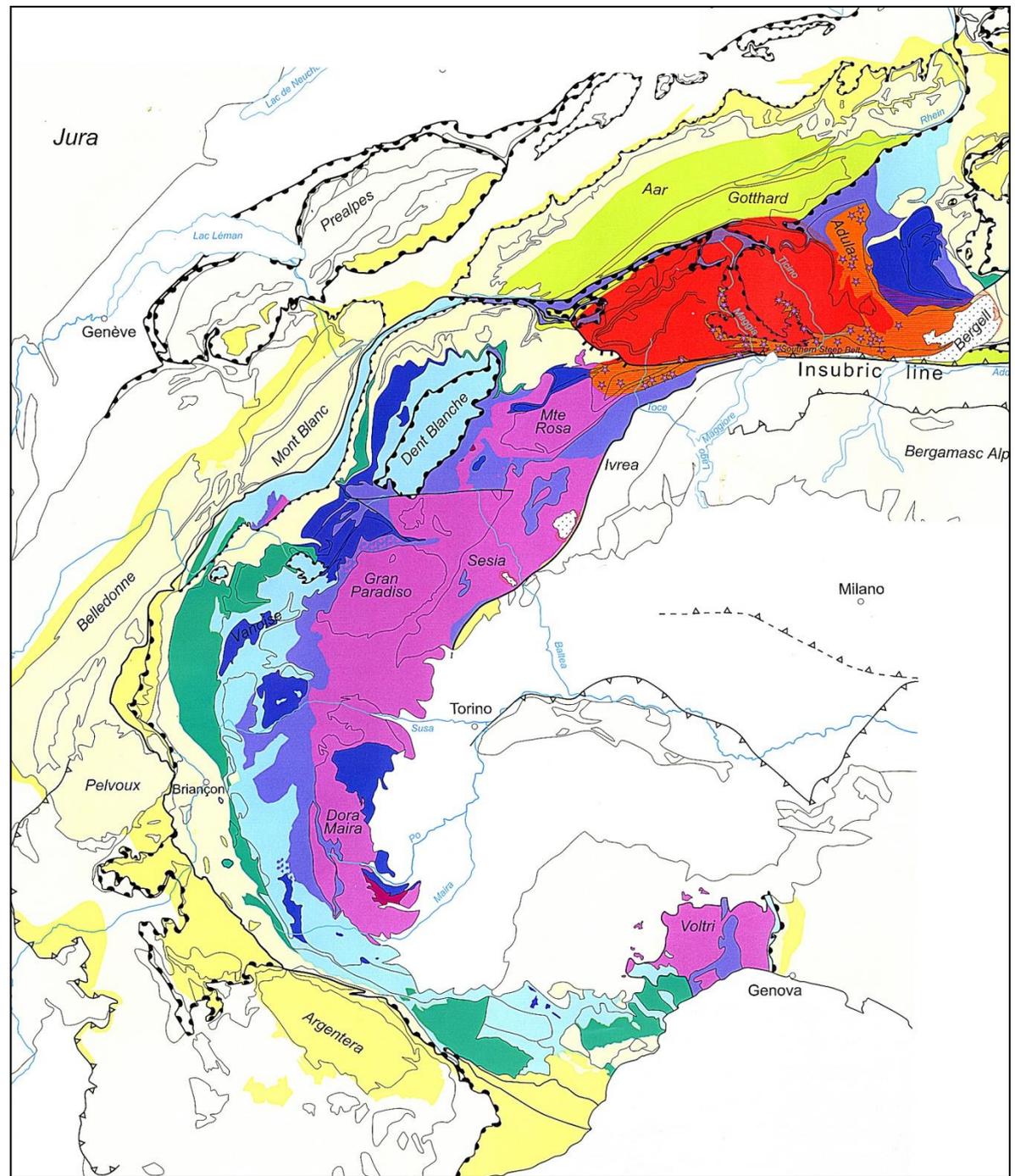


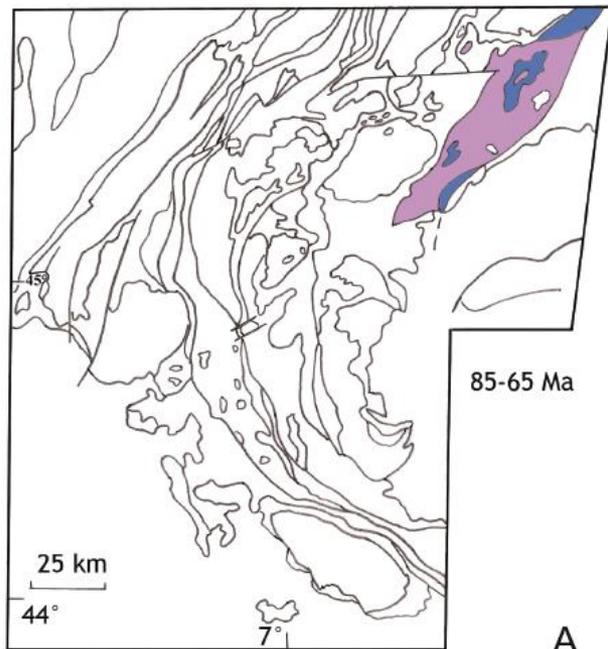
Gradient
métamorphique HP-BT
(~8°C/km) = marqueur
de subduction
océanique/continentale

Gradient
métamorphique MP-MT
(~30°C/km) = marqueur
de collision
continentale

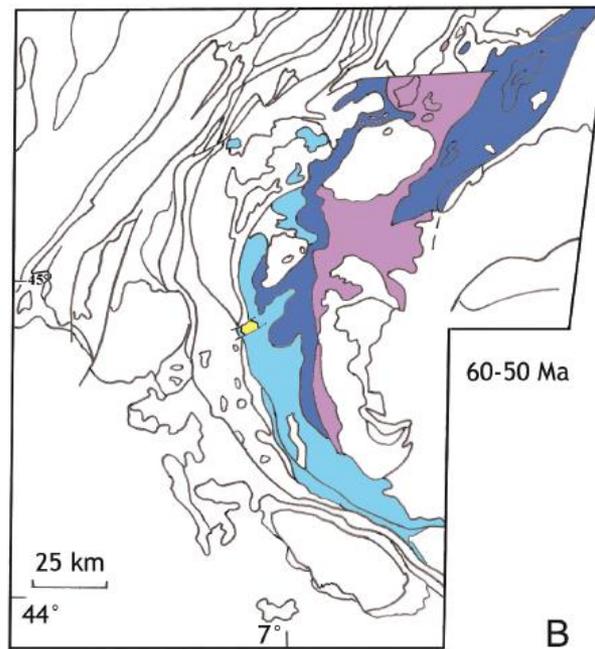


... et une vision plus rigoureuse

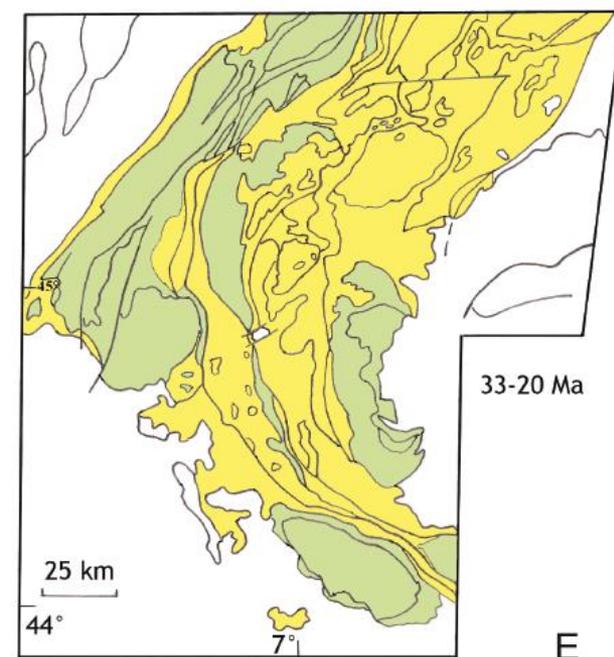




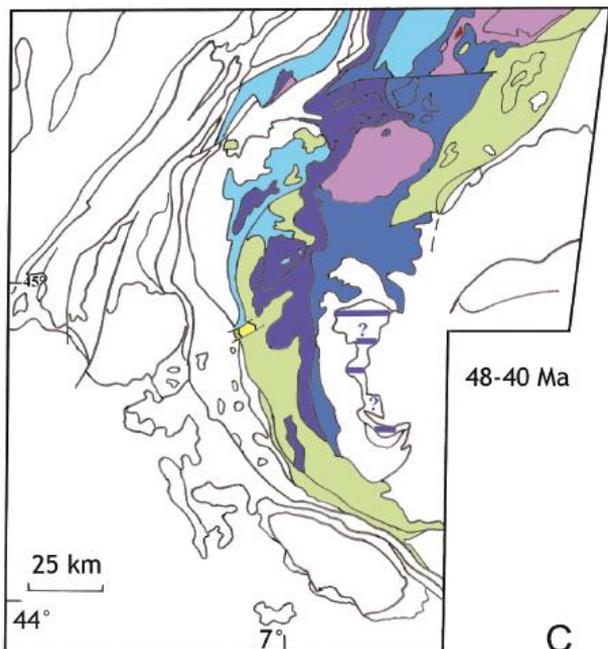
A



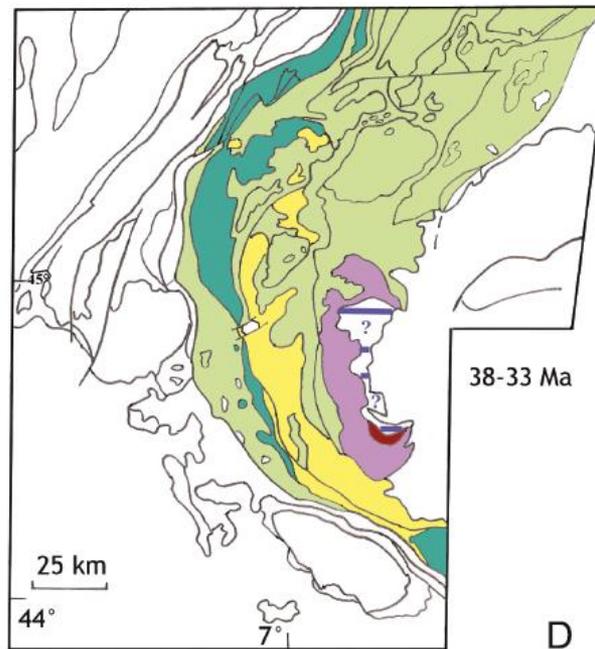
B



E



C

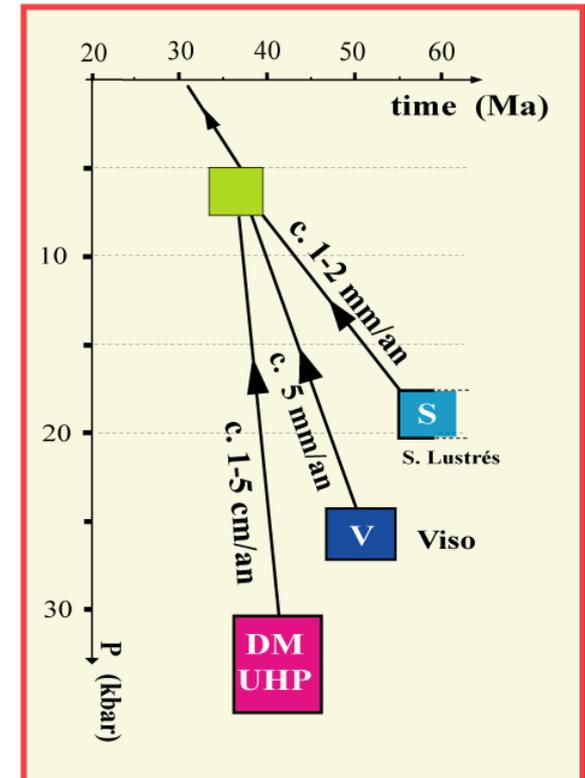
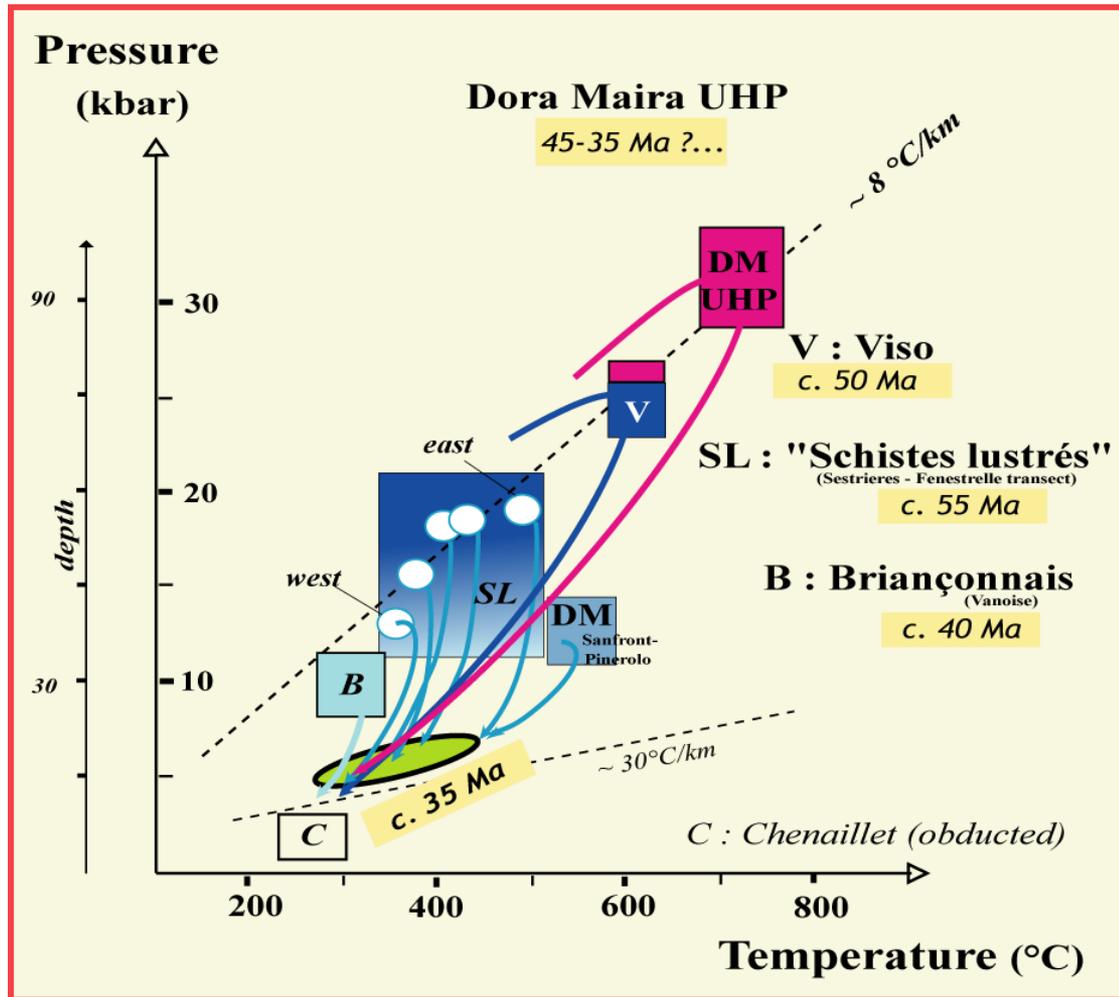


D

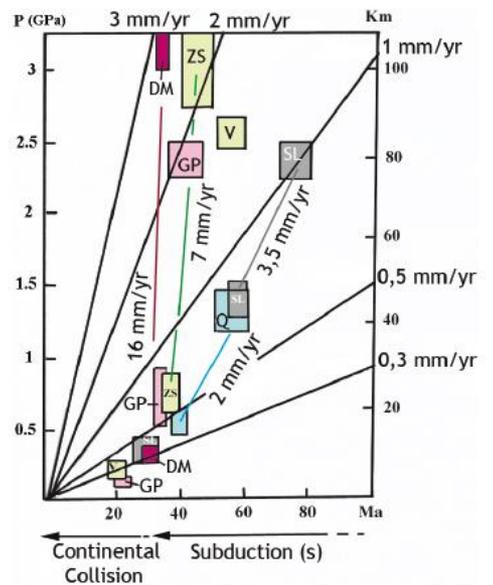
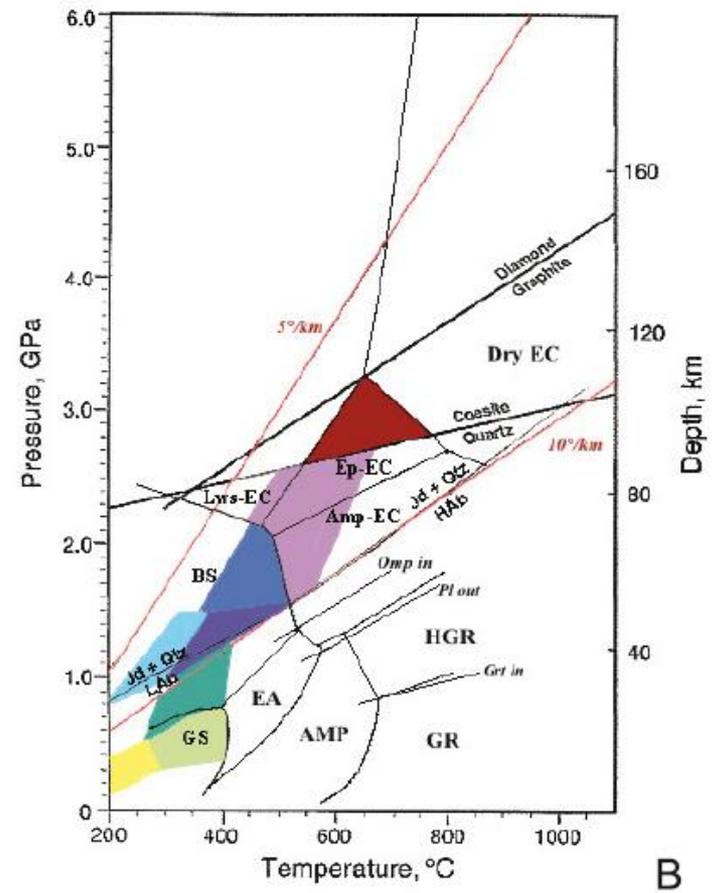
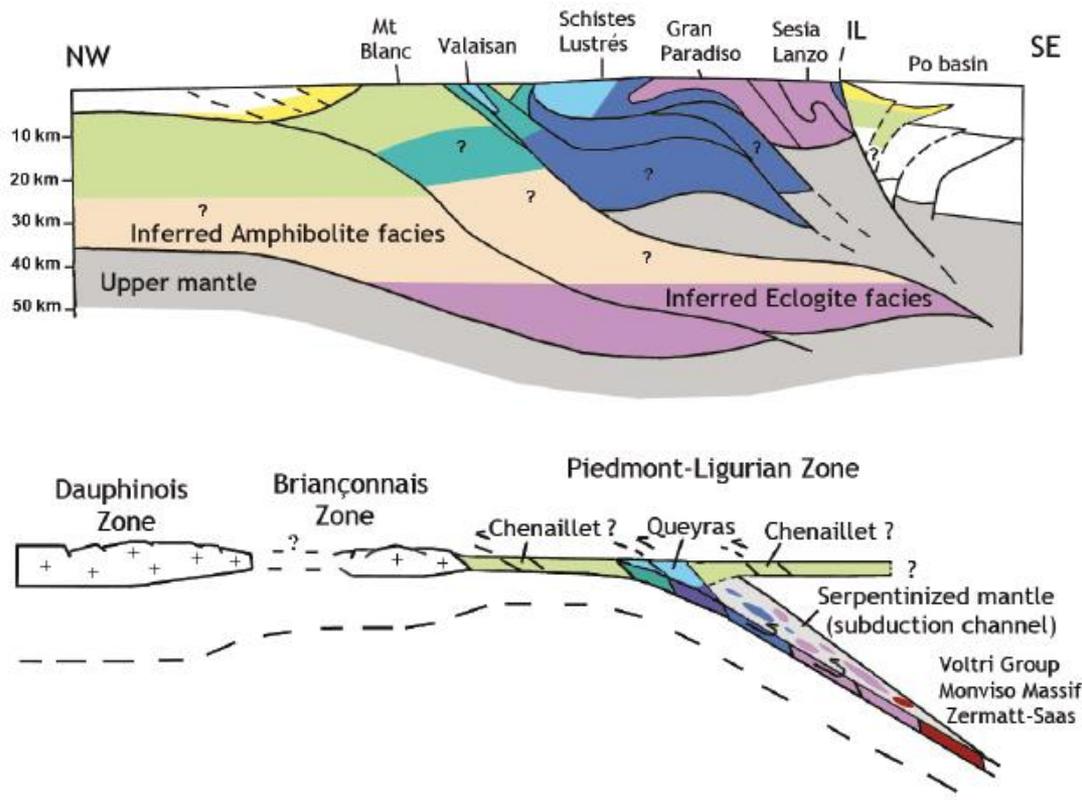
- Quartz-Eclogite
- Blueschist/Eclogite transition
- HT Blueschist
- LT Blueschist
- HP Greenschist
- Greenschist
- Anchizone sub-Greenschist

(Lardeaux, 2014)

Bilan provisoire sur l'exhumation des zones internes

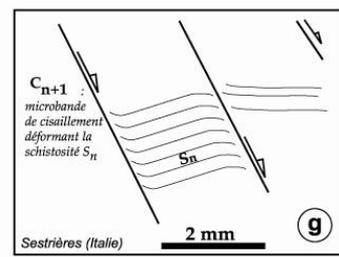
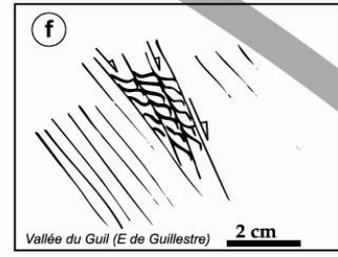
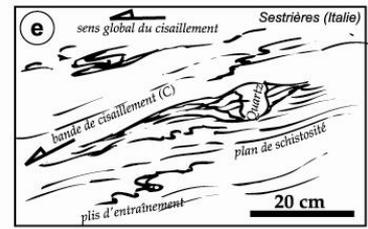
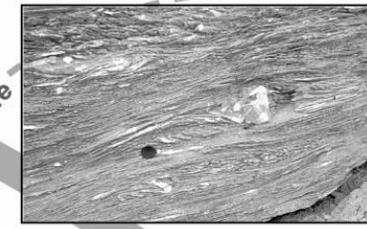
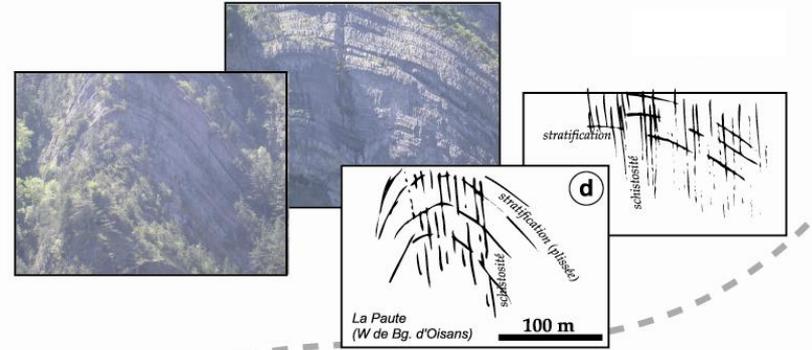
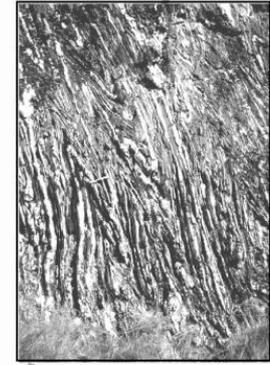
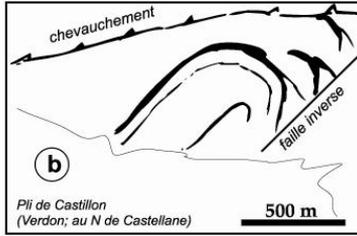
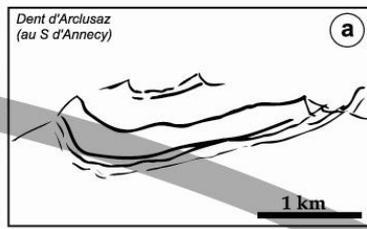
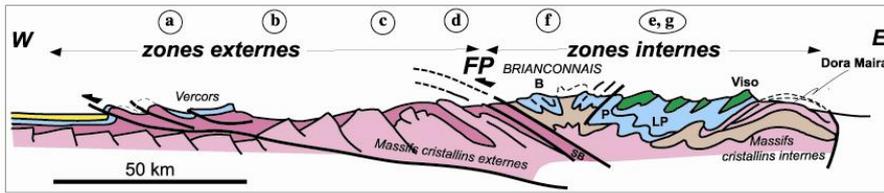


(Agard et Lemoine, 2003)



- Quartz-Eclogite
- Blueschist/Eclogite transition
- HT Blueschist
- LT Blueschist
- HP Greenschist
- Greenschist
- Anchizone sub-Greenschist

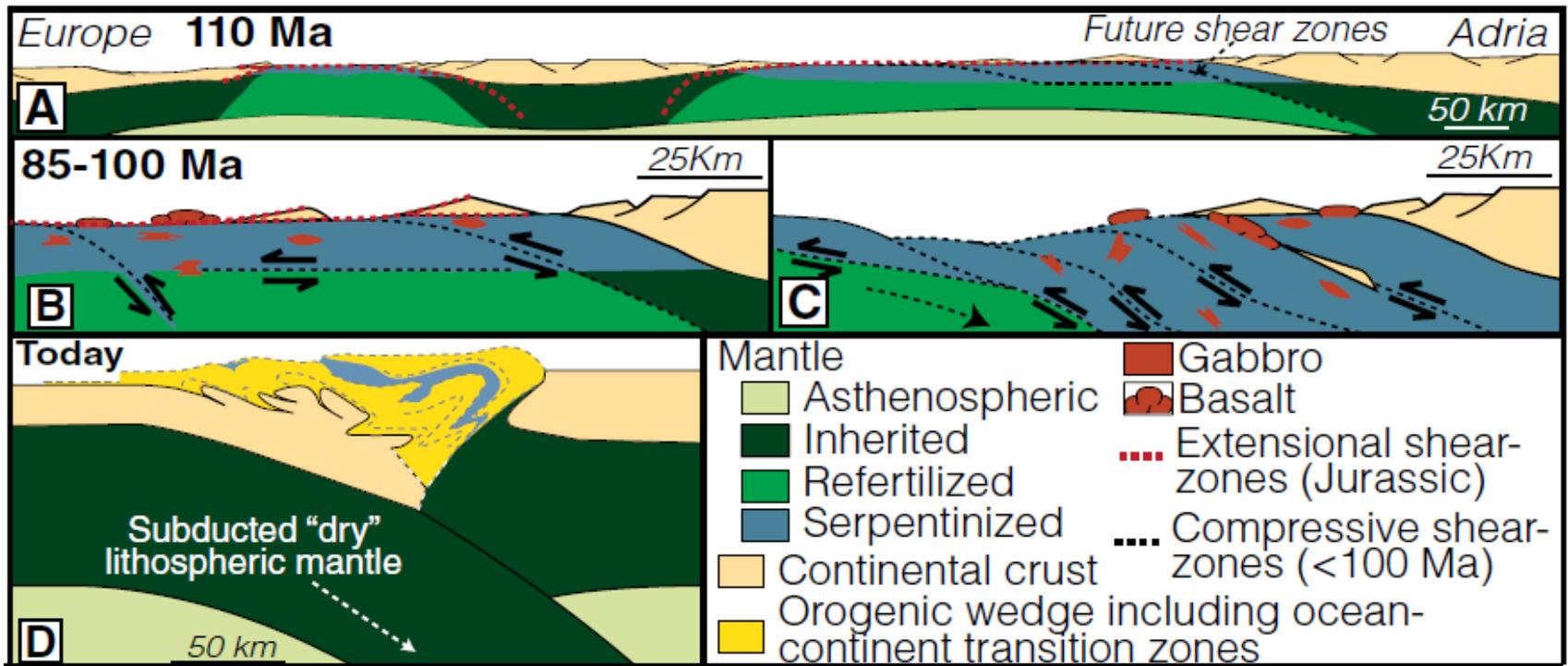
(Lardeaux, 2014)



(Agard et Lemoine, 2003)

I. Les Alpes franco-italiennes : une chaîne de subduction-collision

D. Une absence quasi-totale
de magmatisme orogénique



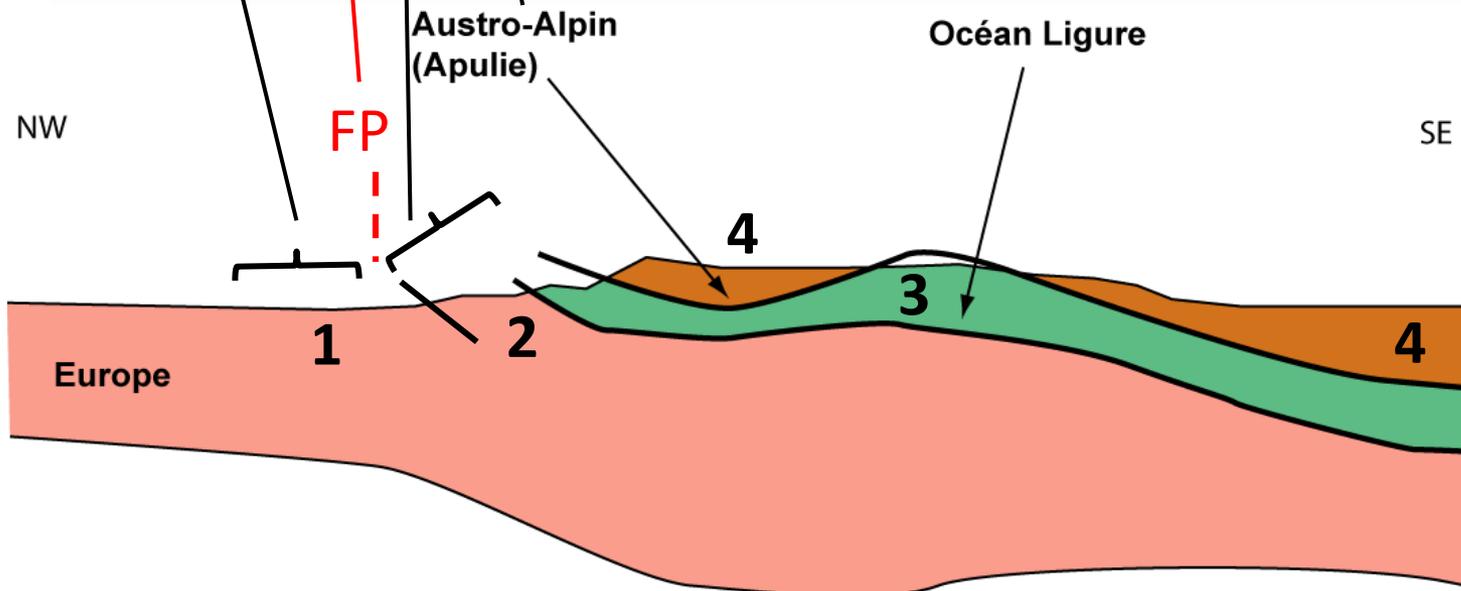
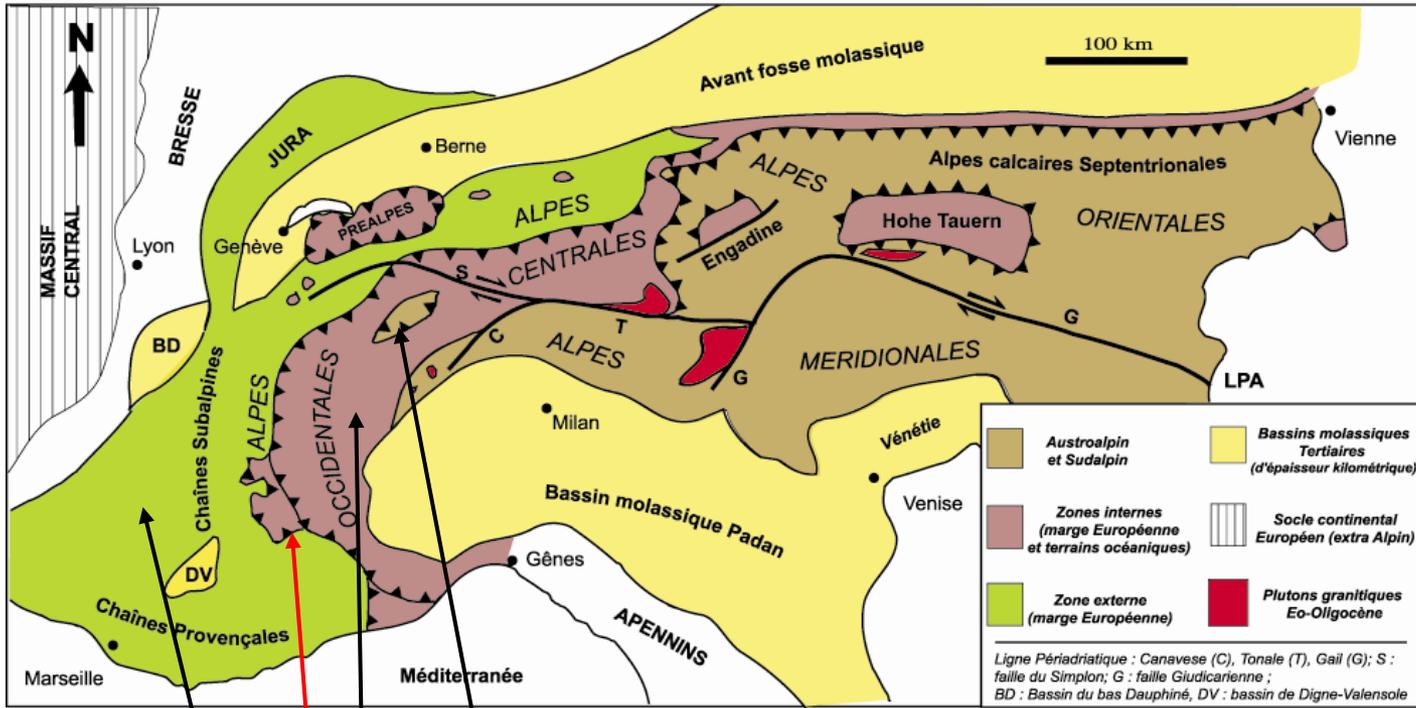
The closure of rift basins forming the **Piemont-Liguria ocean** did not follow a classical **Wadati-Benioff-type** subduction. Instead, subduction initiation at passive margins allowed for the accretion of the hydrated portion of the subducting plate within an orogenic wedge as subduction of dry subcontinental lithosphere inhibited magmatism during subduction initiation and ocean closure.

(McCarthy et al., 2018)

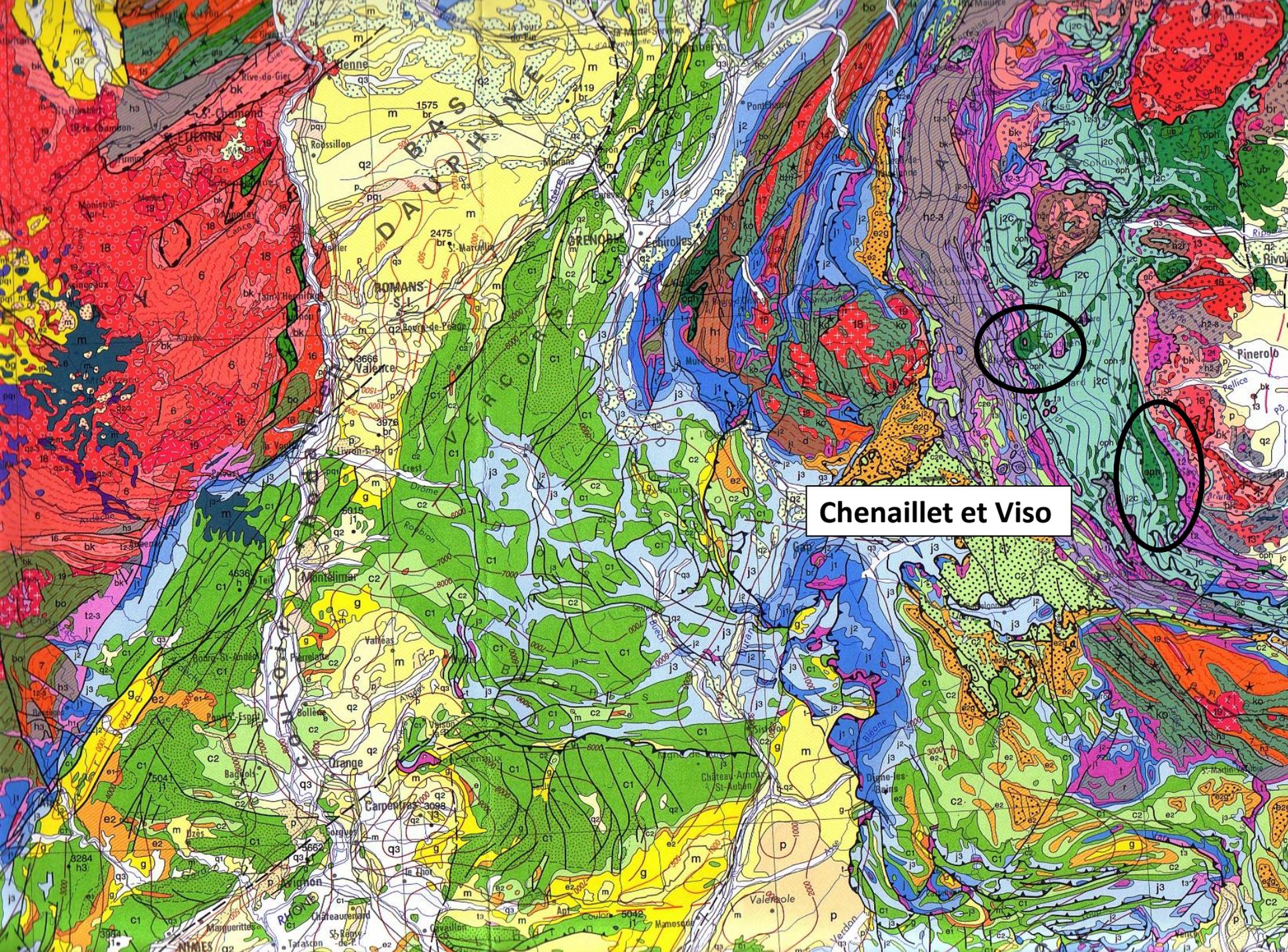
II. Les Alpes franco-italiennes :
une structure impliquant la fermeture
d'un (ou plusieurs?) océan(s) lent(s)
et l'inversion d'une paléomarge passive

II. Les Alpes franco-italiennes :
une structure impliquant la fermeture
d'un (ou plusieurs?) océan(s) lent(s)
et l'inversion d'une paléomarge passive

A. La superposition des nappes de charriage
implique l'existence d'un ou plusieurs
domaines océaniques



B. Les vestiges d'une lithosphère océanique :
les ophiolites alpines



Chenaillet et Viso

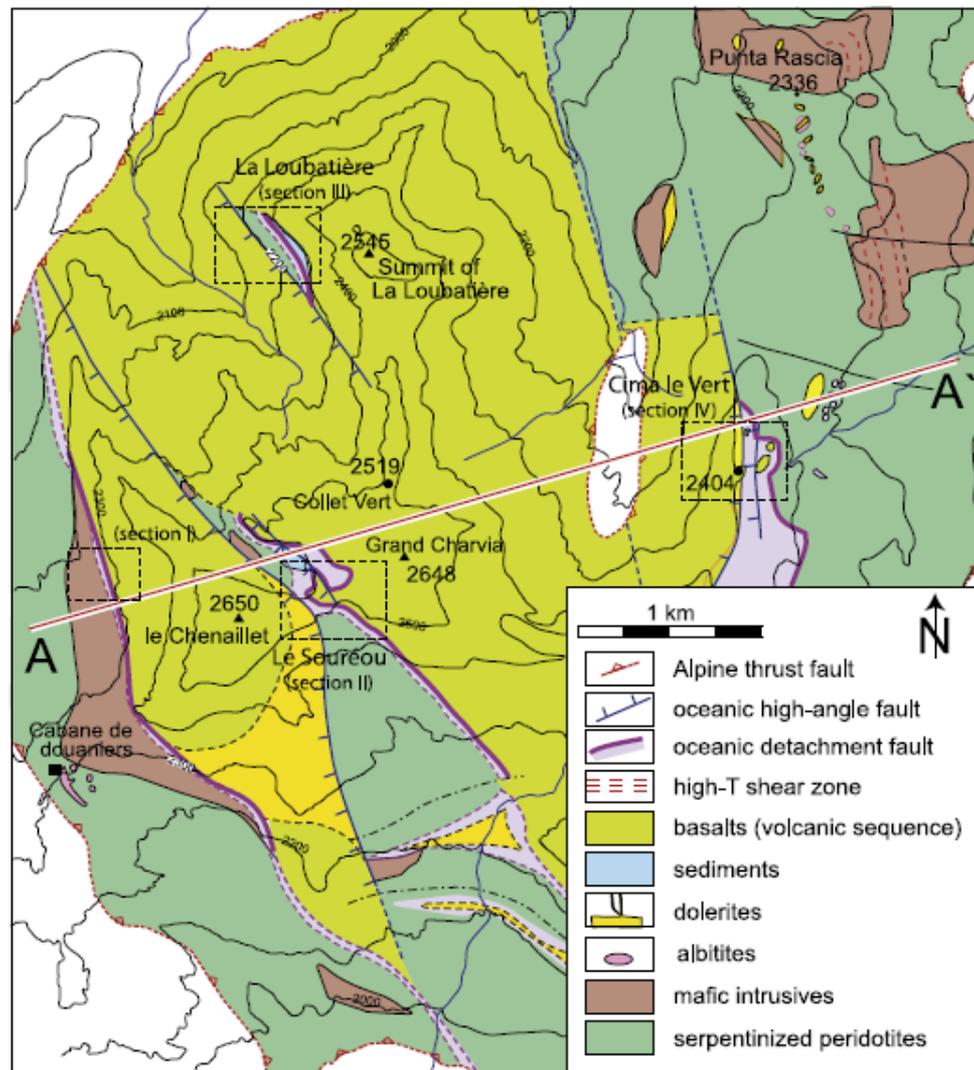




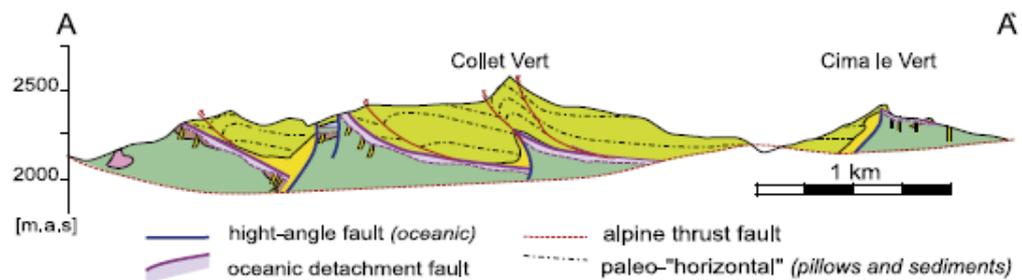




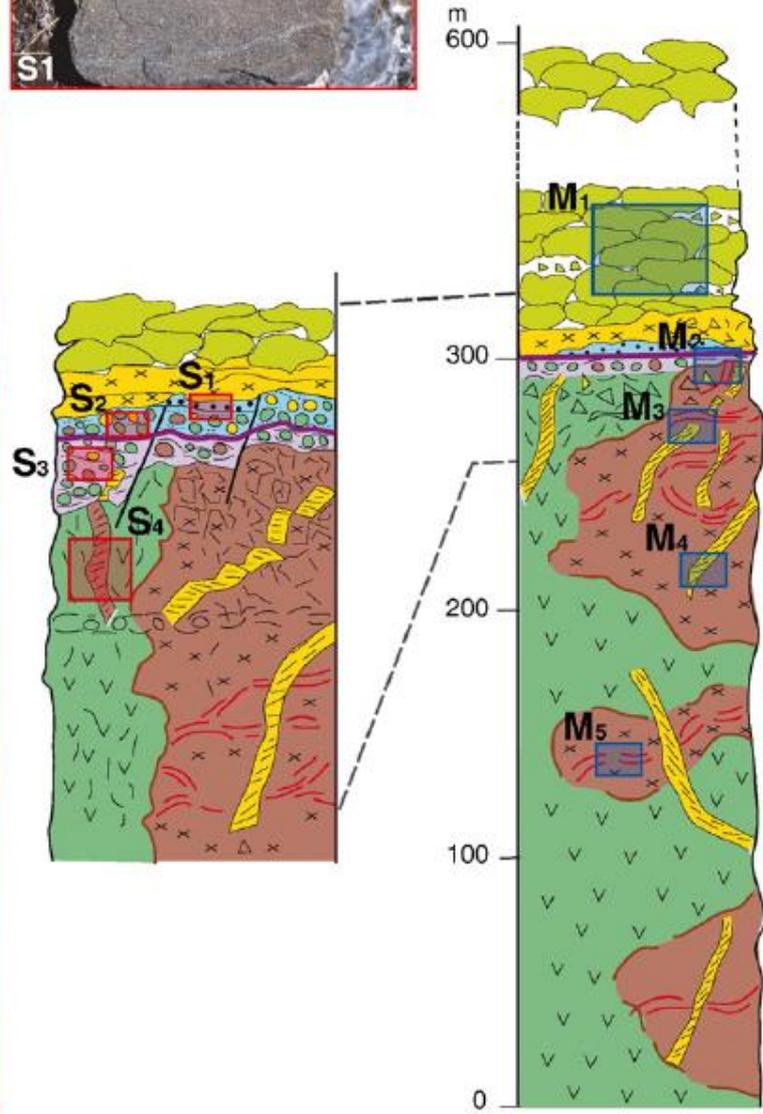




(Manatschal et al, 2011)

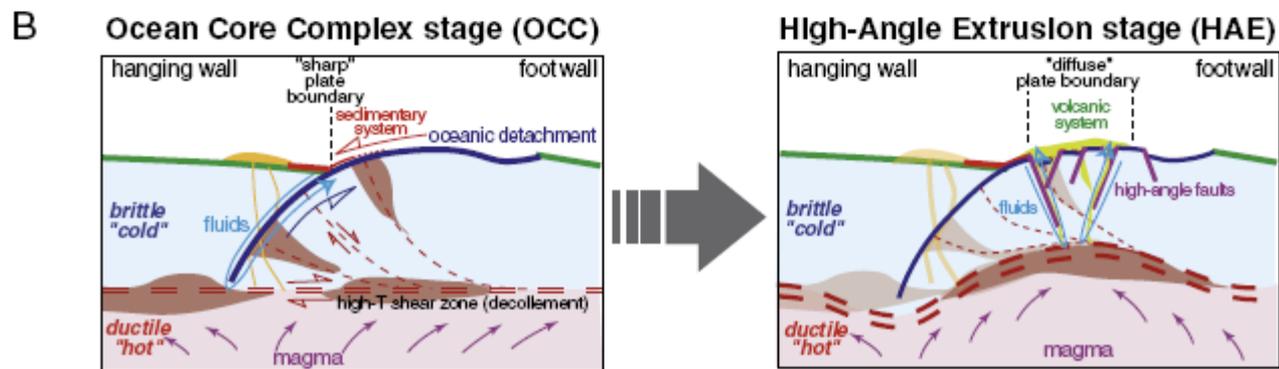
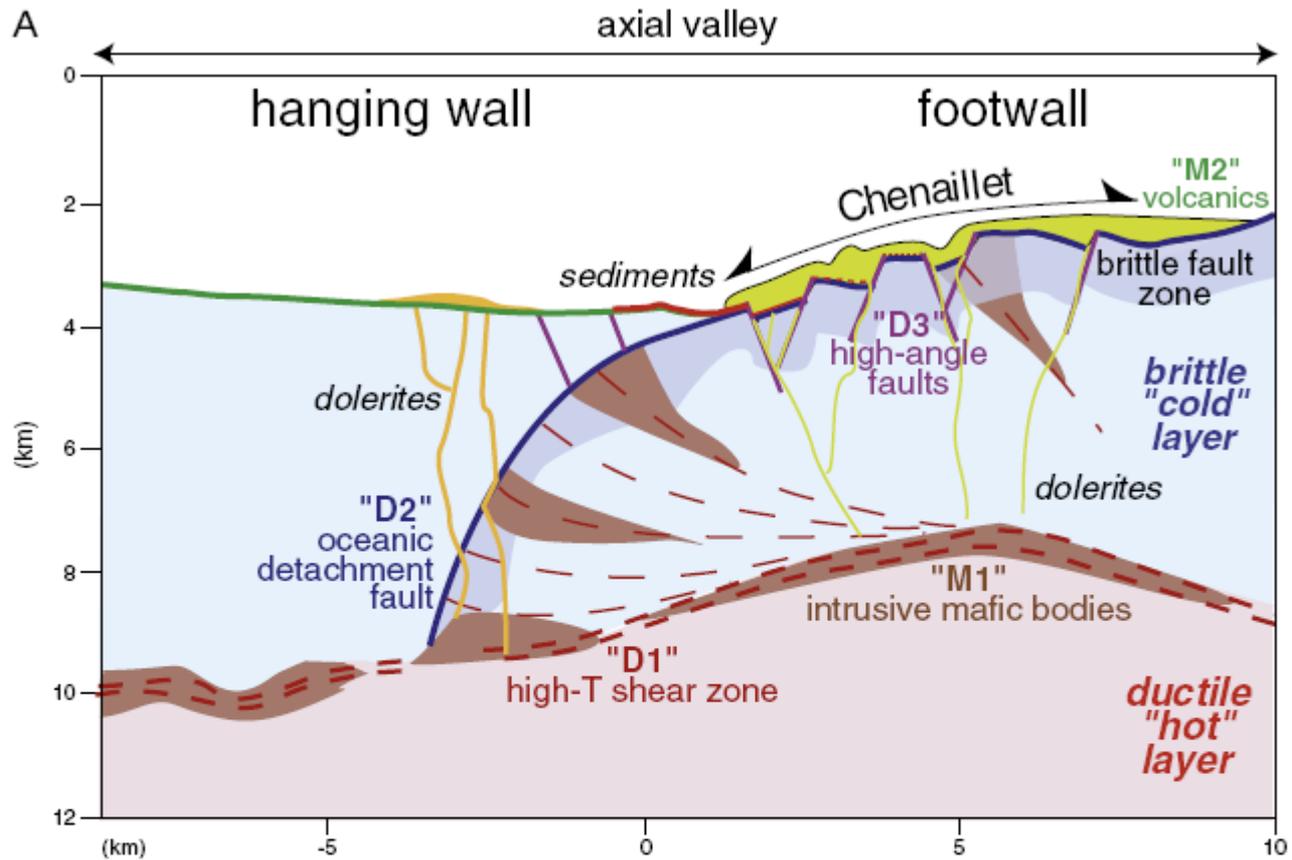


(Manatschal et al, 2011)



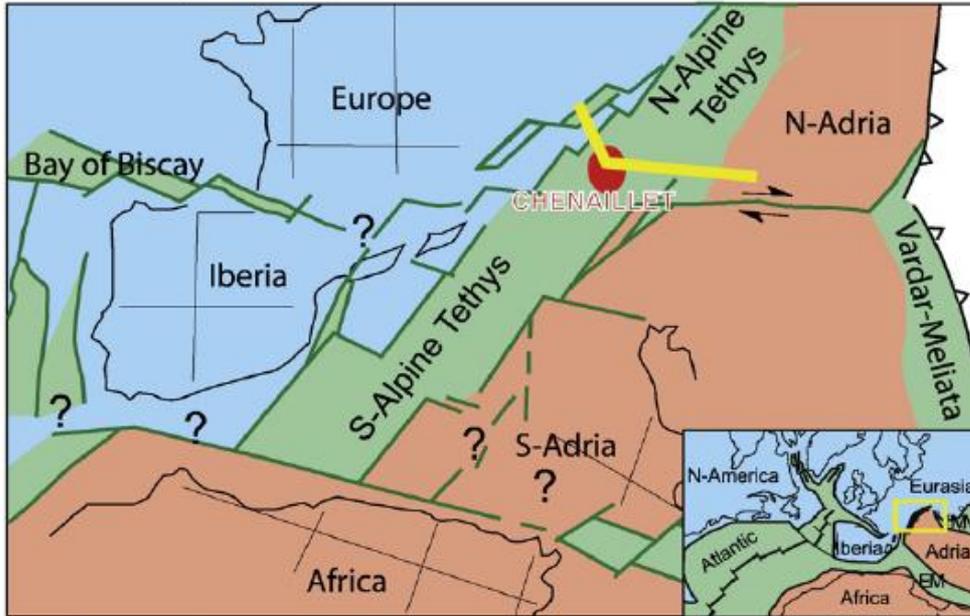
- basalts (*volcanic sequence*)
- dolerites (*massive volcanics*)
- sediments
- mafic intrusives
- serpentinized peridotite
- dolerites
- oceanic detachment fault
- high-T shear zone



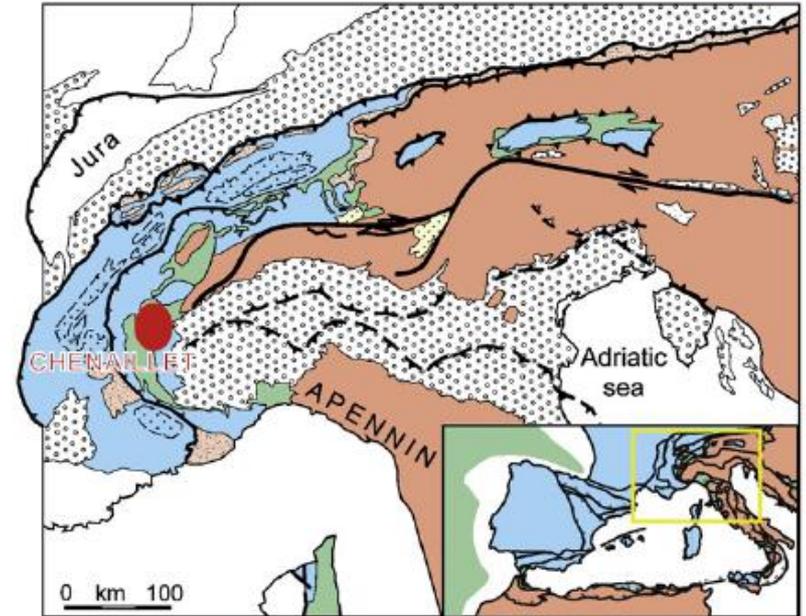


(Manatschal et al,
2011)

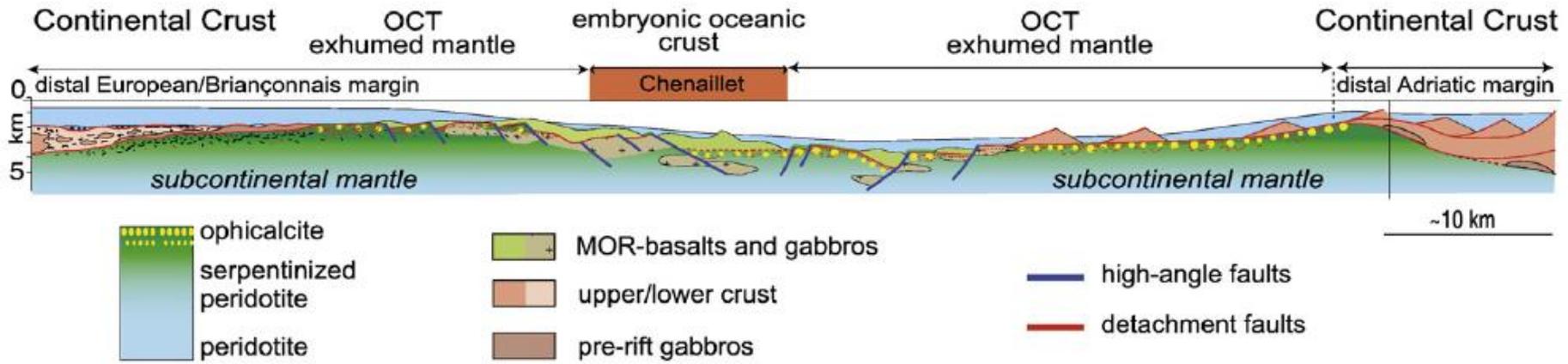
ALBIAN (100 Ma)



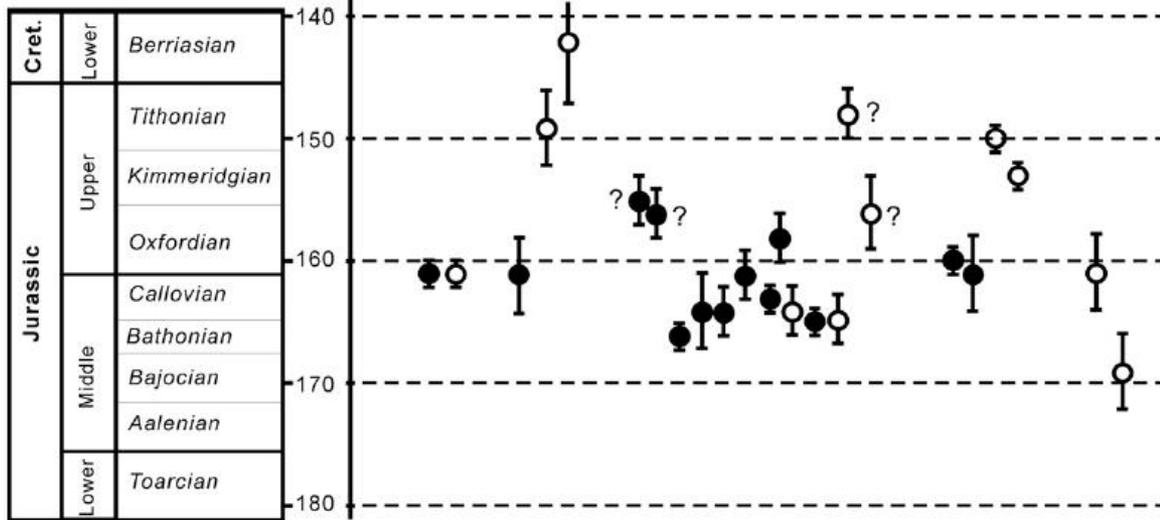
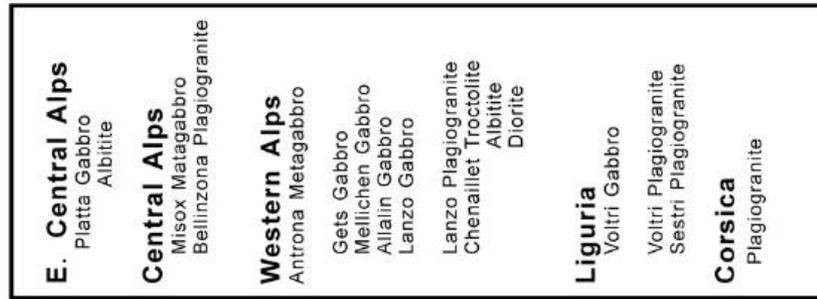
PRESENT DAY



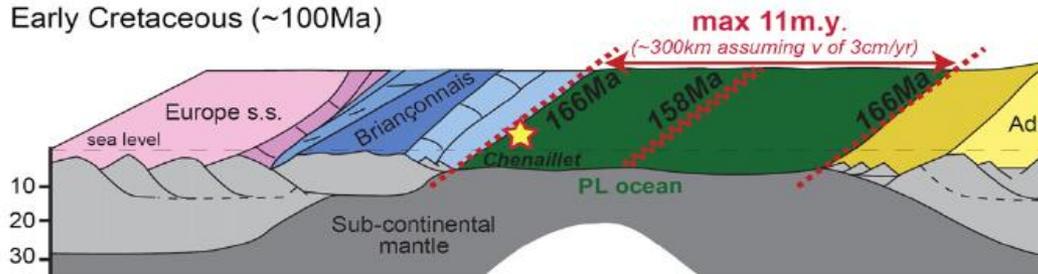
Adriatic/African units
 European/Iberia units
 Oceanic units
 Flysch-units
 Granites (Cenozoic)
 Foreland deposits



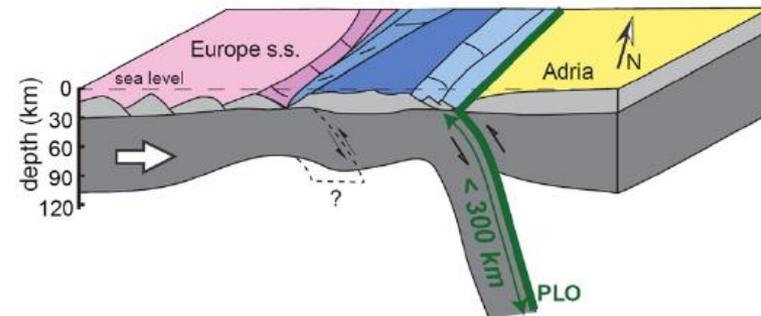
(Li et al, 2014)



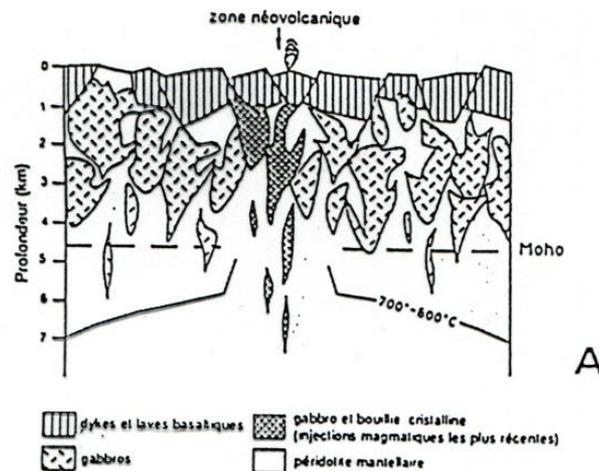
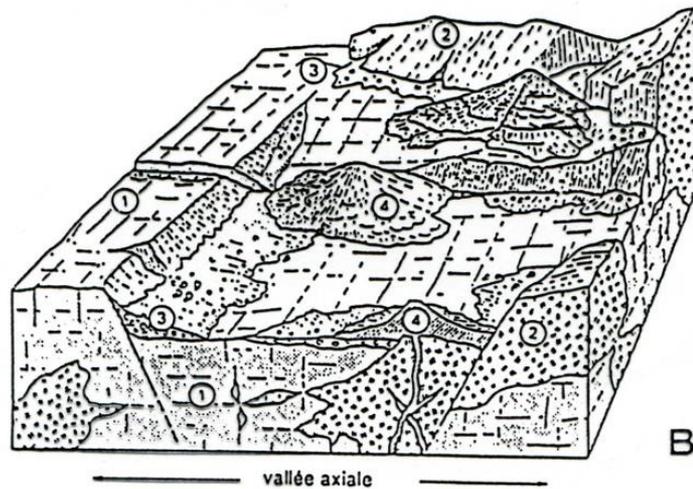
Early Cretaceous (~100Ma)



Middle Eocene (~45Ma)



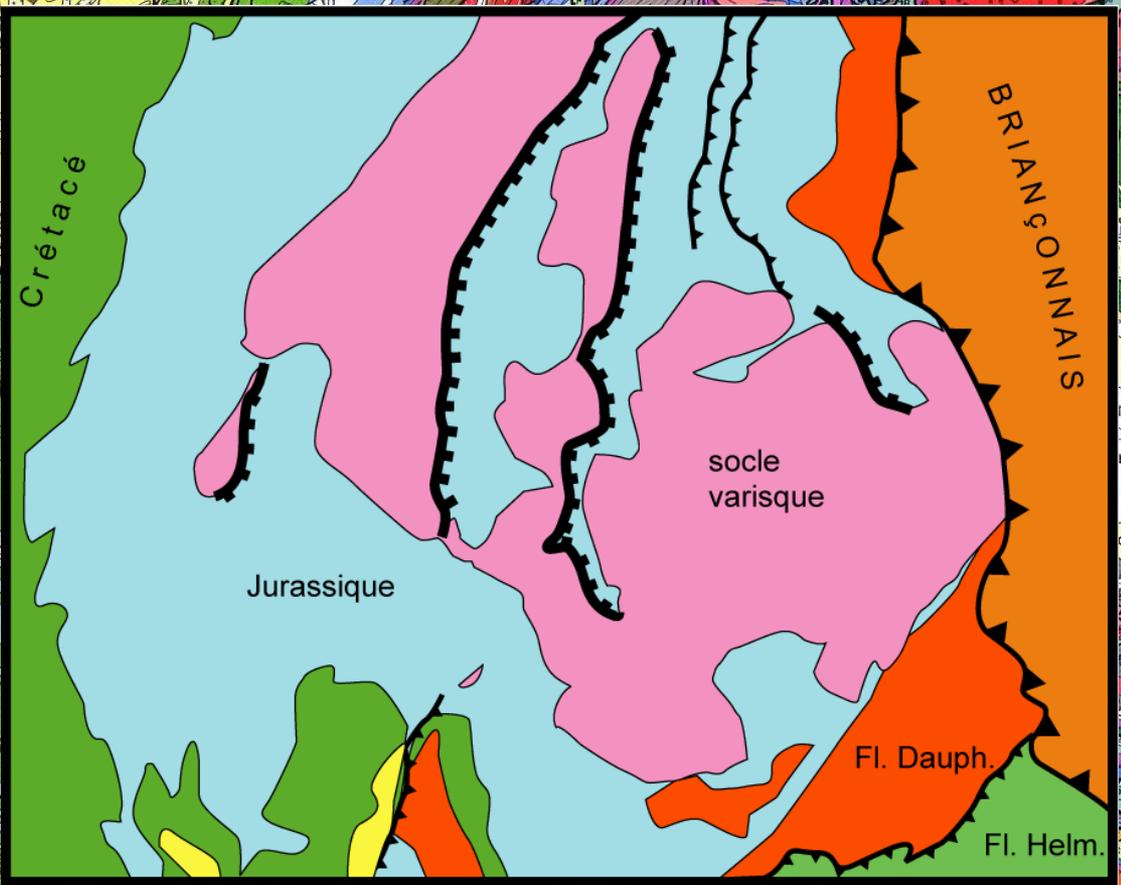
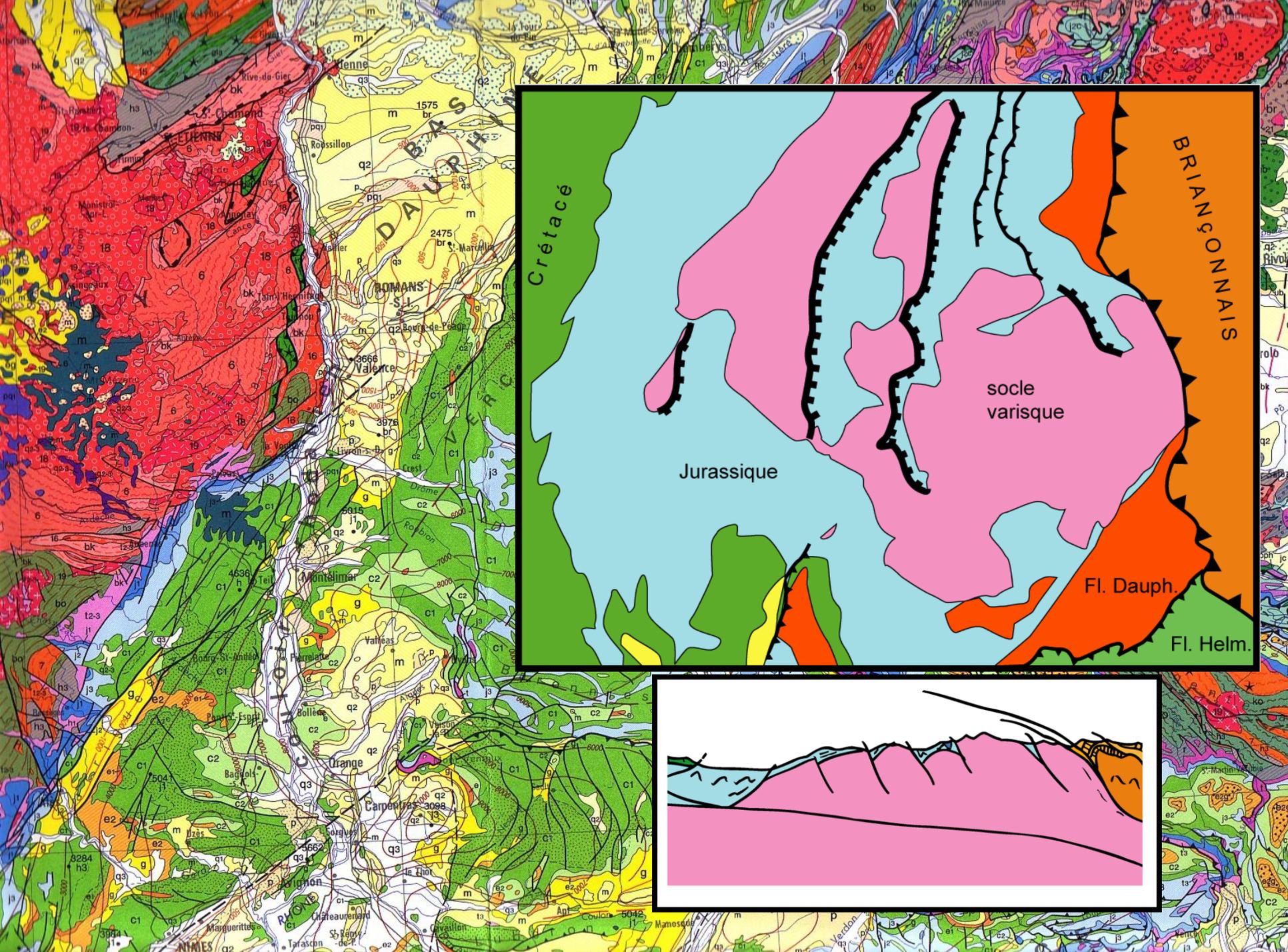
L'océan ligure : des fonds océaniques étroits
de type « atlantique »



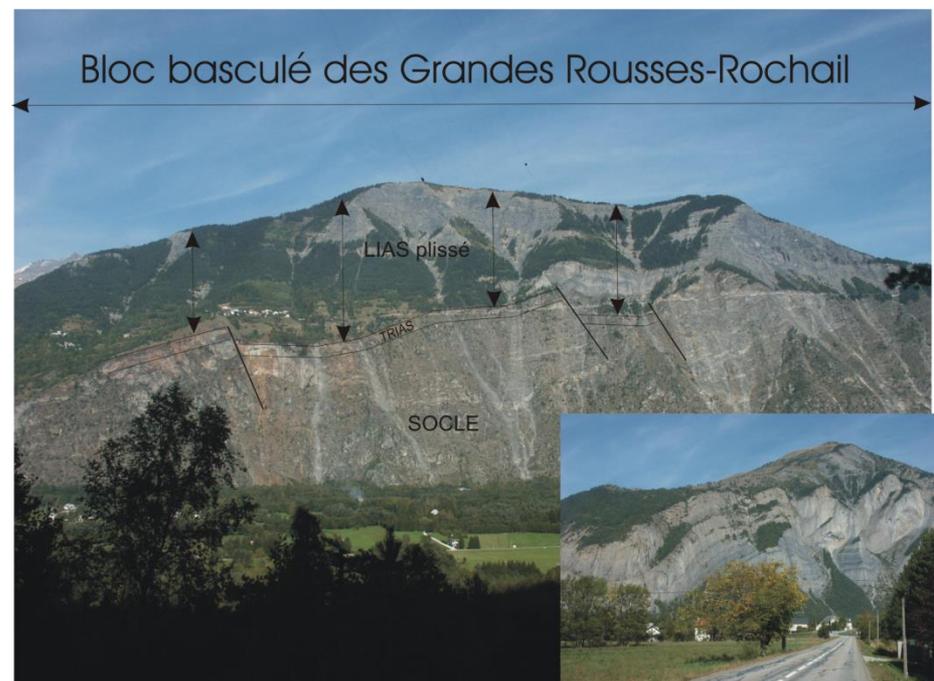
A) Modèle de zone axiale de dorsale lente : l'accrétion tectonique est dominante, des poches magmatiques éphémères cristallisent sous la forme de corps de gabbros intrusifs dans le manteau sommital, sous une couche volcanique discontinue. Le manteau peut affleurer sur le plancher océanique. Dessin de M. Cannat (1990). B) Reconstitution schématique du socle océanique téthysien d'âge jurassique des Alpes franco-italiennes (Bassin liguro-piémontais), basée sur des observations de terrain dans les ophiolites de la zone des Schistes lustrés (Queyras). 1 : lherzolite serpentinisée. 2 : gabbro. 3 : brèches ultramafiques/mafiques, essentiellement brèches de talus. 4 : volcans de pillow lavas isolés et débris volcaniques associés. Noter que les basaltes peuvent reposer directement sur les péridotites serpentinisées, ou sur leurs talus d'éboulis. Dessin de Y. Lagabrielle

II. Les Alpes franco-italiennes :
une structure impliquant la fermeture
d'un (ou plusieurs?) océan(s) lent(s)
et l'inversion d'une paléomarge passive

C. La marge européenne de l'océan ligure



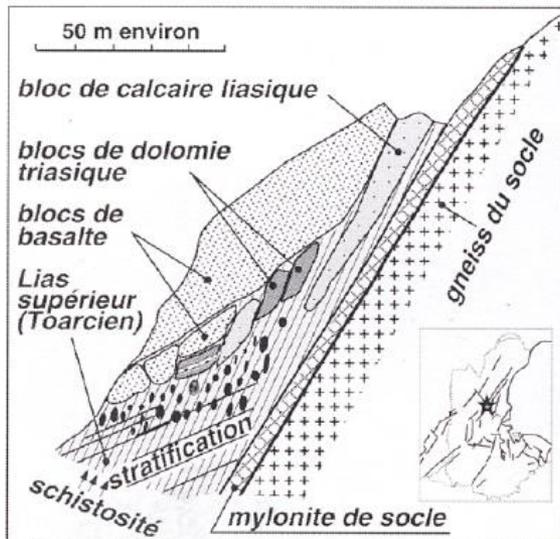


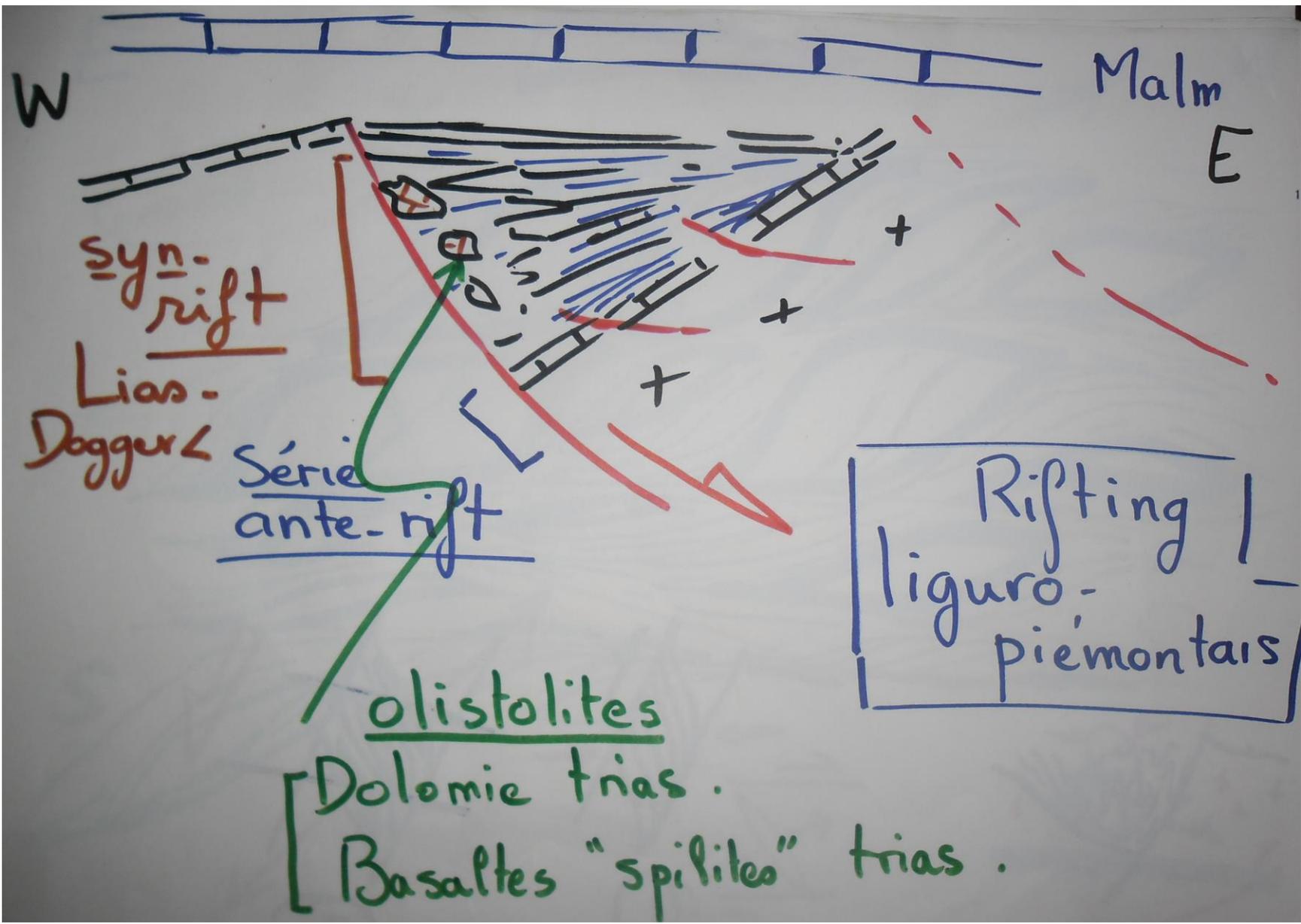






Histoire tectonique
reconstituée à partir
des observations de
terrain





W

Malm
E

syn-rift

Lias-
Dogger

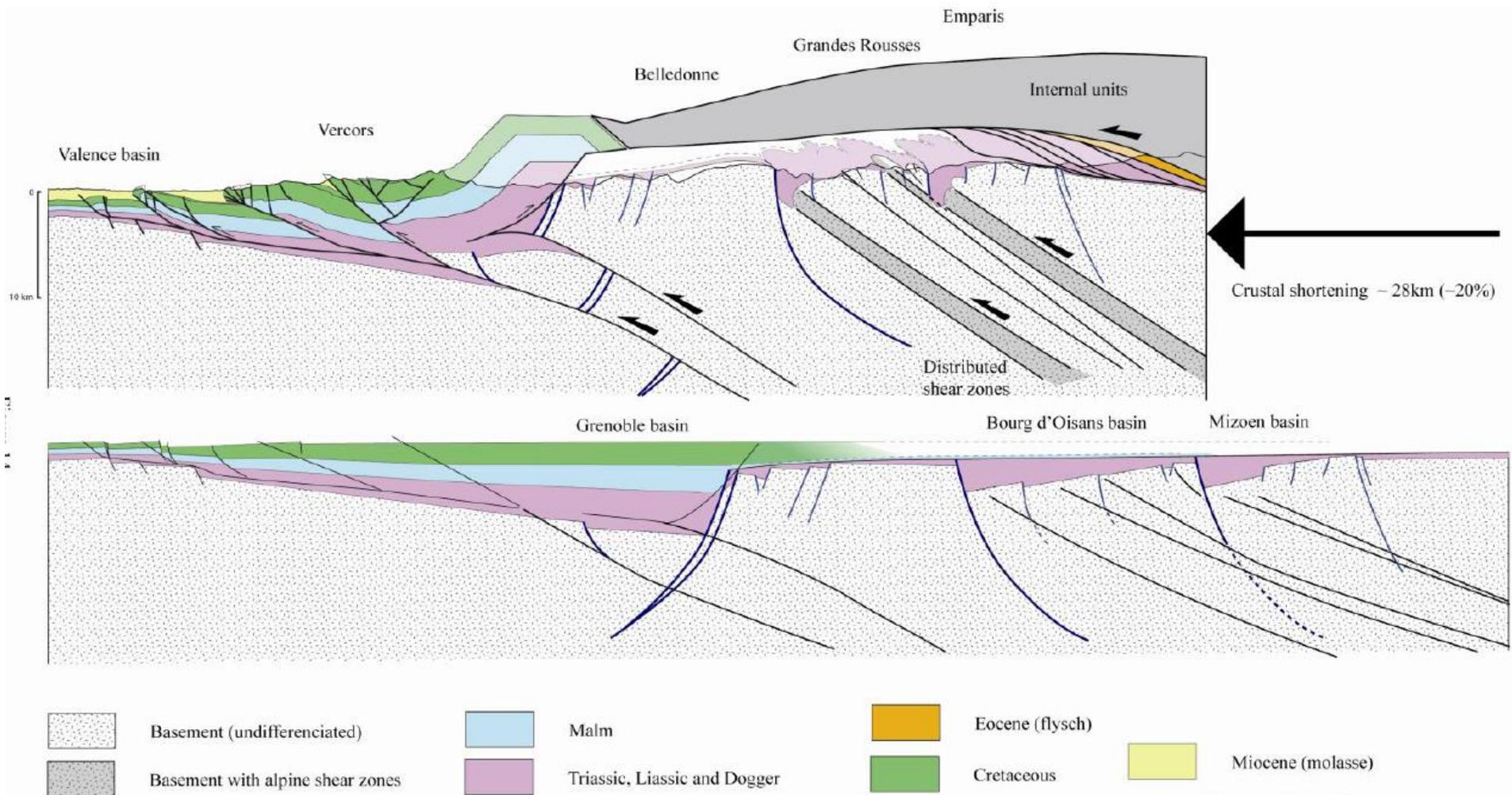
Série
ante-rift

olistolites

[Dolomie trias.

[Basaltes "spilites" trias.

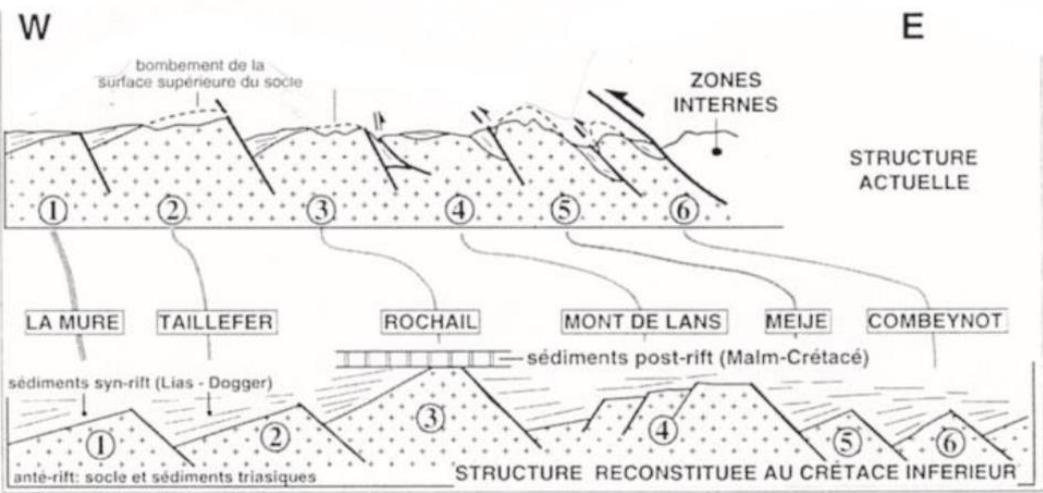
Rifting
liguro-
piémontais



(Bellahsen et al., 2012)

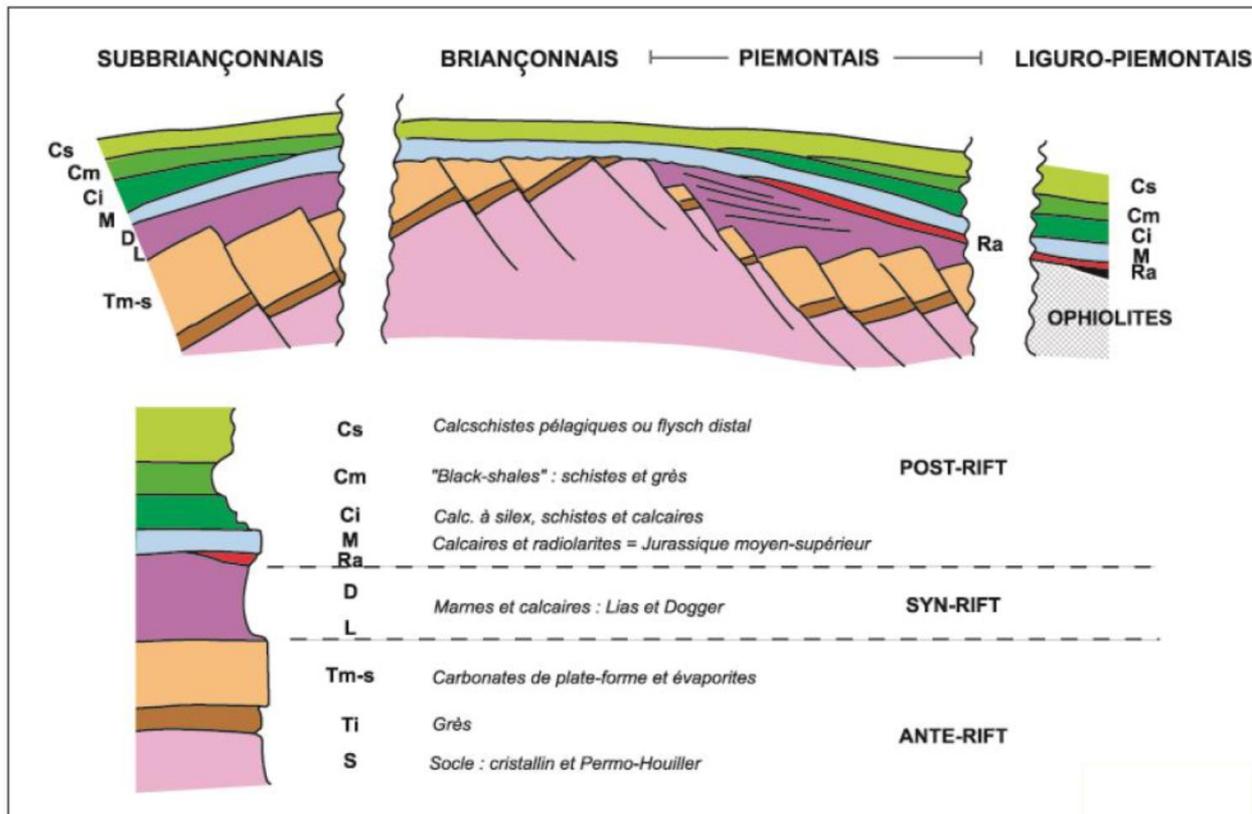


Identification et reconstitution d'une tectonique distensive en blocs basculés dans le domaine dauphinois



II. Les Alpes franco-italiennes :
une structure impliquant la fermeture
d'un (ou plusieurs?) océan(s) lent(s)
et l'inversion d'une paléomarge passive

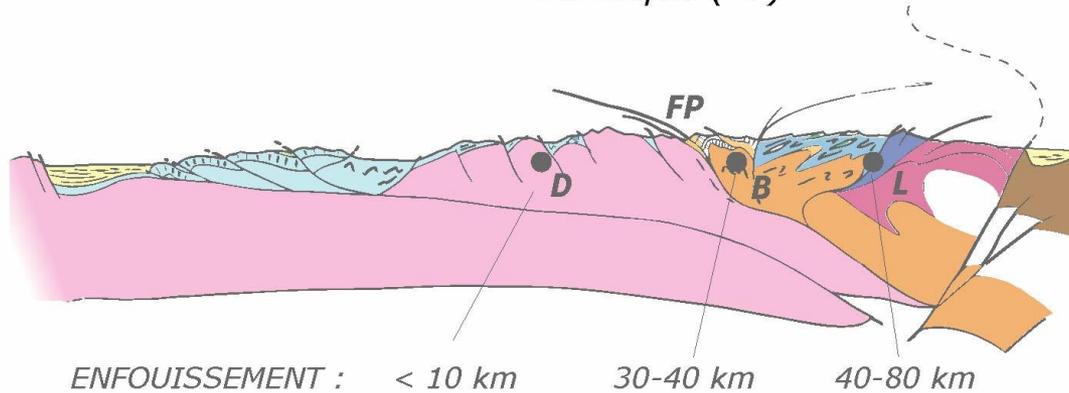
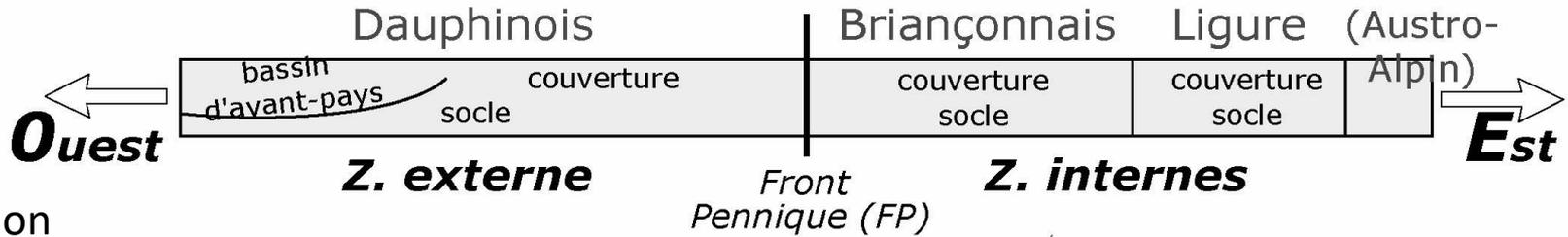
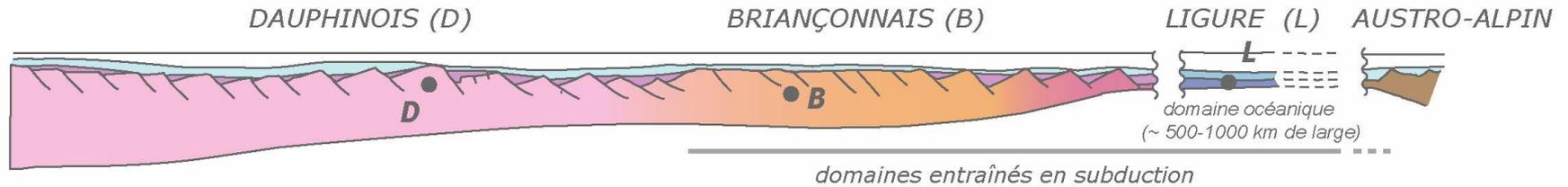
D. Essai de reconstitution paléogéographique



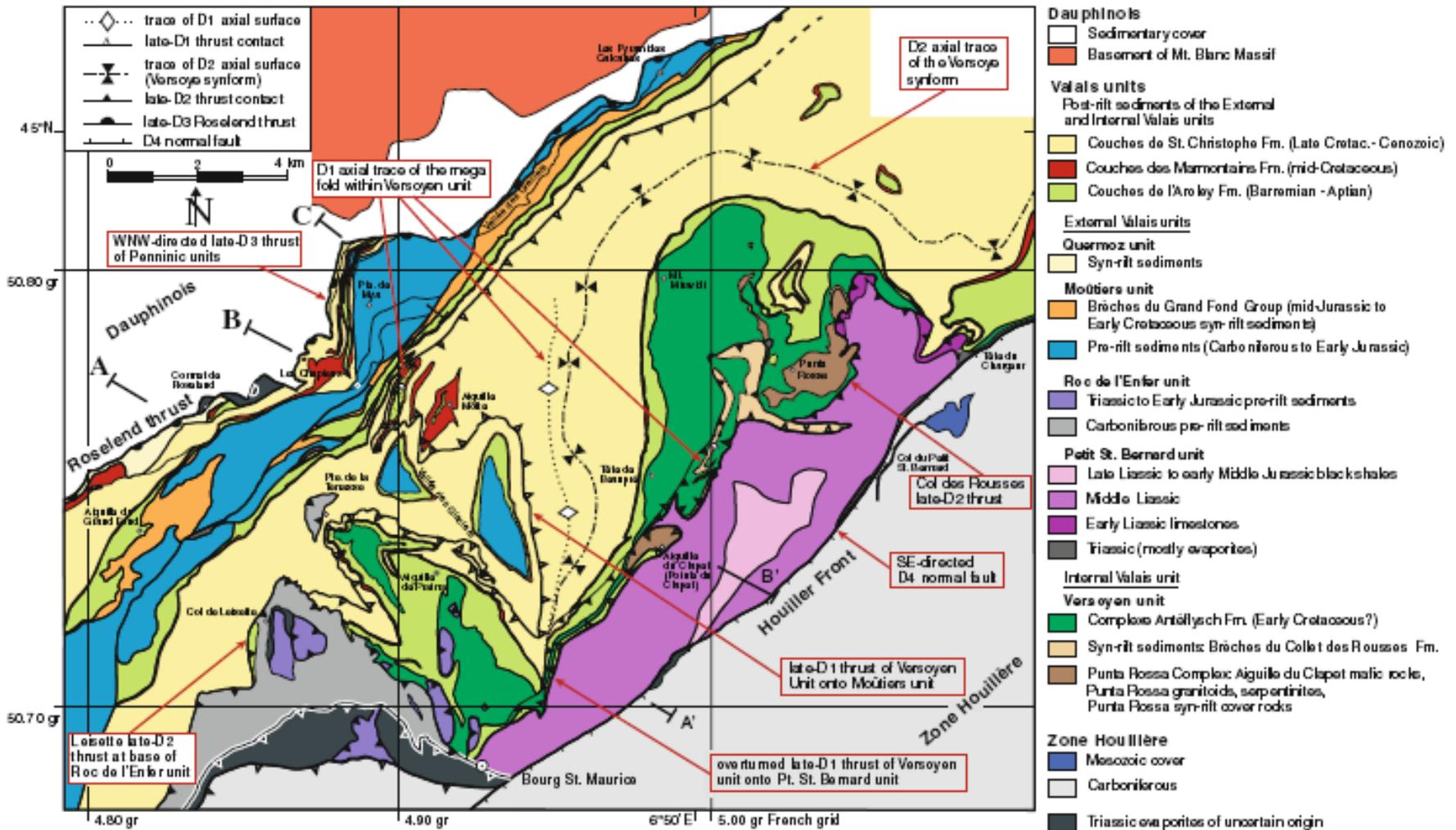
(Agard et Lemoine, 2003)

Un dispositif simple... dans les grandes lignes

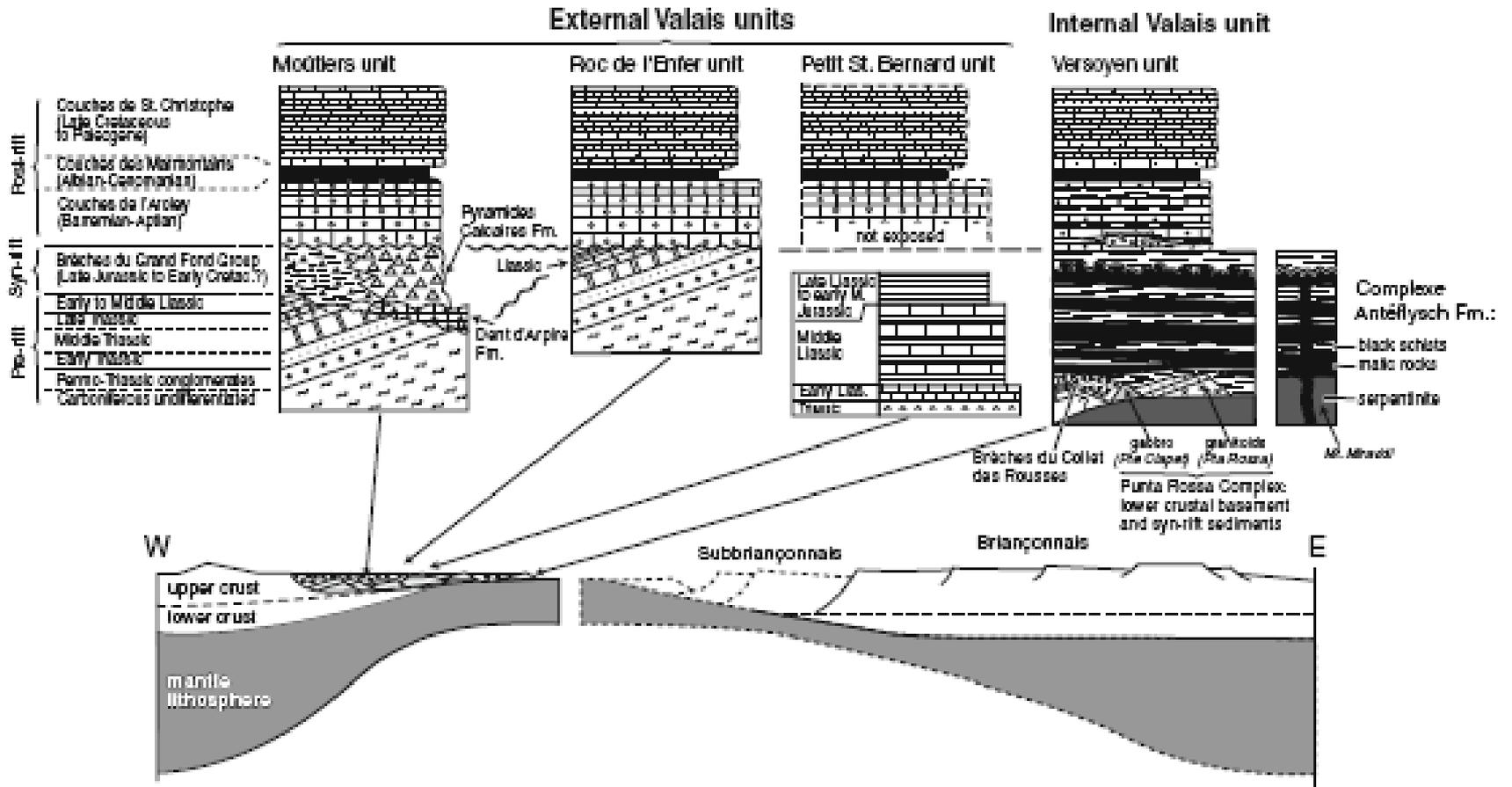
AVANT (~ 120 Millions d'années)



APRES (AUJOURD'HUI)

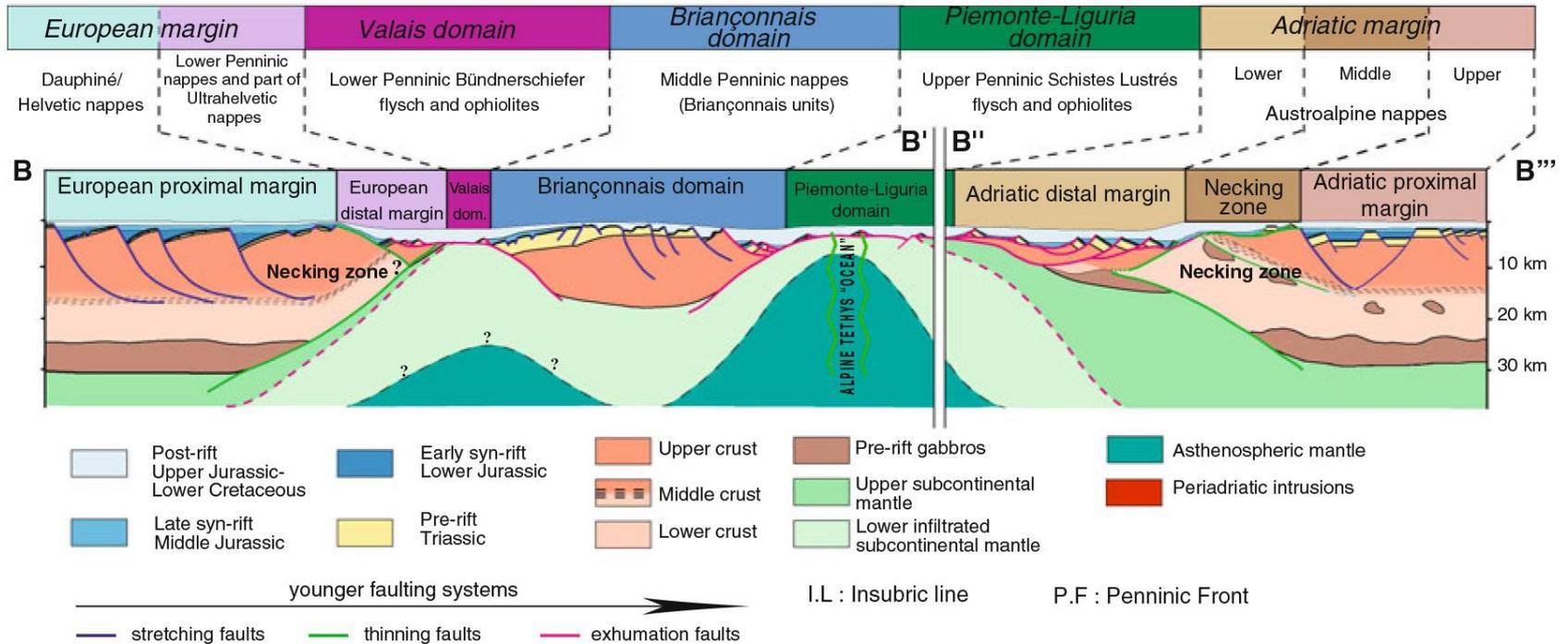
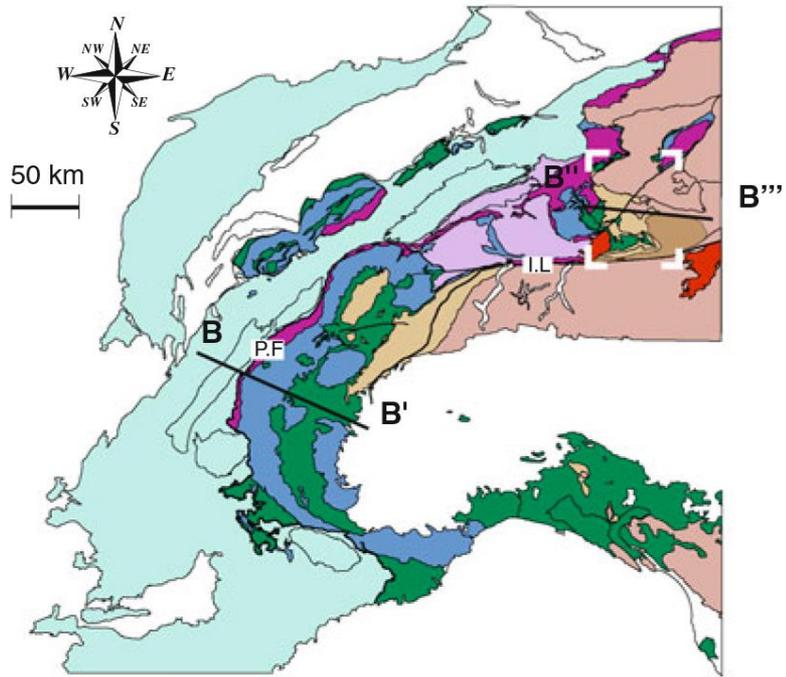


(Loprieno et al., 2011)

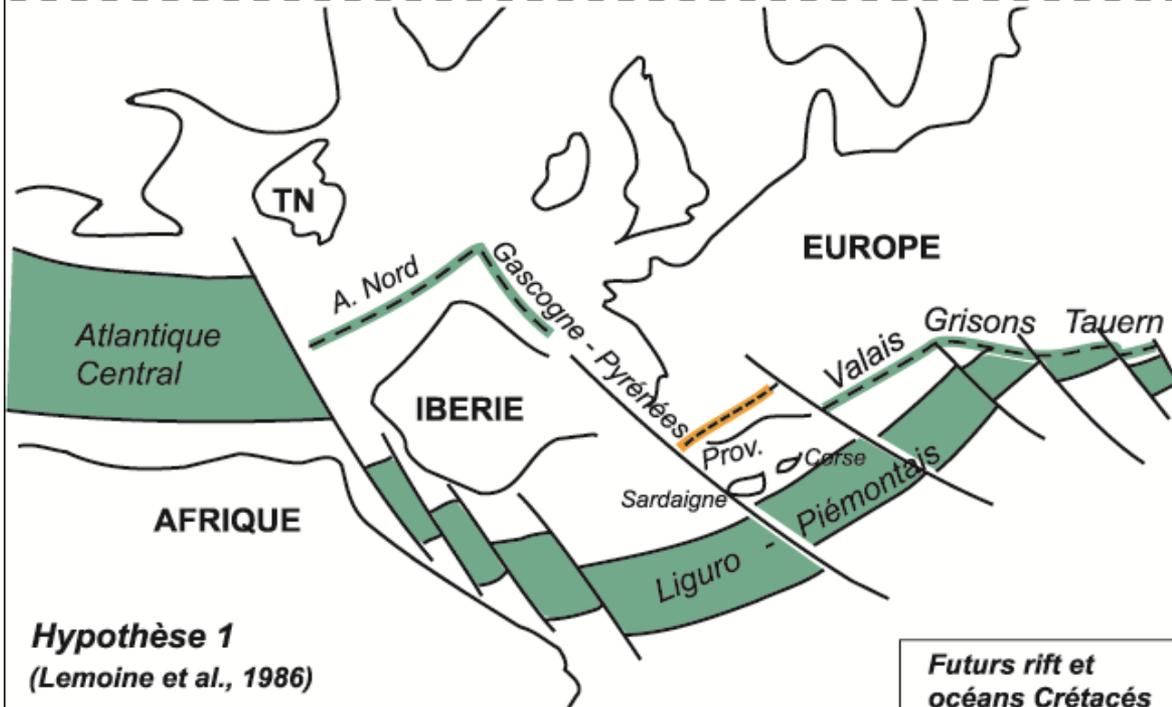


(Loprieno et al., 2011)

(Mohn et al., 2011)



Situation au Jurassique supérieur



Hypothèse 1
(Lemoine et al., 1986)

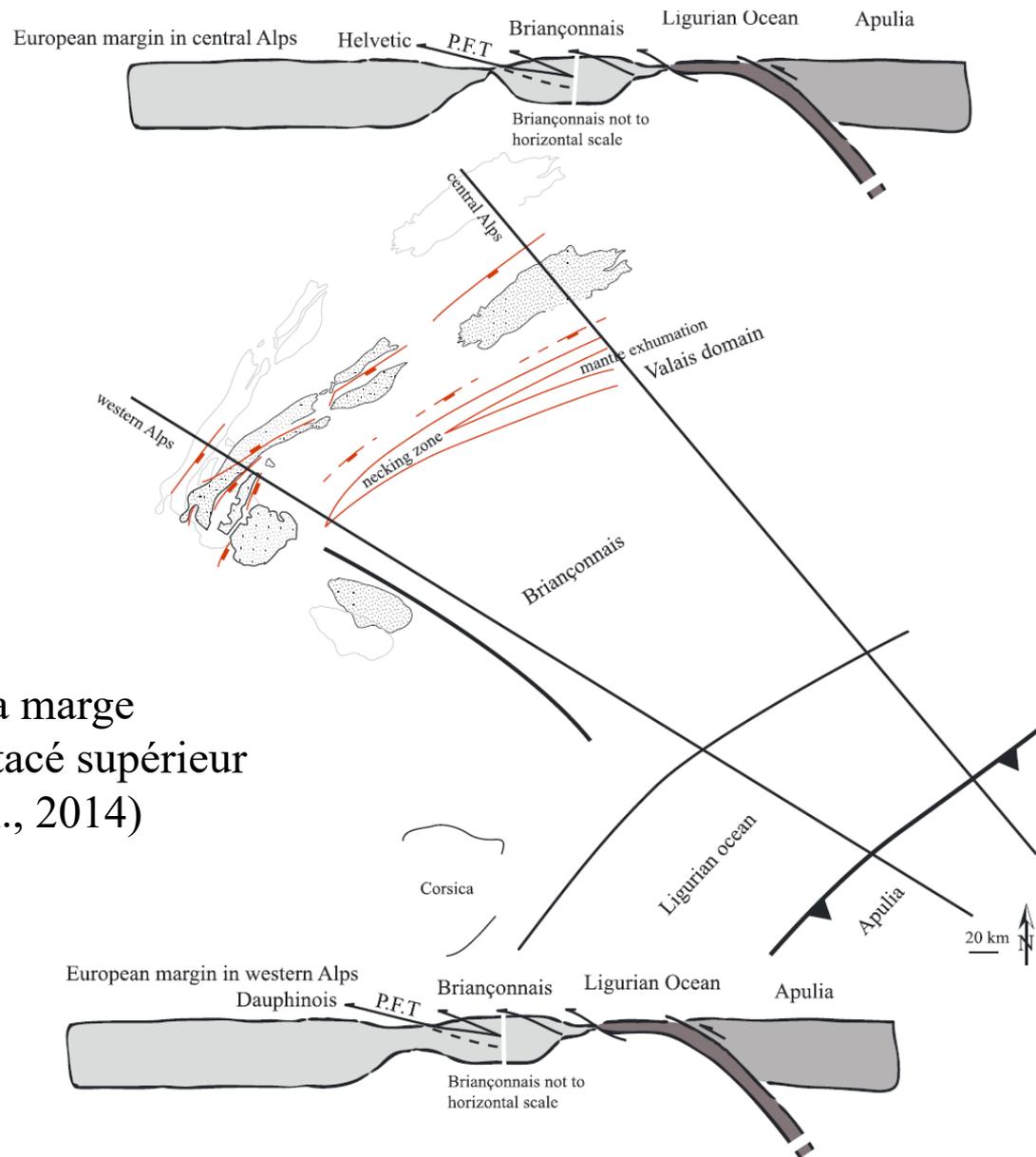
Futurs rift et océans Crétacés
- - - rift océanisé
- - - rift non océanisé

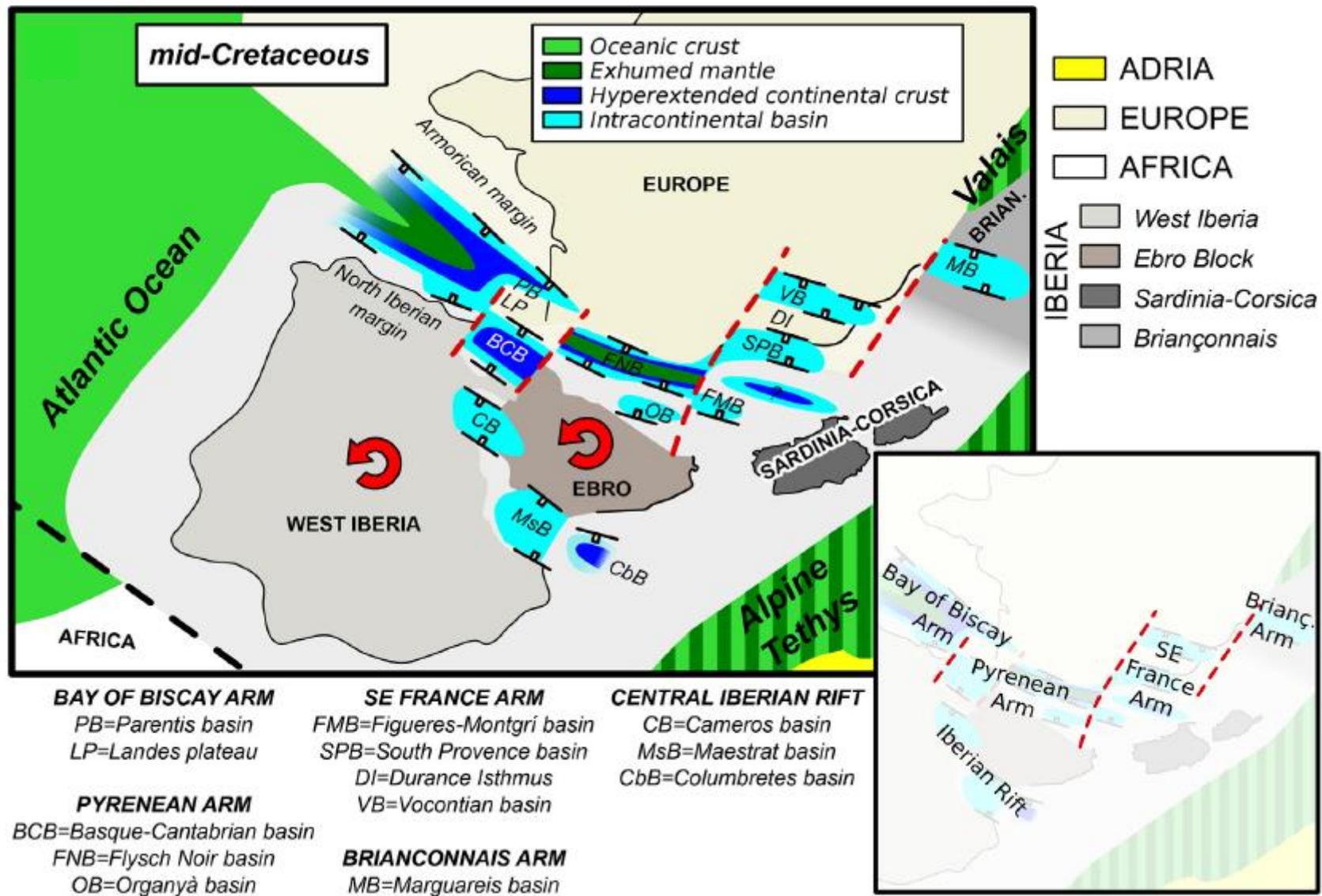


Hypothèse 2
(Stampfli, 1993)

(Agard et Lemoine, 2003)

Géométrie de la marge
européenne au Crétacé supérieur
(Bellahsen et al., 2014)





Collision APULIE - EURASIE

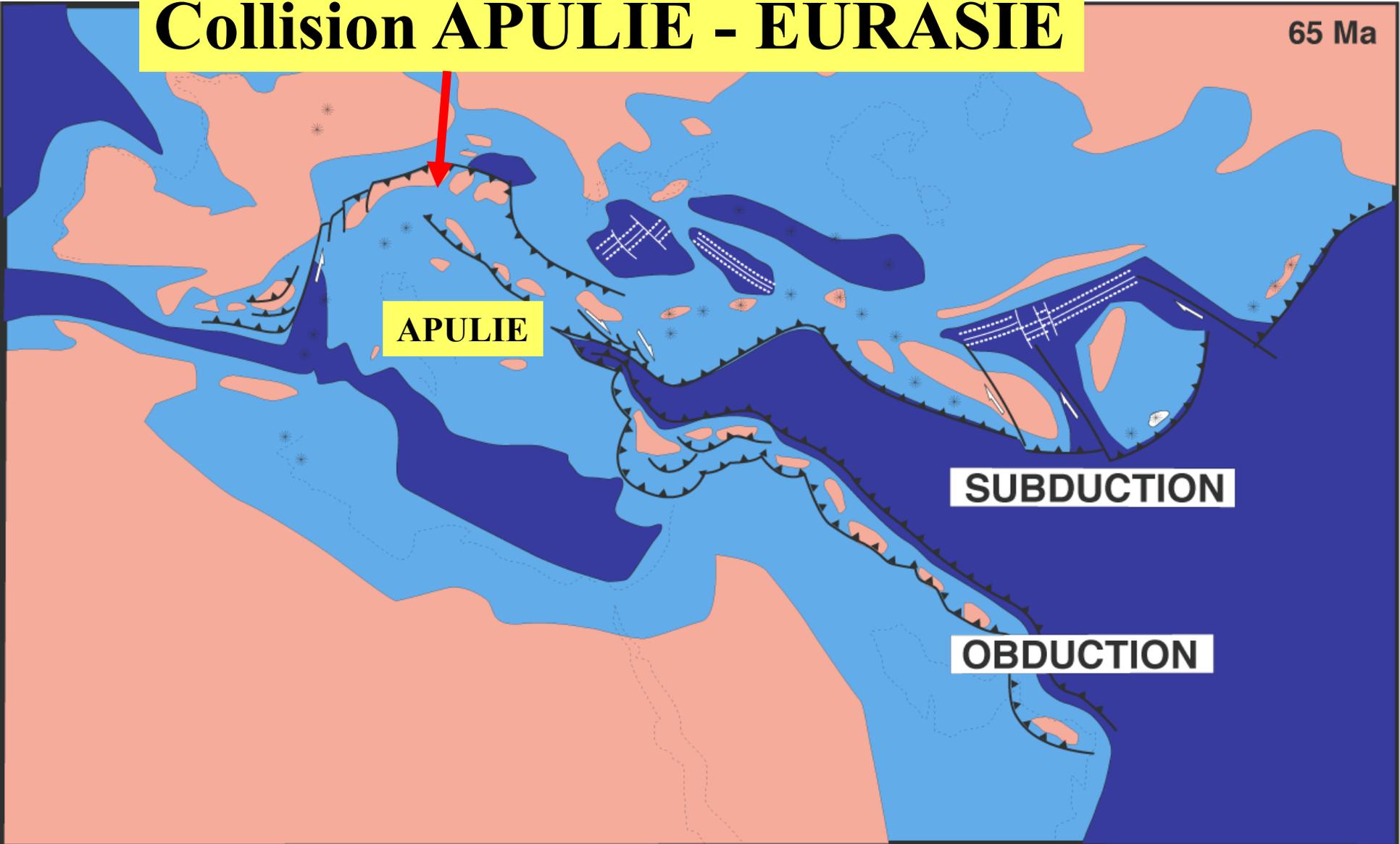
65 Ma

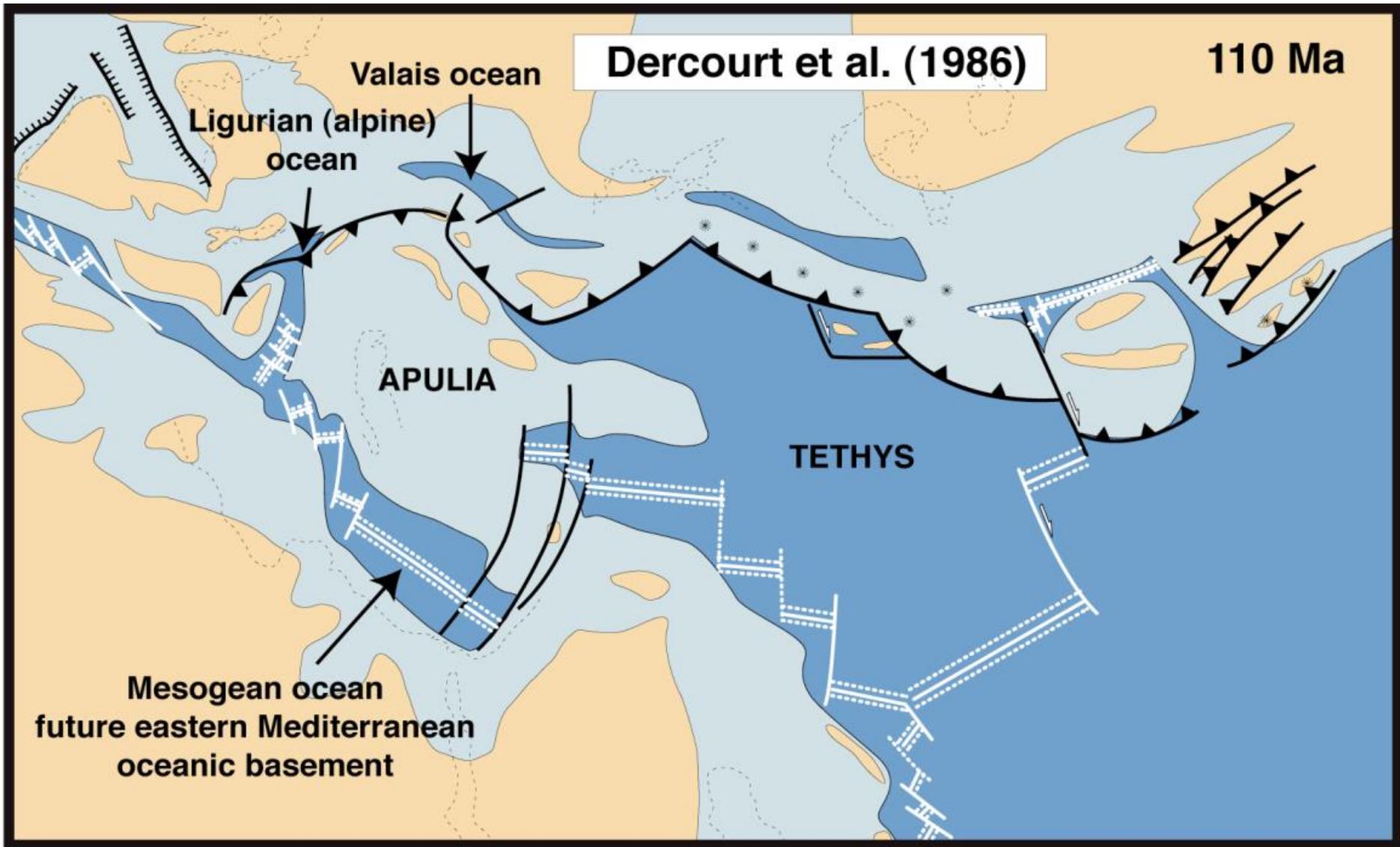
APULIE

SUBDUCTION

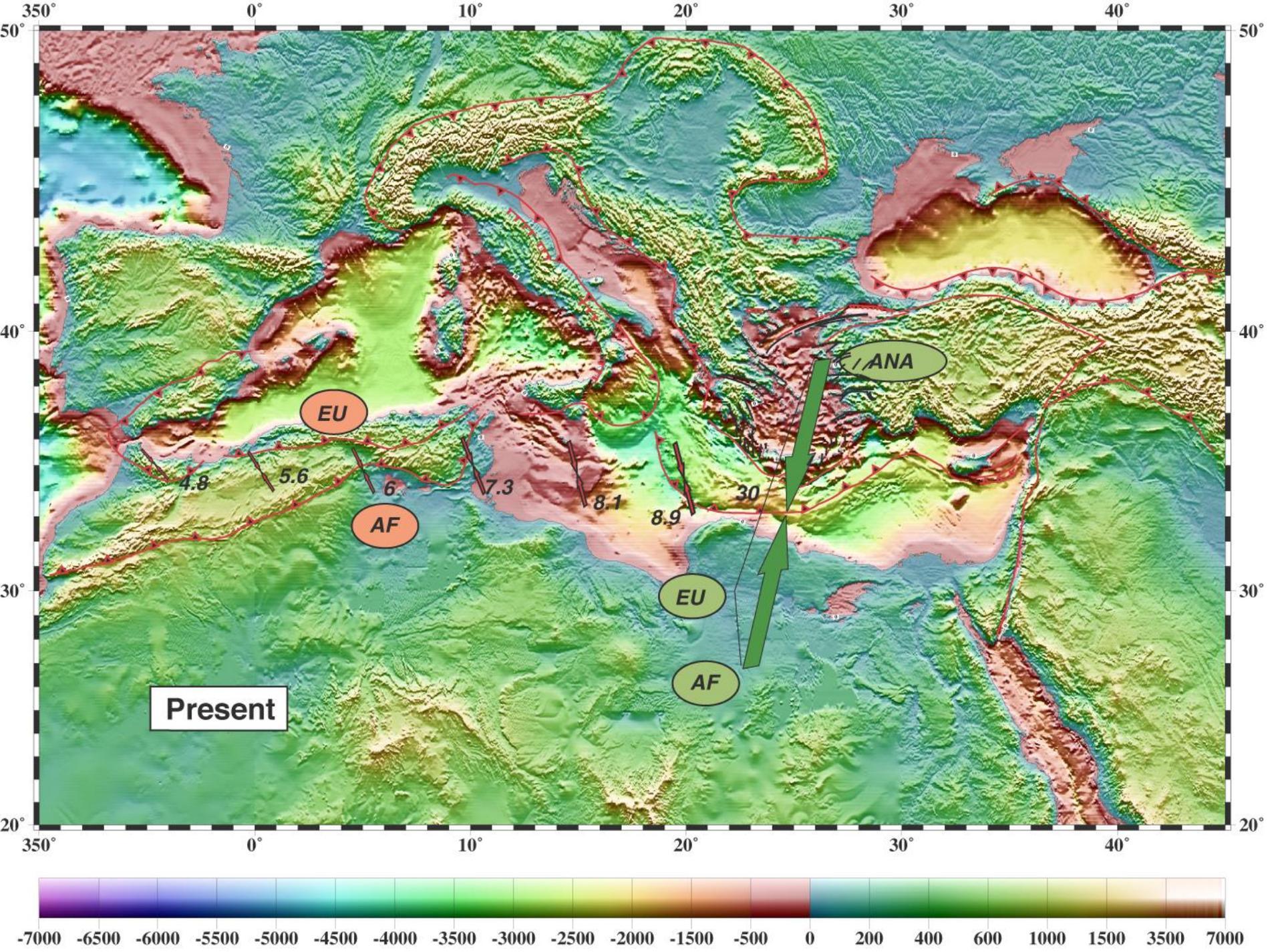
OBDUCTION

Dercourt et al., 1986

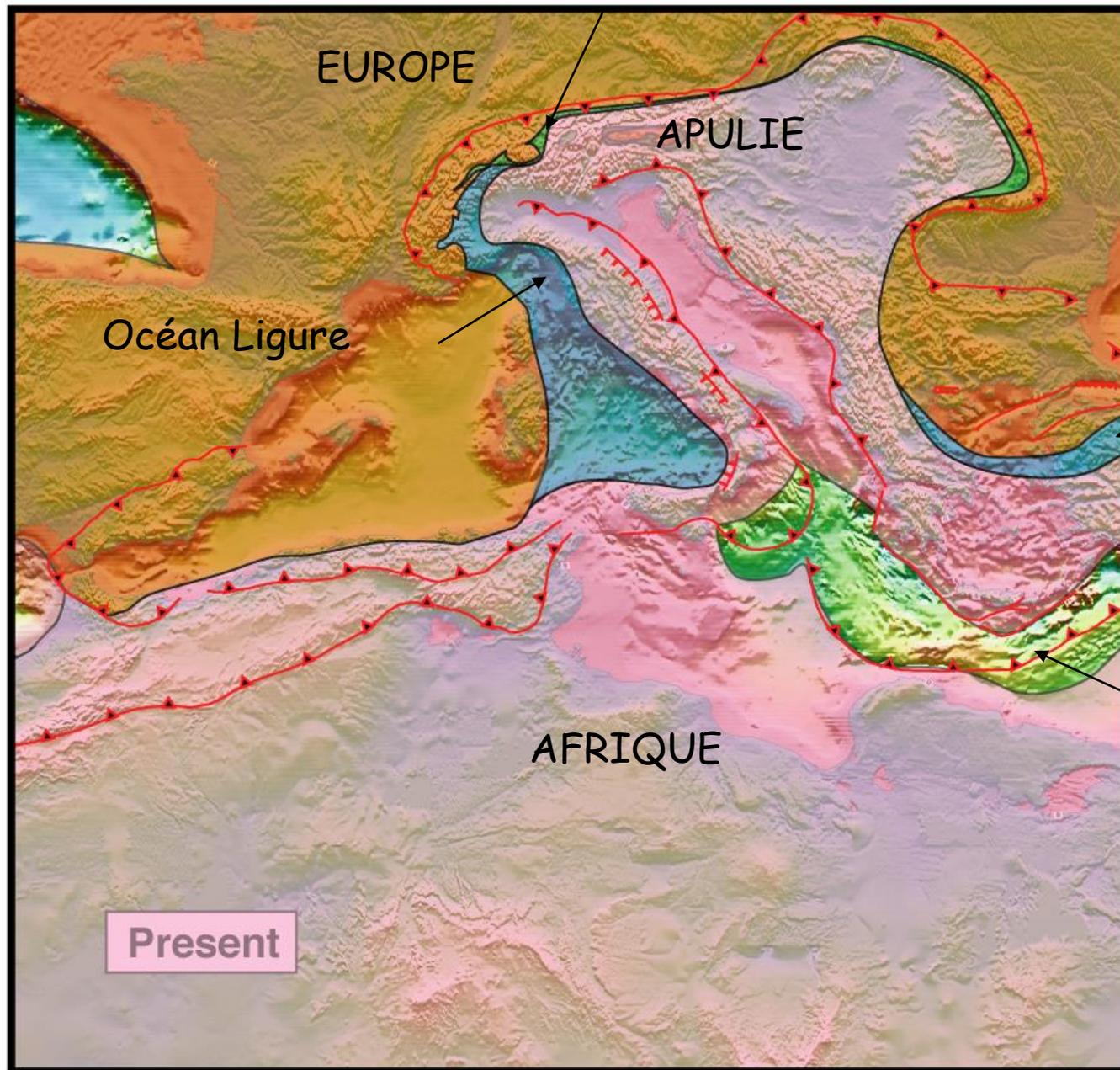




Mésogée : existence récemment remise en cause !!!



Océan Valaisan



EUROPE

APULIE

Océan Ligure

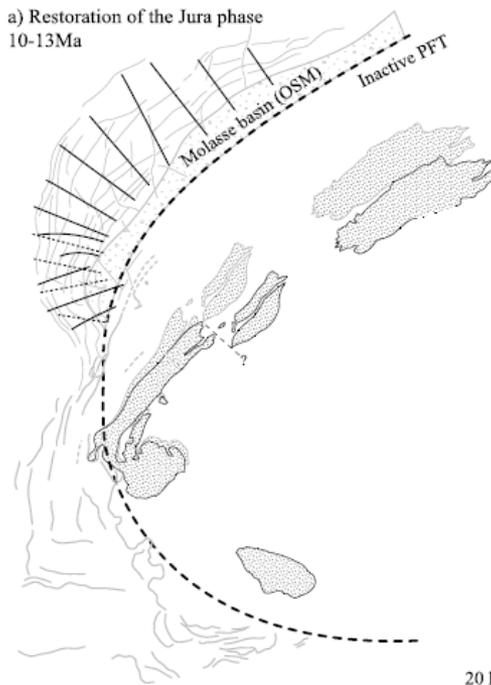
Téthys

AFRIQUE

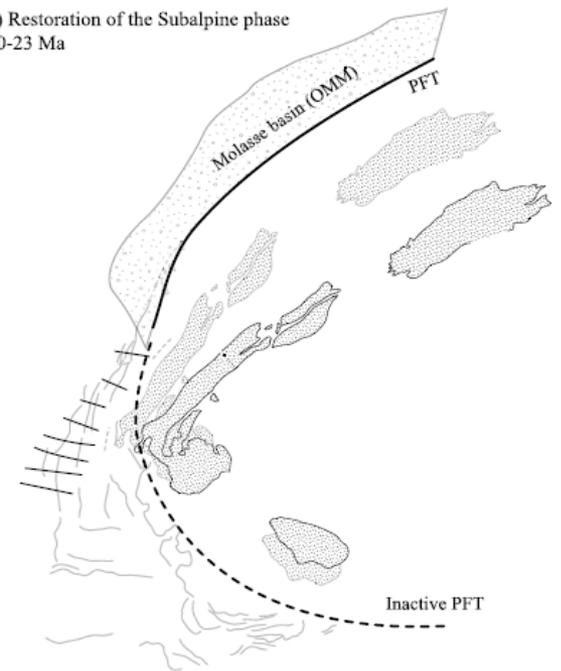
Mésogée (?)

Present

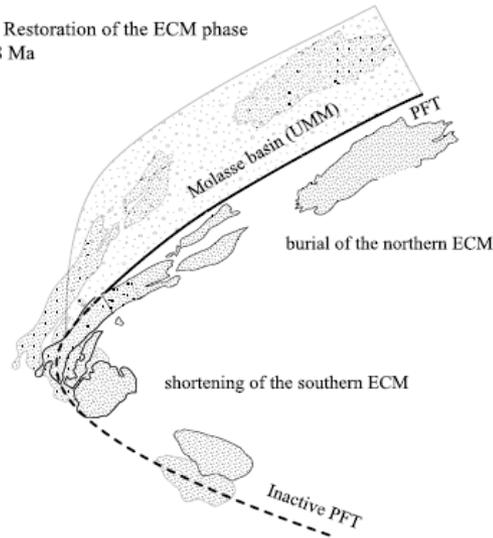
a) Restoration of the Jura phase
10-13Ma



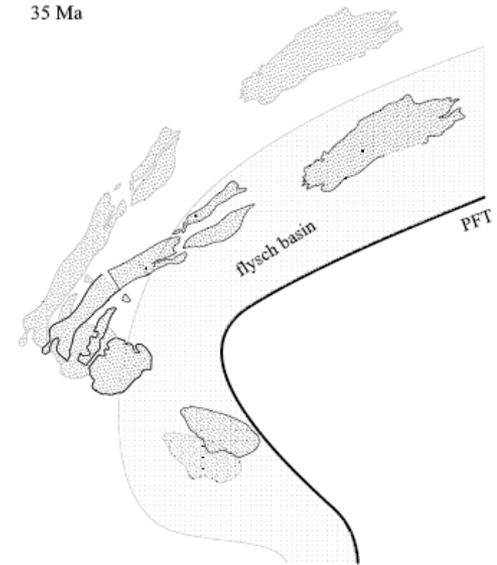
b) Restoration of the Subalpine phase
20-23 Ma



c) Restoration of the ECM phase
28 Ma



d) Restoration at the flysch basin time
35 Ma

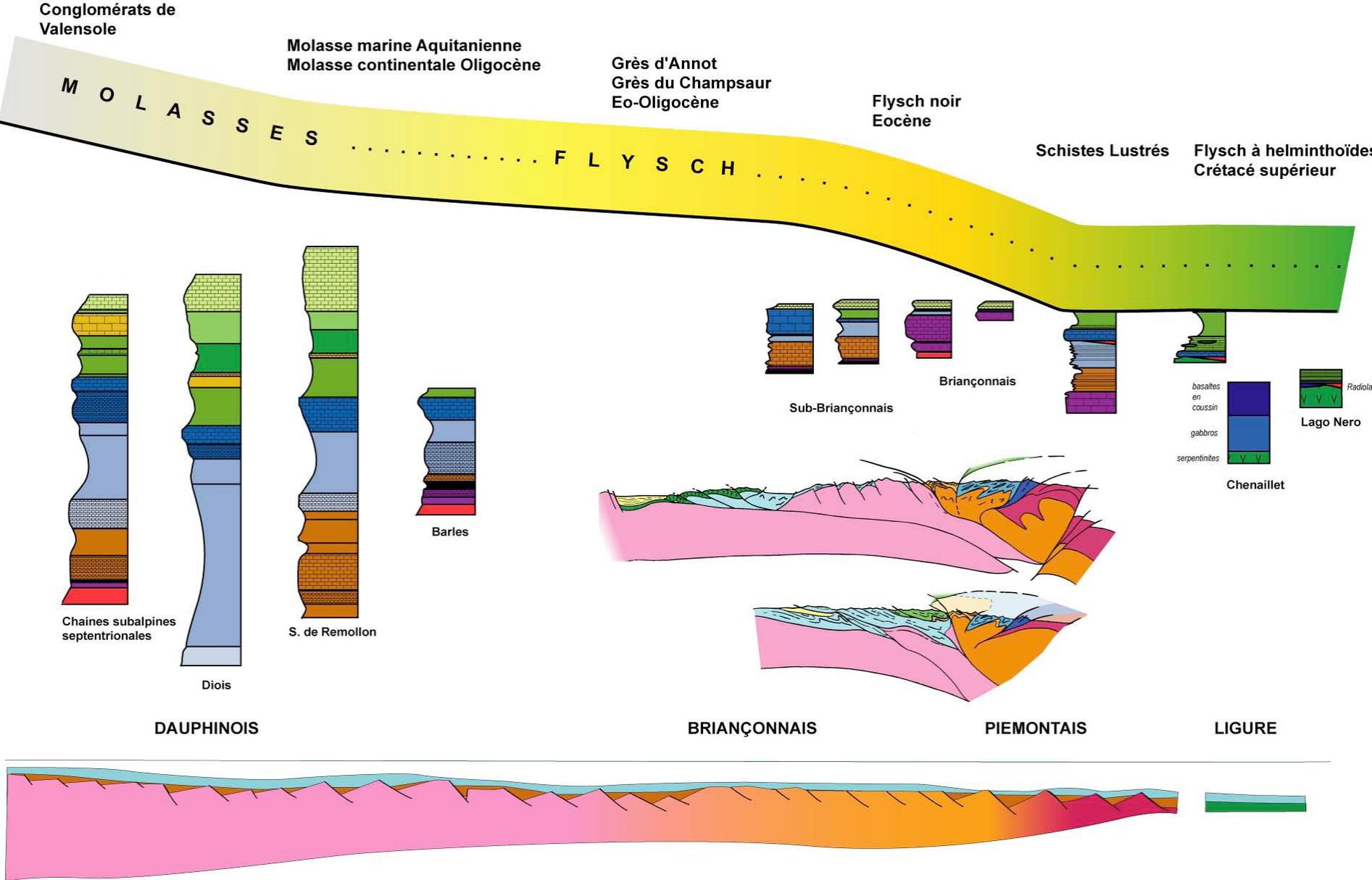


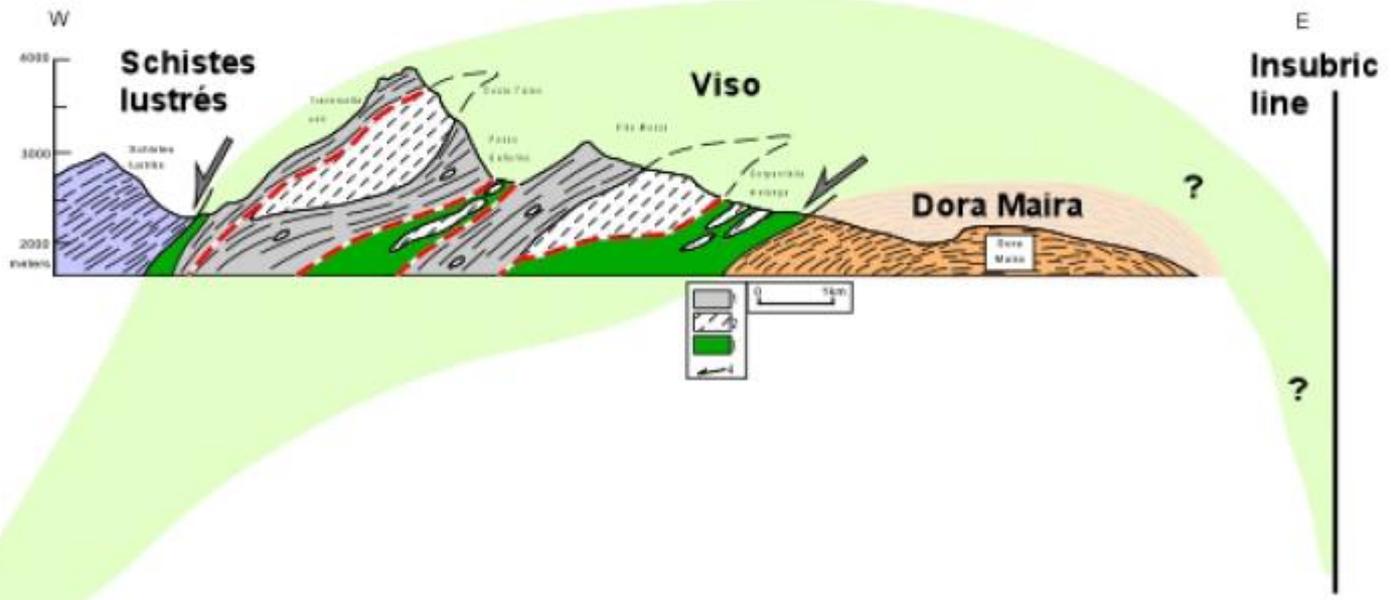
Reconstitution palinspastique
des structures dauphinoises
depuis 35 Ma (Bellahsen et al., 2014)

III. Calendrier et modèle d'évolution
des Alpes franco-italiennes; évolution récente;
réflexion sur la structure :

III. Calendrier et modèle d'évolution des Alpes franco-italiennes; évolution récente; réflexion sur la structure.

A. Calendrier et modèle d'évolution





Bilan :

Les indices de rifting et d'océanisation dans les Alpes occidentales :

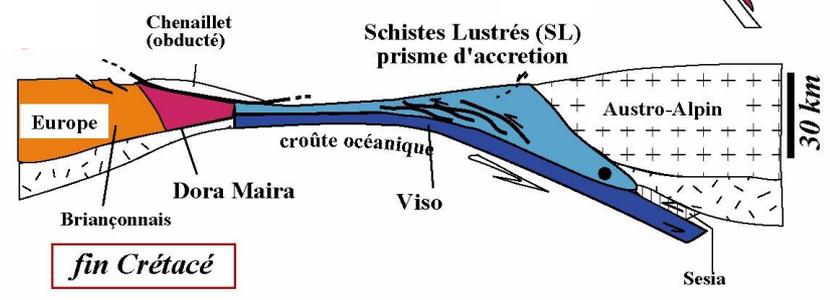
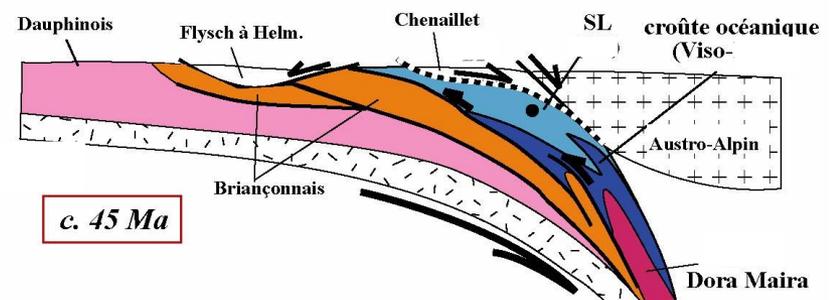
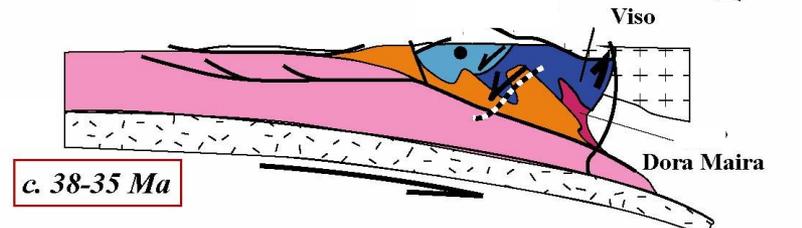
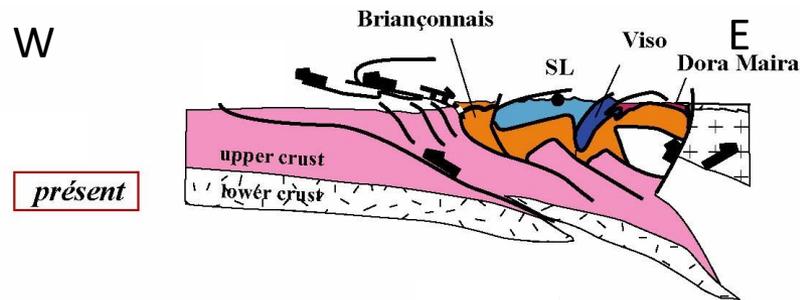
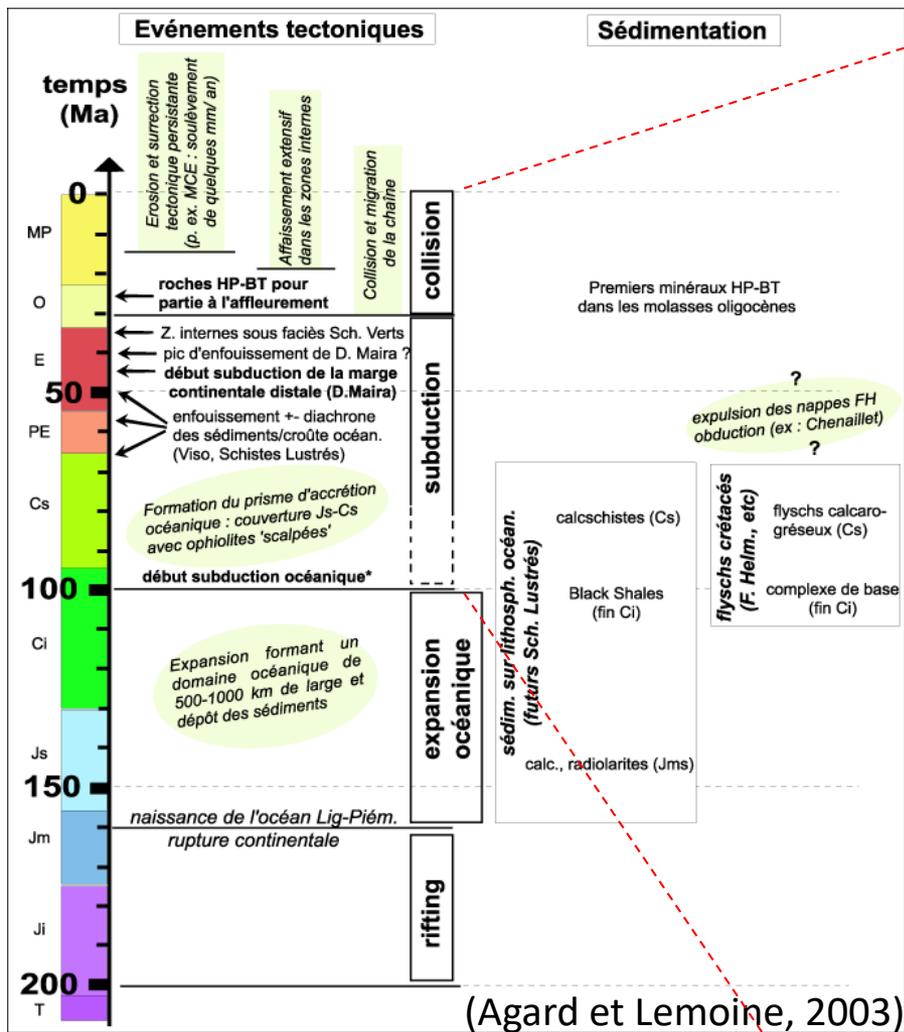
- les failles normales (Jurassique inférieur, 200-170 Ma)
- les ophiolites (Jurassique supérieur, Crétacé inférieur (170-100 Ma)
- les roches sédimentaires déposées en milieu profond (radiolarites)

Les indices de subduction océanique et continentale dans les Alpes occidentales :

- le Flysch à Helminthoïdes (Crétacé supérieur, ~80Ma) déposé dans une fosse océanique au Crétacé supérieur et accrété en un prisme d'accrétion
- le métamorphisme HP-BT (Paléocène –Eocène, 70-35 Ma) dans les zones internes

Les indices de collision continentale dans les Alpes occidentales :

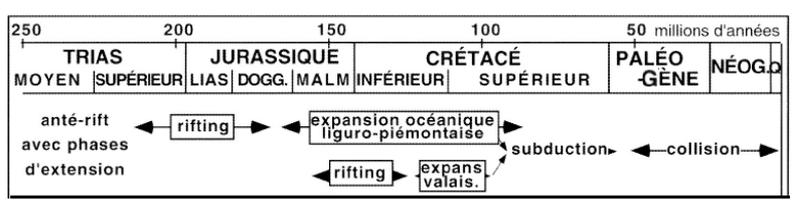
- la transition flysch –molasse dans le Dauphinois et la formation des épais bassins molassiques (Oligocène-Miocène, ~34-35 Ma)
- les grands chevauchements, l'épaississement crustal et la genèse des reliefs dès l'Oligocène (~35Ma)
- le métamorphisme MP-MT (Oligocène, 33-23 Ma) dans les Massifs Cristallins Externes (Dauphinois interne)



COLLISION

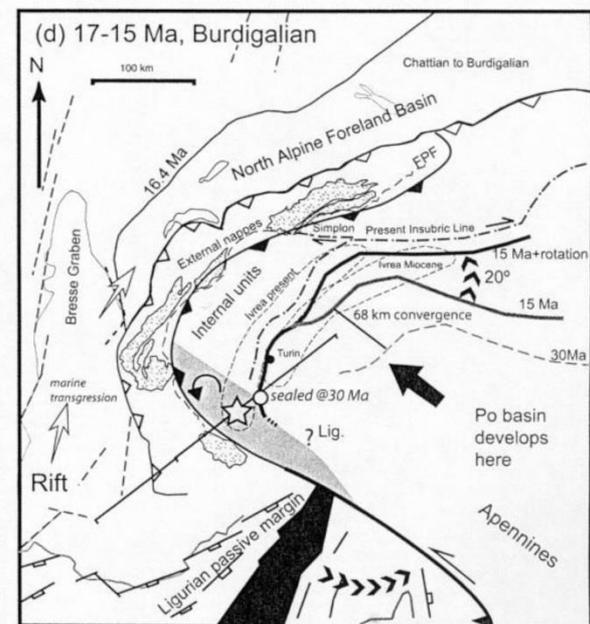
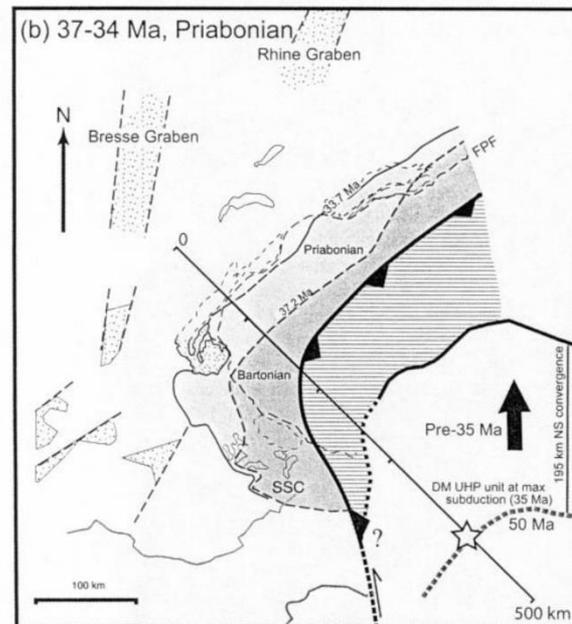
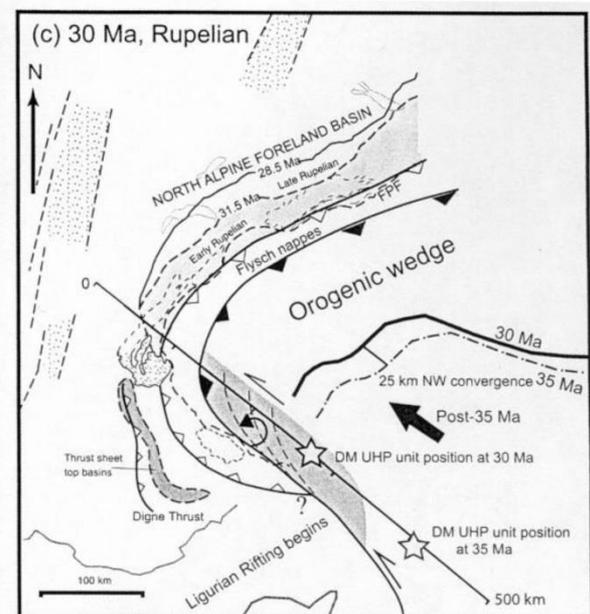
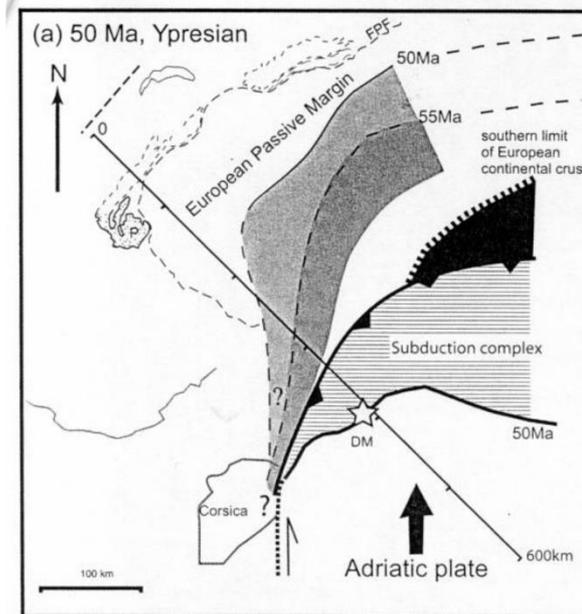
SUBDUCTION CONTINENTALE

SUBDUCTION OCEANIQUE



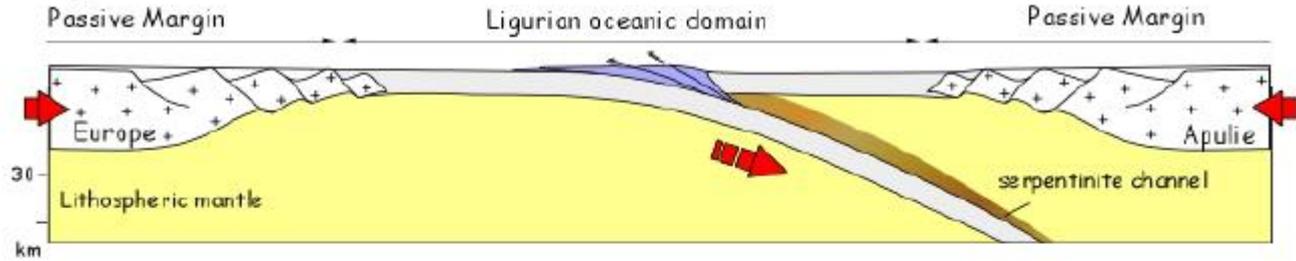
Lemoine (2000)

(D'après Jolivet)

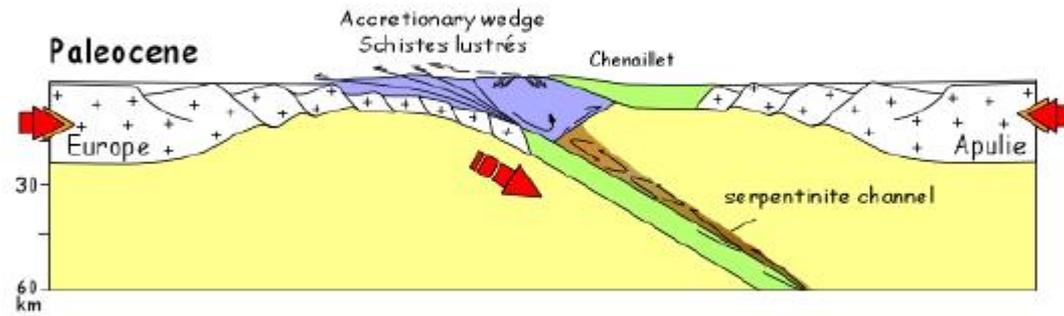


(Ford et al. , 2006)

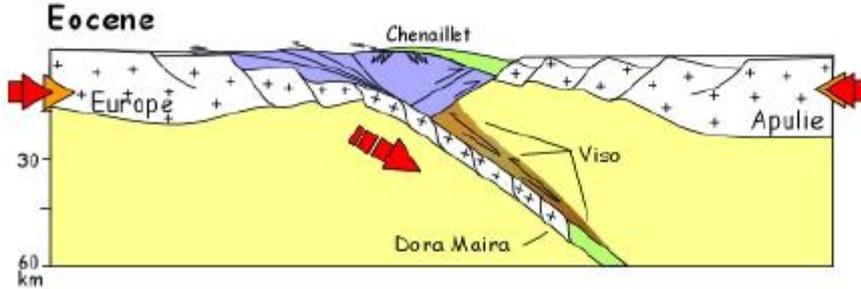
Upper Cretaceous

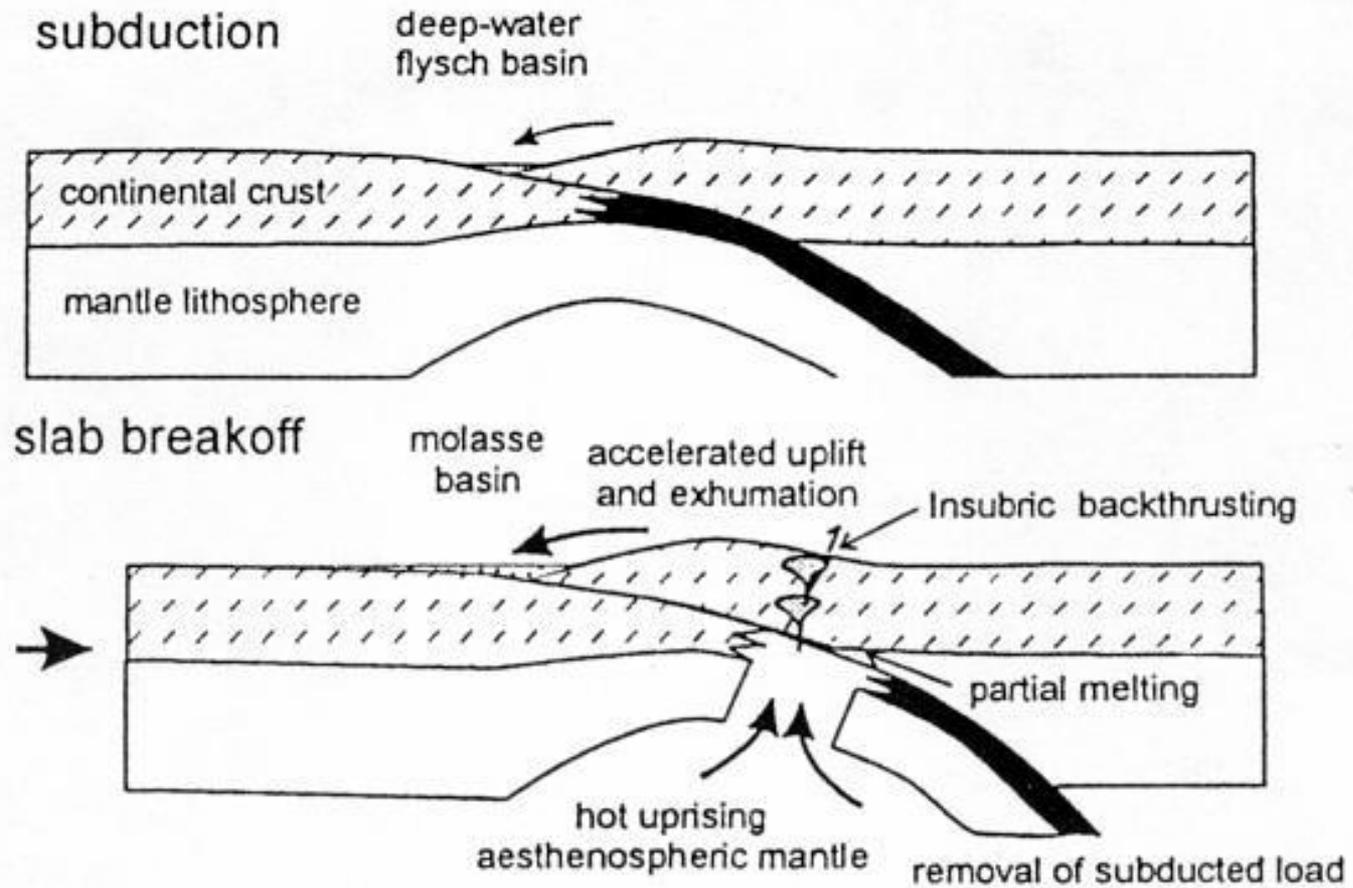


Paleocene

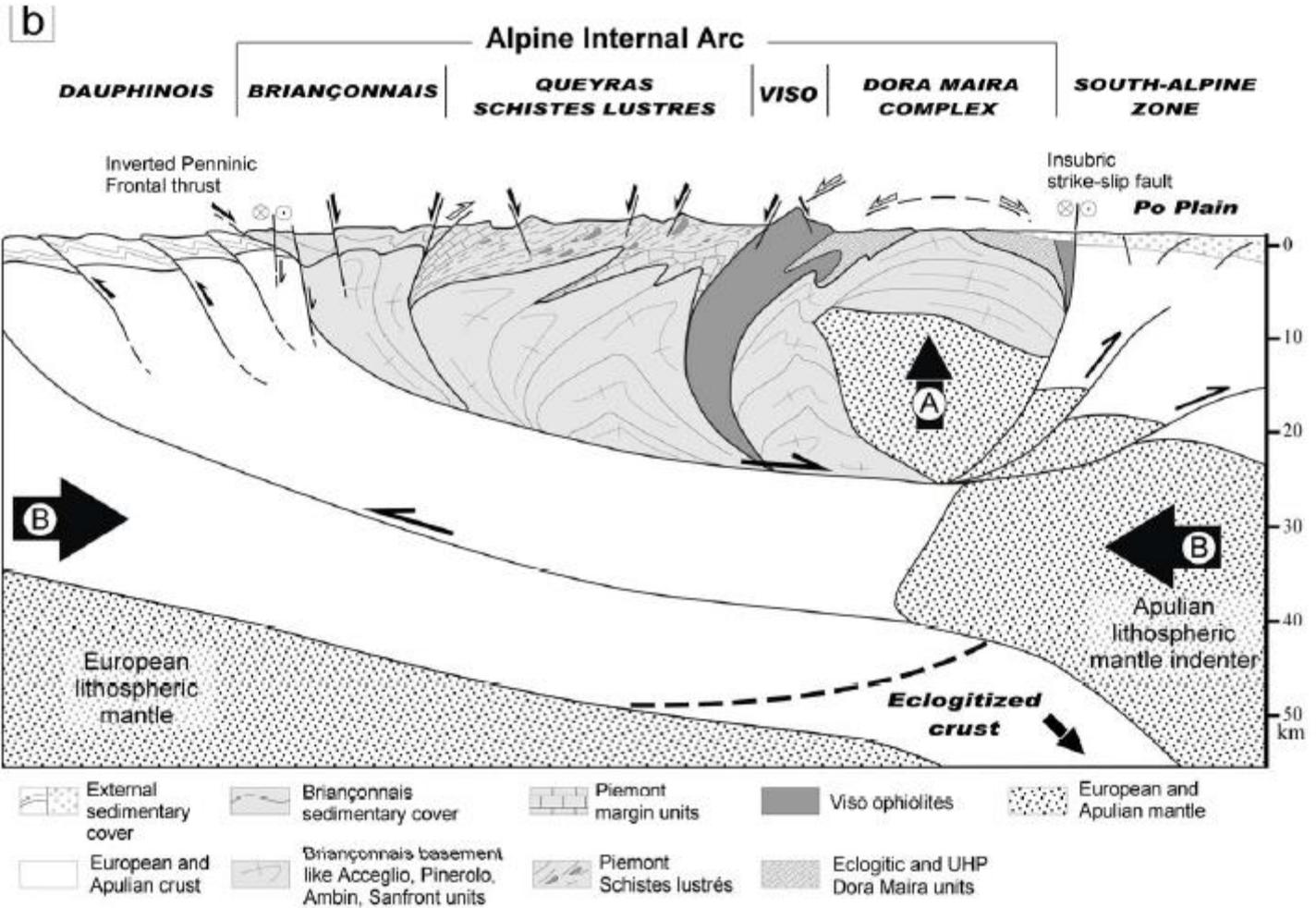


Eocene



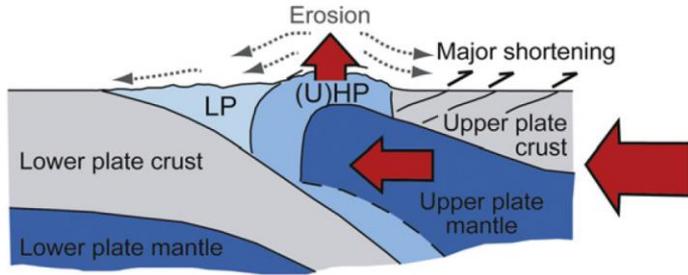


(D'après Sinclair)



(Lardeaux et al., 2006)

SYNCONVERGENT (U)HP ROCK EXHUMATION FOLLOWED BY UPPER-PLATE MANTLE INDENTATION



(U)HP ROCK AND MANTLE WEDGE EXHUMATION TRIGGERED BY UPPER PLATE DIVERGENT MOTION

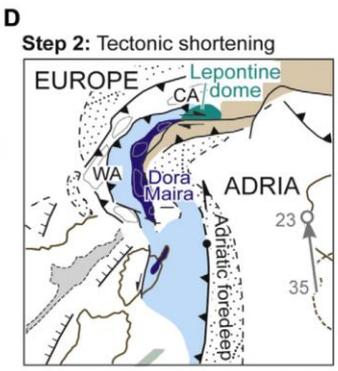
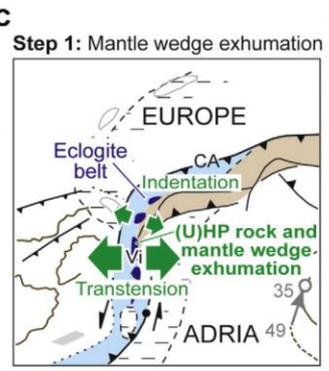
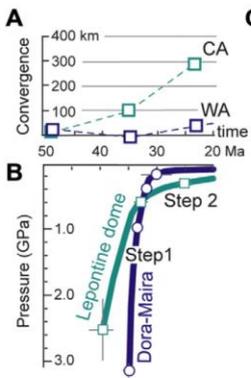
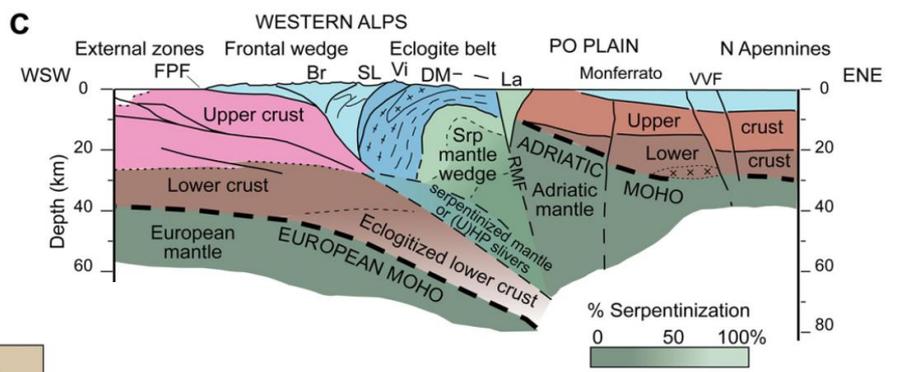
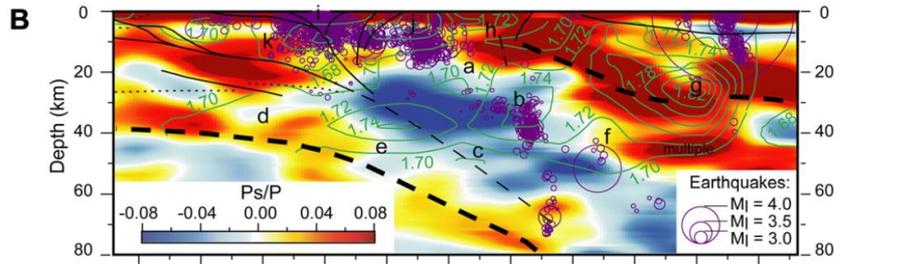
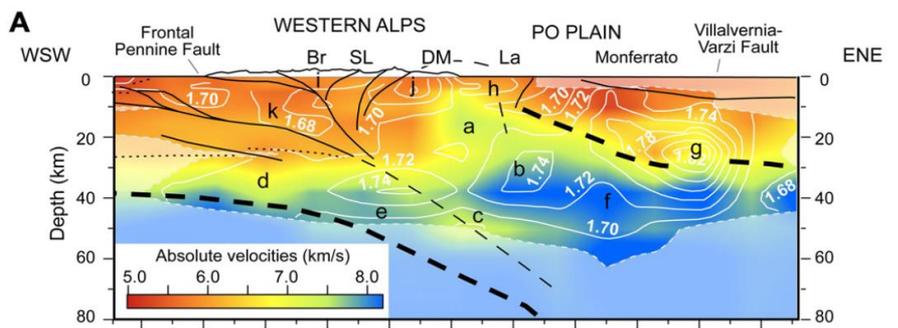
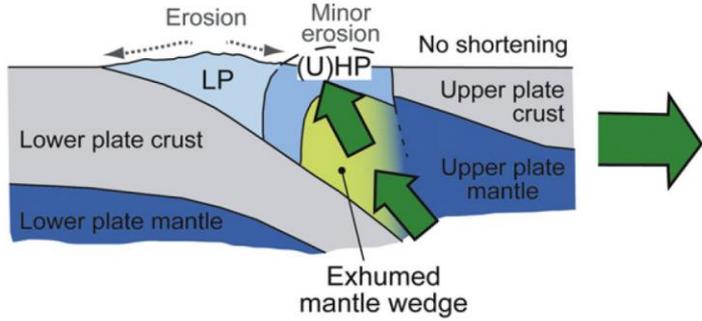
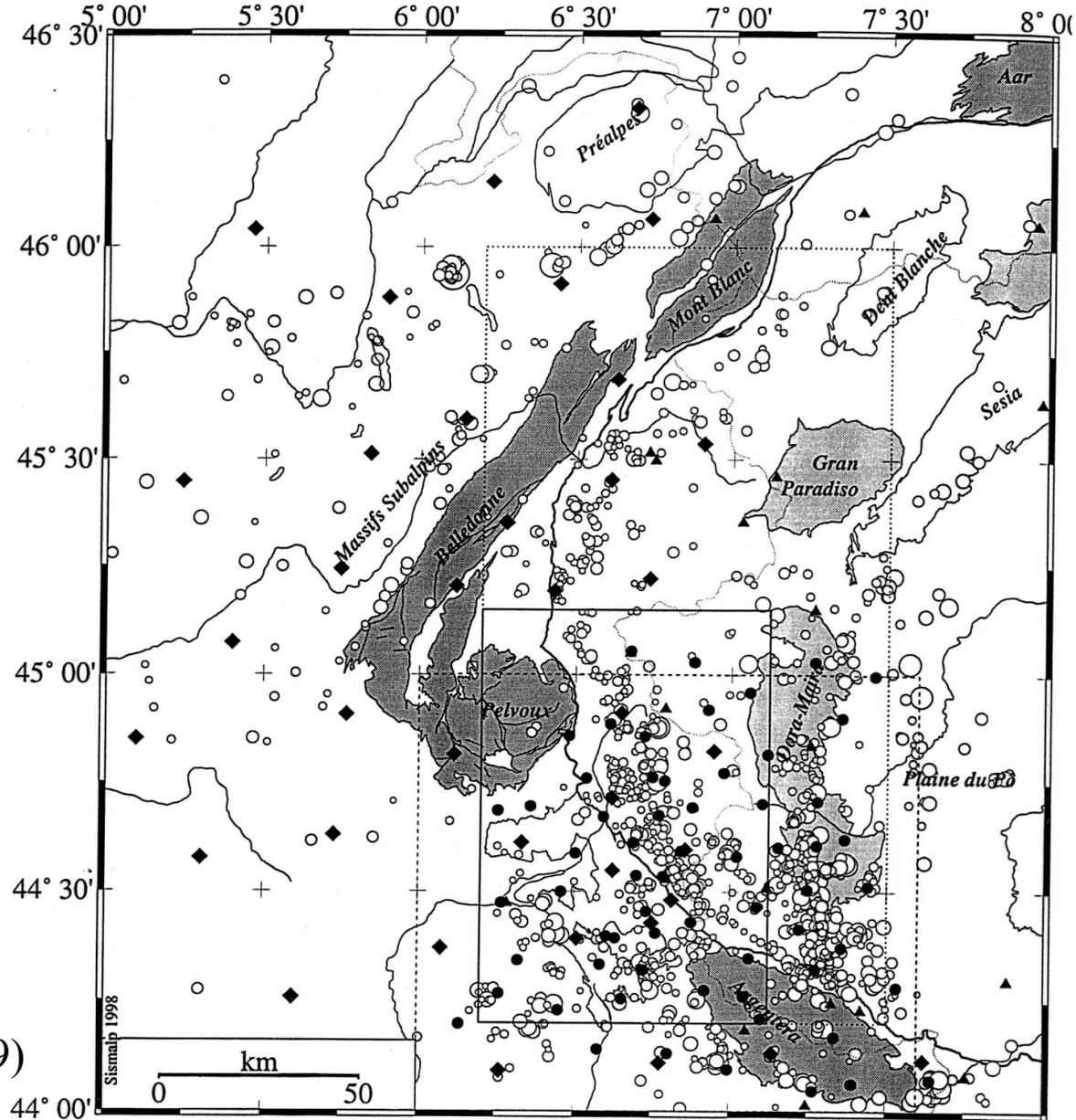


Fig. 8. Geodynamic framework of mantle wedge exhumation. A) Trench-normal component of Adria-Europe relative motion in the Central (CA) and Western Alps (WA) segments of the Alpine subduction zone (Malusà et al., 2015). B) Pressure-time exhumation paths (Dora-Maira: Chopin et al., 1991; Rubatto and Hermann, 2001; Lepontine dome: Becker, 1993; Gebauer, 1996; Brouwer et al., 2004; Nagel, 2008). C,D) Late Eocene transtension leading to (U)HP rock and mantle wedge exhumation, and subsequent tectonic shortening in the early Oligocene; grey arrows indicate Adria motion relative to Europe (modified after Malusà et al., 2015).

(Solarino et al., 2018)

III. Calendrier et modèle d'évolution
des Alpes franco-italiennes; évolution récente;
réflexion sur la structure.

B. Evolution récente



(Sue et al., 1999)

Figure 3.7 - Localisation des réseaux Sismalp (losanges noirs), IGG (triangles noirs) et GéoFrance3D (disques noirs) dans l'arc alpin occidental, sur fond de sismicité instrumentale (Sismalp).
 Cadre plein : zone cible (chapitre III-2) ; cadre pointillé : zone élargie étudiée dans le chapitre III-3 ;
 cadre tireté : zone GéoFrance3D.

(Sue et al., 1999)

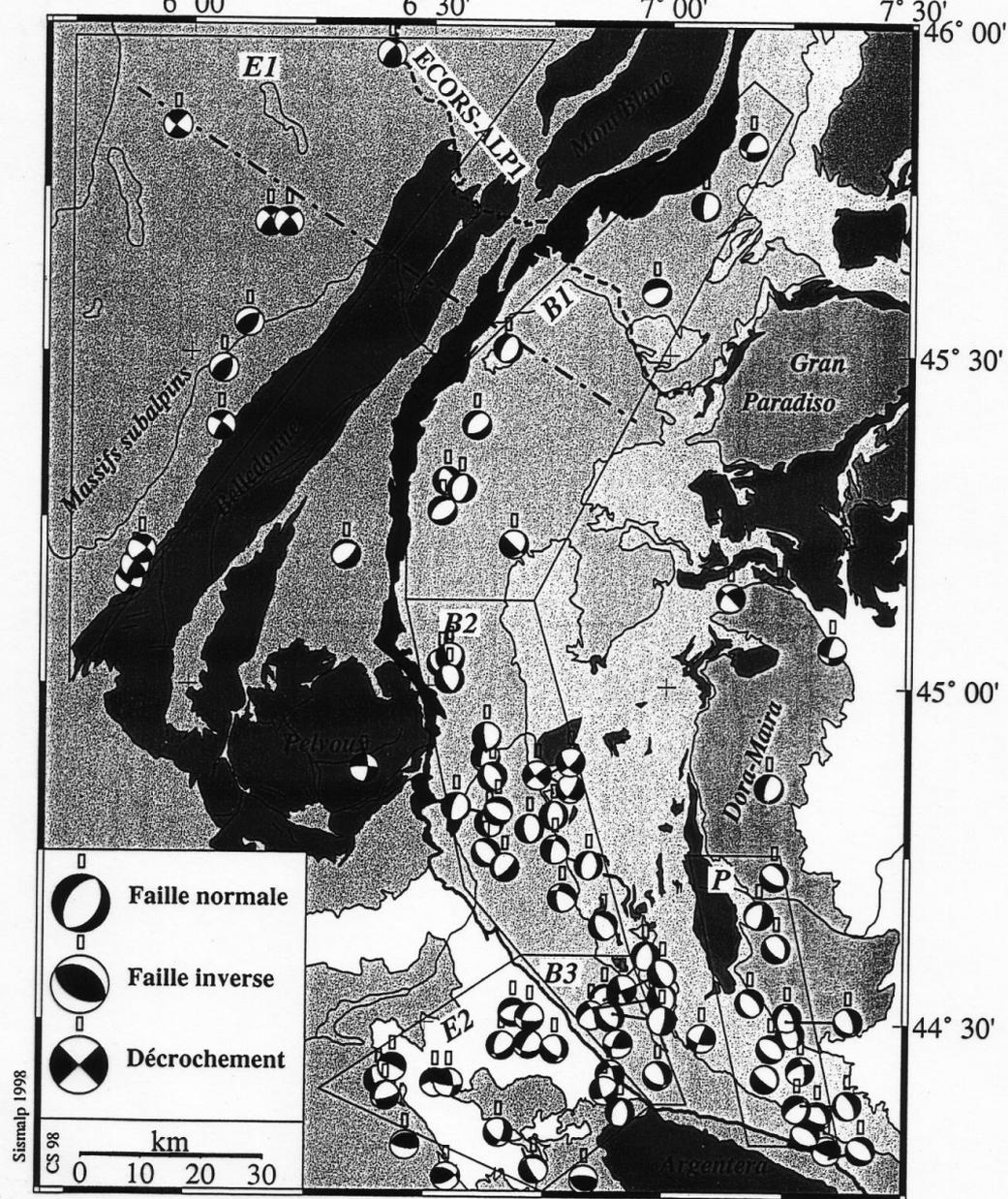
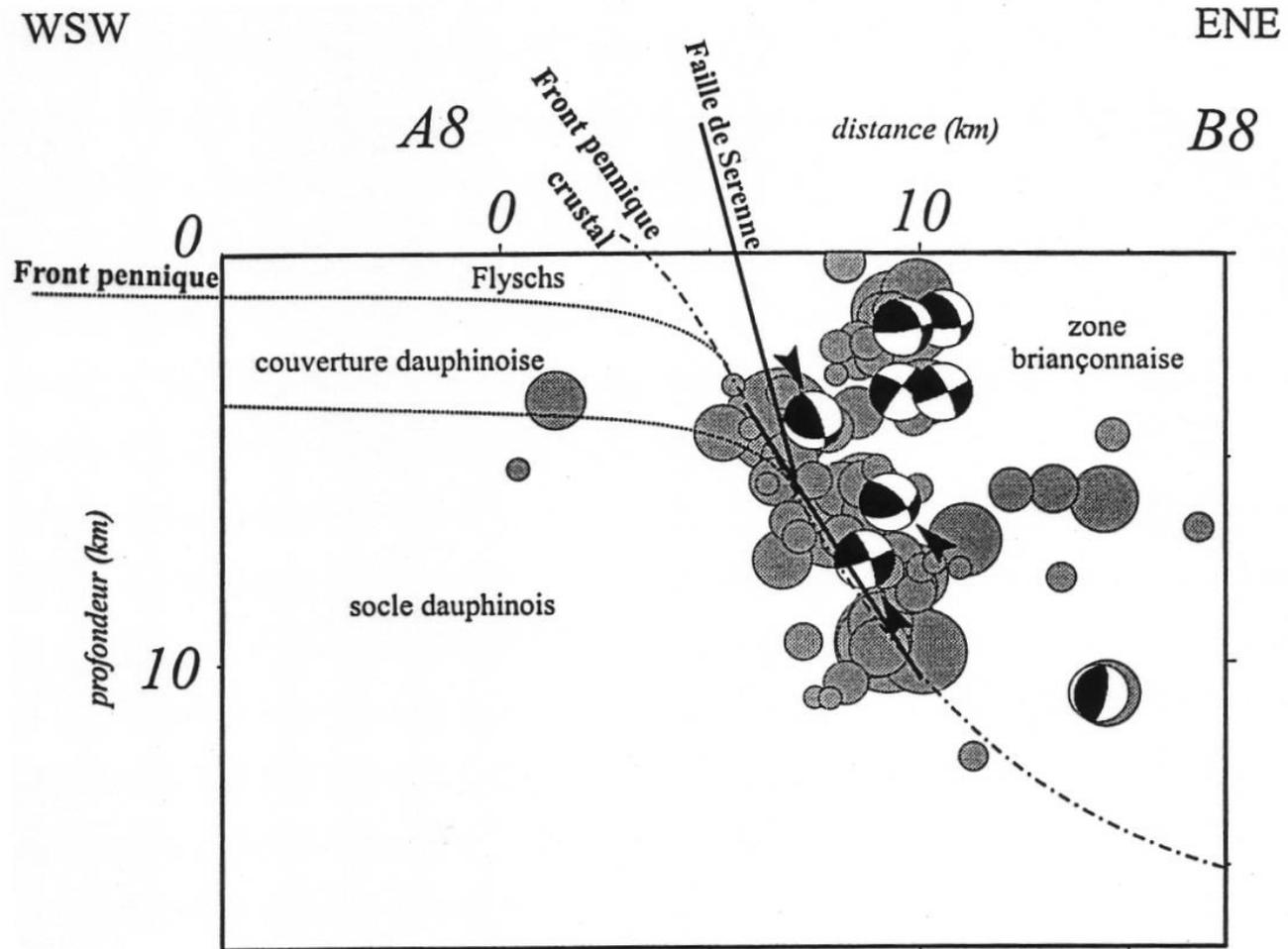
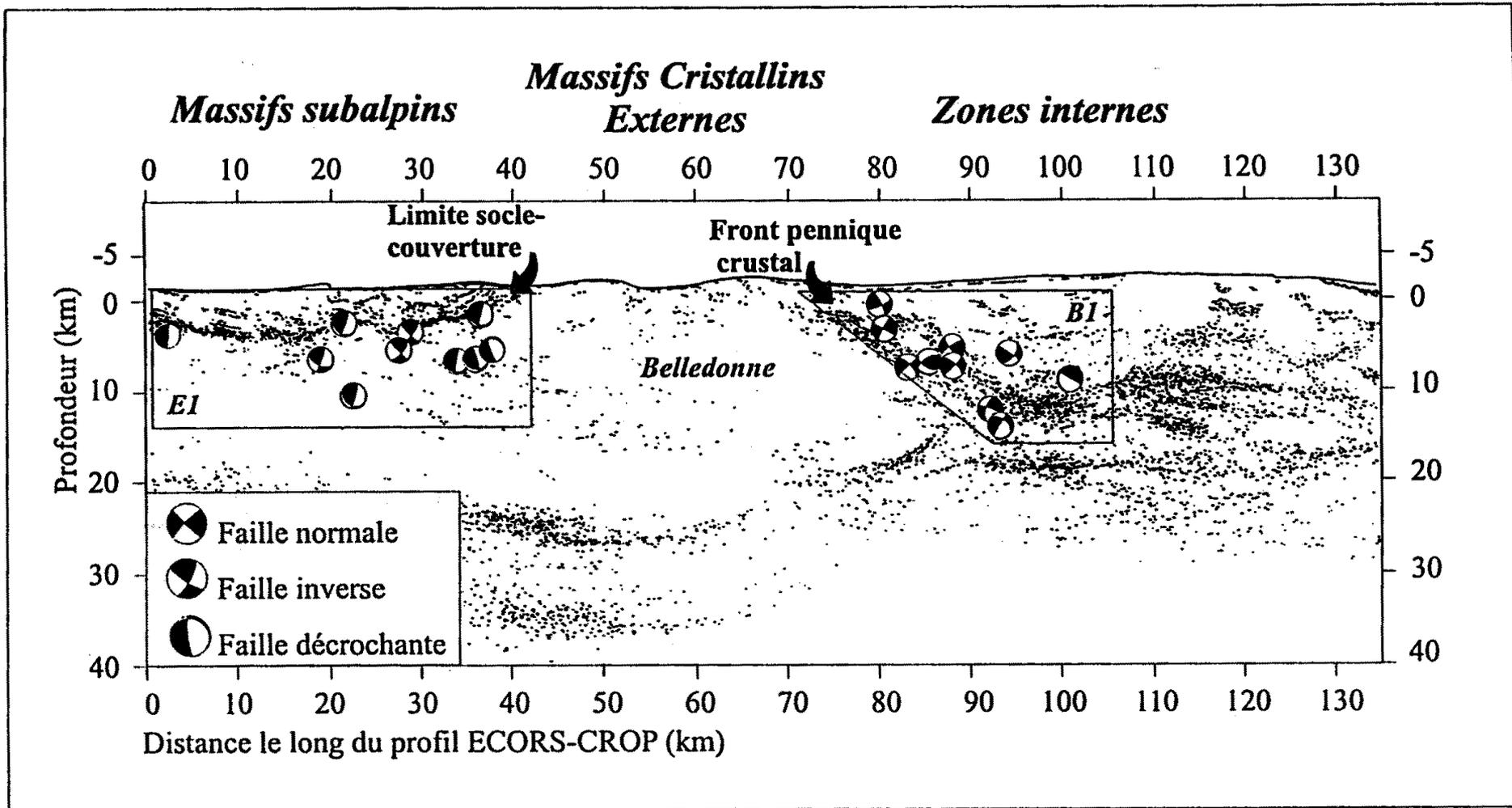


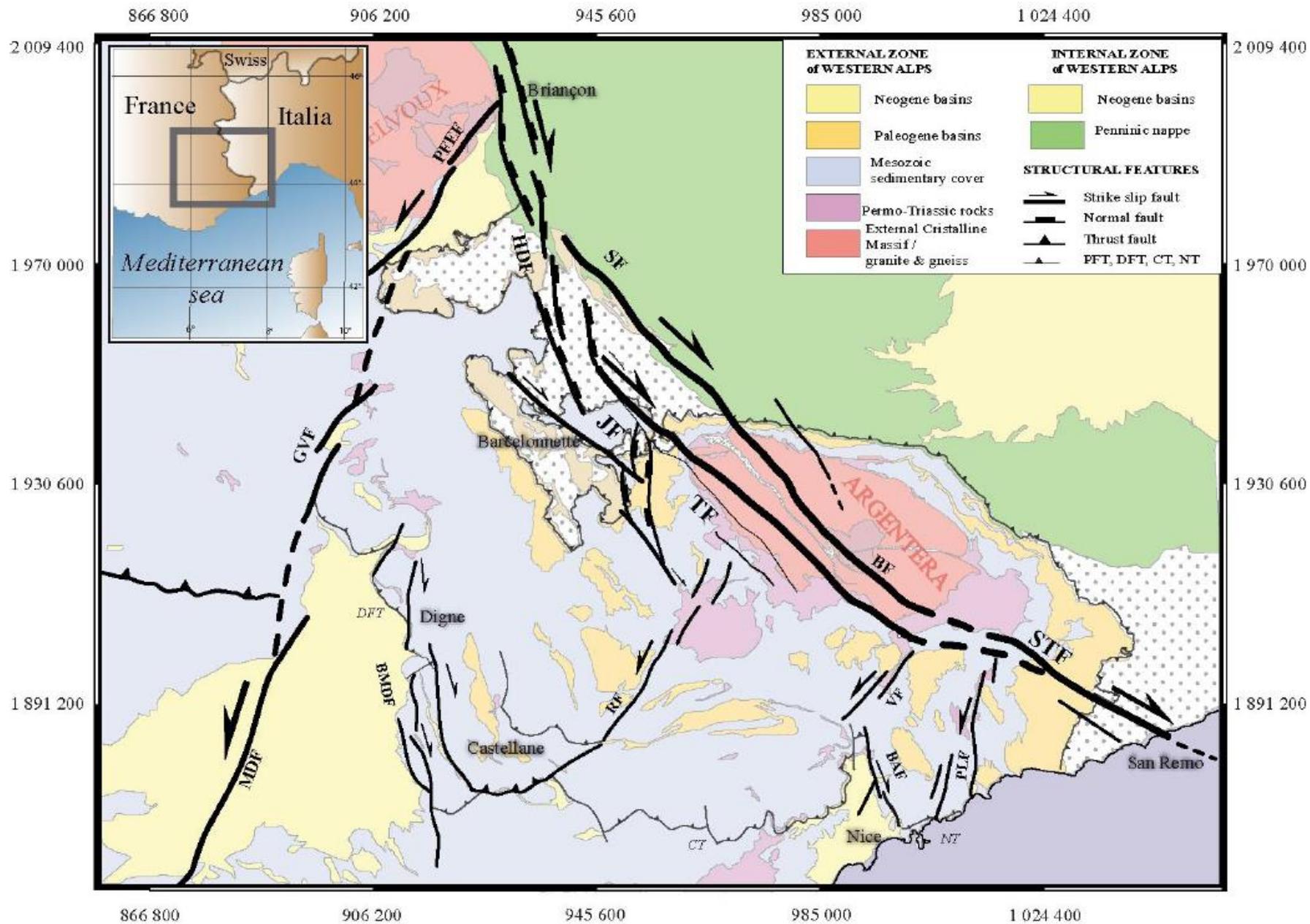
Figure 3.59 - Carte sismotectonique synthétique regroupant l'ensemble des solutions focales fiables accumulées dans cette partie avec les données Sismalp. Les zones E1, E2, B1, B2, B3 et P renvoient au chapitre III.4 sur l'inversion des solutions focales. Le trait pointillé situe la coupe de la figure 3.60.



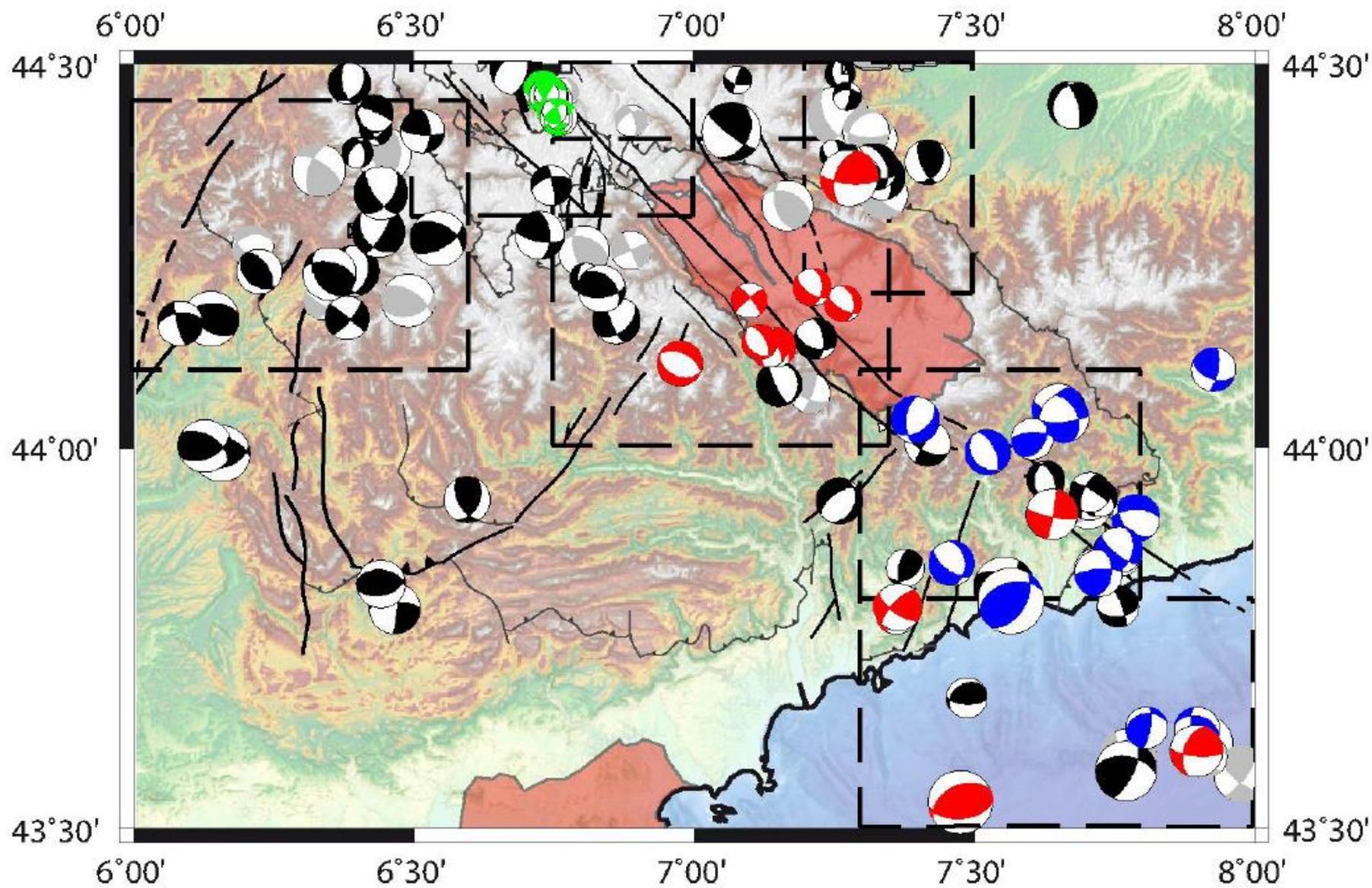
(Sue et al., 1999)



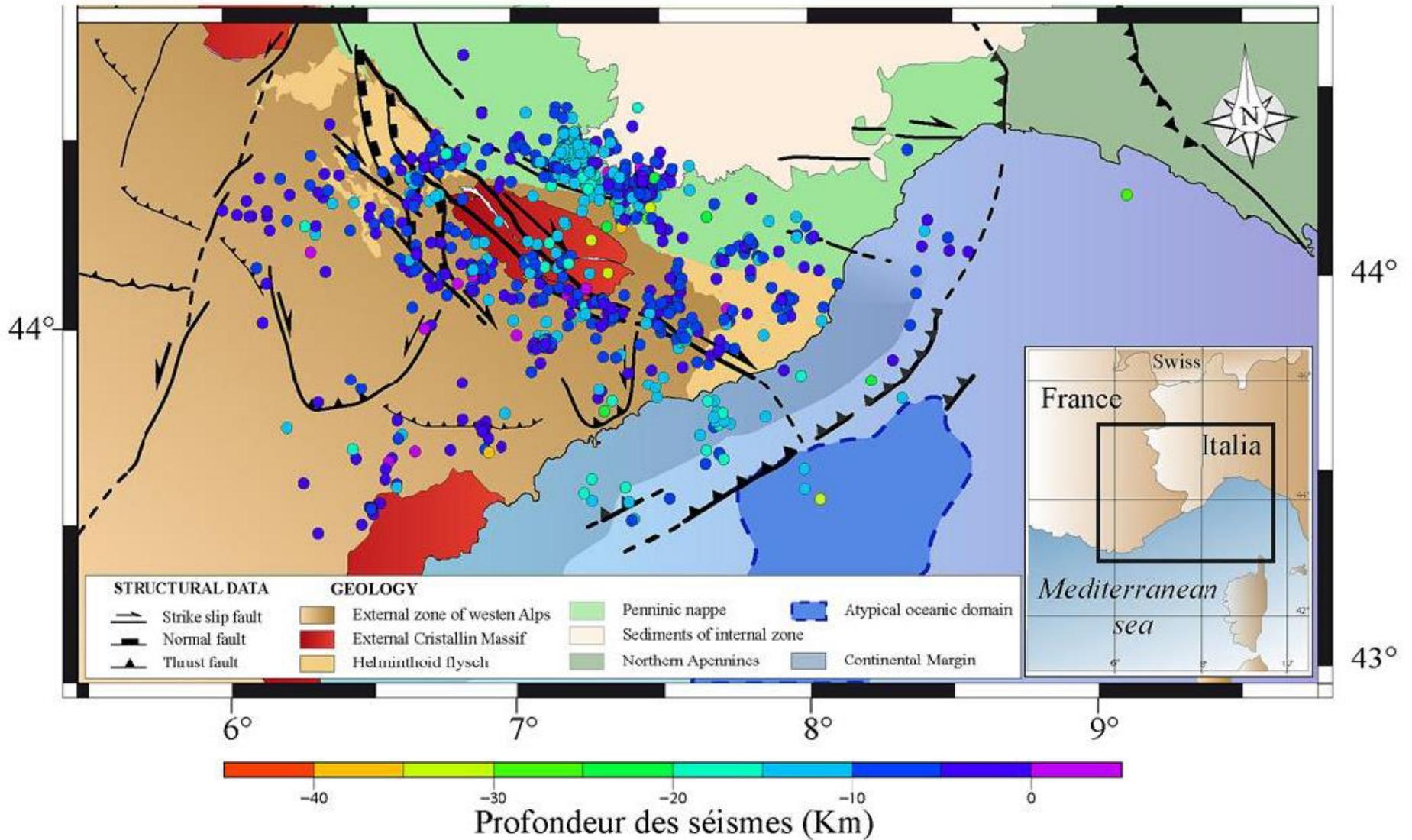
(Sue et al., 1999)



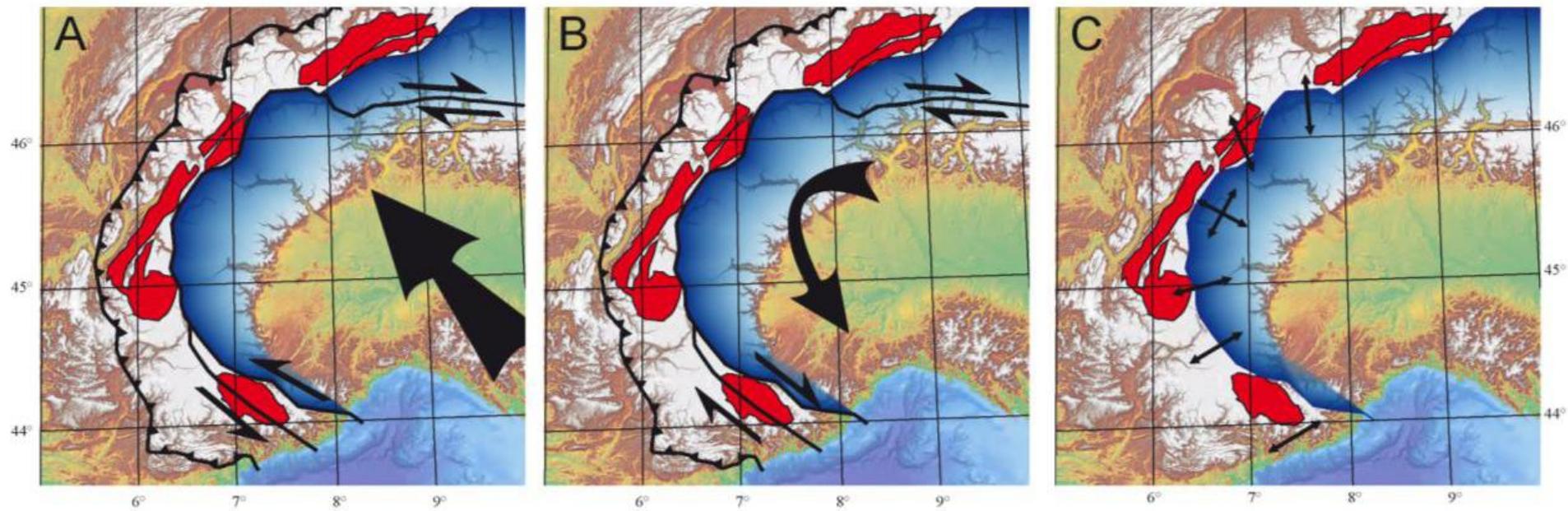
(Sanchez et al., 2010, 2011)



(Bauve, thèse, 2013)



(Bauve, thèse, 2013)

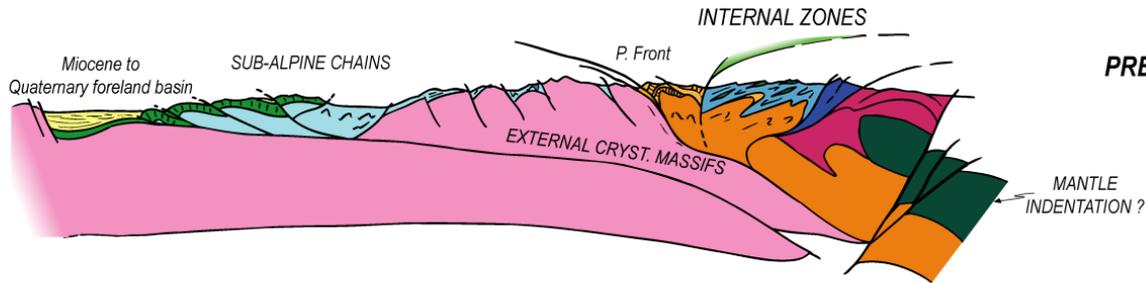


(Bauve, thèse, 2013)

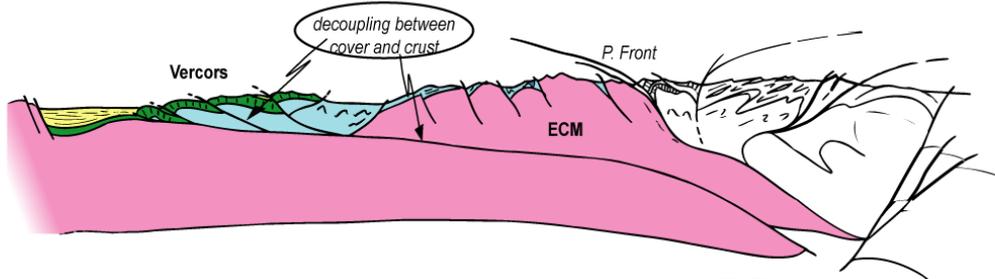
III. Calendrier et modèle d'évolution des Alpes franco-italiennes; évolution récente; réflexion sur la structure.

C. Une structure d'ensemble résultant
de l'emboîtement de 3 prismes
d'accrétion dans le temps et dans l'espace

(section across Vercors and the ECM)

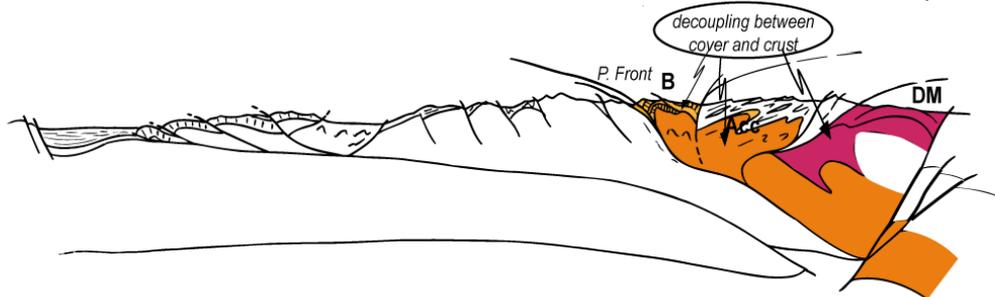


**PRESENT STATE: THE OROGENIC WEDGE
A LITHOSPHERIC-SCALE
ACCRETIONARY SYSTEM**



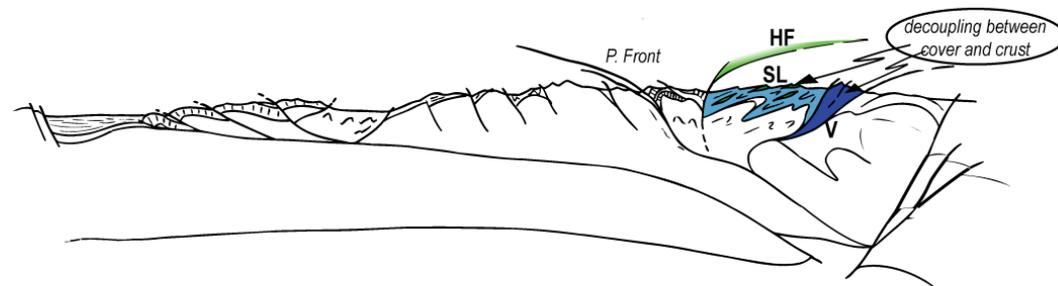
ACCRETION OF THE
EXTERNAL ZONES

3



REMNANTS OF AN EARLIER
ACCRETIONARY SYSTEM:
THE THINNED CONTINENTAL CRUST
= BRIANCONNAIS

2

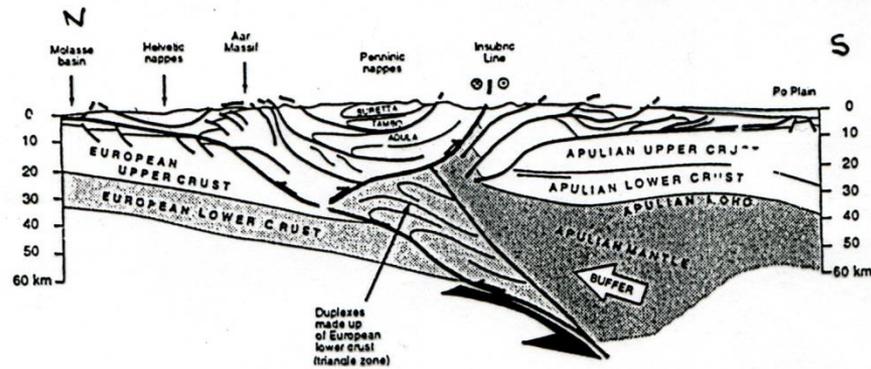
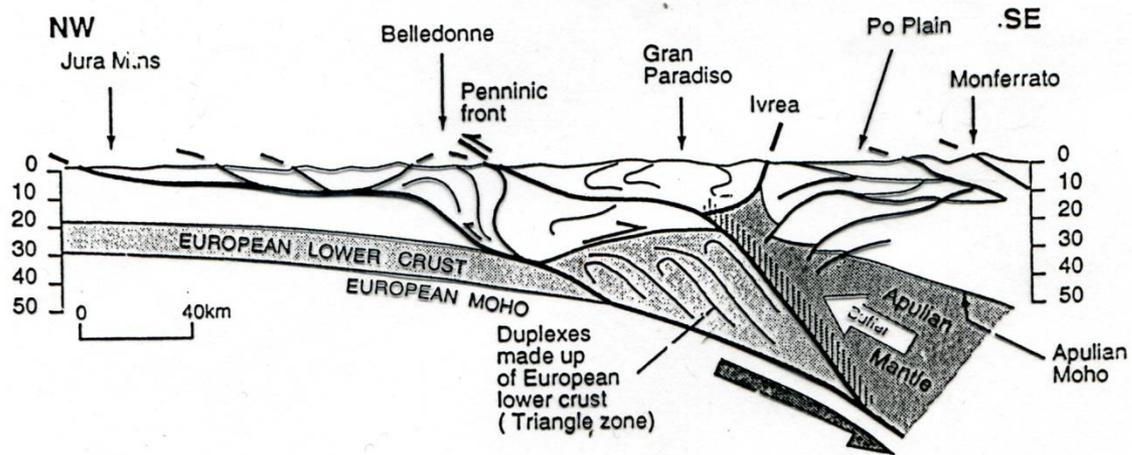
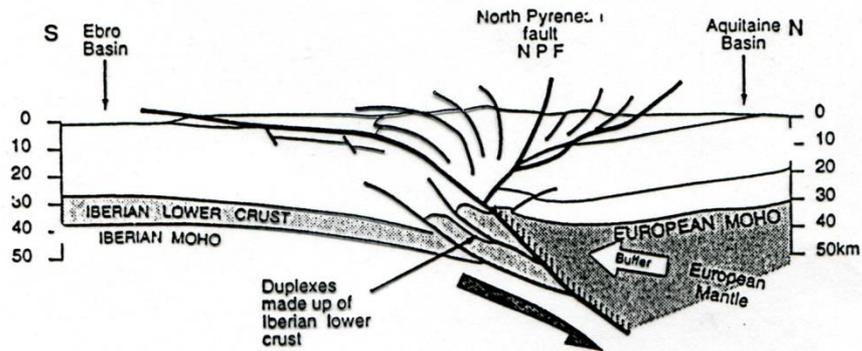


REMNANTS OF THE EARLIEST
ACCRETIONARY SYSTEM:
THE OCEANIC ACCRETIONARY WEDGE
= LIG.-PIEMONTESE

1

THREE IMBRICATED ACCRETIONARY SYSTEMS

- REMARKABLE FEATURES**
- 3 time intervals
 - 3 imbrication scales
 - decoupling between crust and cover

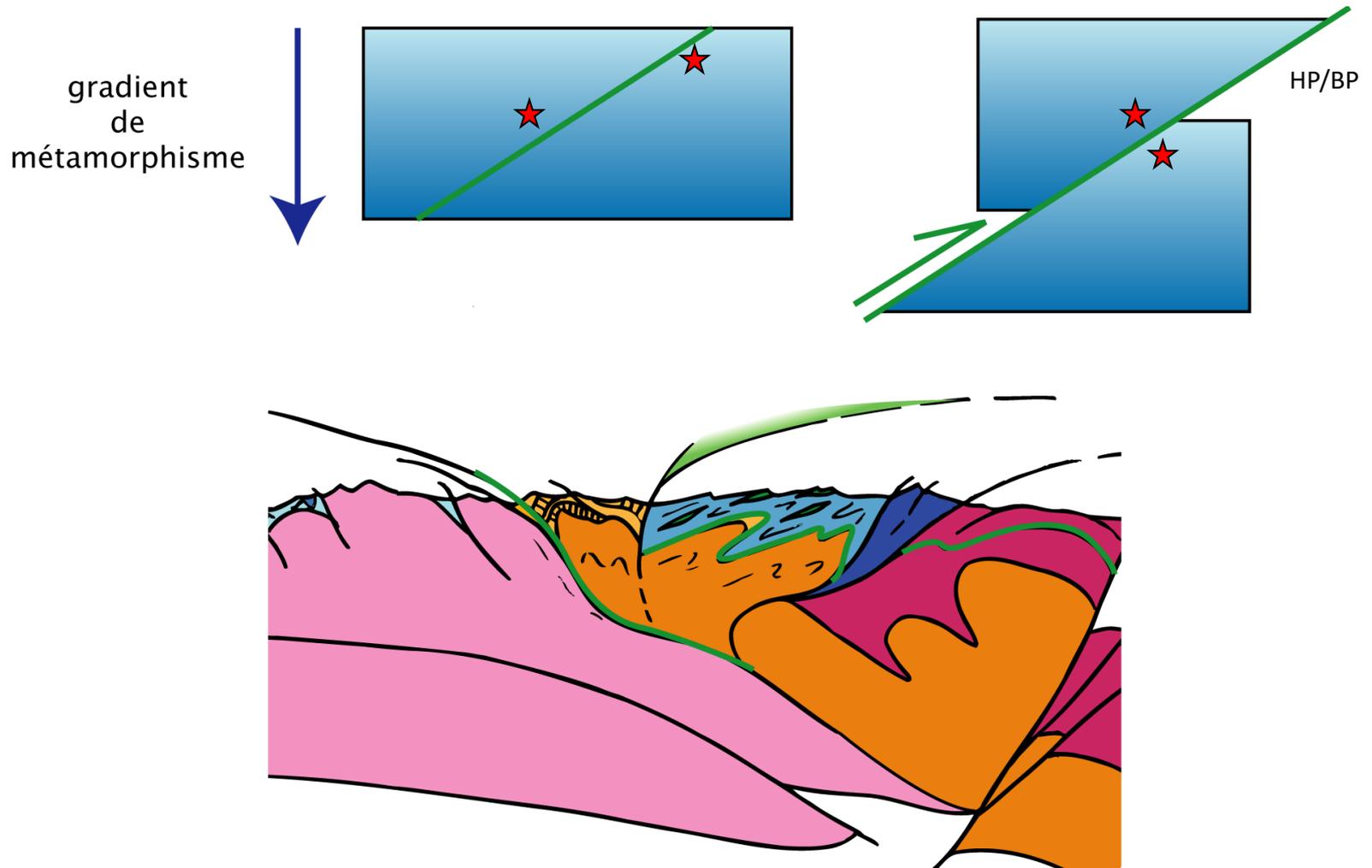


III. Calendrier et modèle d'évolution
des Alpes franco-italiennes; évolution récente;
réflexion sur la structure.

E. Éléments de brainstorming alpin

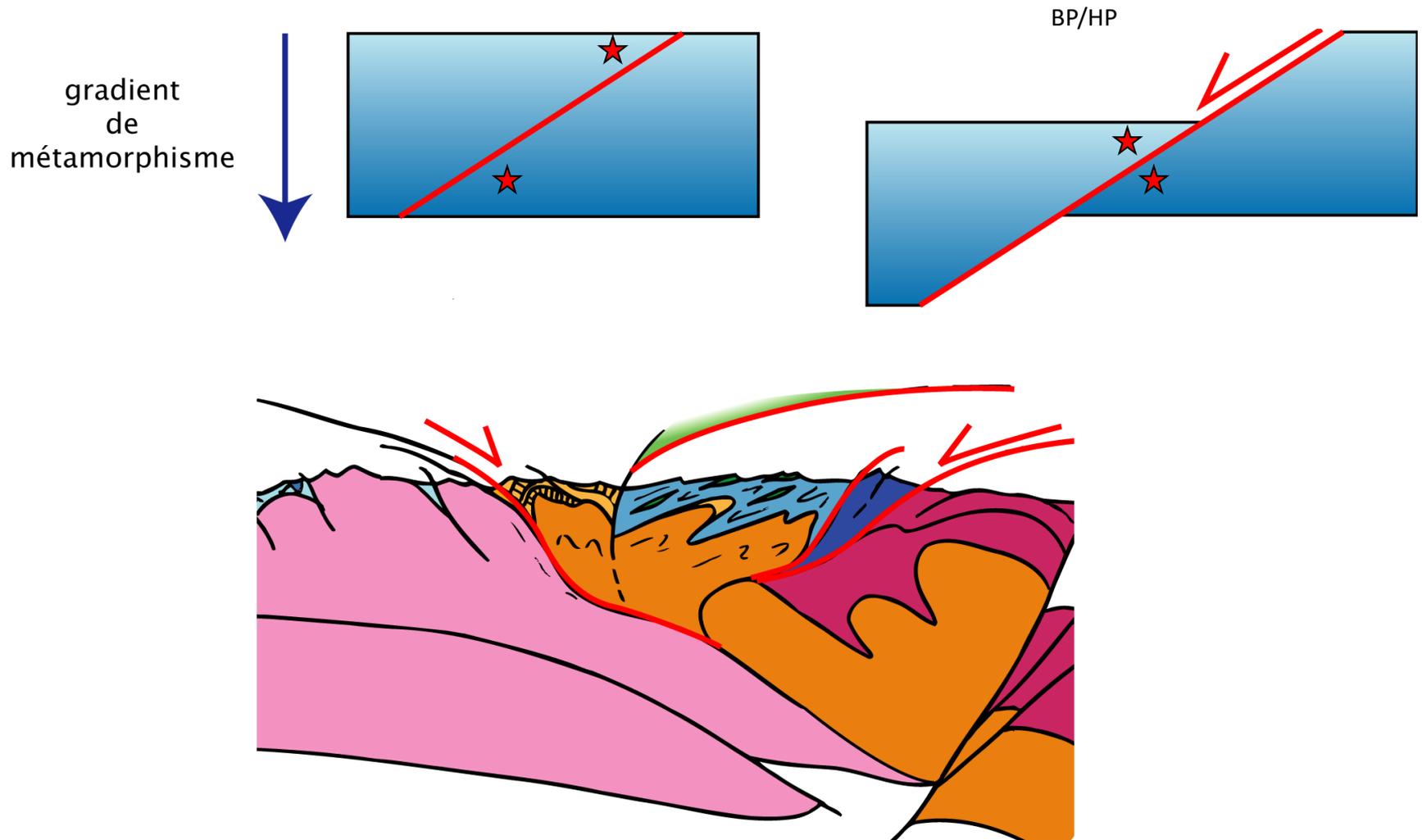
La signification
des principaux contacts tectoniques

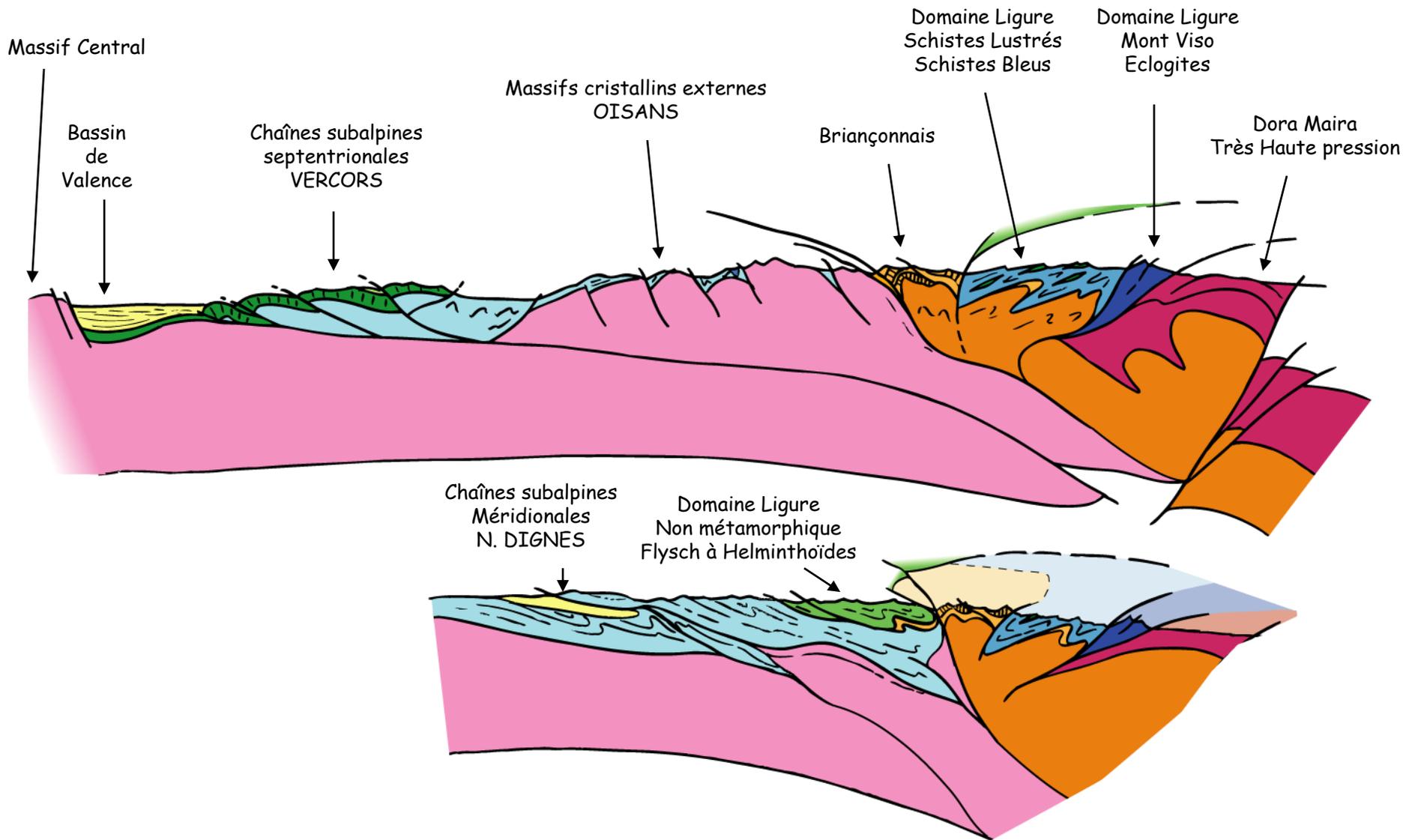
« chevauchement »



Les chevauchements épaississent la croûte

« détachement »

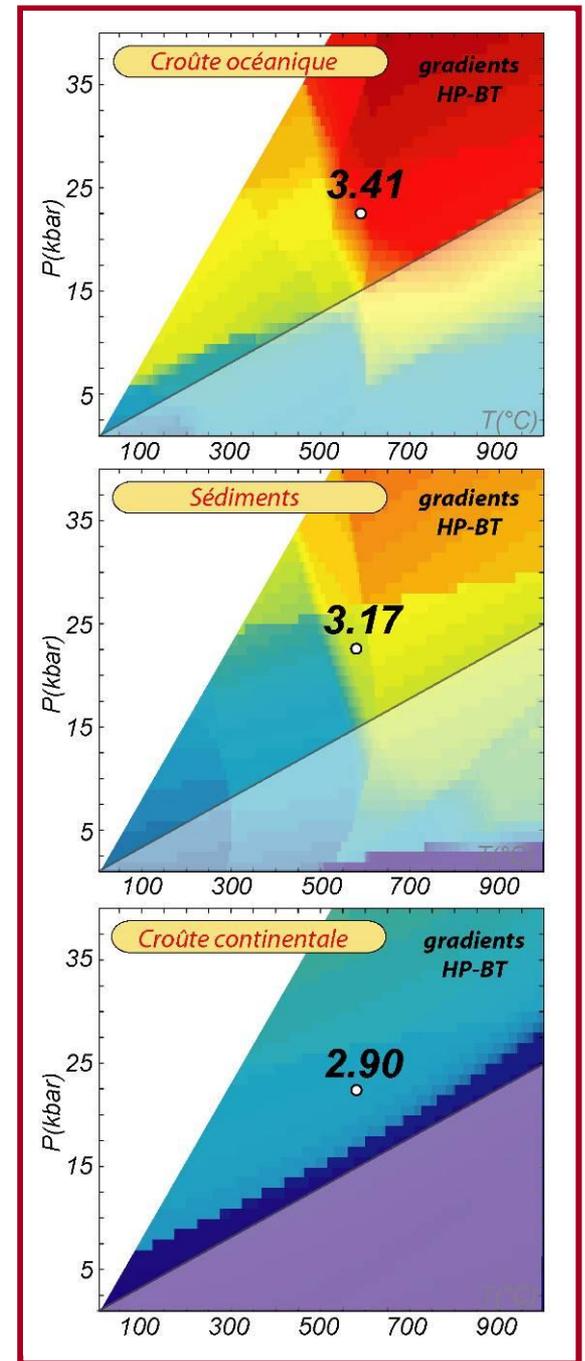
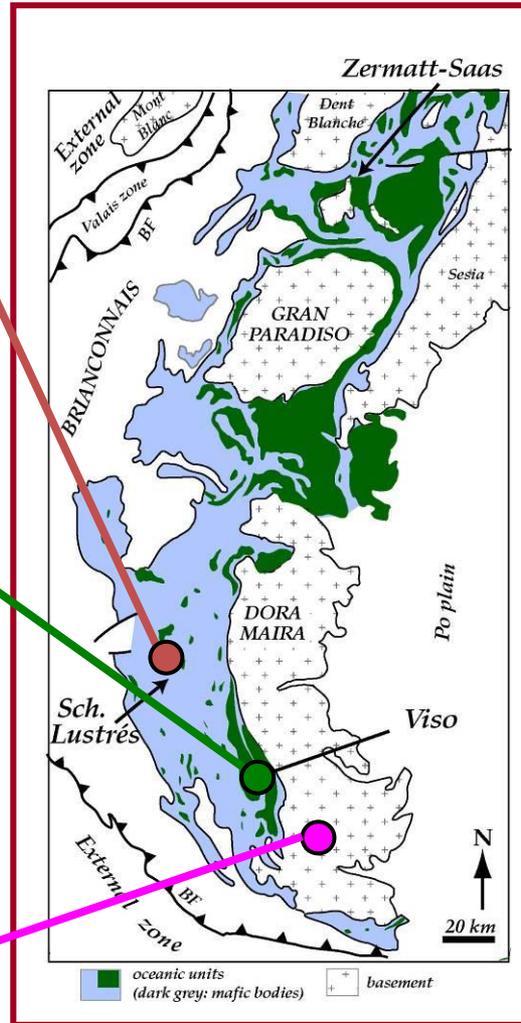
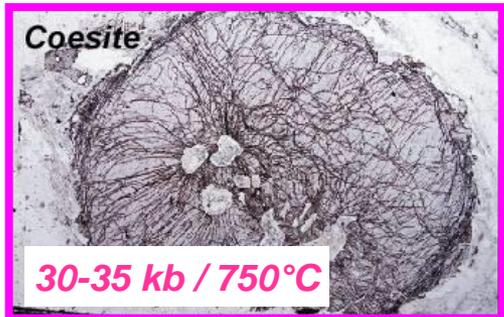
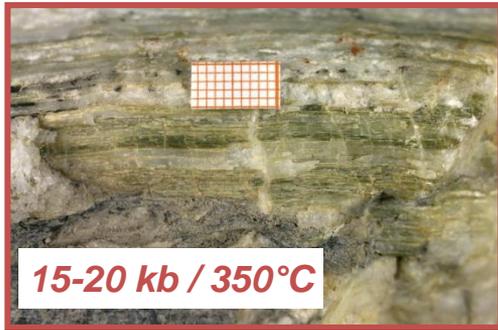




3 prismes emboîtés

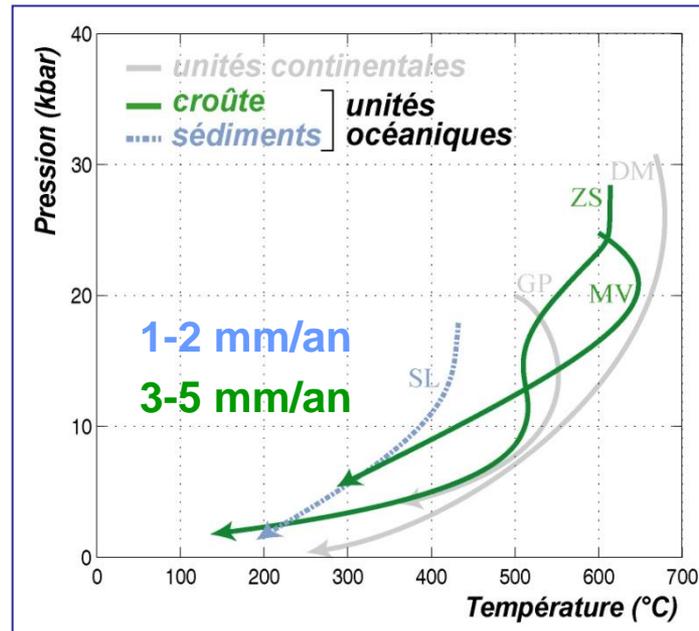
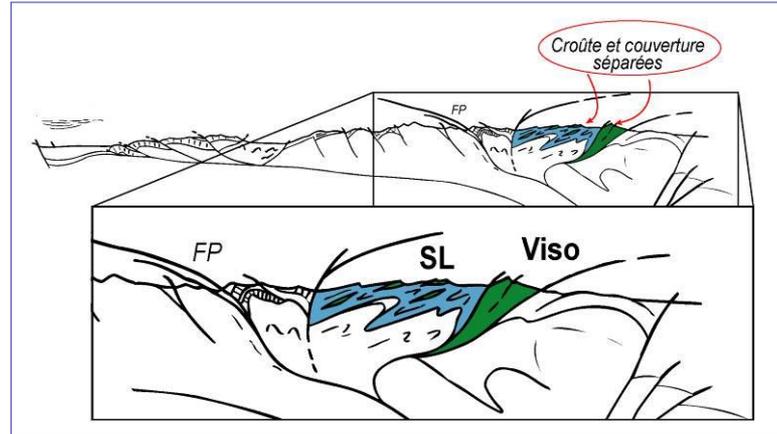
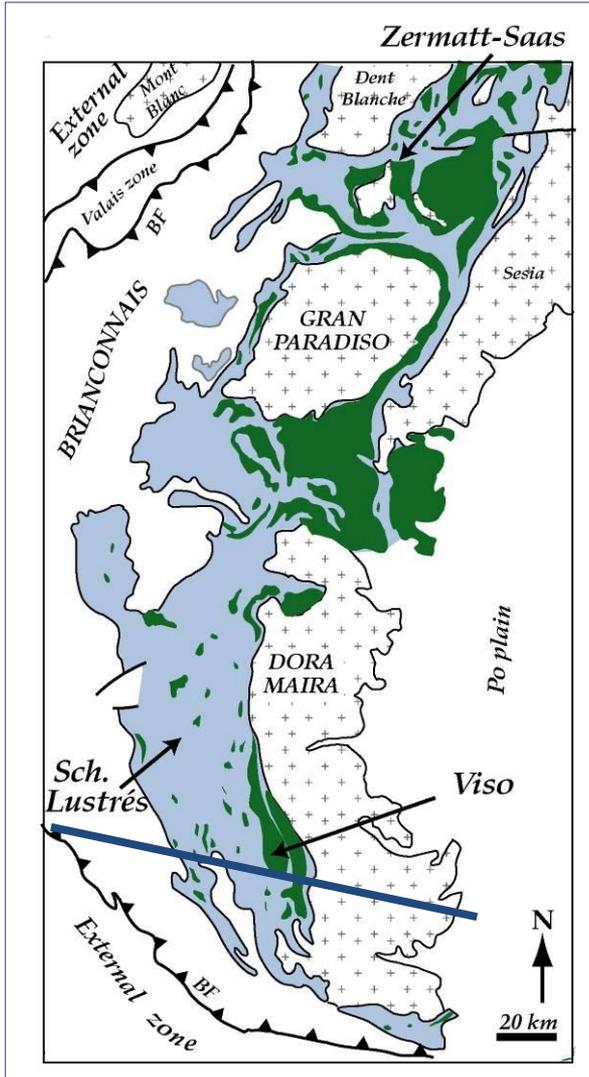
Subduction, exhumation...

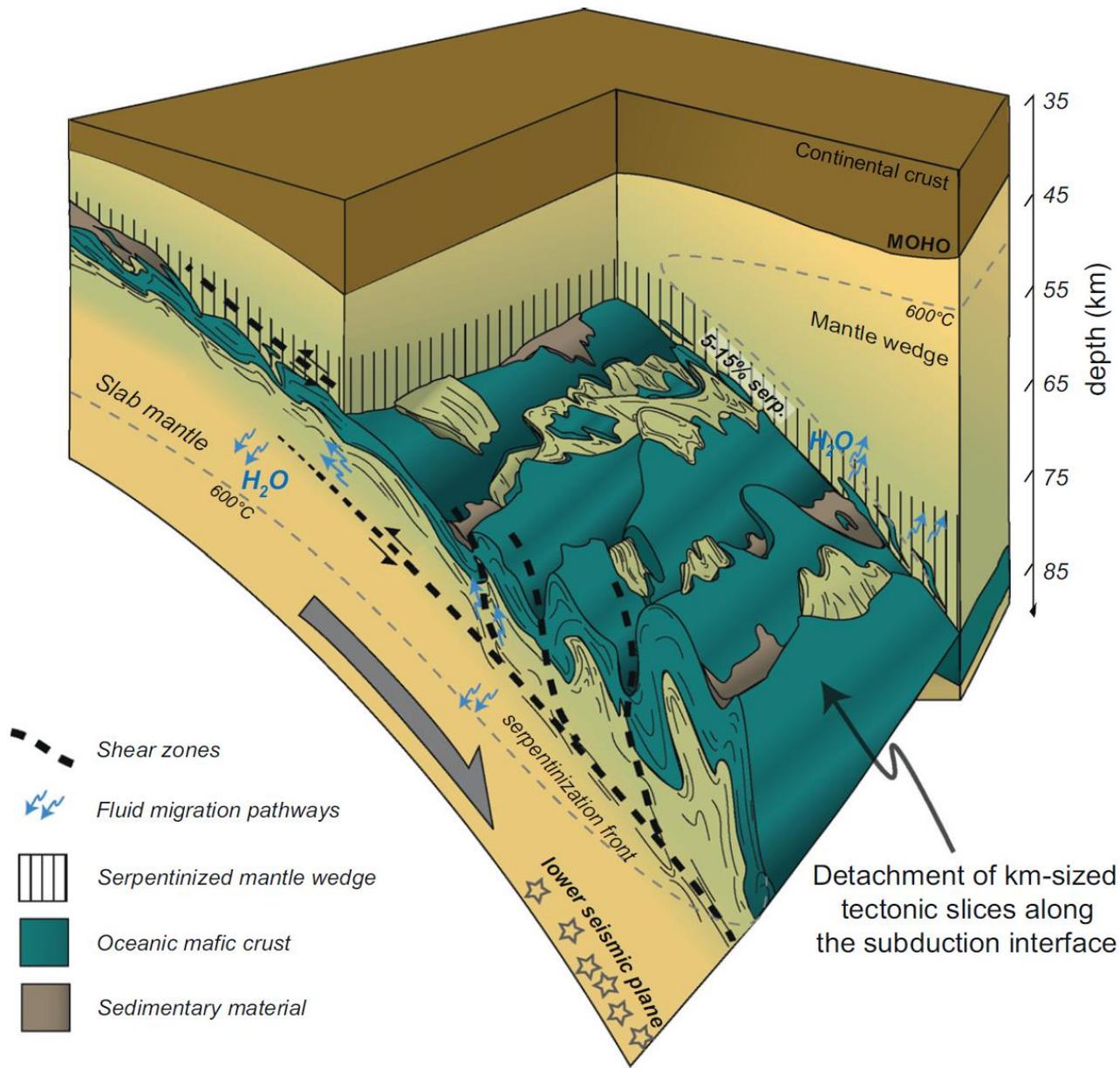
Des matériaux mis en jeu différents



... avec des densités bien particulières

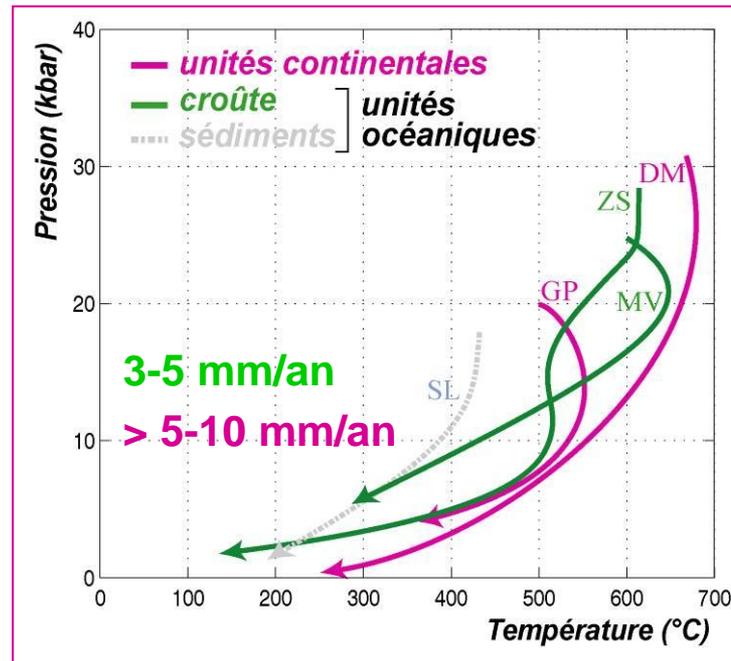
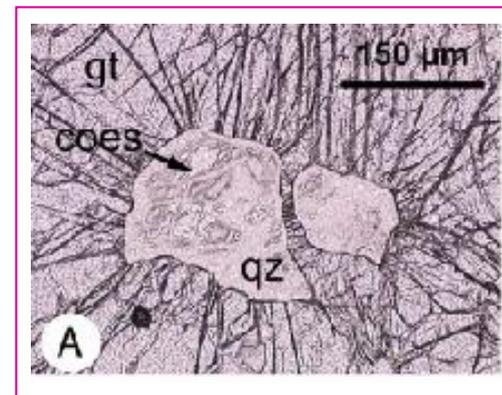
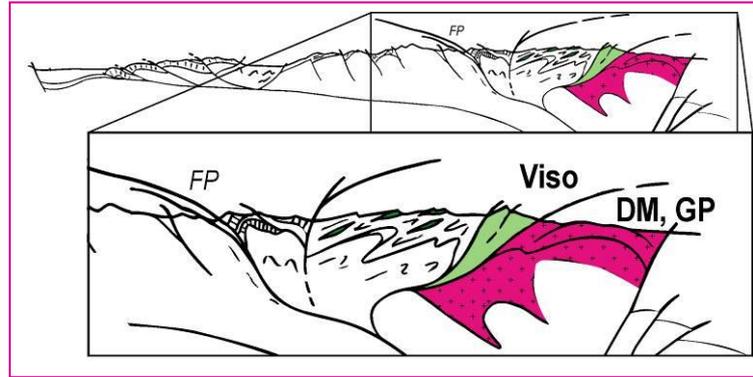
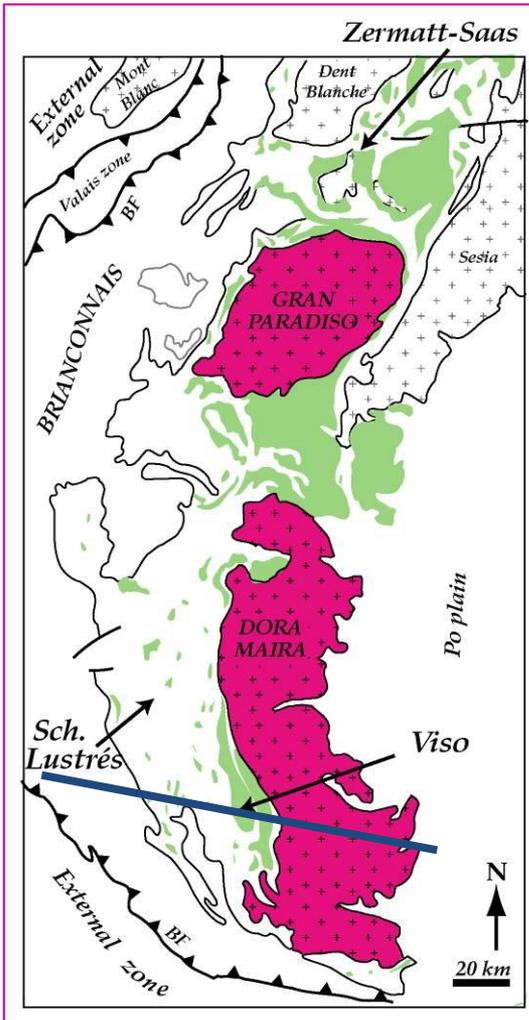
La subduction océanique





(Angiboust et al., 2012)

La subduction continentale



Observations importantes

- Exhumation de la marge subduite

- Conditions P-T-t et Vitesses d'exhumation

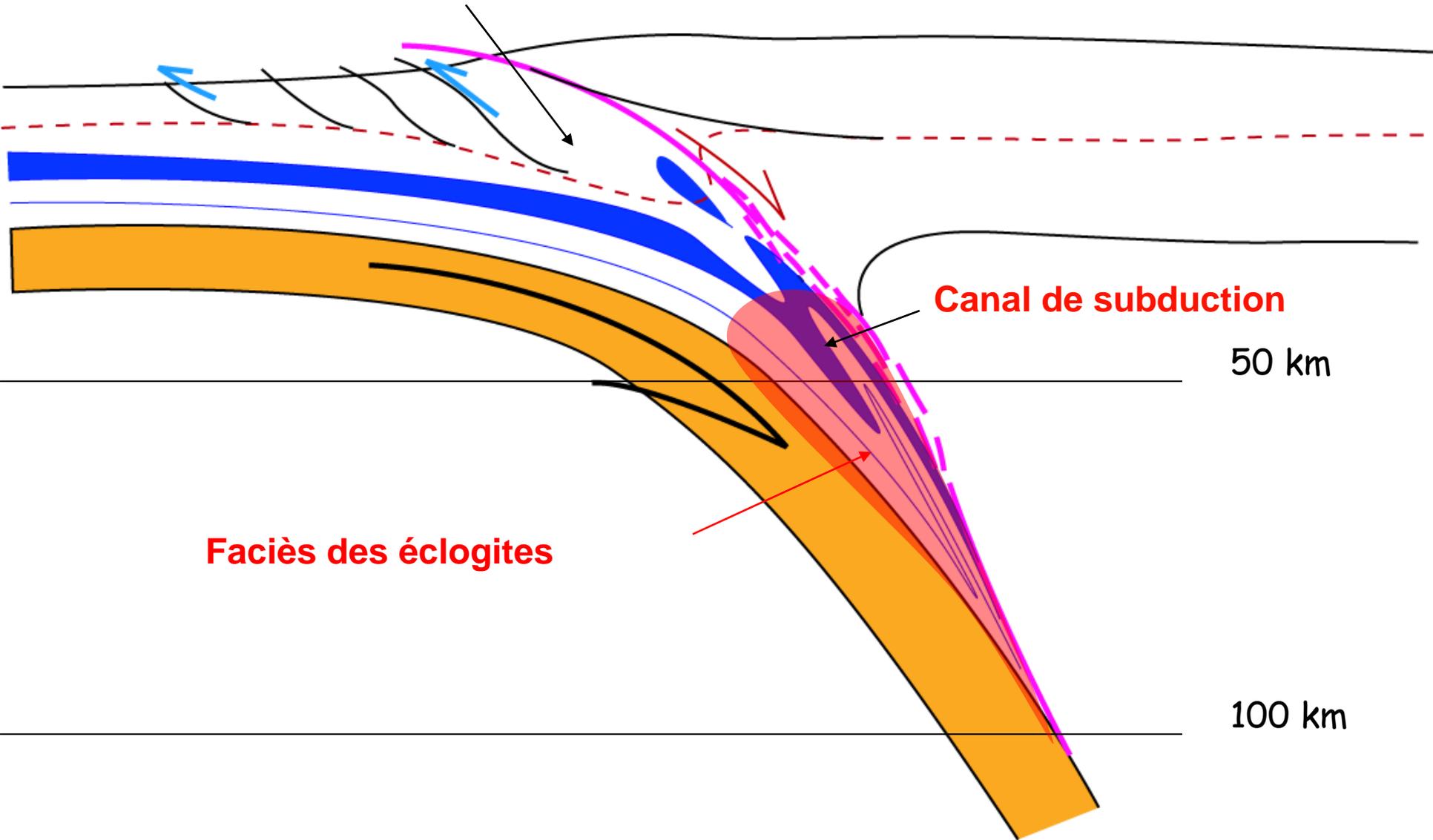
3-5 mm/an

> 5-10 mm/an

- Forte ressemblance avec l'exhumation de matériel océanique

Présence de roches métamorphisées à très grande profondeur,
plus profondément que le prisme d'accrétion

Prisme d'accrétion

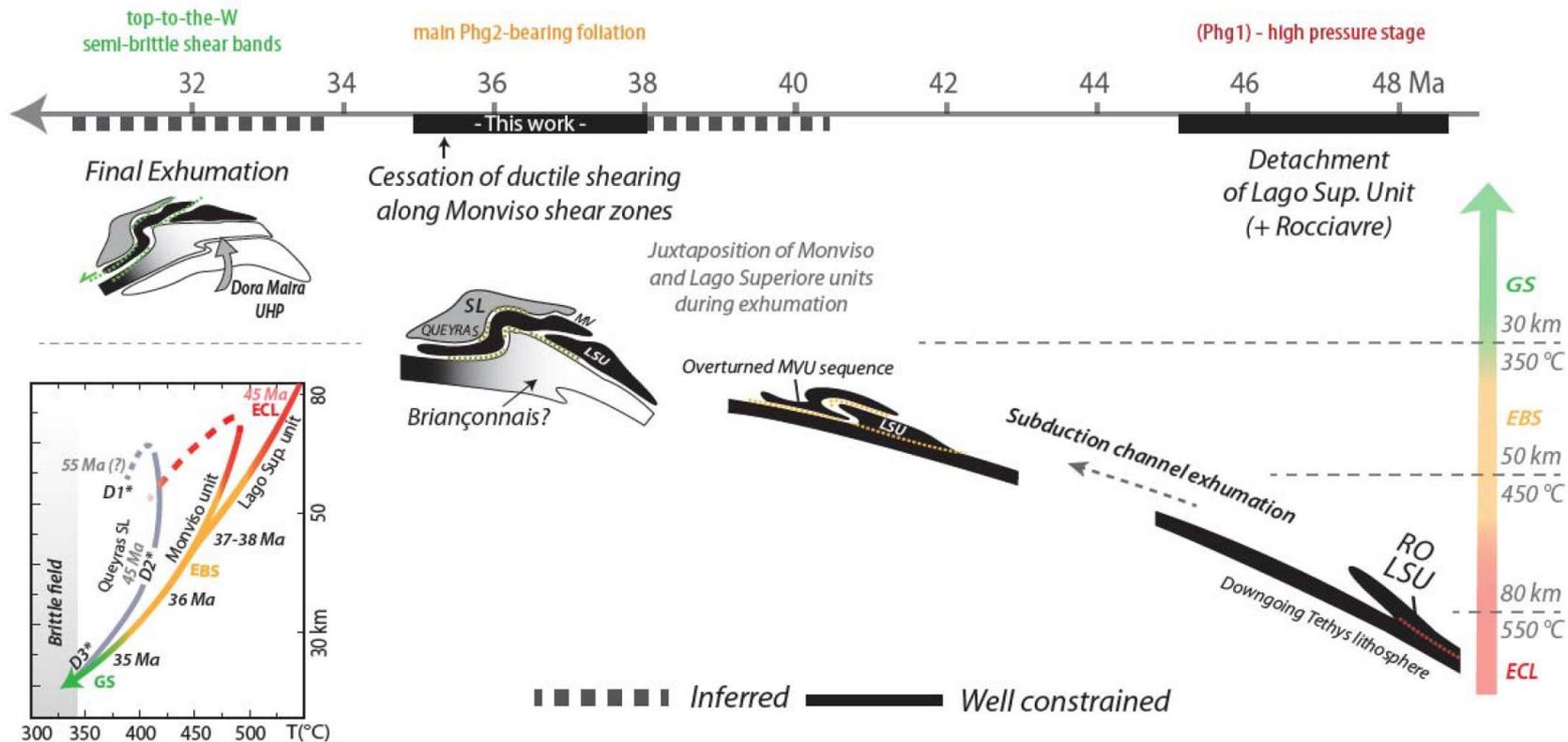


Canal de subduction

50 km

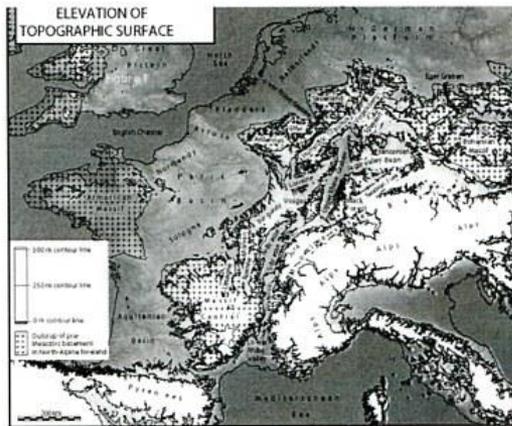
Faciès des éclogites

100 km

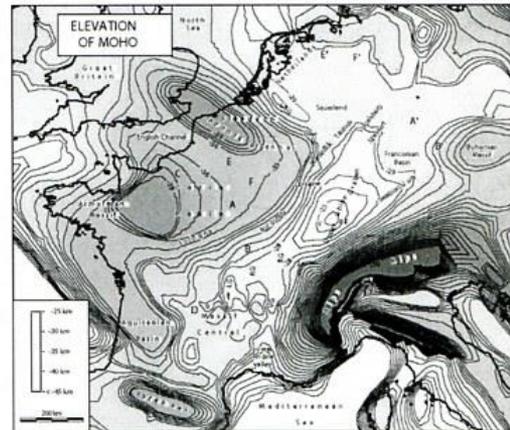


(Angiboust and Glodny, 2020)

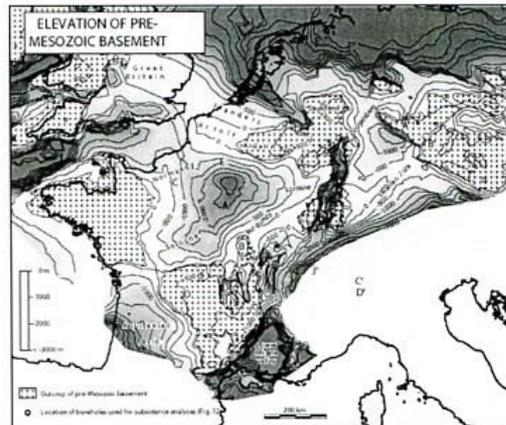
Un flambage lithosphérique alpin
dans l'avant-pays ?



Topographic map. The NW Alpine foreland is composed of topographic blocks (elevations above +250 m), where the pre-Mesozoic basement crops out, alternating with topographic basins (elevations below +250 m), where Mesozoic sediments have been deposited. The ECRS forms a system of linear topographic troughs.

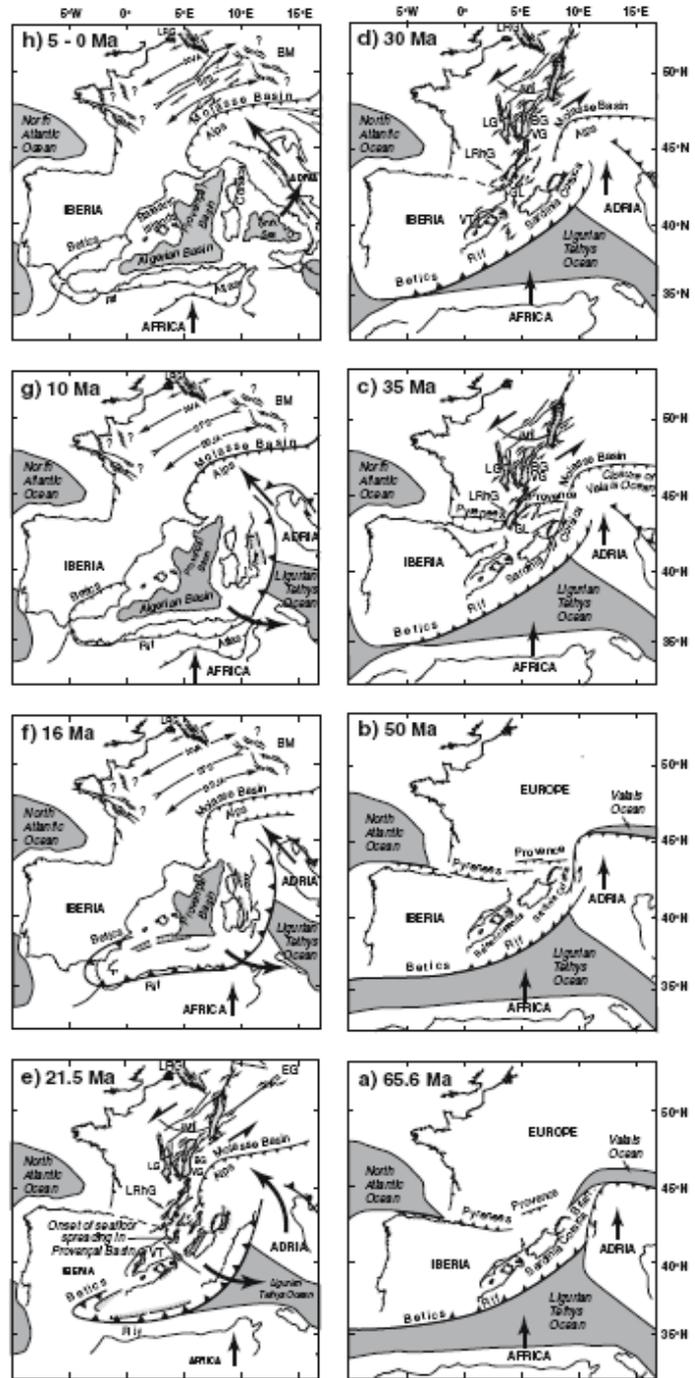


Contoured elevation map of the Moho in the NW Alpine foreland (adapted from Diers et al., 2008).
 G: Gabels; J: Jura fold and thrust belt; LG: Lower Rhine Graben; LING: Lower Rhine Graben; RG: Roanne Graben; V: Vosges; VG: Valence Graben; BF: Black Forest; BG: Bresse.



(Bourgeois et al., 2007)

Structural maps showing the evolution of the Alpine orogen and of its foreland during the Cenozoic. Geodynamic evolution of Mediterranean region after Lacombe and Jolivet (2005); location and geometry of faults in foreland after Dézes et al. (2004). Development of Jura thin-skinned fold-and-thrust belt (from 11 Ma onwards) not shown for clarity of drawing. *NVA* Normandy–Vogelsberg Anticline, *BSJA* Burgundy–Swabian Jura Anticline, *BG* Bresse Grabens, *BM* Bohemian Massif, *EG* Eger Graben, *GL* Gulf of Lion, *LG* Limagne Graben, *LRG* Lower Rhine Graben, *LRhG* Lower Rhône Grabens, *SFS* Sologne–Franconian Basin Syncline, *VT* Valencia Trough



(Bourgeois et al., 2007)

