



European Geosciences Union – General Assembly

GEOSCIENCE INFORMATION FOR TEACHERS (GIFT) WORKSHOP

Vienna, 23-26 April 2017 The Mediterranean

Tectonics of the Mediterranean Sea and subduction of the African plate: *from basins to mountains, from mountains to basins*

Laurent Jolivet

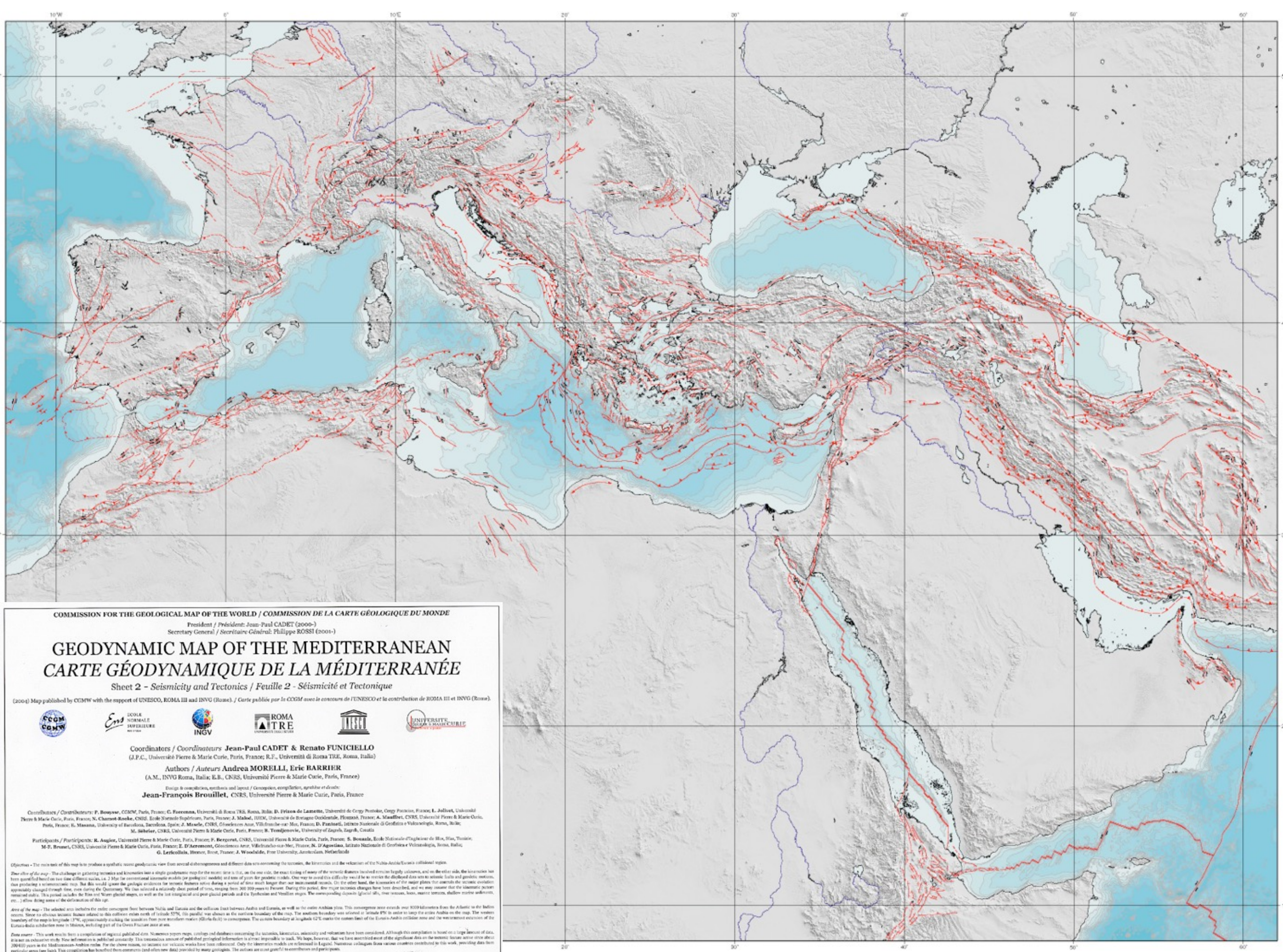
Institut des Sciences de la Terre d'Orléans (ISTO), Université d'Orléans, France

with Laurent Arbaret, Romain Augier, Eloïse Bessière, Erdin Bozkurt, Yannick Branquet, Jean-Pierre Brun, Oman Candan, Yoann Denèle, Maxime Ducoux, Claudio Faccenna, Vincent Famin, Pierre Gautier, Bruno Goffé, Bernhard Grasemann, Charles Gumiaux, Benjamin Huet, Loïc Labrousse, Olivier Lacombe, Valentin Laurent, Emmanuel Lecomte, Laetitia le Pourhiet, Caroline Mehl, Armel Menant, Patrick Monié, Aral Okay, Teddy Parra, Martin Patriat, Pascal Philippot, Aurélien Rabillard, Gaëtan Rimmele, Vincent Roche, Nikos Skarpellis, Pietro Sternai, Fabien Trotet, Olivier Vidal



A scenic coastal landscape. In the foreground, there is a dense field of low-lying bushes with bright red berries. Beyond this, a small, calm bay with turquoise water is visible. The bay is flanked by two rocky headlands with sparse green vegetation. The sea extends to the horizon under a clear blue sky. The text "1. Geodynamic and geological context" is overlaid in the center of the image in a white, italicized serif font.

1. Geodynamic and geological context



COMMISSION FOR THE GEOLOGICAL MAP OF THE WORLD / COMMISSION DE LA CARTE GÉOLOGIQUE DU MONDE

President / Président: Jean-Paul CADET (2000-)
Secretary General / Secrétaire Général: Philippe ROSSI (2001-)

GEODYNAMIC MAP OF THE MEDITERRANEAN CARTE GÉODYNAMIQUE DE LA MÉDITERRANÉE

Sheet 2 - Seismicity and Tectonics / Feuille 2 - Séismicité et Tectonique

(2004) Map published by CGMW with the support of UNESCO, ROMA III and INVG (Rome). / Carte publiée par la CGMW avec le concours de l'UNESCO et la contribution de ROMA III et INVG (Rome).



Coordinators / Coordinateurs **Jean-Paul CADET & Renato FUNICIELLO**
(J.P.C., Université Pierre & Marie Curie, Paris, France; R.F., Università di Roma TRE, Roma, Italia)

Authors / Auteurs **Andrea MORELLI, Eric BARRIER**
(A.M., INVG Roma, Italia; E.B., CNRS, Université Pierre & Marie Curie, Paris, France)

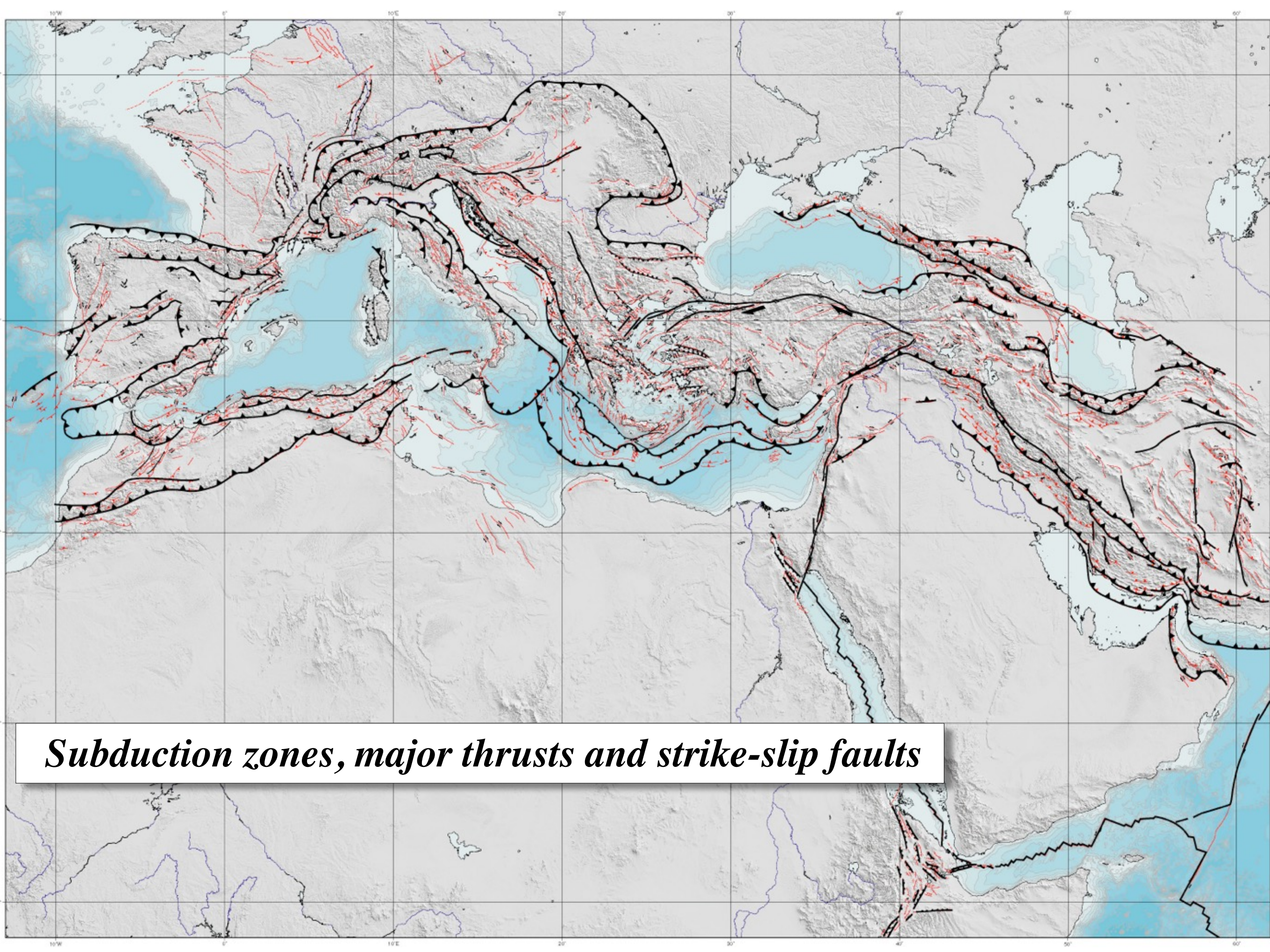
Design & compilation, synthesis and layout / Conception, compilation, synthèse et design:
Jean-François Brouillet, CNRS, Université Pierre & Marie Curie, Paris, France

Contributors / Contributeurs: P. Bouvier, CGMW, Paris, France; G. Faccenna, Università di Roma TRE, Roma, Italia; D. Fiasca de Lamotte, Université de Cergy Pontoise, Cergy Pontoise, France; L. Jolivet, Université Pierre & Marie Curie, Paris, France; N. Chabert-Rouck, CNRS, Ecole Normale Supérieure, Paris, France; J. Malod, IRM, Université de Bourgogne Orientale, Dijon, France; A. Mauffret, CNRS, Université Pierre & Marie Curie, Paris, France; R. Manass, University of Barcelona, Barcelona, Spain; J. Mawle, CNRS, Observatoire Midi-Pyrénées, Toulouse, France; M. Mer, France; D. Panfili, Istituto Nazionale di Geofisica e Vulcanologia, Roma, Italia; M. Scharer, CNRS, Université Pierre & Marie Curie, Paris, France; B. Tondjoriev, University of Zagreb, Zagreb, Croatia

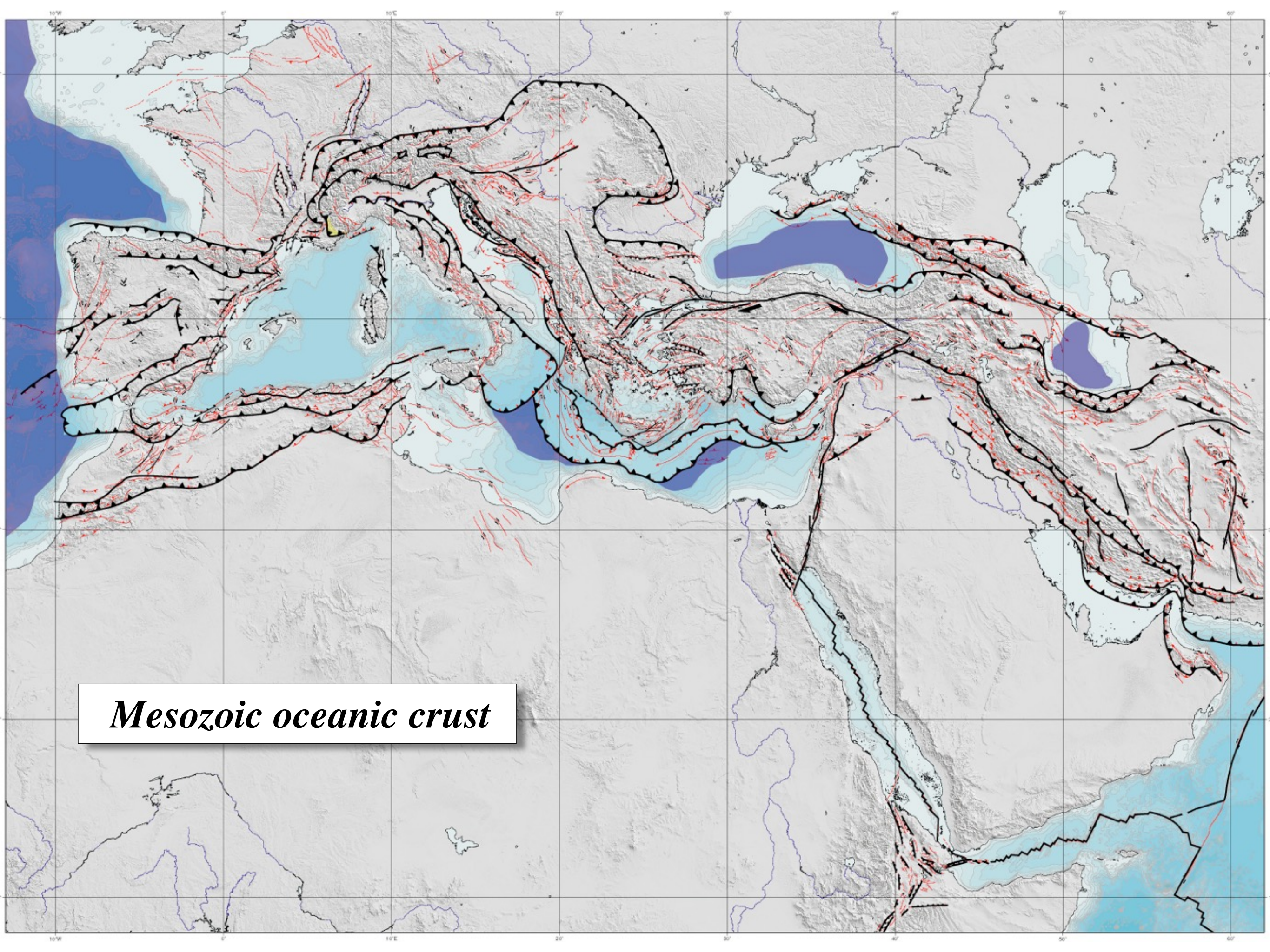
Participants / Participants: R. Augier, Université Pierre & Marie Curie, Paris, France; F. Bergerat, CNRS, Université Pierre & Marie Curie, Paris, France; S. Bonvalle, Ecole Nationale d'Ingénieurs de Sfax, Sfax, Tunisie; M.-S. Brunet, CNRS, Université Pierre & Marie Curie, Paris, France; E. D'Aleandro, Géosciences Azur, Villefranche-sur-Mer, France; N. D'Agostino, Istituto Nazionale di Geofisica e Vulcanologia, Roma, Italia; G. Lericollais, Honorary, France; J. Woodsworth, Free University, Amsterdam, Netherlands

Objectives - The main task of this map is to produce a synthetic view of the geodynamic processes and different data sets concerning the tectonics, the kinematics and the volcanism of the North-Africa/Eurasia collisional region.
Scope of the map - The challenge in gathering tectonics and kinematics into a single geodynamic map for the recent time is that, on the one side, the exact timing of many of the tectonic features involved remains largely unknown, and on the other side, the kinematics has been quantified based on two time different scales, i.e. 2 Myr for conventional kinematic models (or geological models) and tens of years for geodetic models. One way to avoid this difficulty would be to restrict the displayed data sets to seismic faults and geodetic motions, thus producing a kinematic map. But this would ignore the paleogeographic evidence for tectonic features active during a period of time much longer than our instrumental records. On the other hand, the kinematics of the major plates that controls the tectonic evolution, especially changed through time, even during the Quaternary. We thus selected a relatively short period of time, ranging from 300 000 years to Present. During this period, few major tectonic changes have been described, and we may assume that the kinematic pattern remained stable. This period includes the Pleistocene and Holocene glacial periods and the Tiberian and Neotectonic stages. The corresponding aspects (glacial cycles, river incision, basin, master faults, shallow master faults, etc.) follow during some of the deformation of this age.
Area of the map - The selected area includes the entire convergence front between Africa and Eurasia and the collisional front between Arabia and Eurasia, as well as the entire Arabian plate. This convergence zone extends over 3000 kilometers from the Atlantic to the Indian oceans. Since a obvious tectonic feature related to this collision extends north of latitude 55°N, this parallel was chosen as the northern boundary of the map. The southern boundary was selected at latitude 5°N in order to keep the entire Arabia on the map. The western boundary of the map is longitude 15°W, approximately marking the transition from pure mid-ocean ridges (Mid-Atlantic Ridge) to convergence. The eastern boundary at longitude 62°E marks the eastern limit of the Eurasia-Arabia collision zone and the westernmost extension of the Eurasia-India subduction zone in India, including part of the Owen Fracture zone at sea.

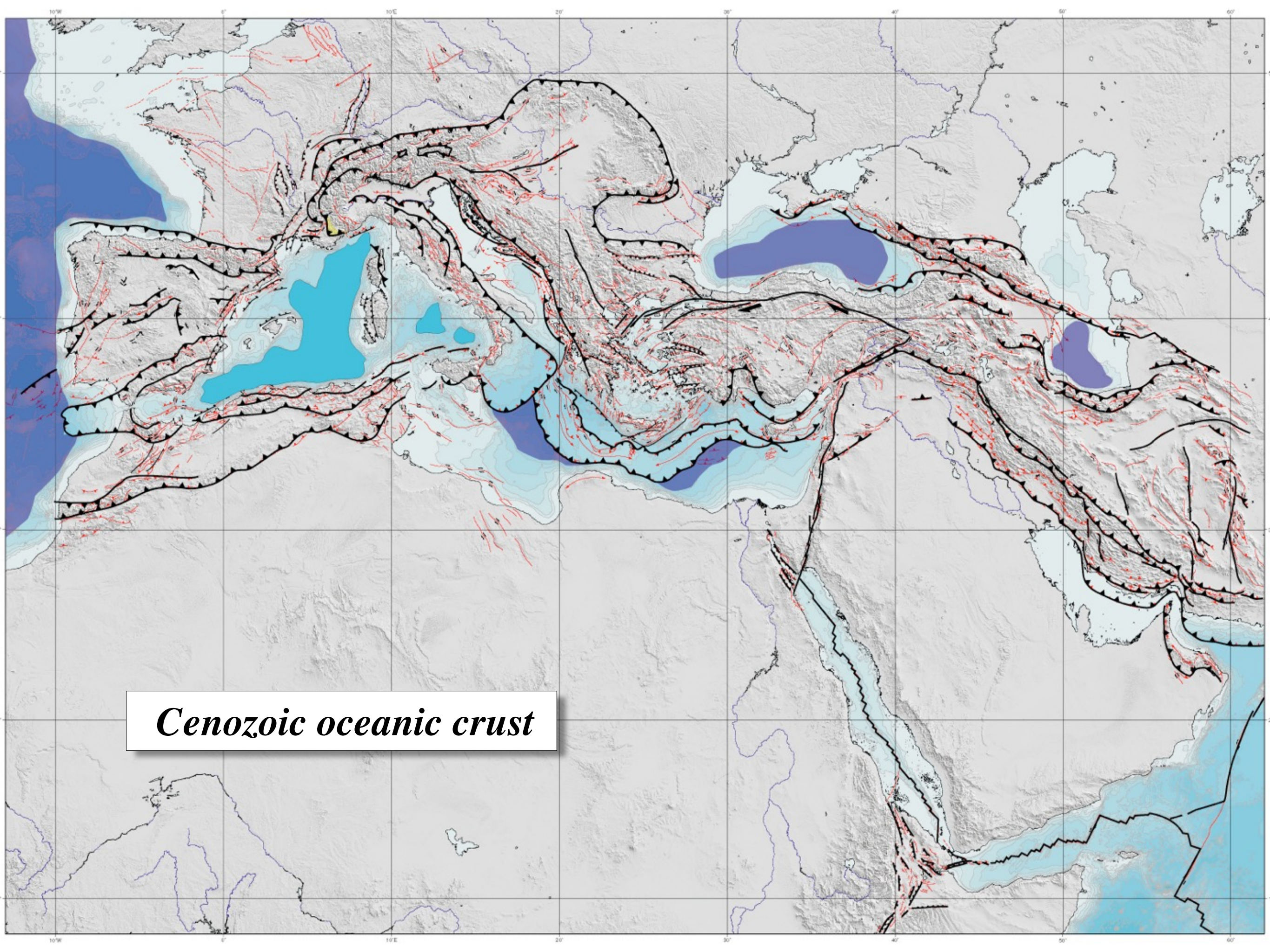
Data source - This work results from a compilation of regional published data. Numerous regional maps, catalogs and databases concerning the tectonics, kinematics, seismicity and volcanism have been considered. Although this compilation is based on a large amount of data, it is not an exhaustive study. Some information is published uncertainty. This extensive amount of published geophysical information is almost impossible to track. We hope, however, that we have assembled most of the significant data on the tectonic features active since about 300 000 years in the Mediterranean-Arabian region. For the above reason, no tectonic or volcanic works have been collected. Only the kinematic models are referenced in Legend. Numerous colleagues from various countries contributed to this work, providing data from particular areas (see back). This compilation has benefited from comments (and often new data) provided by many geologists. The authors are most grateful to contributors and participants.



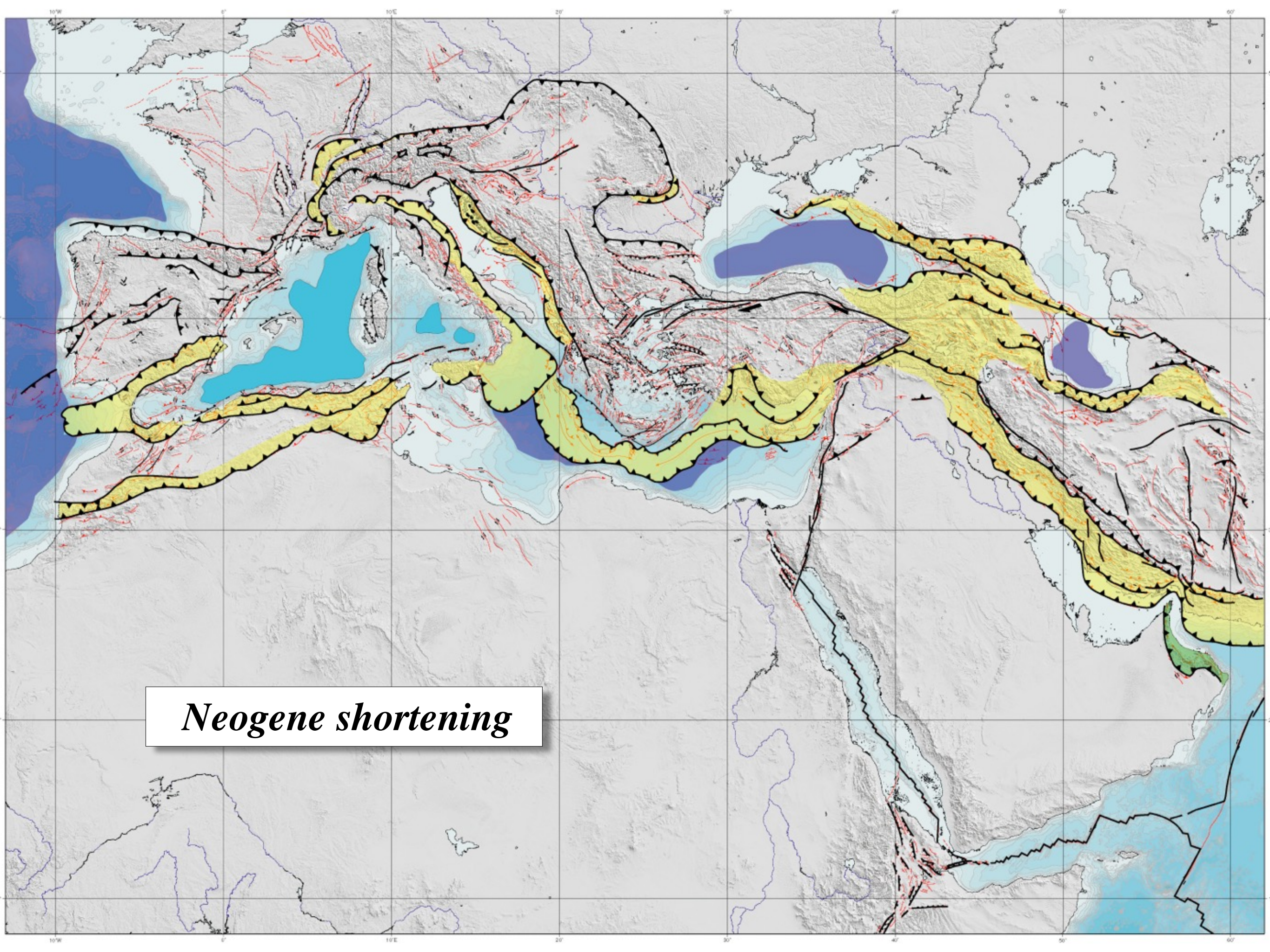
Subduction zones, major thrusts and strike-slip faults



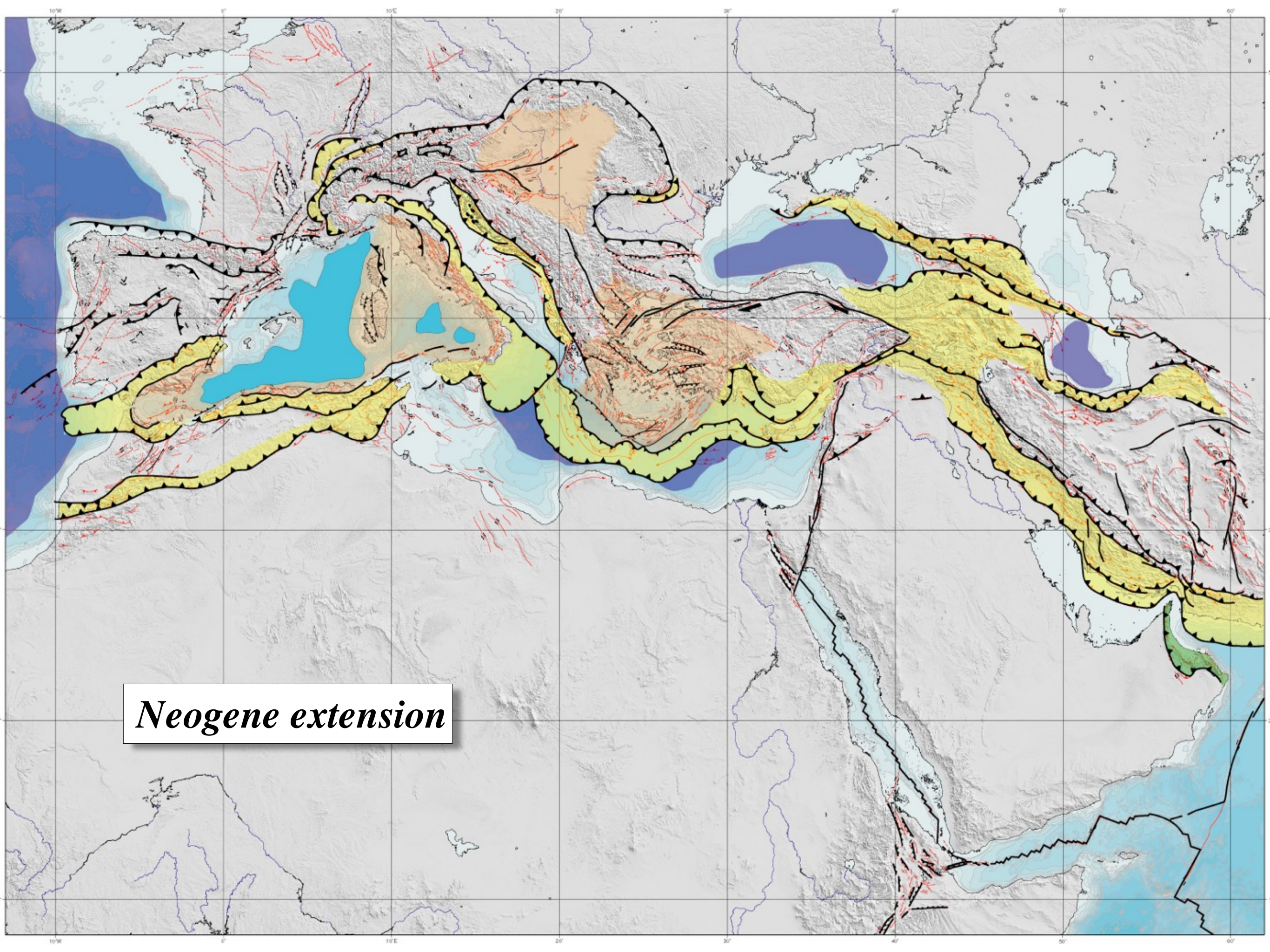
Mesozoic oceanic crust



Cenozoic oceanic crust



Neogene shortening



Neogene extension

Eurasia

ADRIA - APULIA

TETHYAN SUTURE
Late Cretaceous obduction

NAF

10 Ma

BACKARC BASINS

MESOGEEAN OCEAN
Jurassic spreading

25 Ma

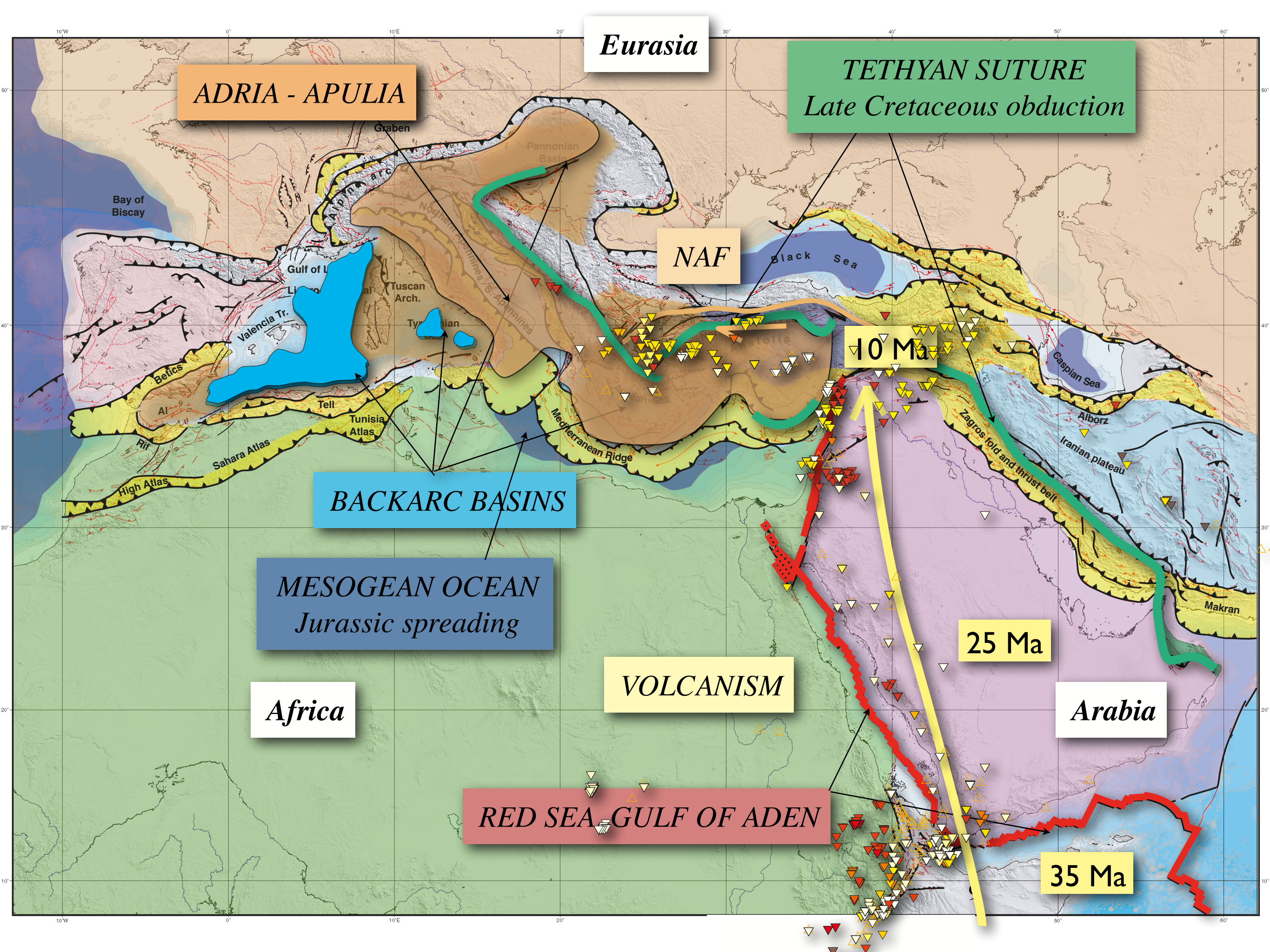
VOLCANISM

Africa

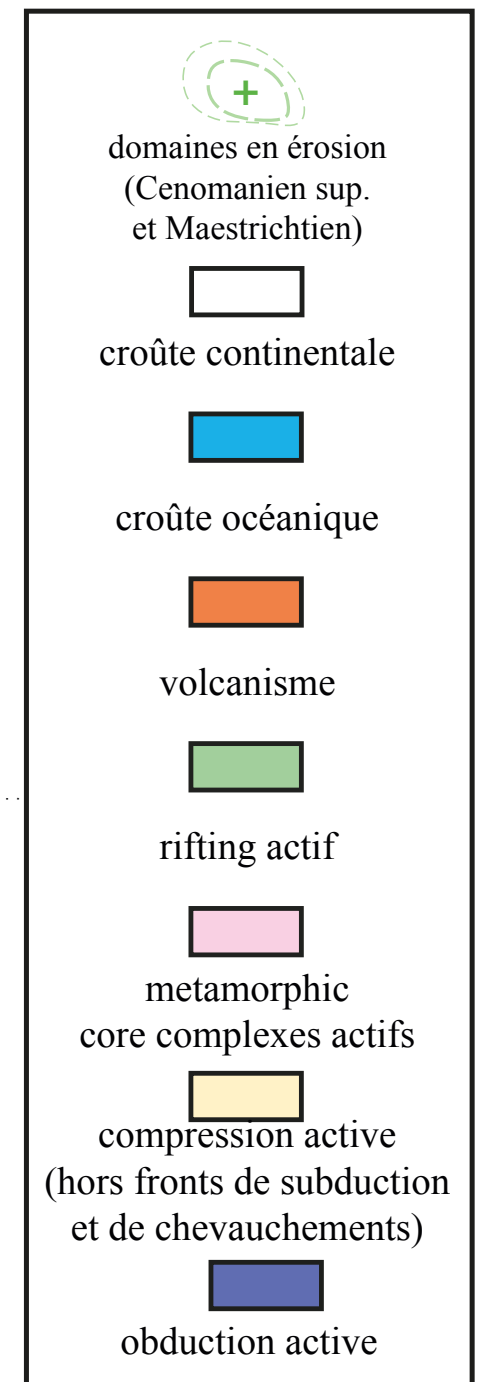
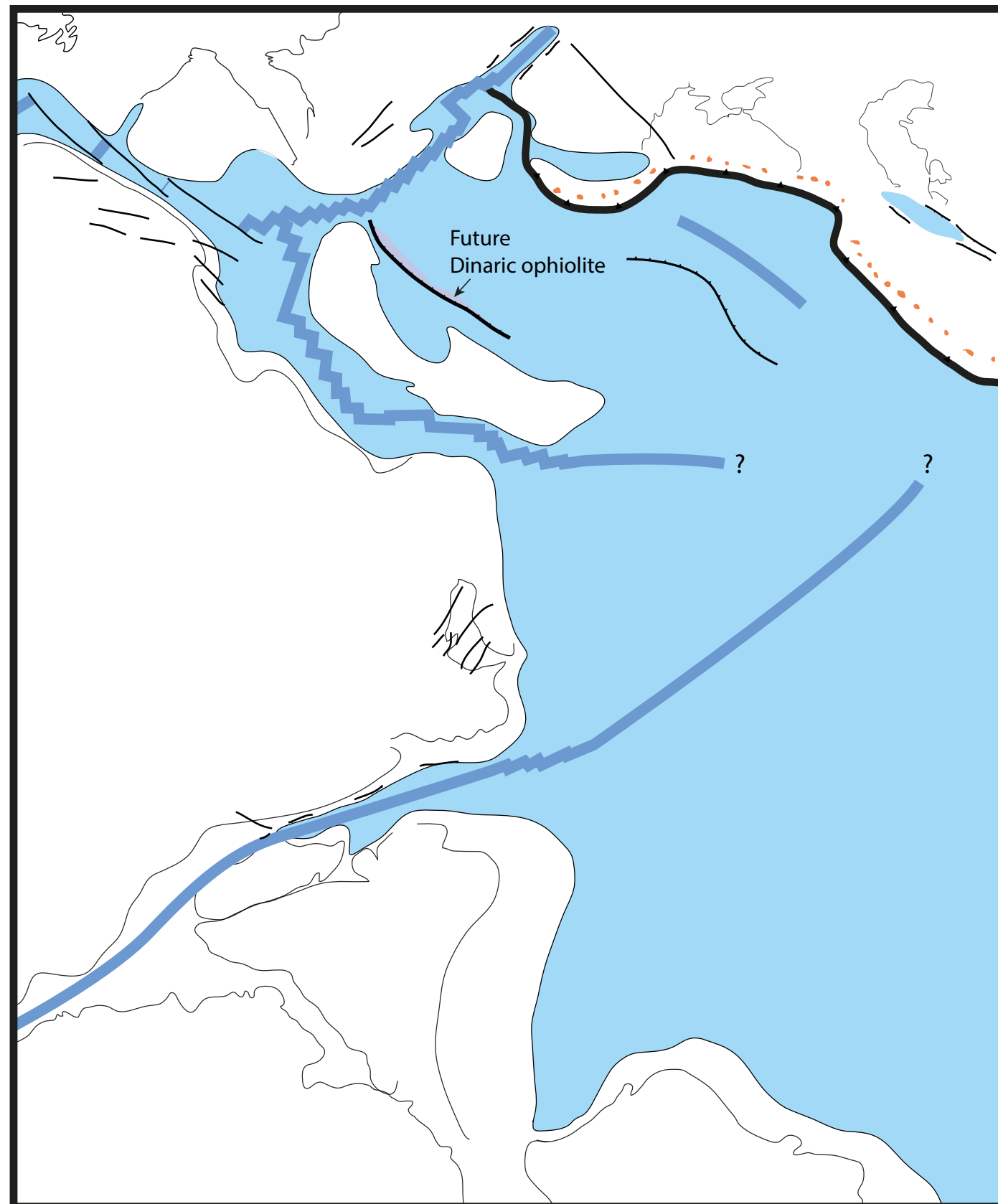
Arabia

RED SEA - GULF OF ADEN

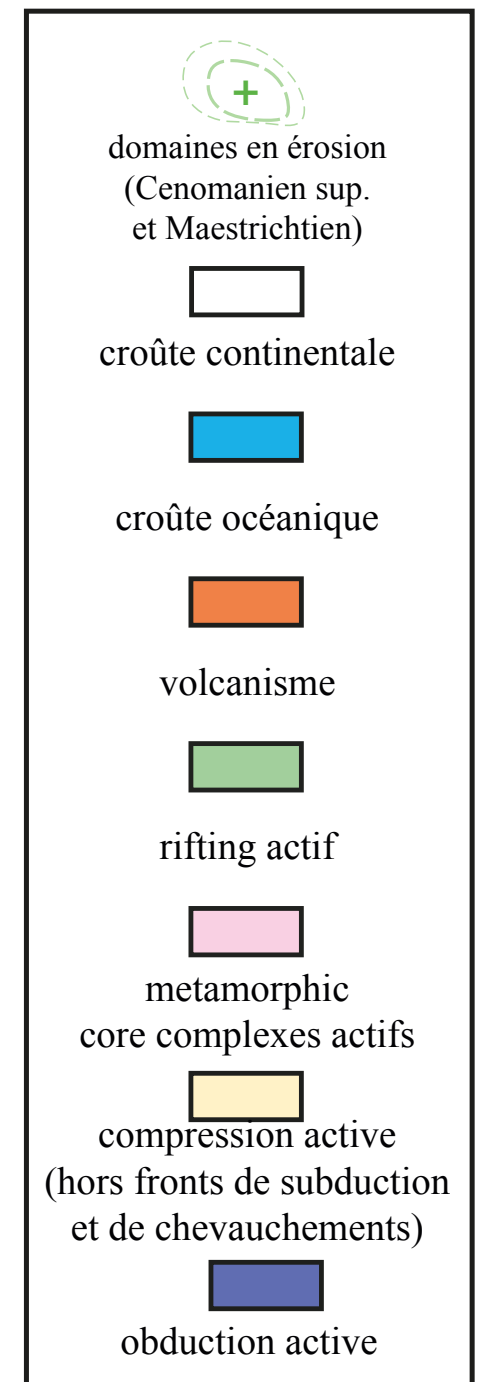
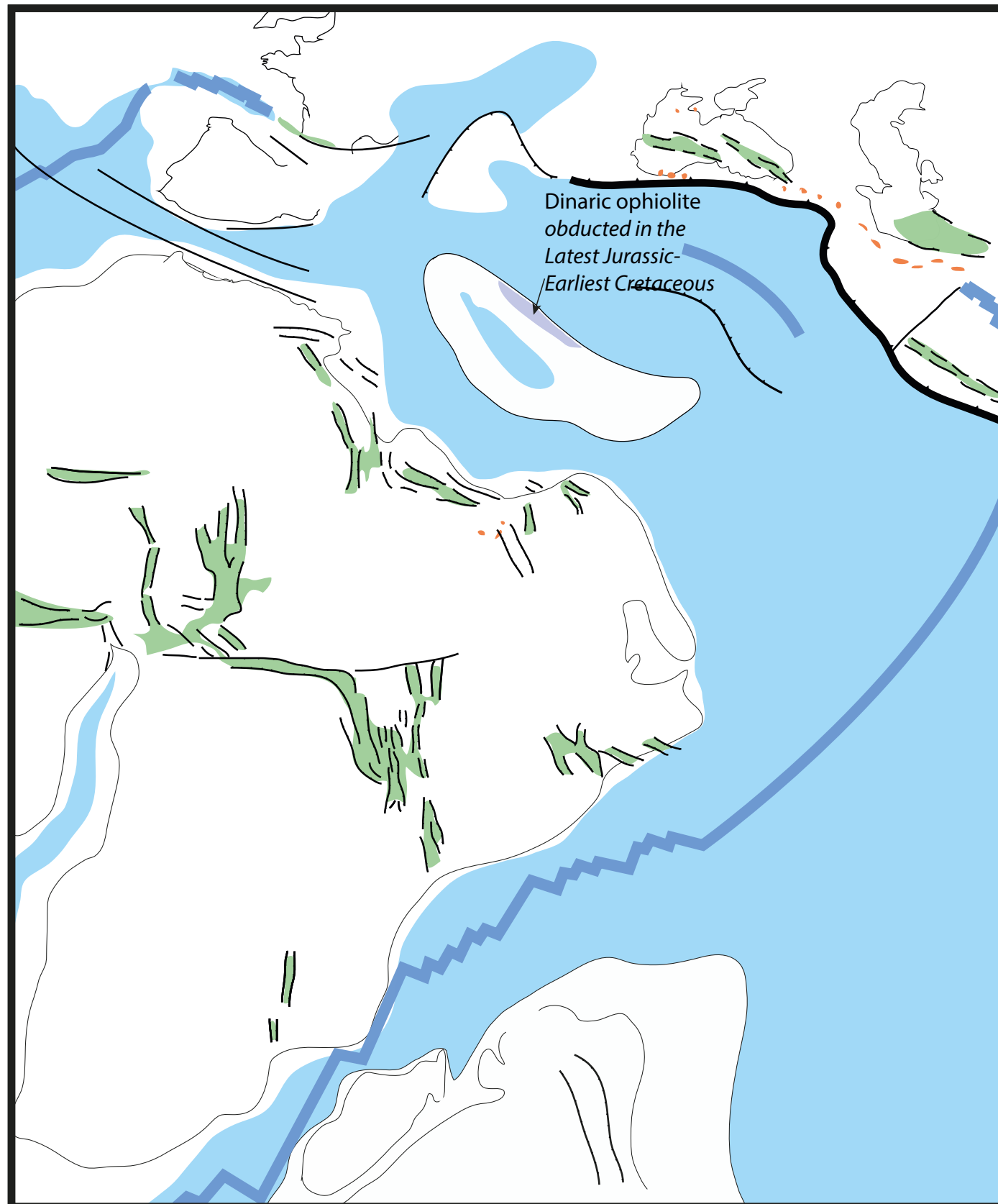
35 Ma



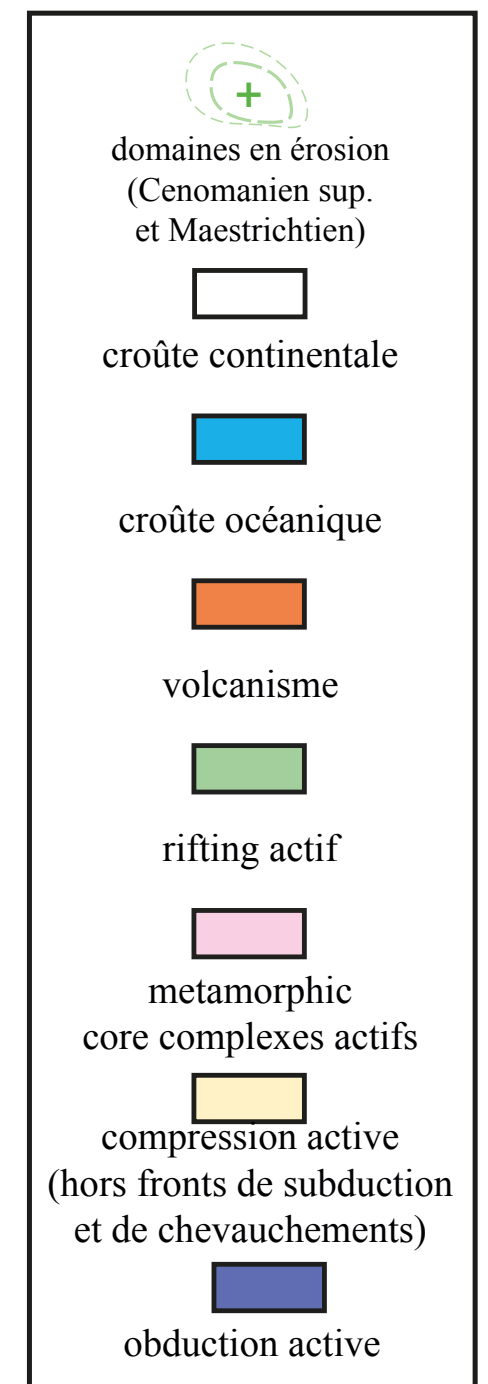
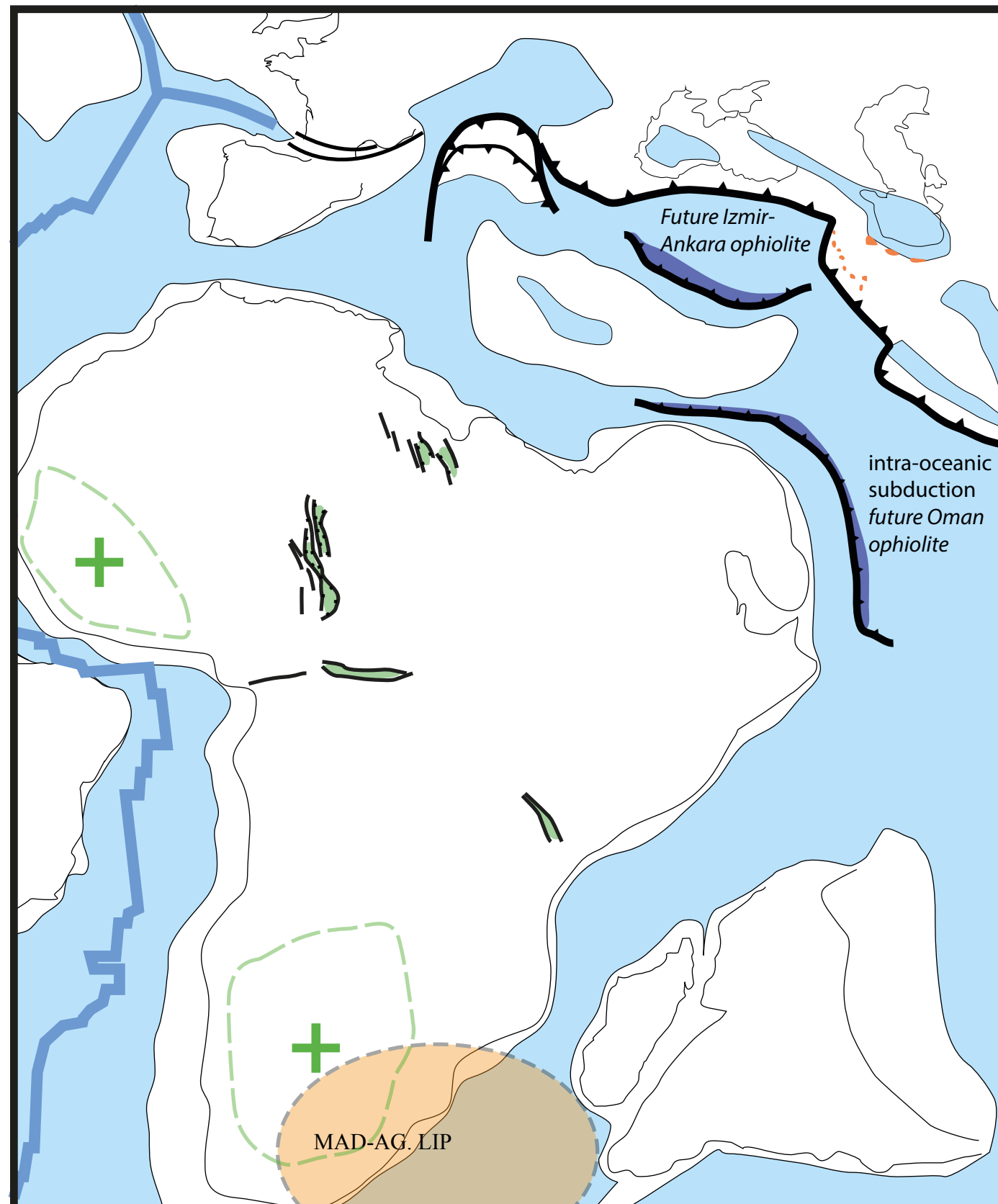
Jurassic ~170 Ma



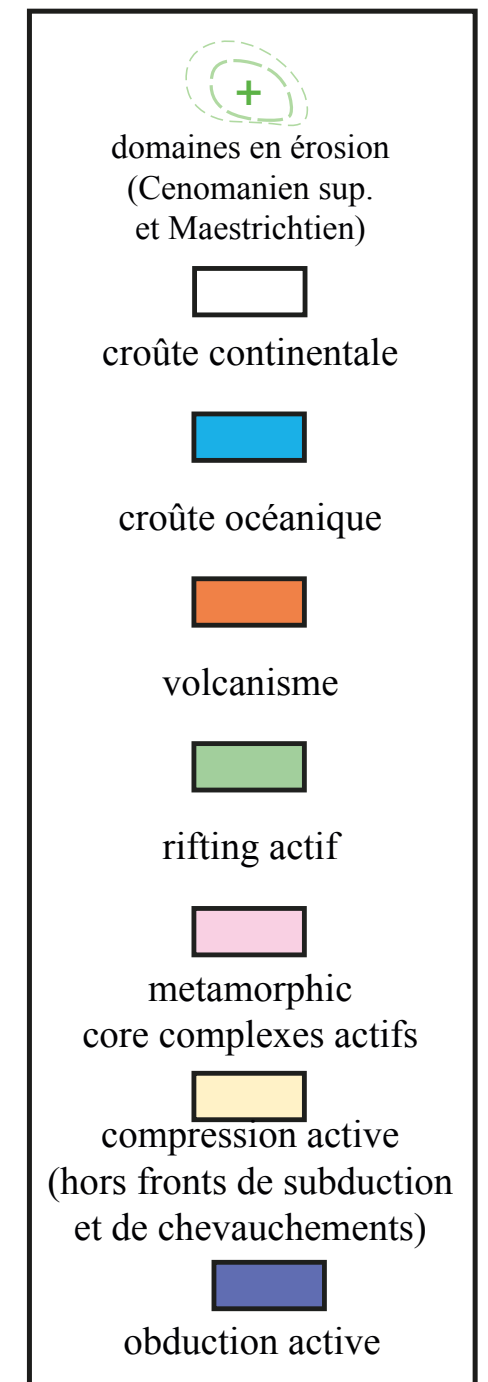
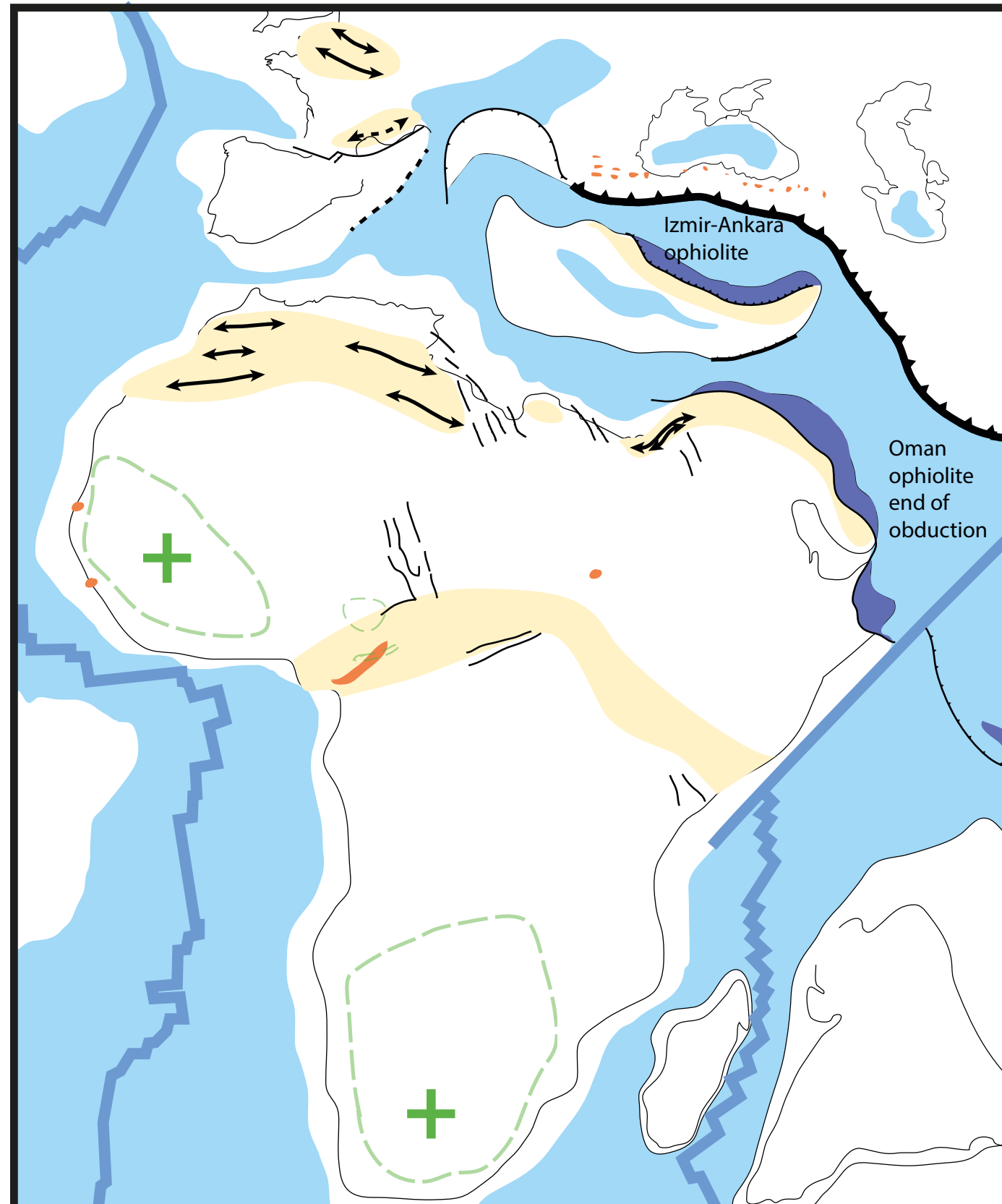
Early Crétacé ~120 Ma



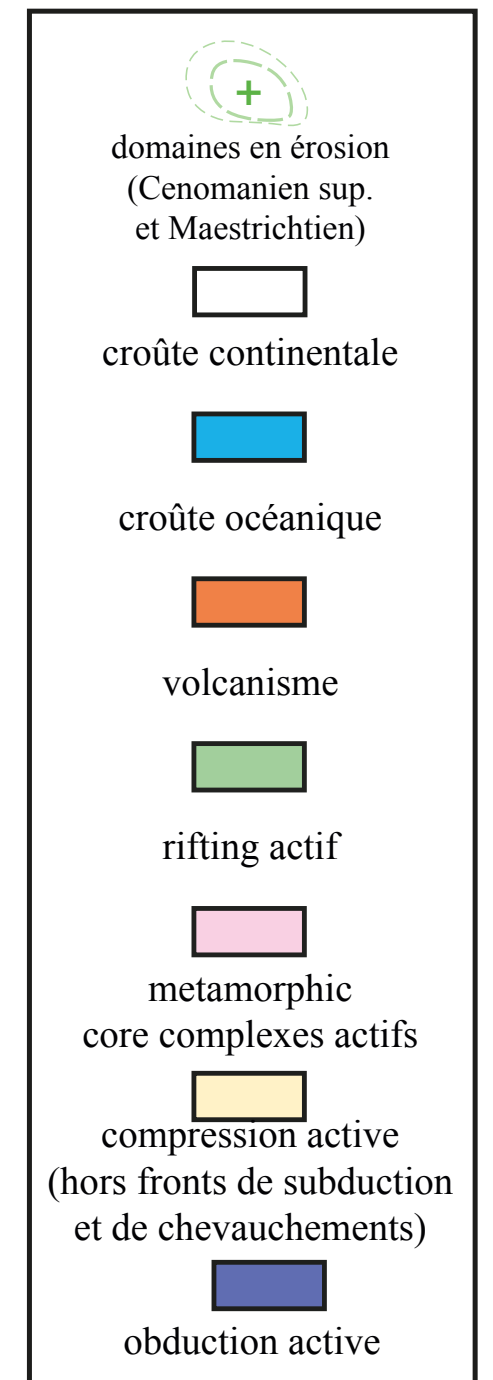
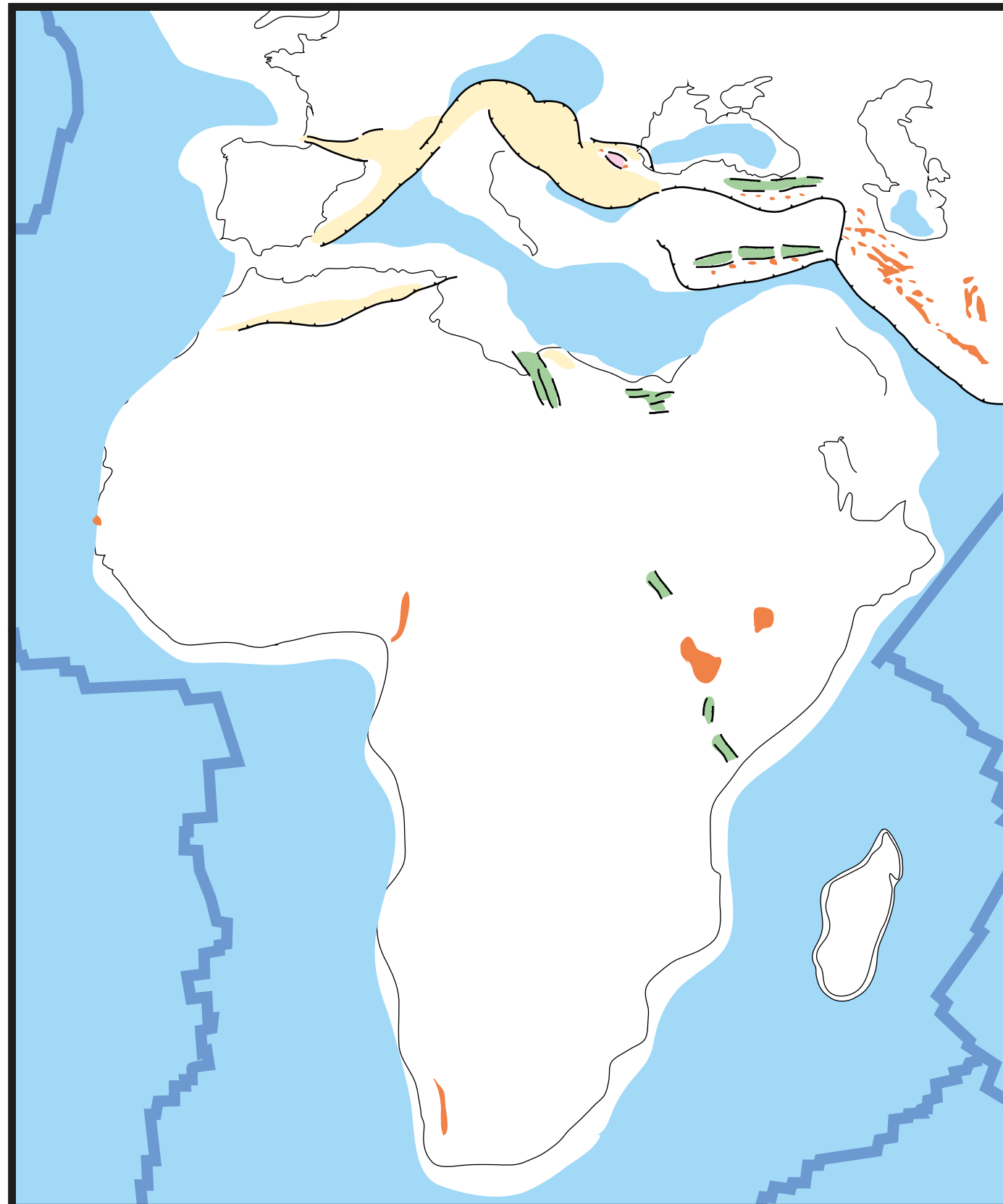
Late Cretaceous ~95 Ma



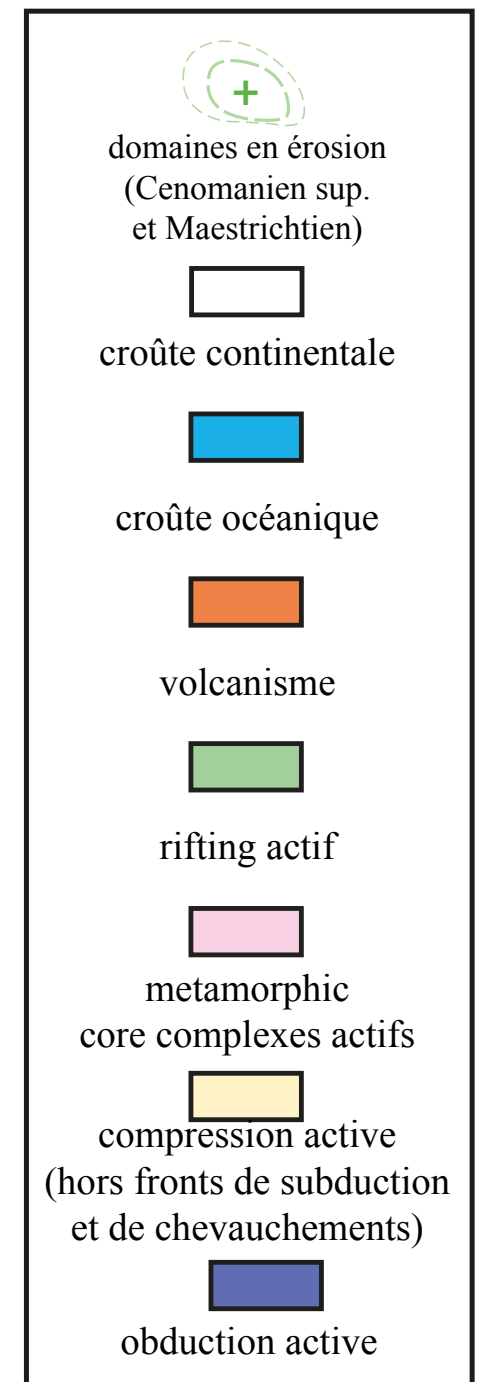
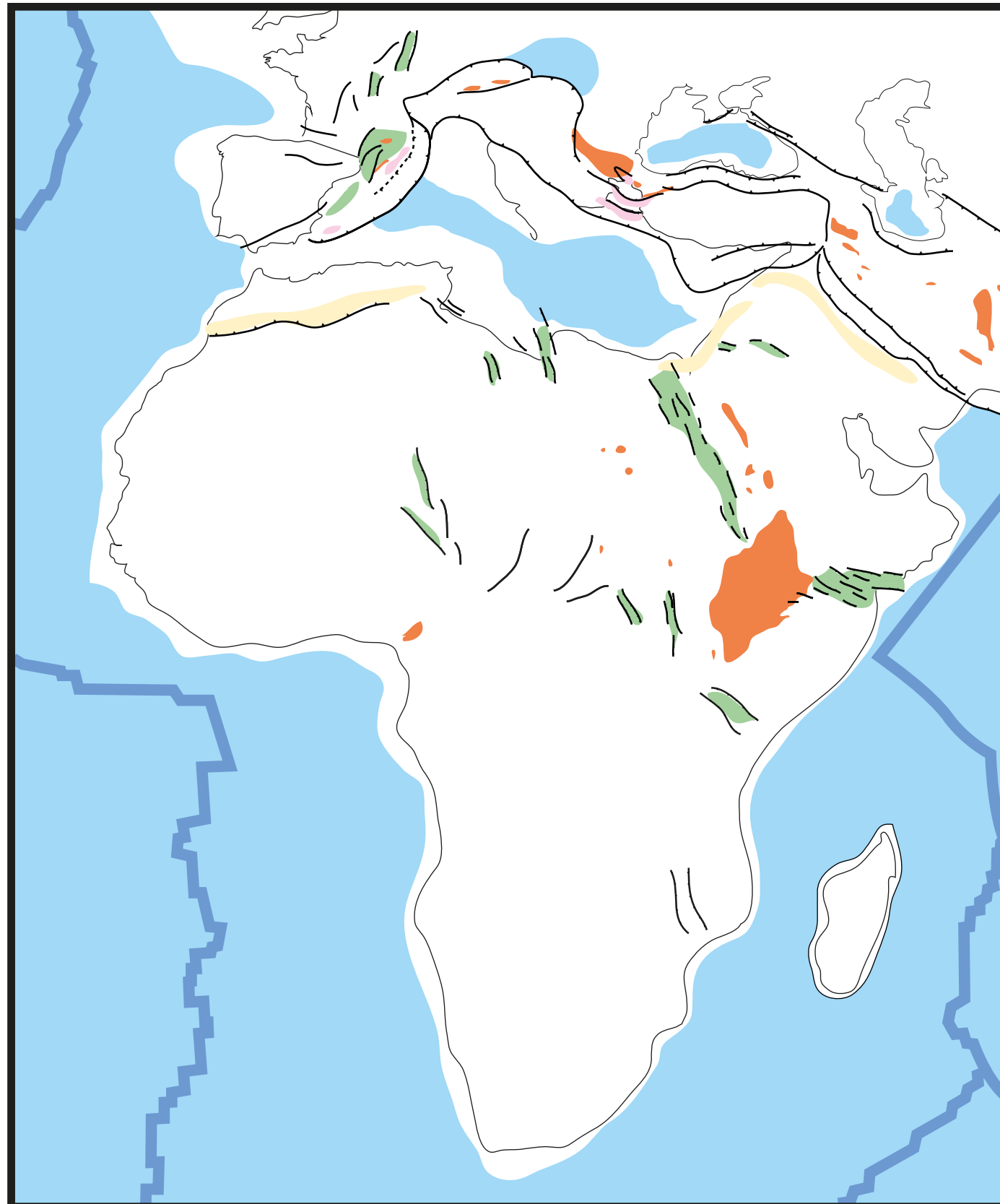
Late Cretaceous ~80 Ma



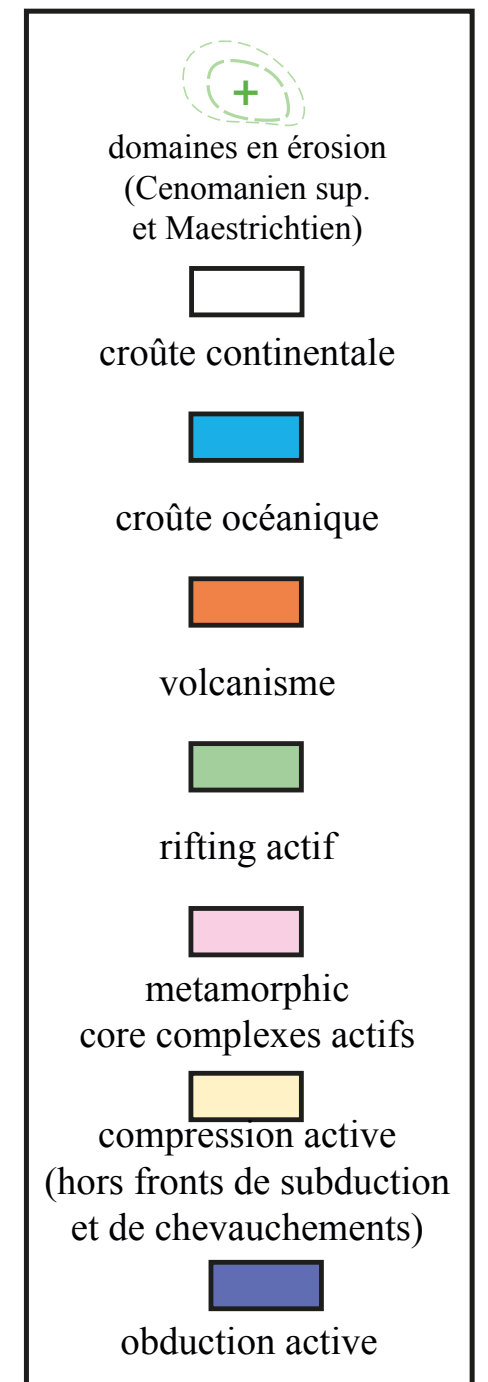
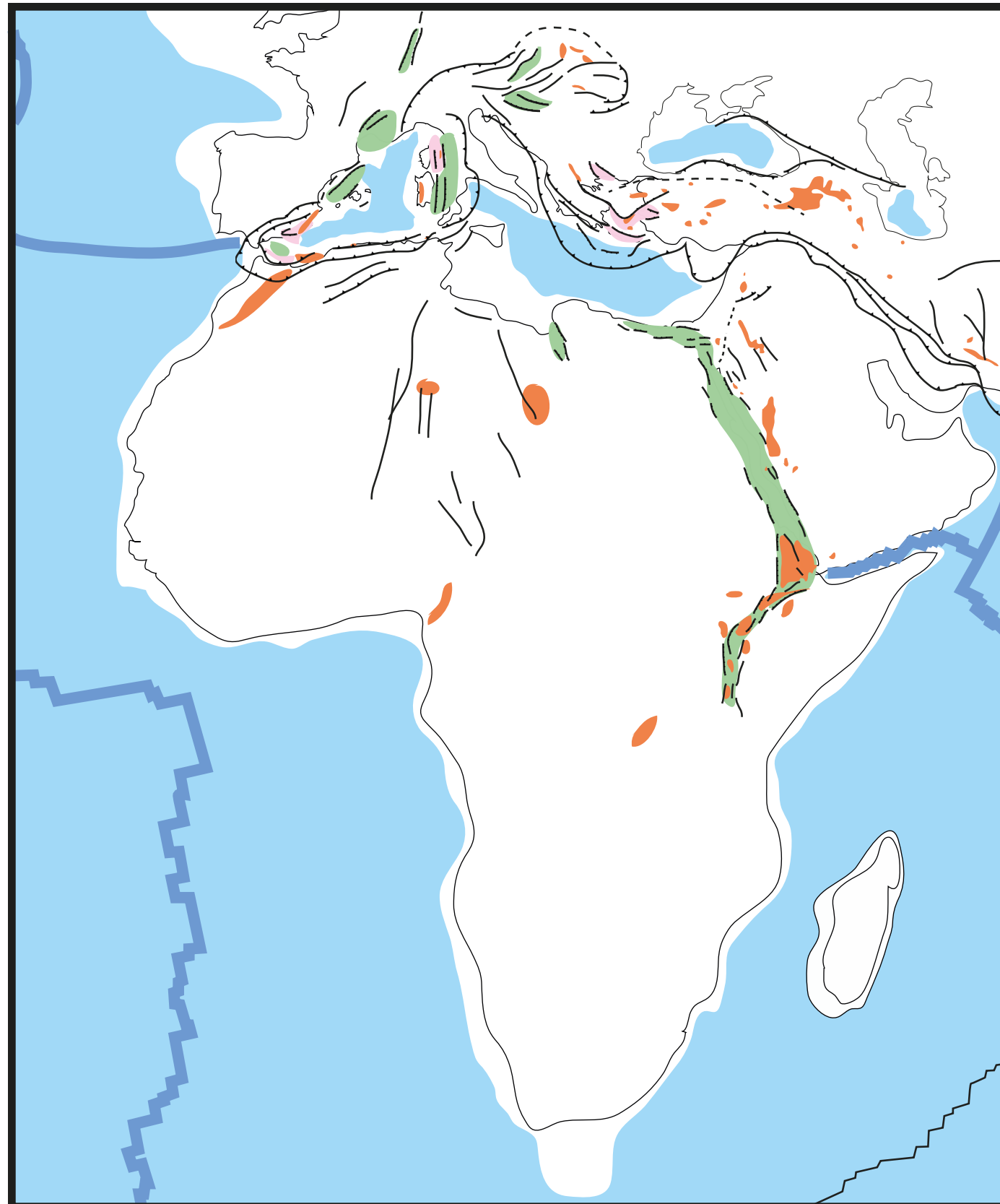
Eocene ~45 Ma



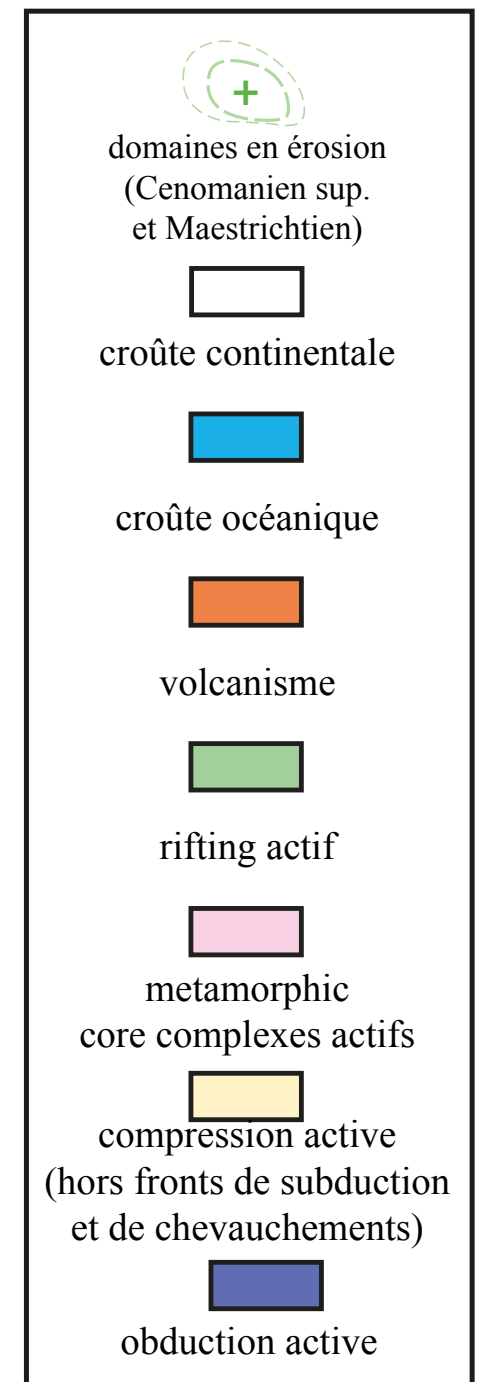
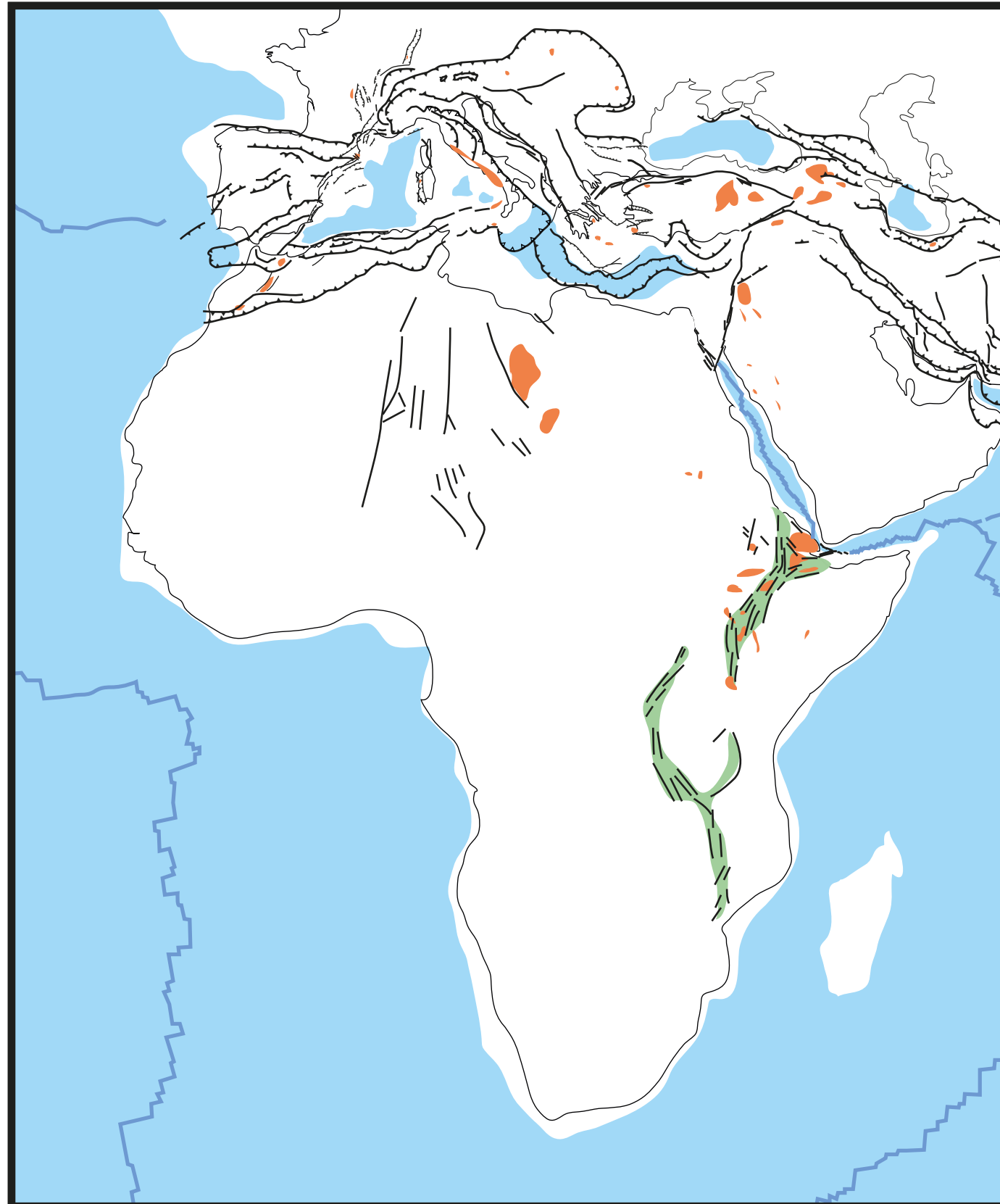
Oligocene ~30 Ma

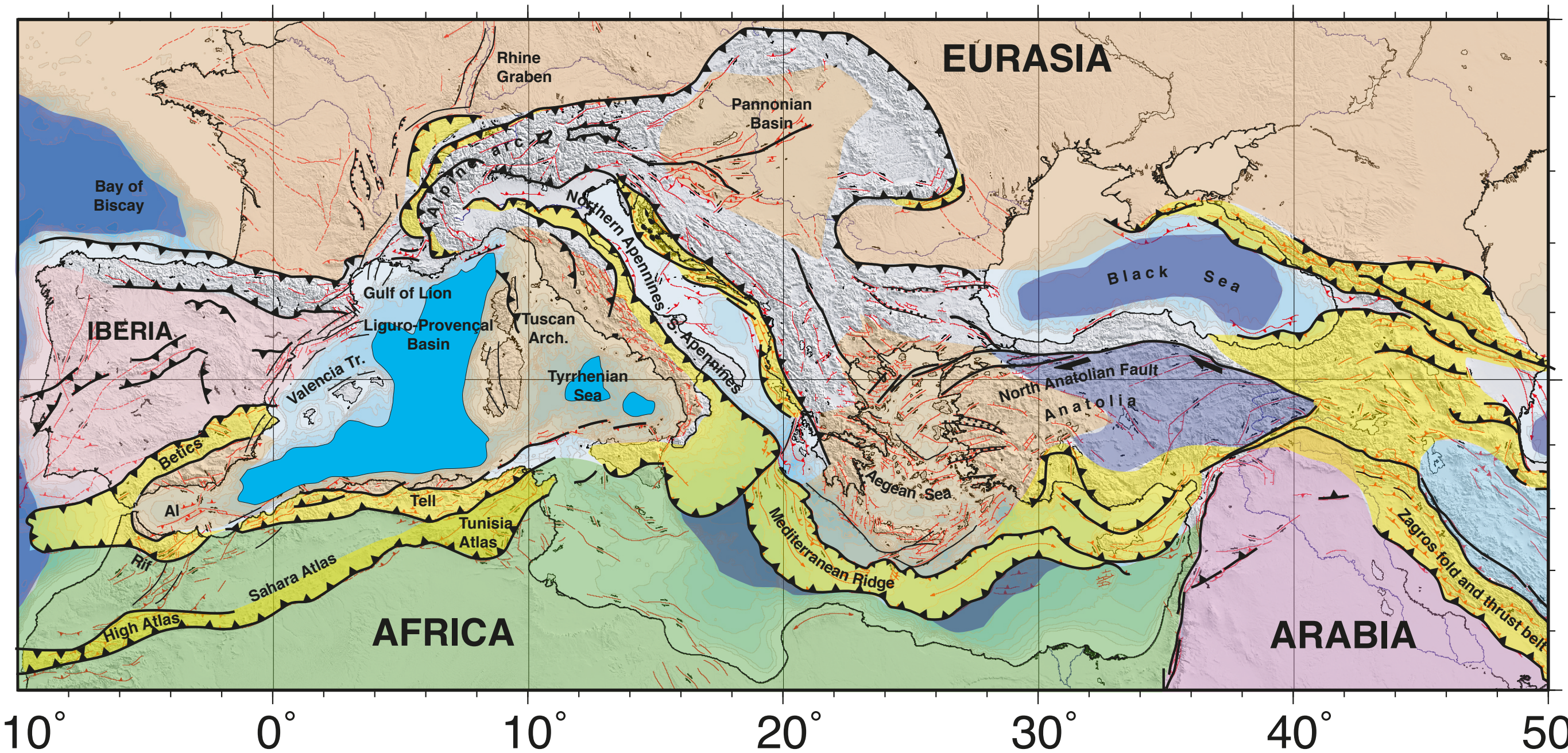


Miocene ~10 Ma

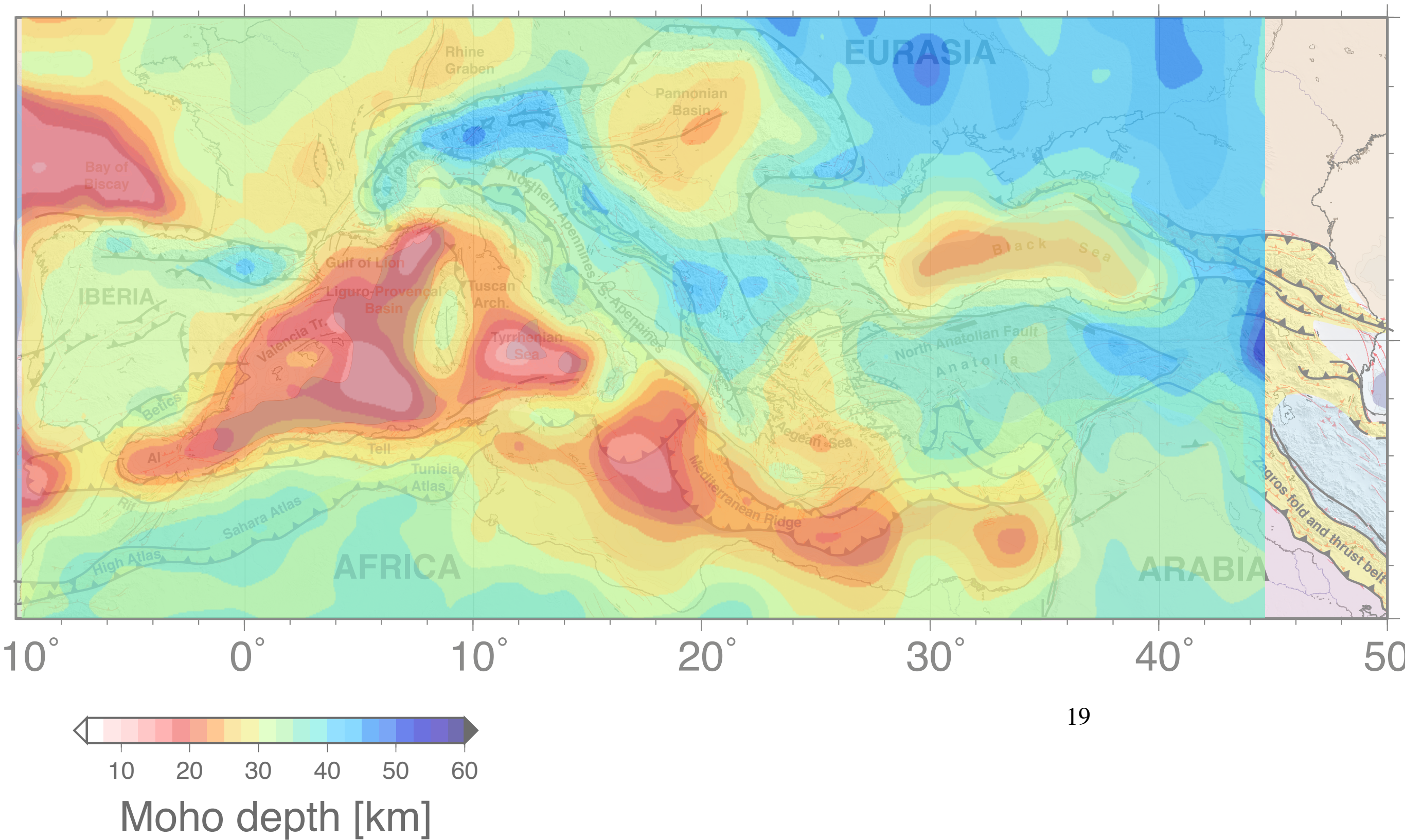


Present

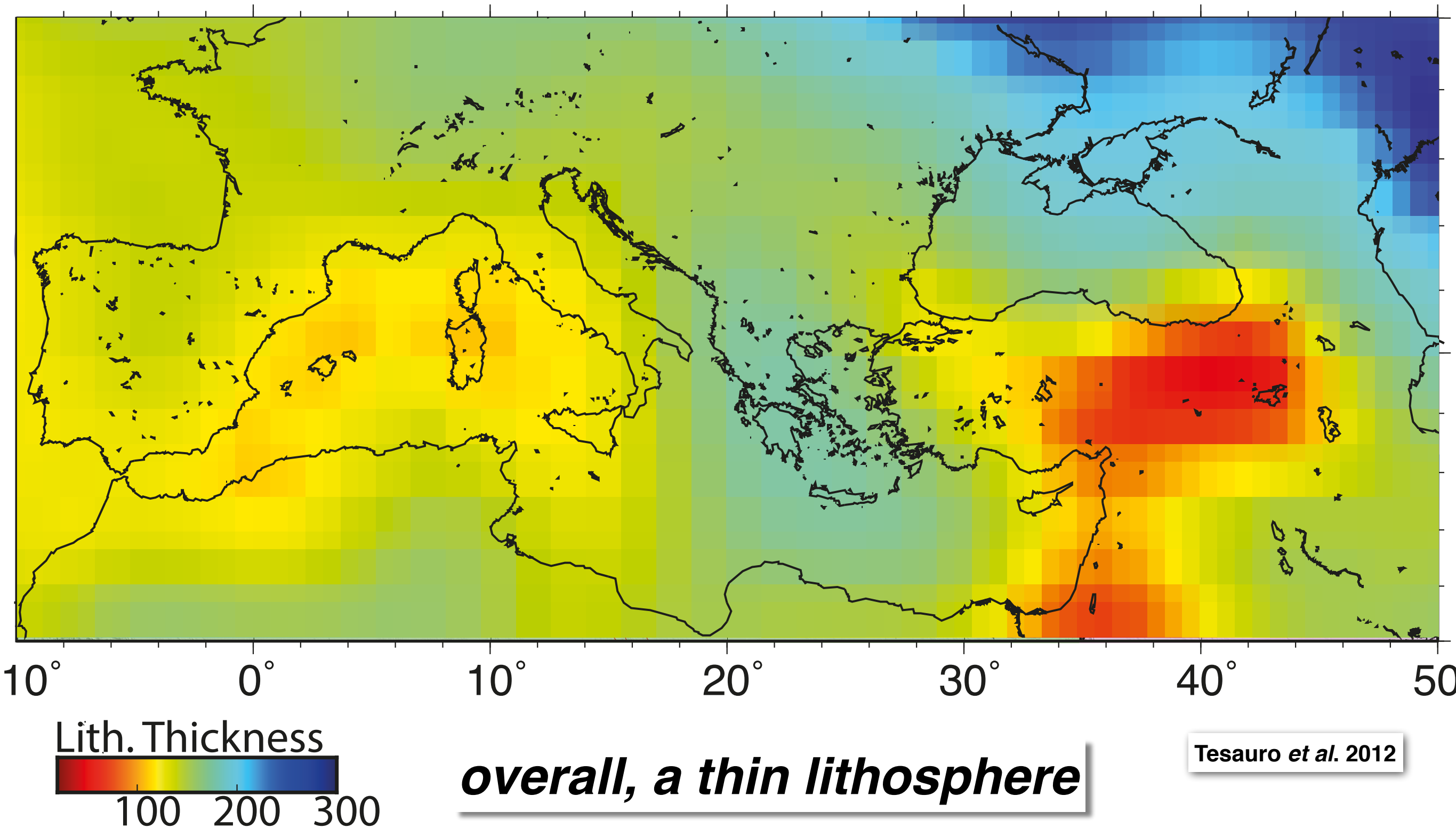




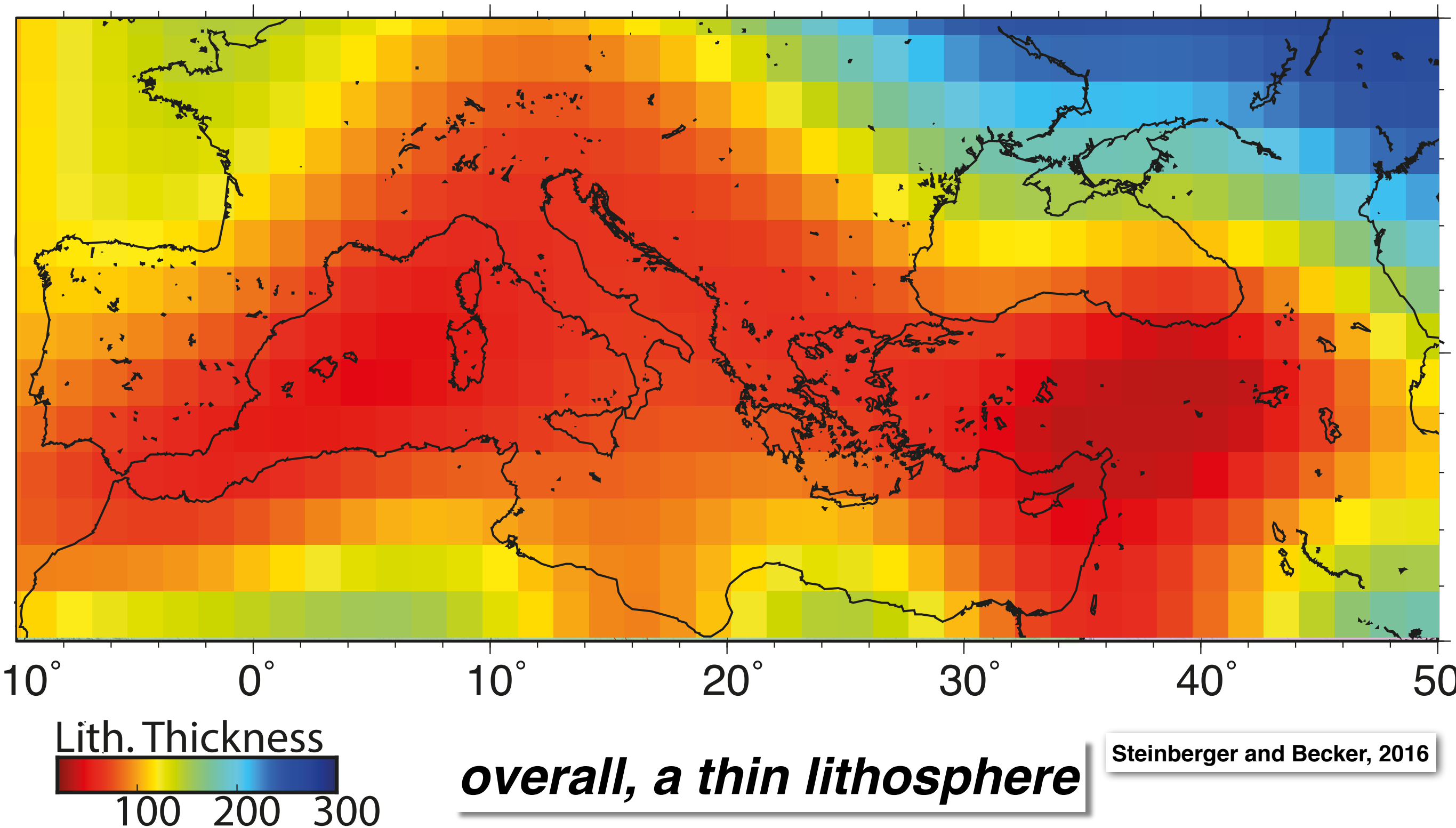
Crustal thickness



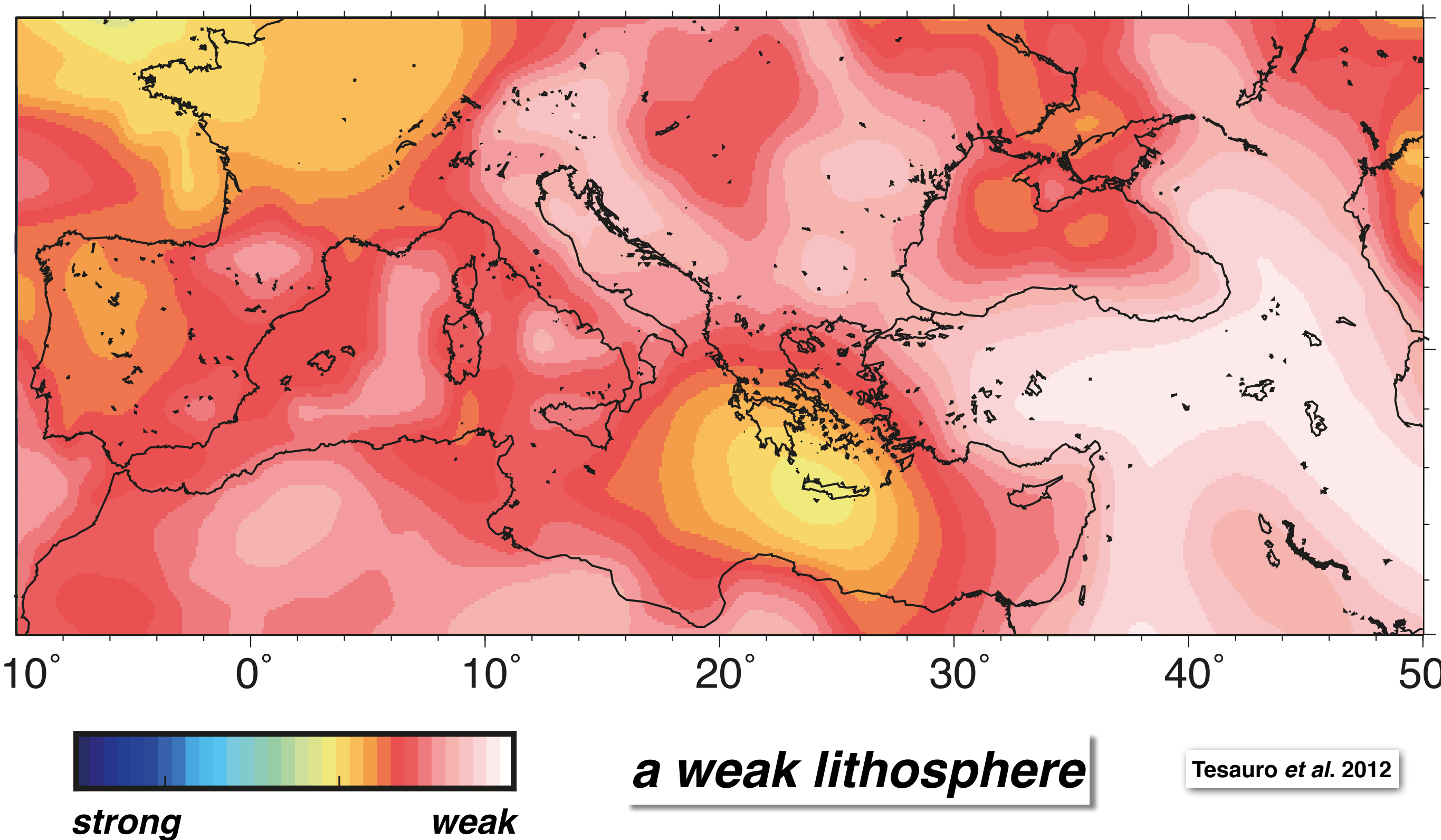
Lithospheric thickness



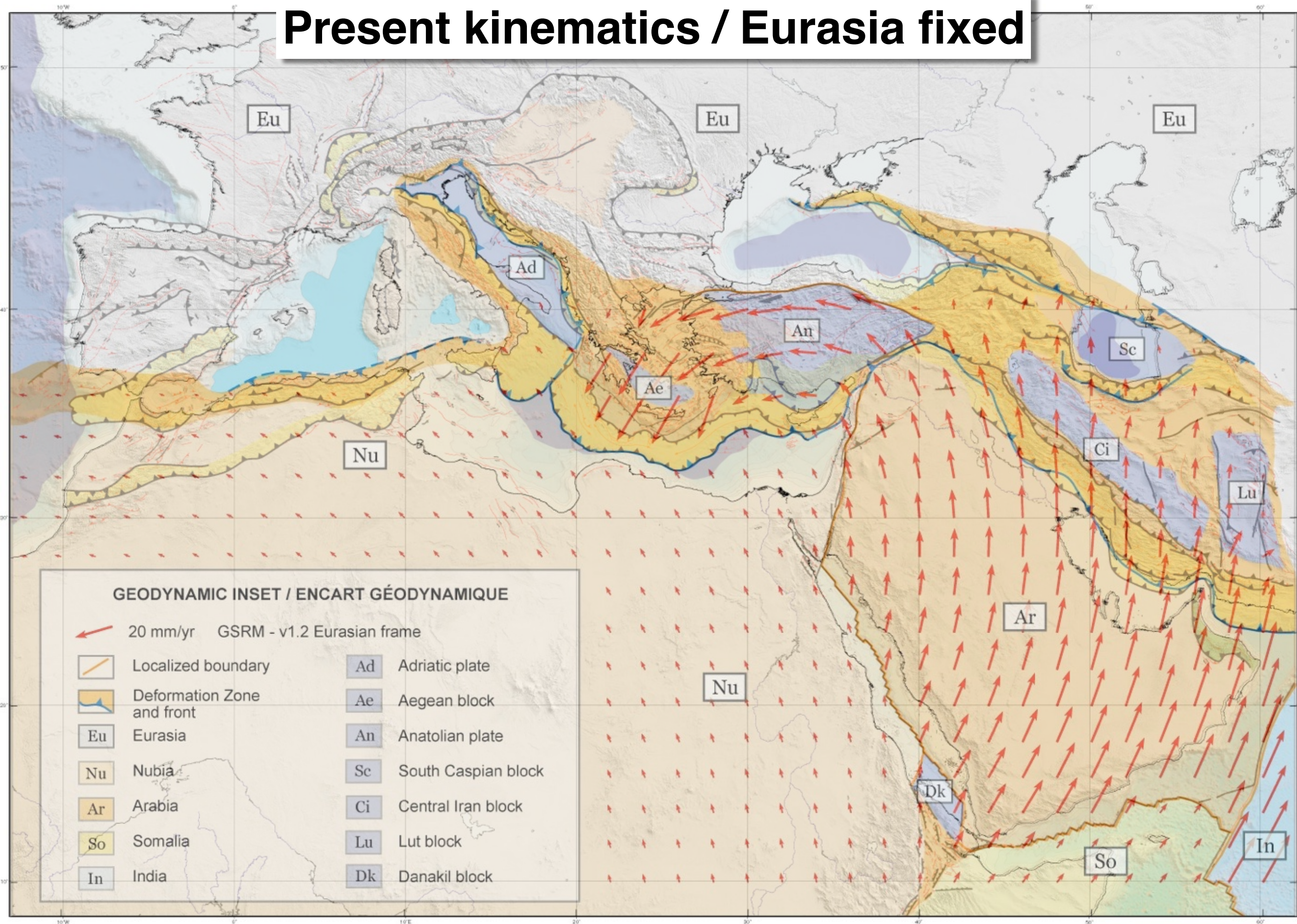
Lithospheric thickness



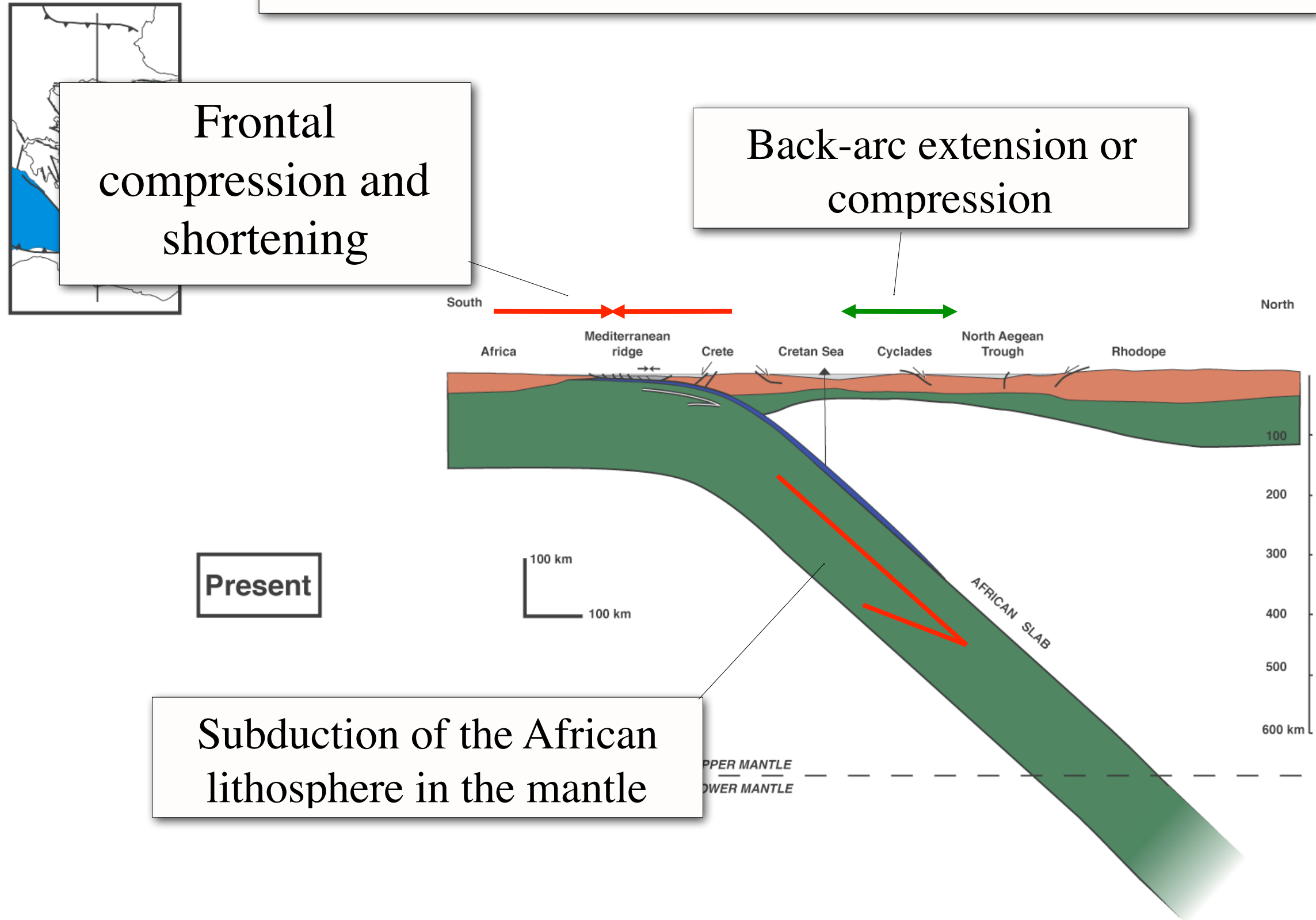
Lithosphere resistance



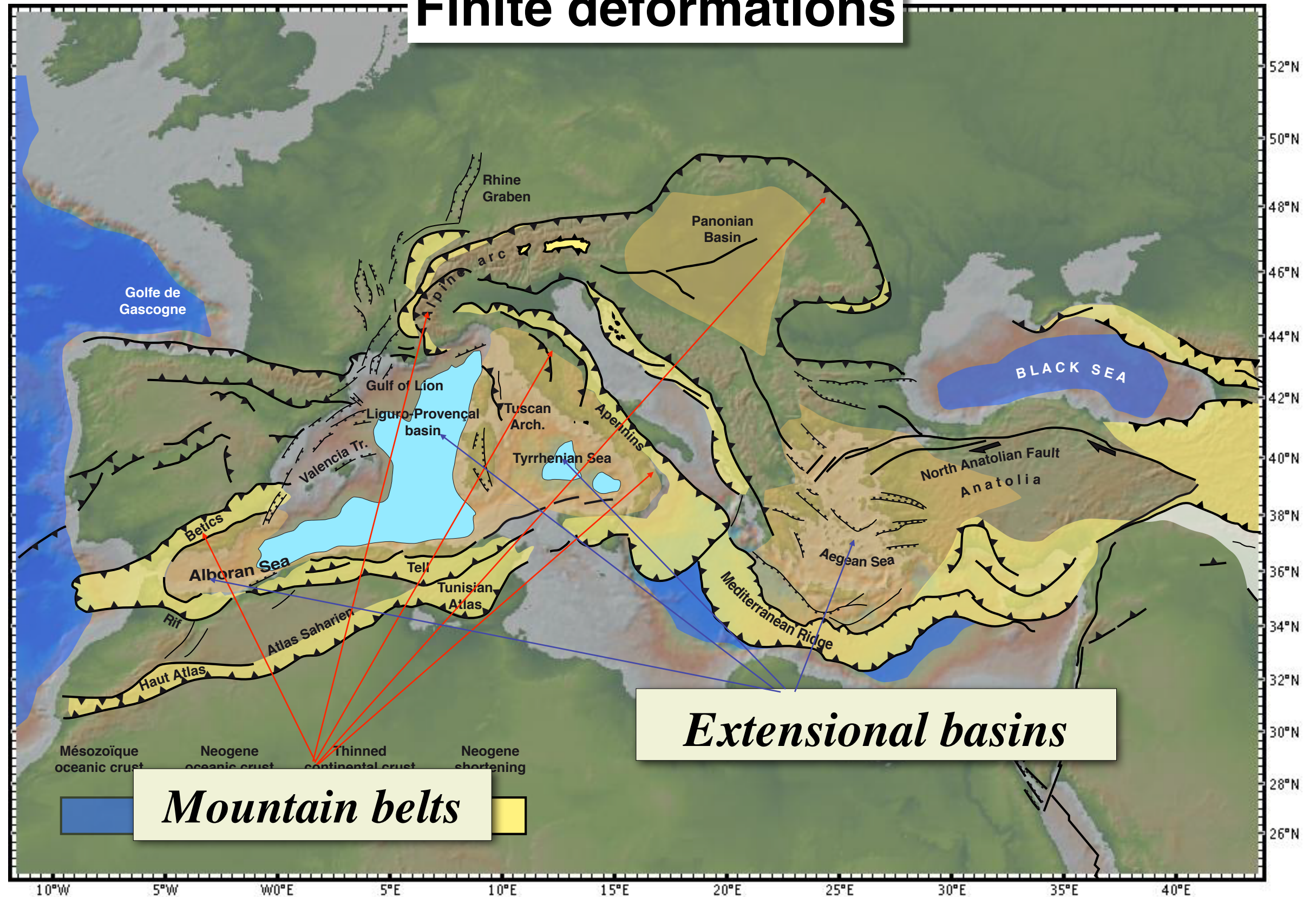
Present kinematics / Eurasia fixed



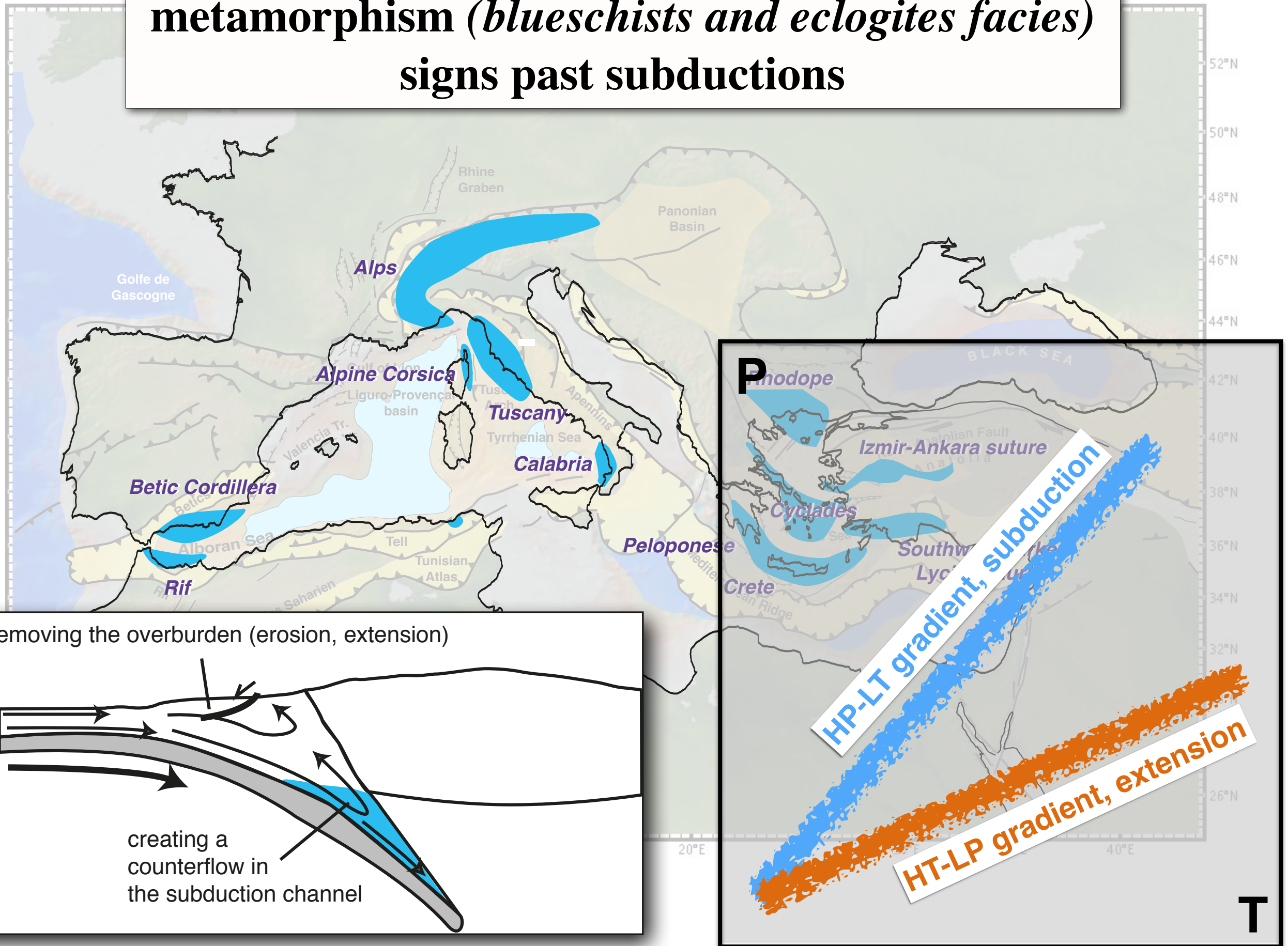
Subduction is the first-order geodynamic driver of Mediterranean tectonics



Finite deformations

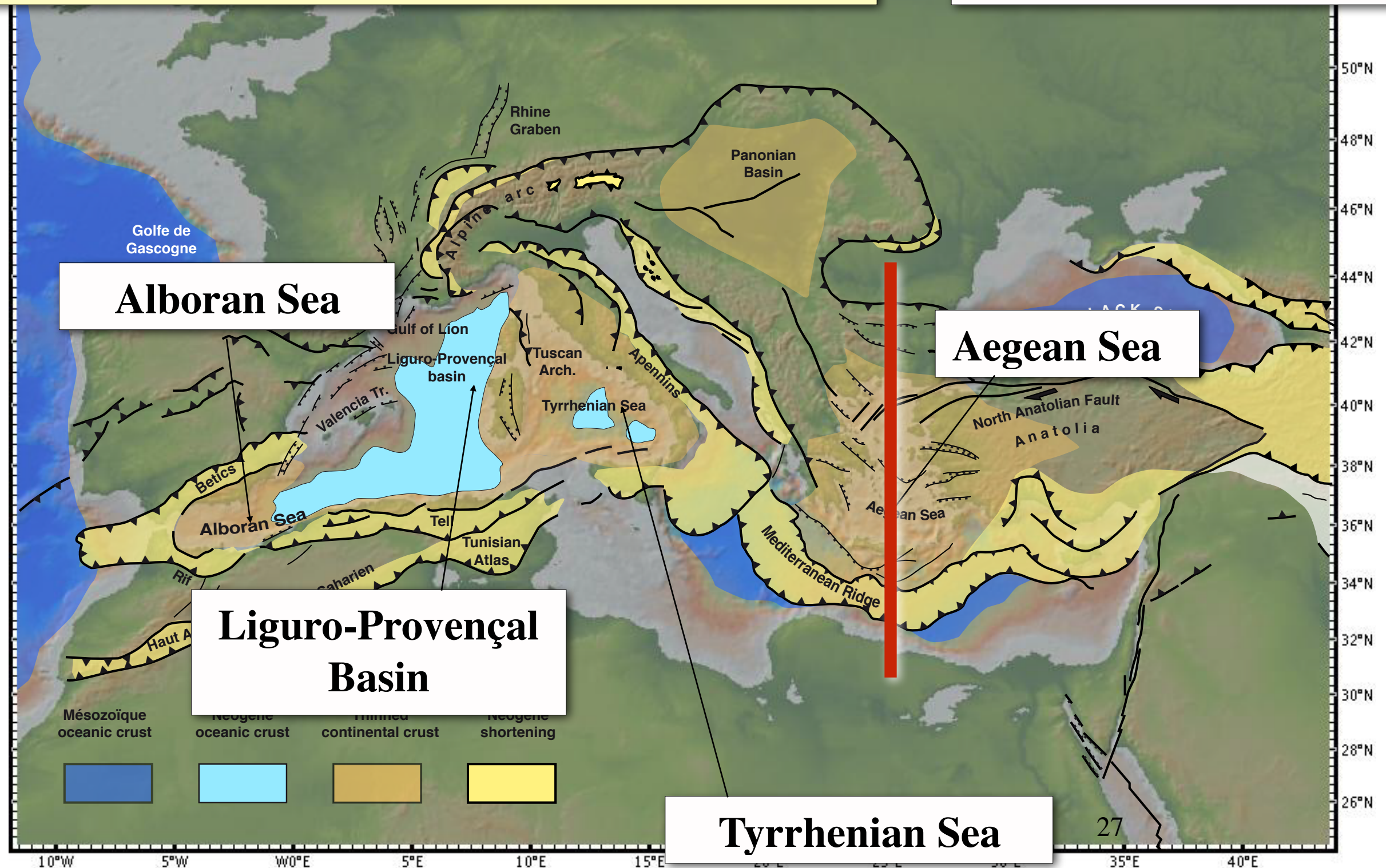


High-pressure/low-temperature metamorphism (*blueschists and eclogites facies*) signs past subductions



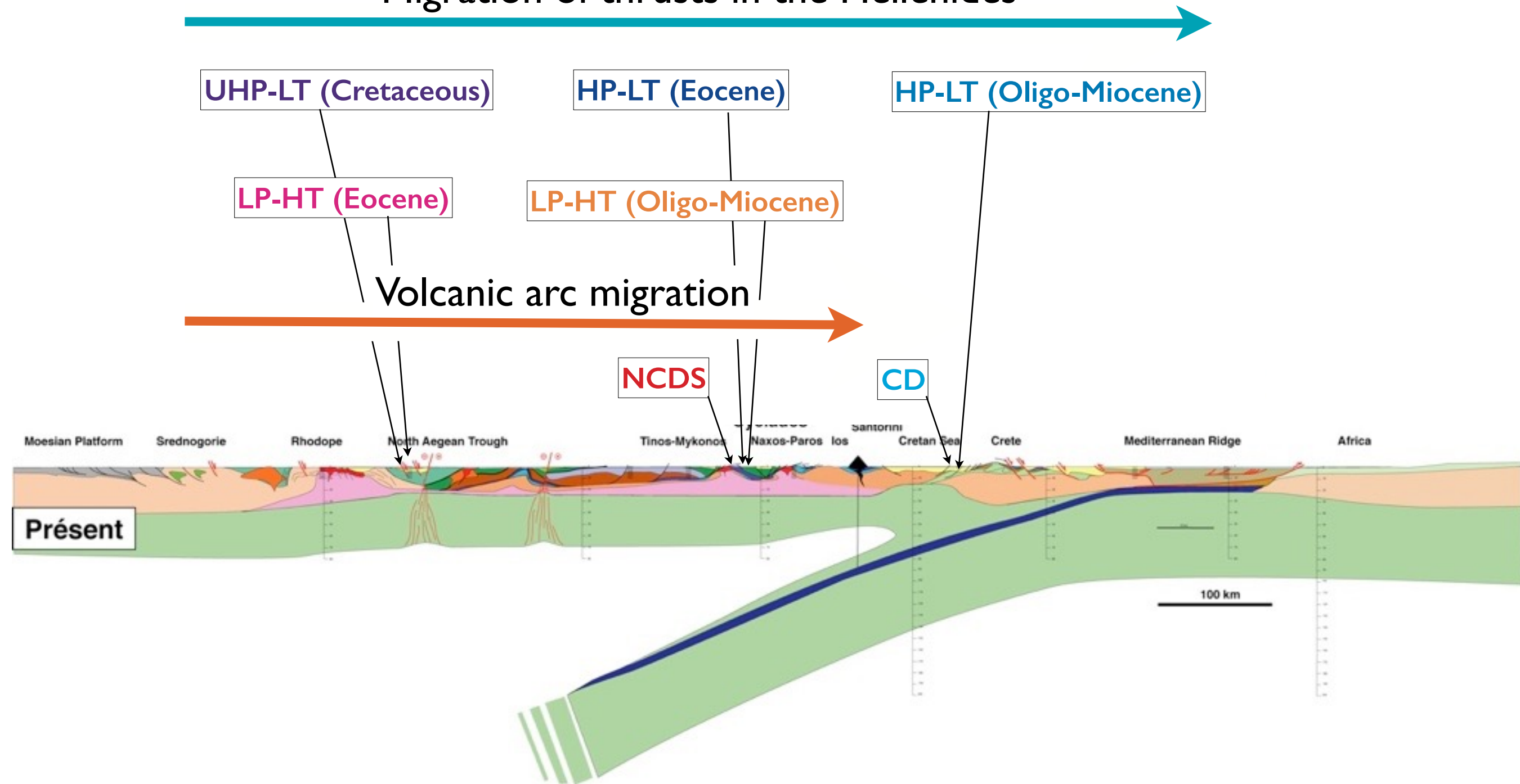
Back-arc extension started, or rather accelerated, ~35 Myrs ago

Extensional
basins

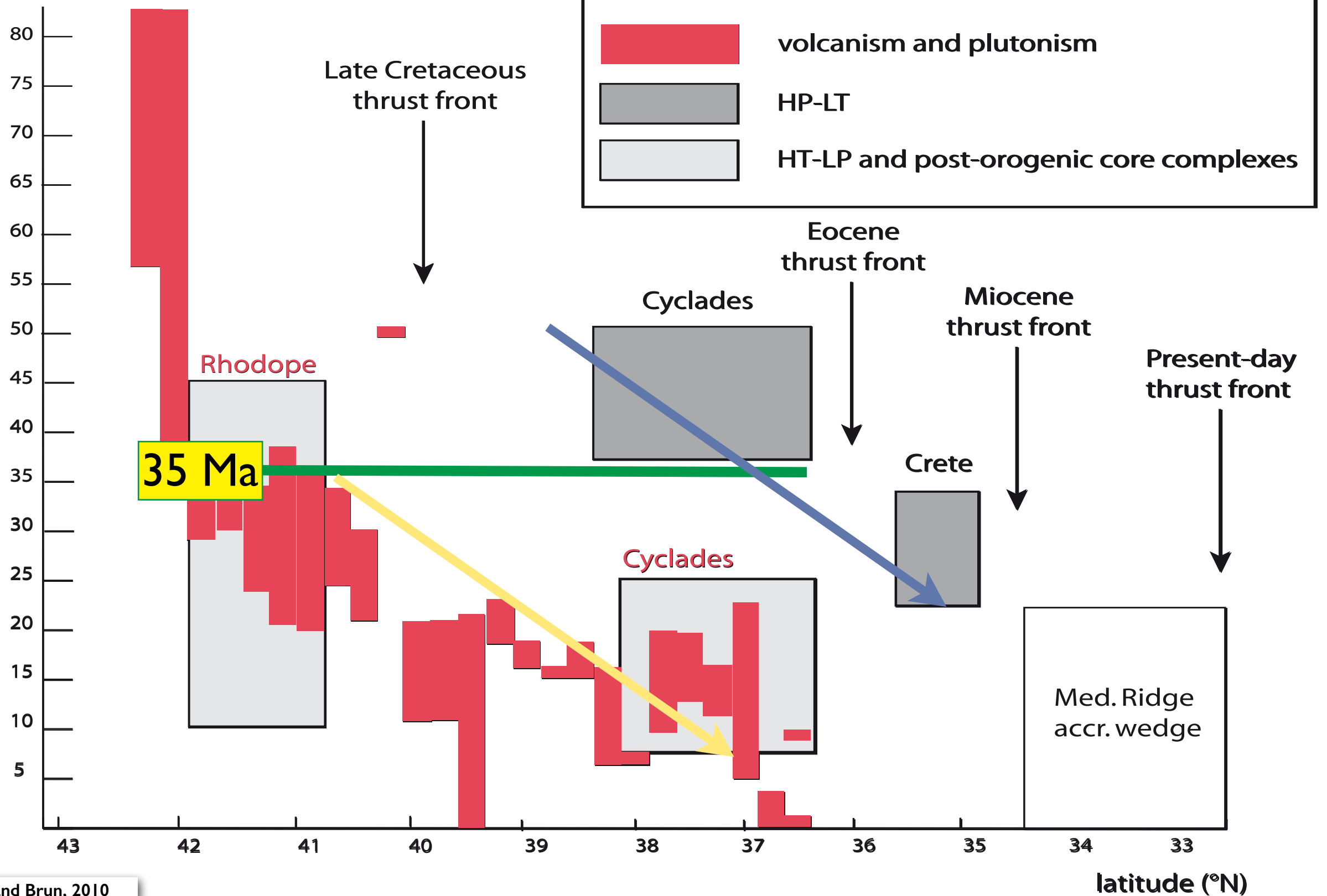


A N-S lithospheric cross-section

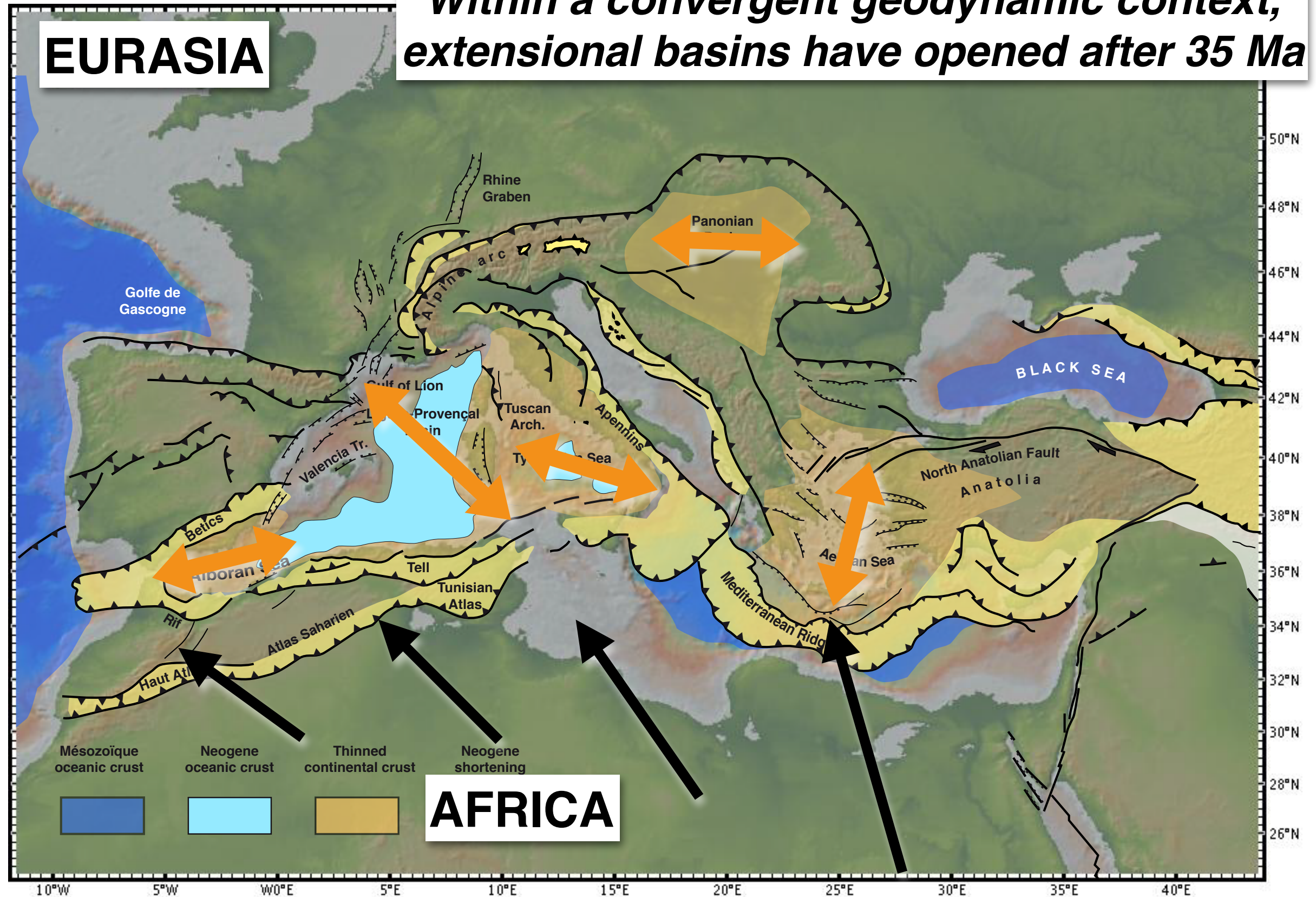
Migration of thrusts in the Hellenides



Age (Ma)

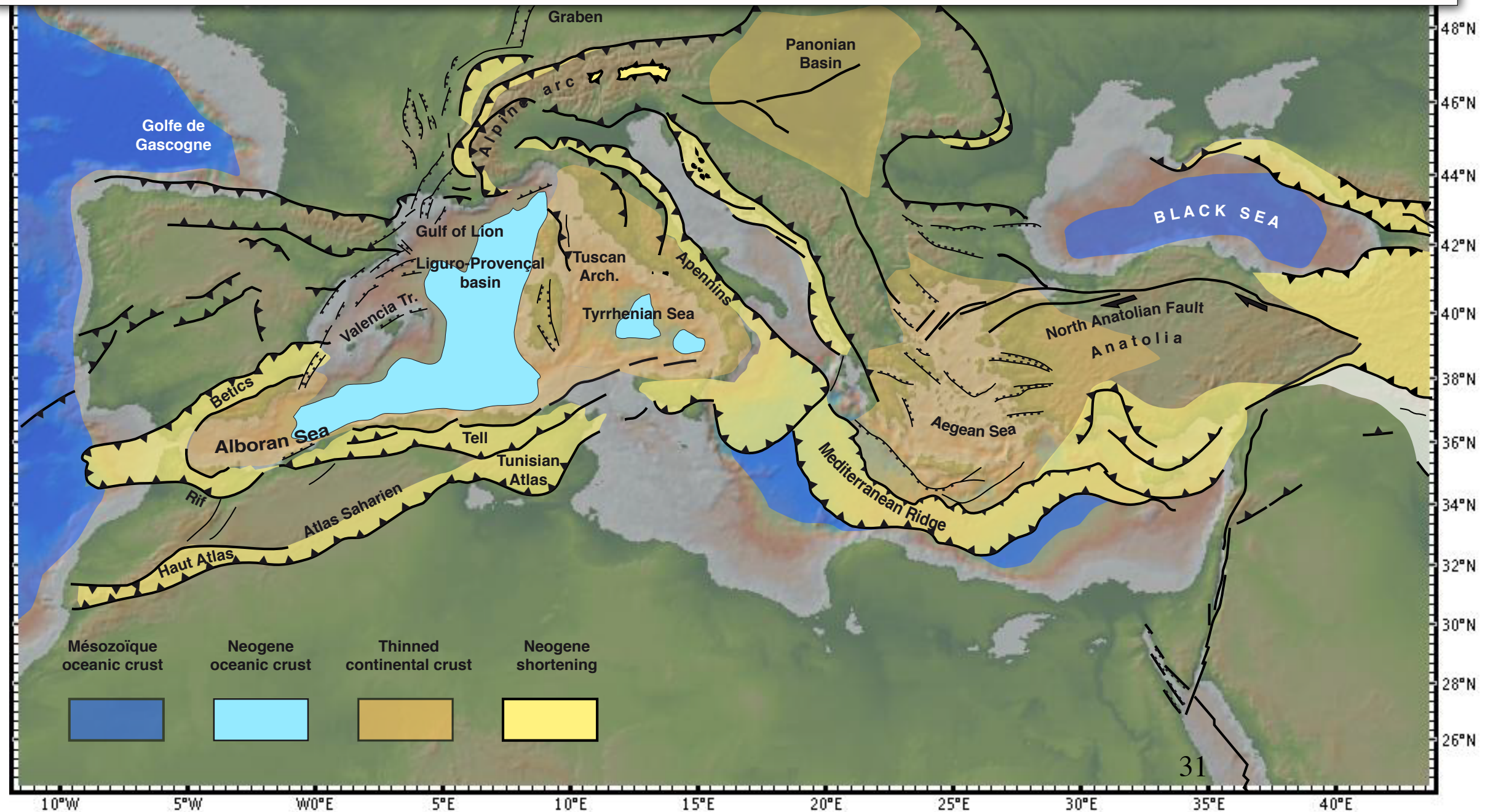


*Within a convergent geodynamic context,
extensional basins have opened after 35 Ma*



Which forces control this evolution ?

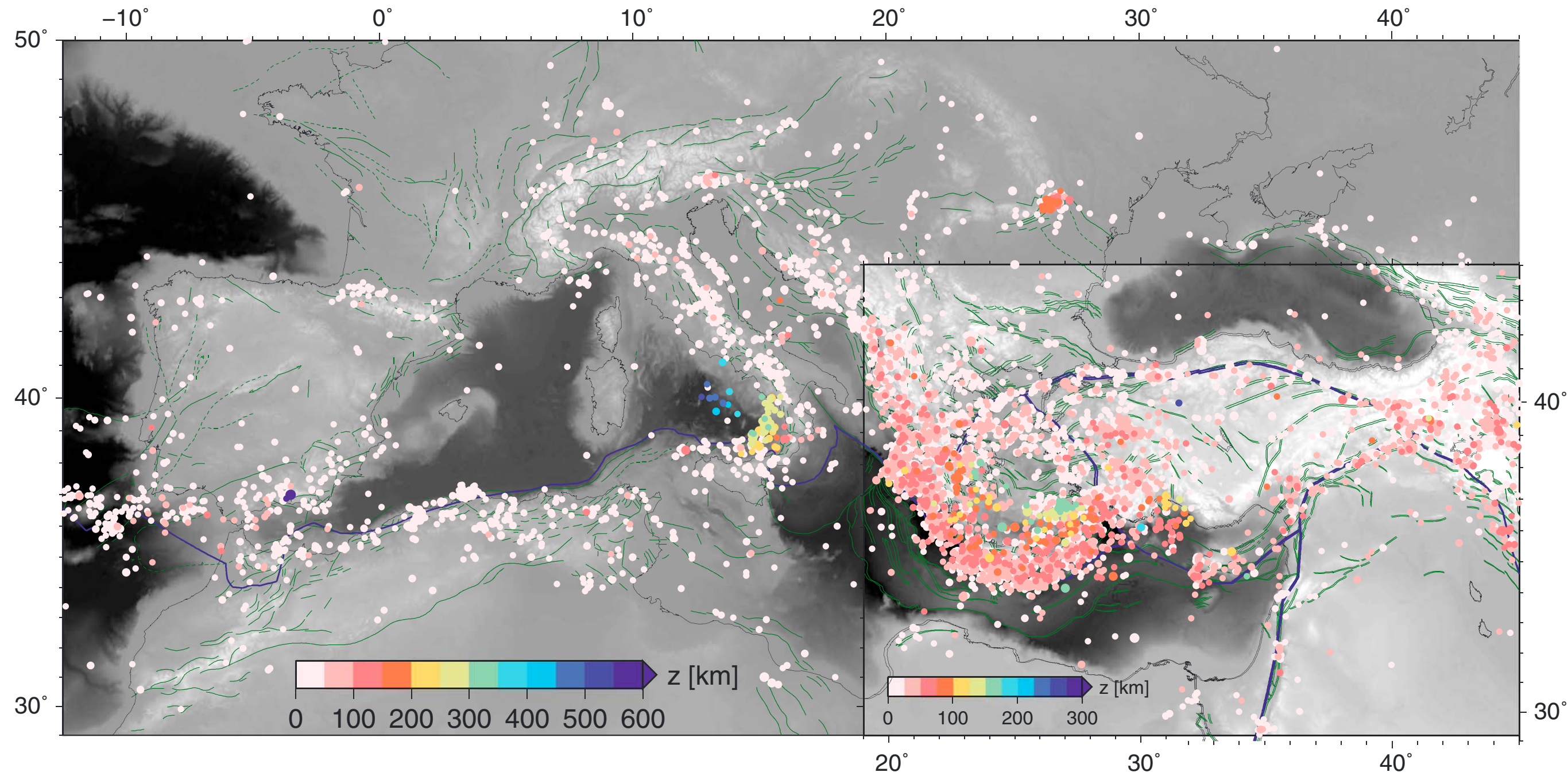
Which dynamic relations between convergence, subduction and extension ?



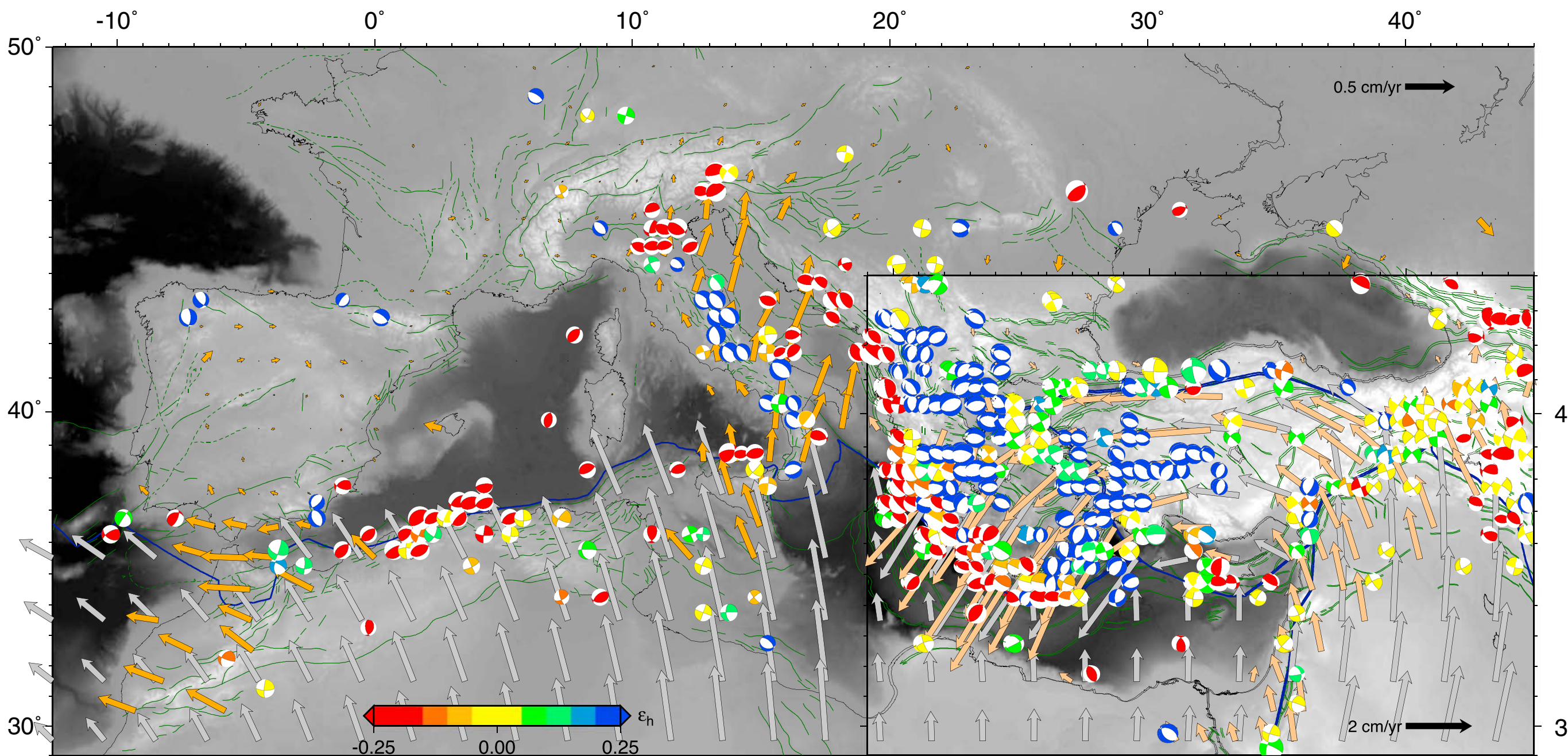
A scenic landscape photograph showing a rocky coastline. In the foreground, there is a dense field of low-lying bushes with bright red berries. The middle ground features a calm bay with clear blue water, surrounded by rugged, light-colored rock formations. The background shows a vast expanse of the sea under a clear sky, with distant landmasses visible on the horizon.

2. Active Mediterranean tectonics

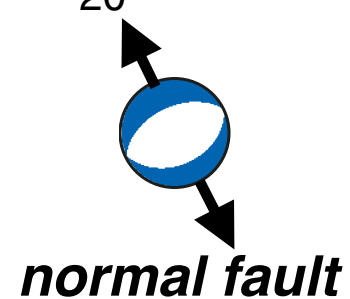
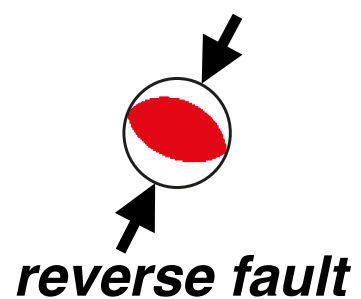
Seismicity



Focal mechanisms of earthquakes



Faccenna *et al.*, Rev. Geophys., 2014



Normal faults often shape Mediterranean landscapes

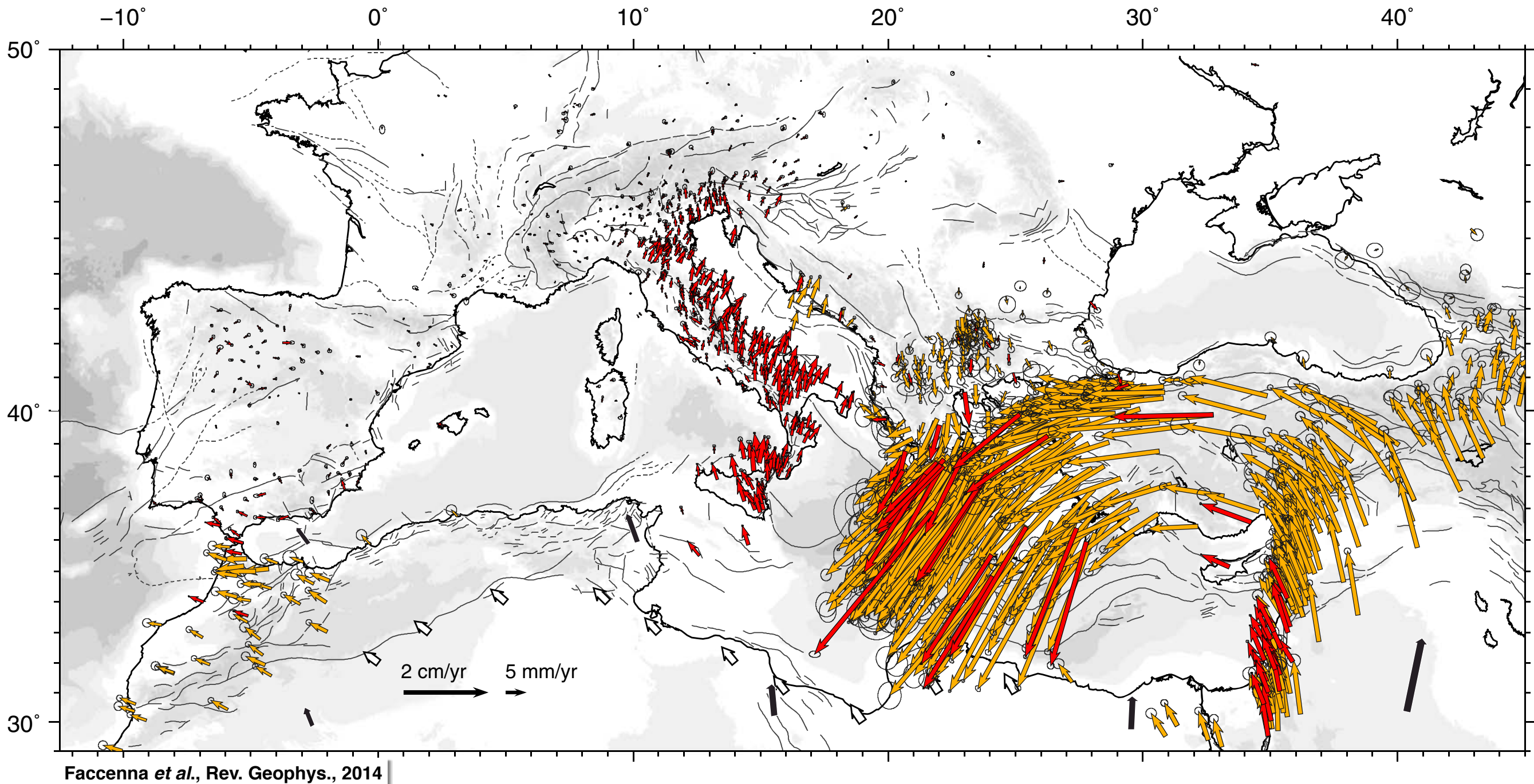


***Lastros normal fault
(Eastern Crete)***



GPS velocity field

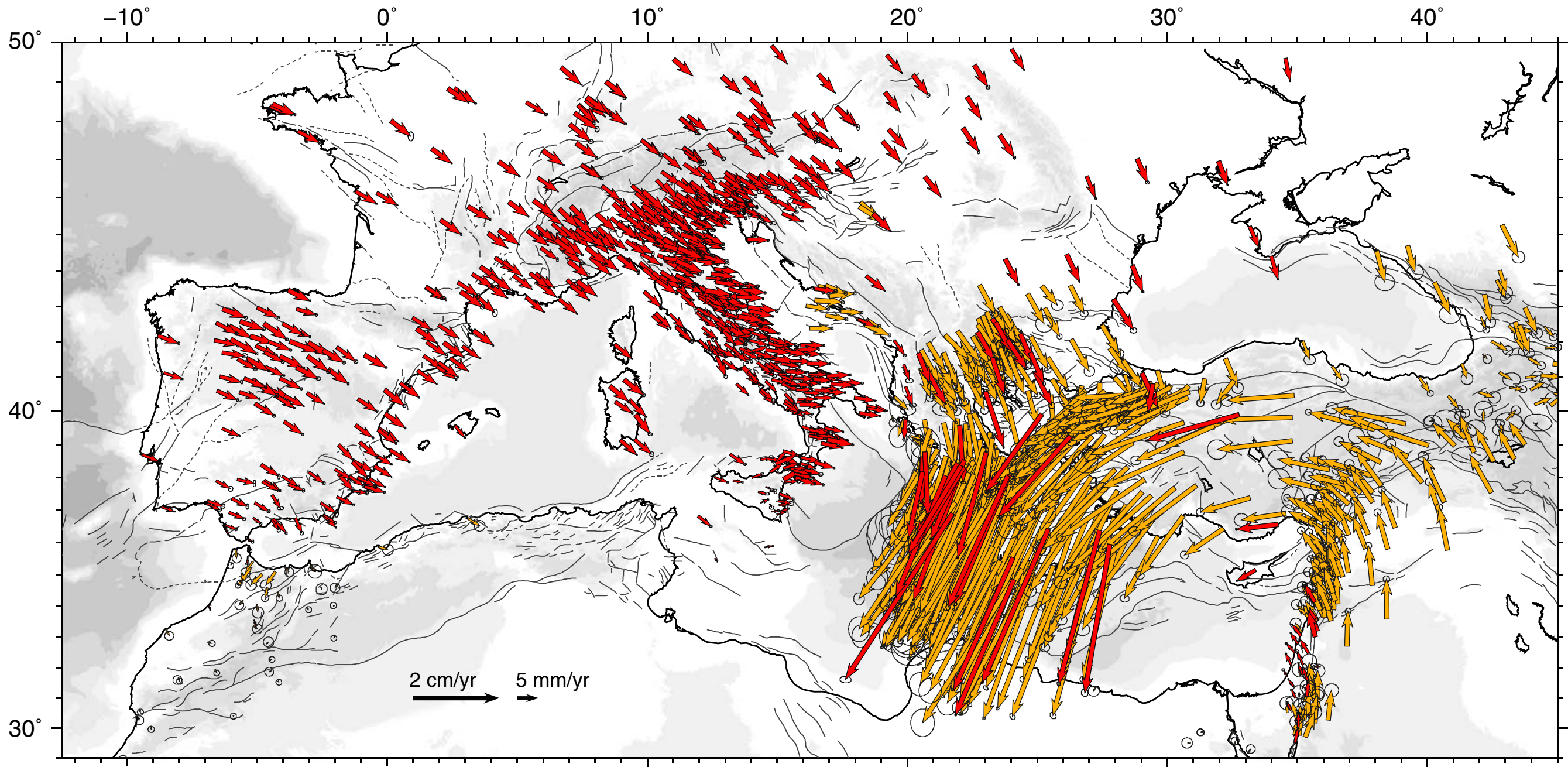
fixed Eurasia



This image shows an important characteristics of the Mediterranean region: internal displacements are faster than relative plate motions at the boundary of the system ... *looking for an internal engine*

GPS velocity field

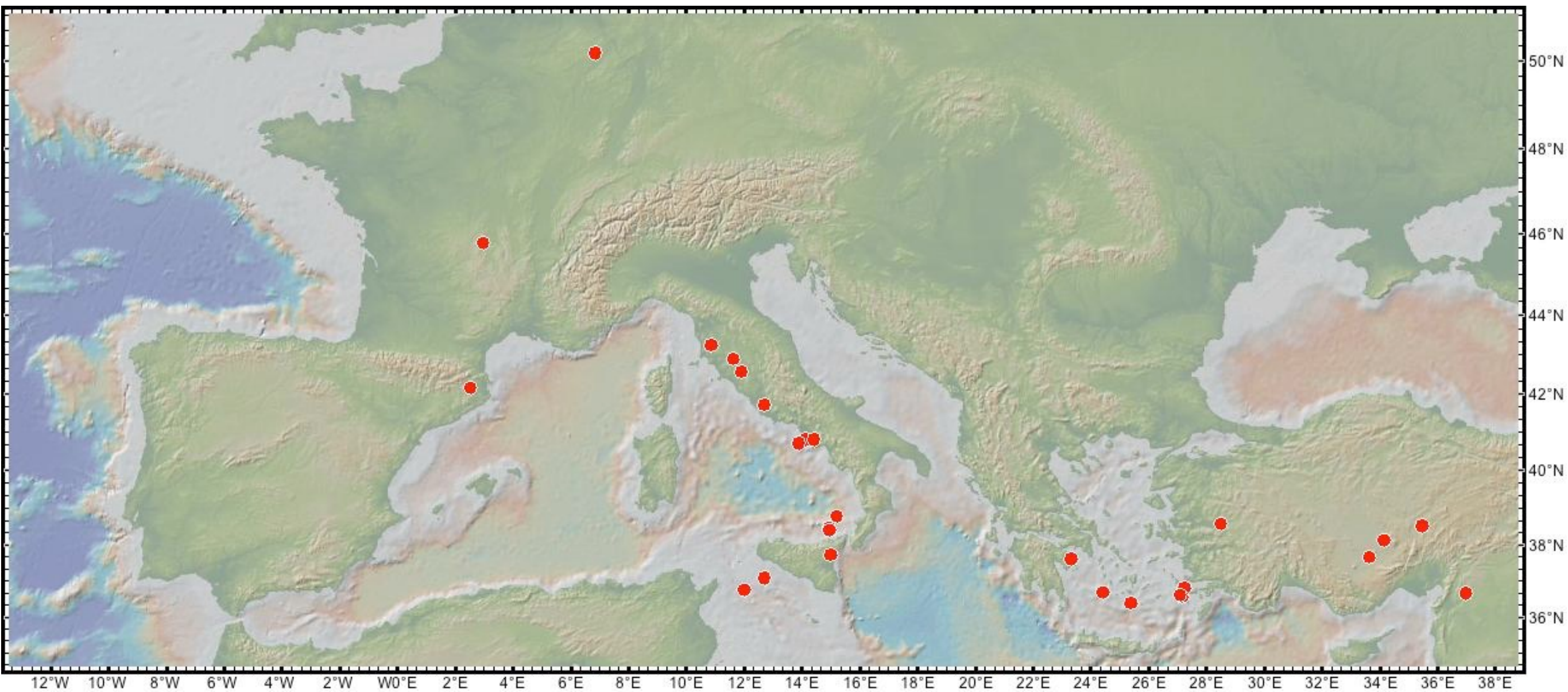
fixed Africa



Faccenna *et al.*, Rev. Geophys., 2014

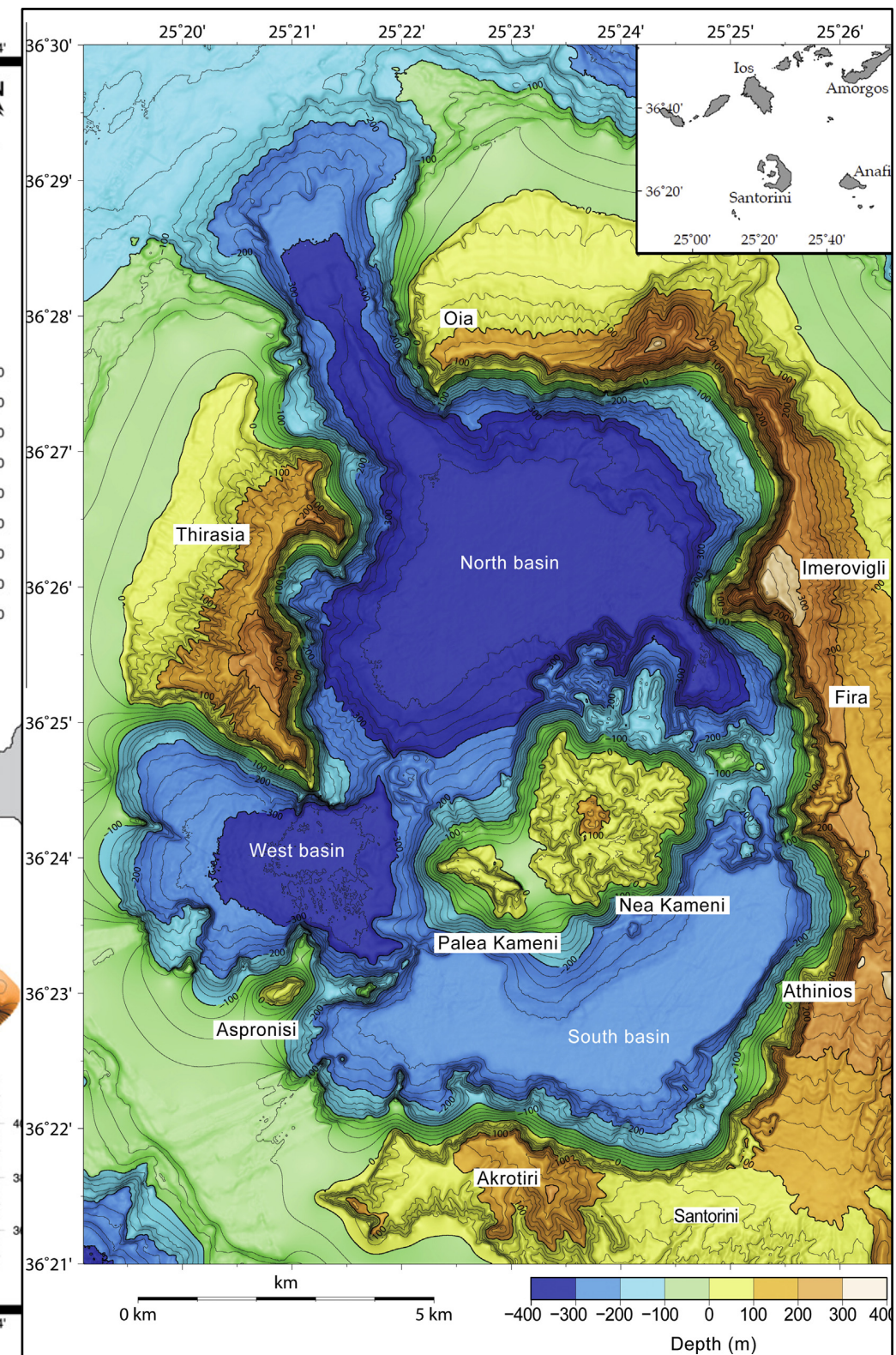
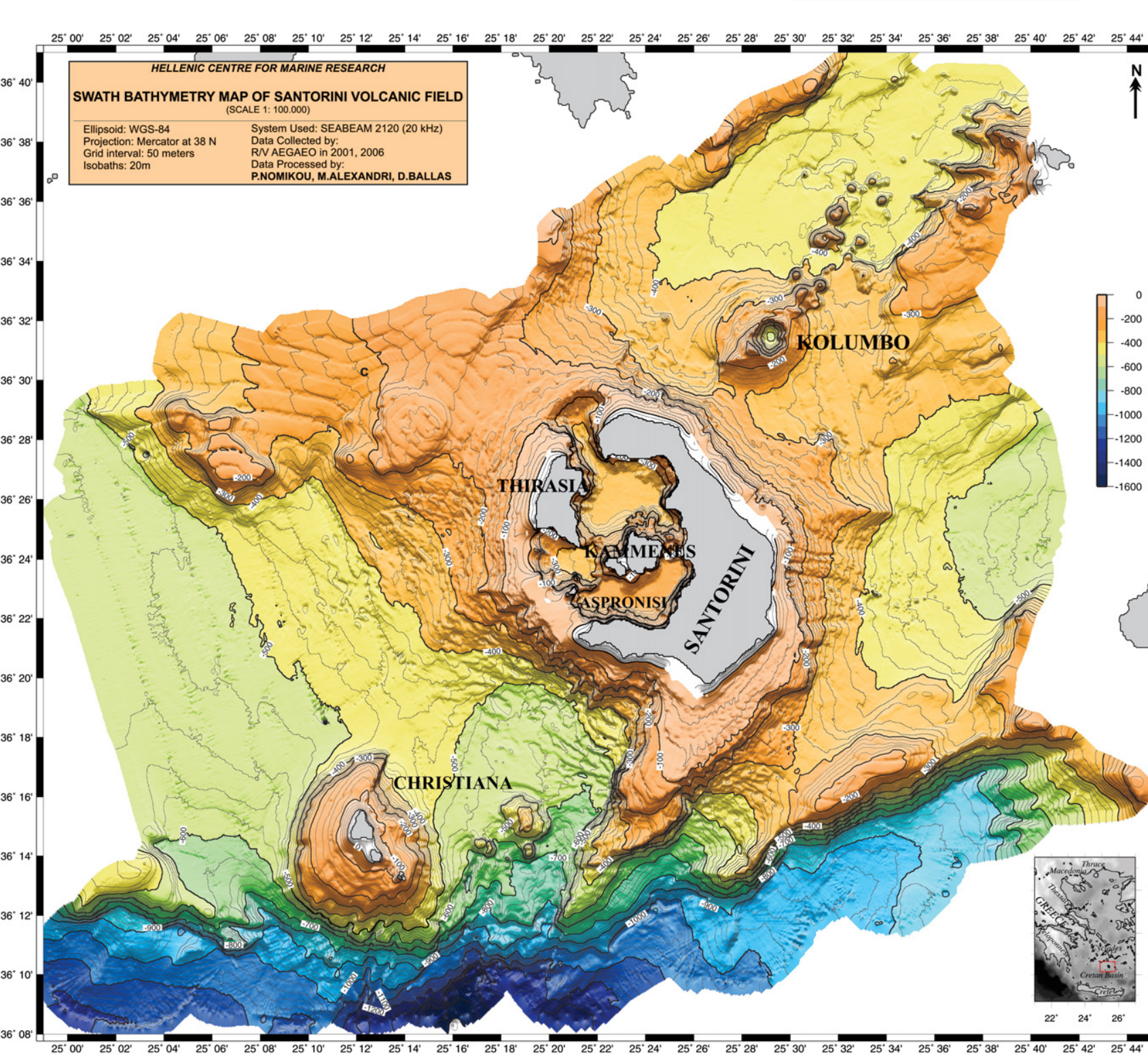
This image shows an important characteristics of the Mediterranean region: internal displacements are faster than relative plate motions at the boundary of the system ... *looking for an internal engine*

Active and recent volcanoes



(source GeoMapApp)

Santorini



Santorini



Santorini

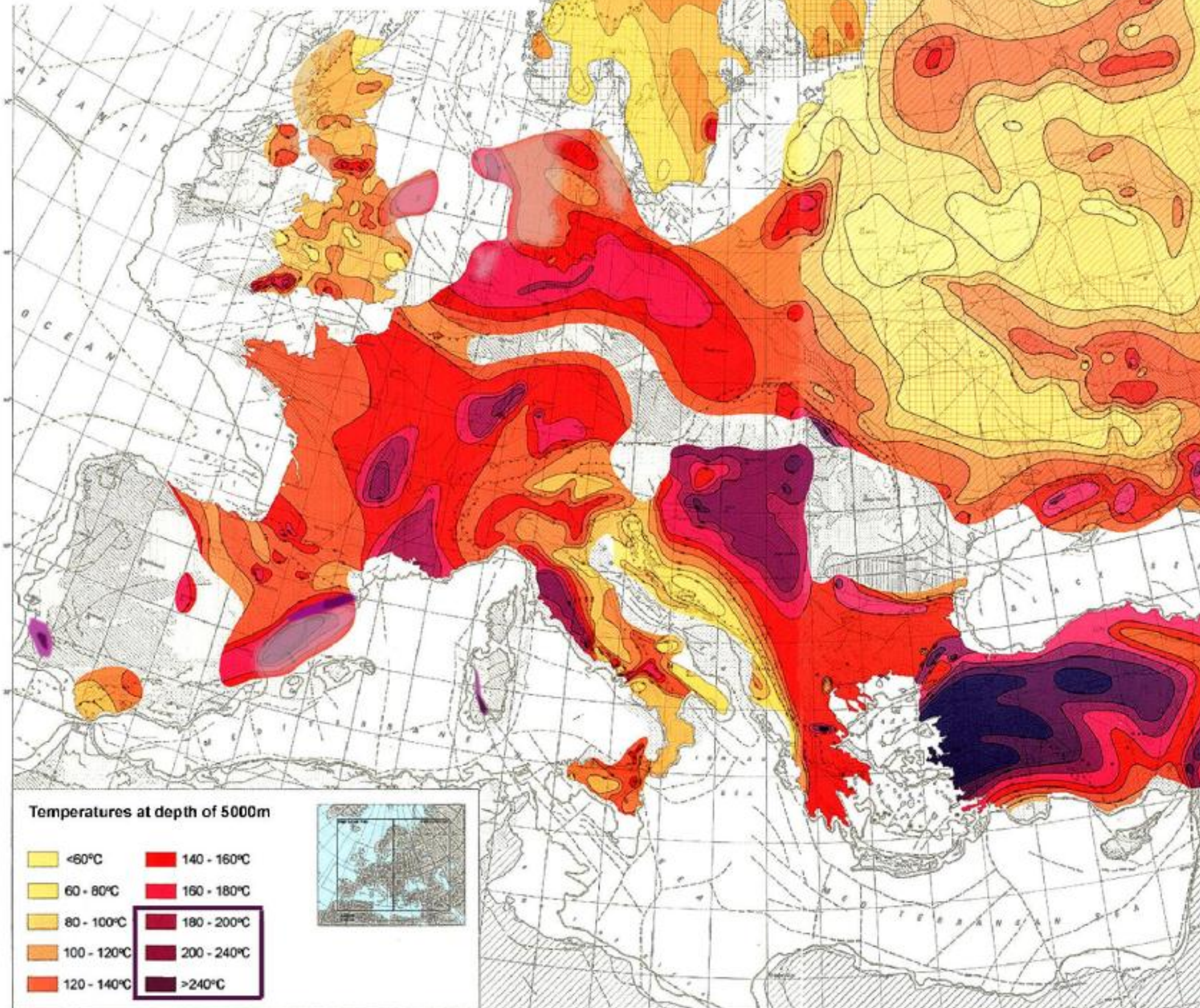


Santorini



Geothermal resources in Europe

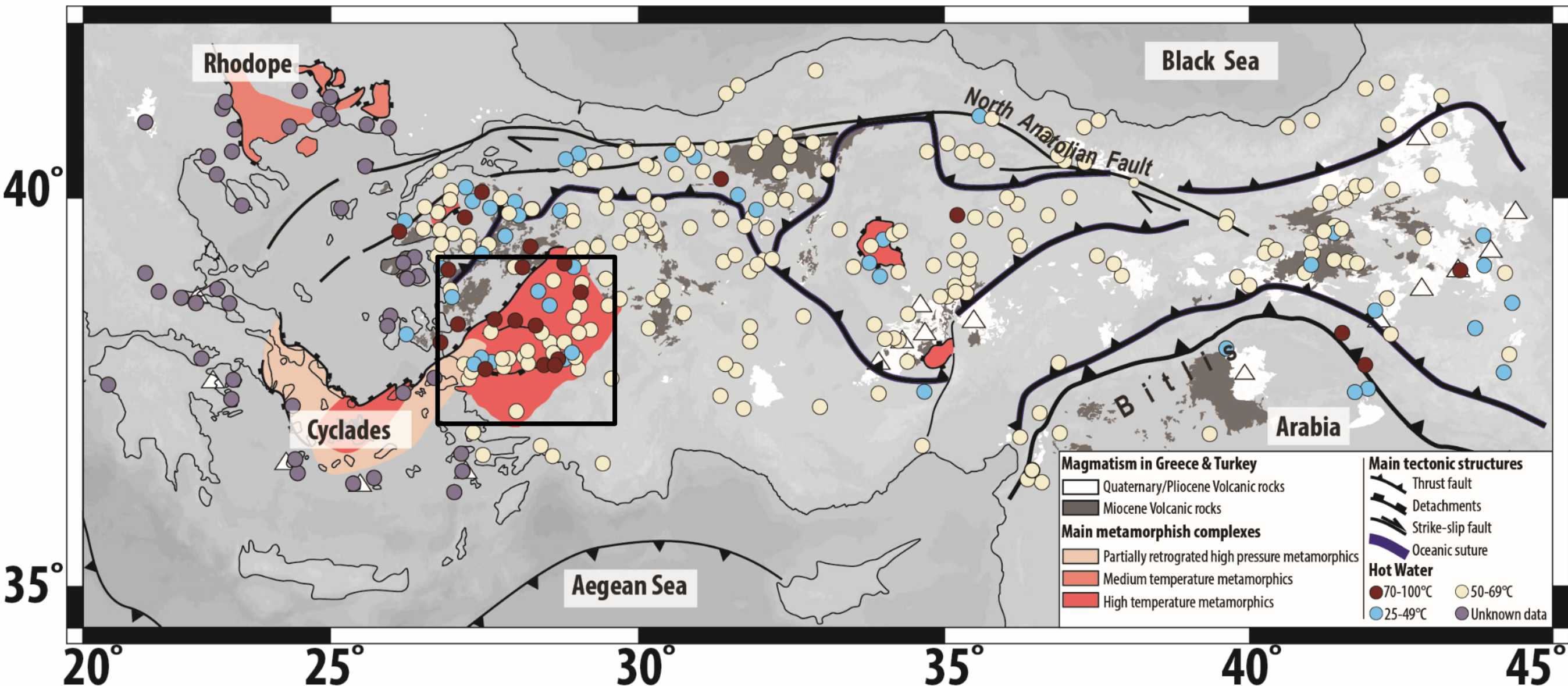
Working Document based on data
integrated on 01/09/2000



Geothermal plants in Western Turkey

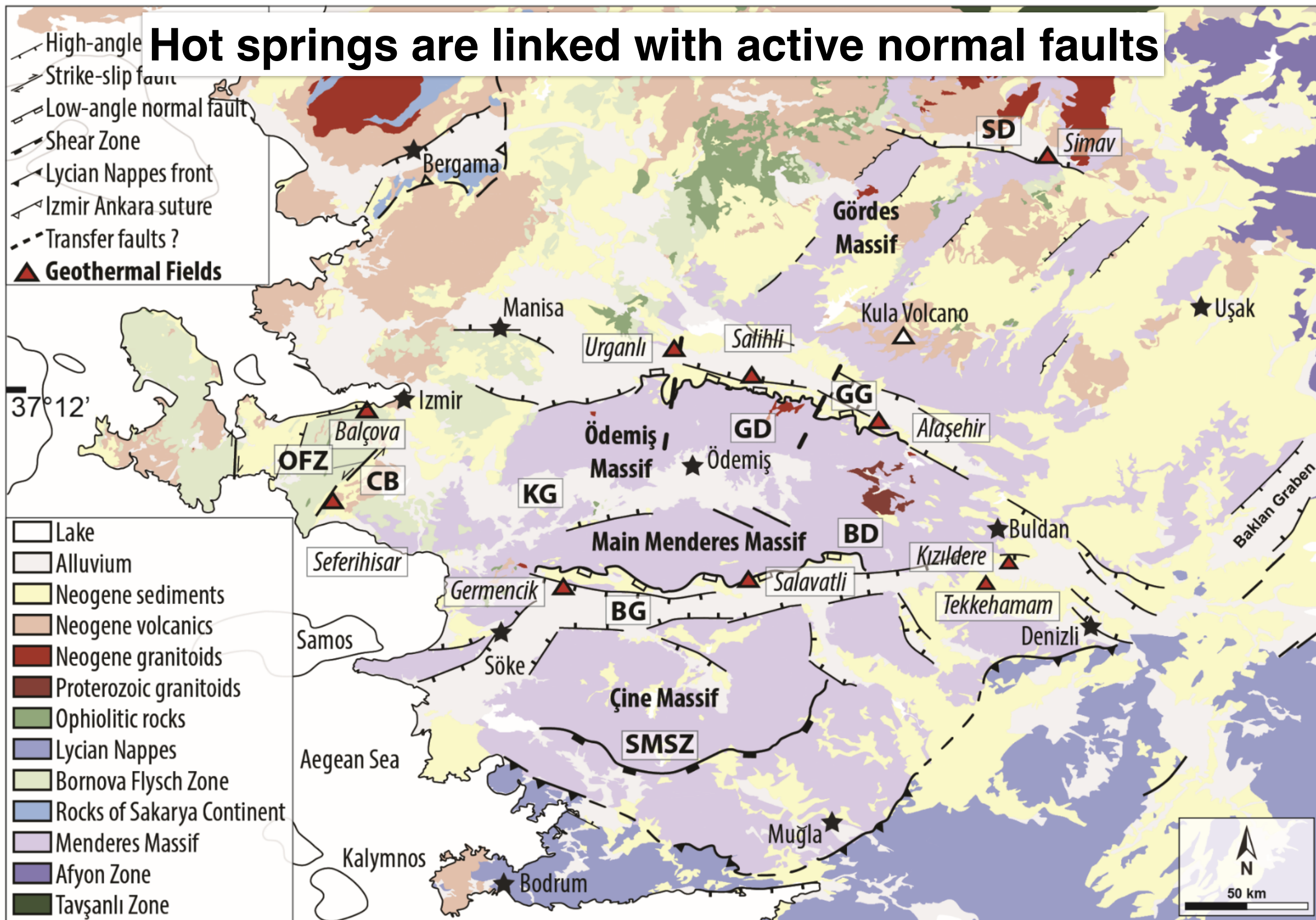


Most of the hottest springs are located far from active volcanoes



Tectonics and geodynamics control the position of many geothermal fields

Hot springs are linked with active normal faults



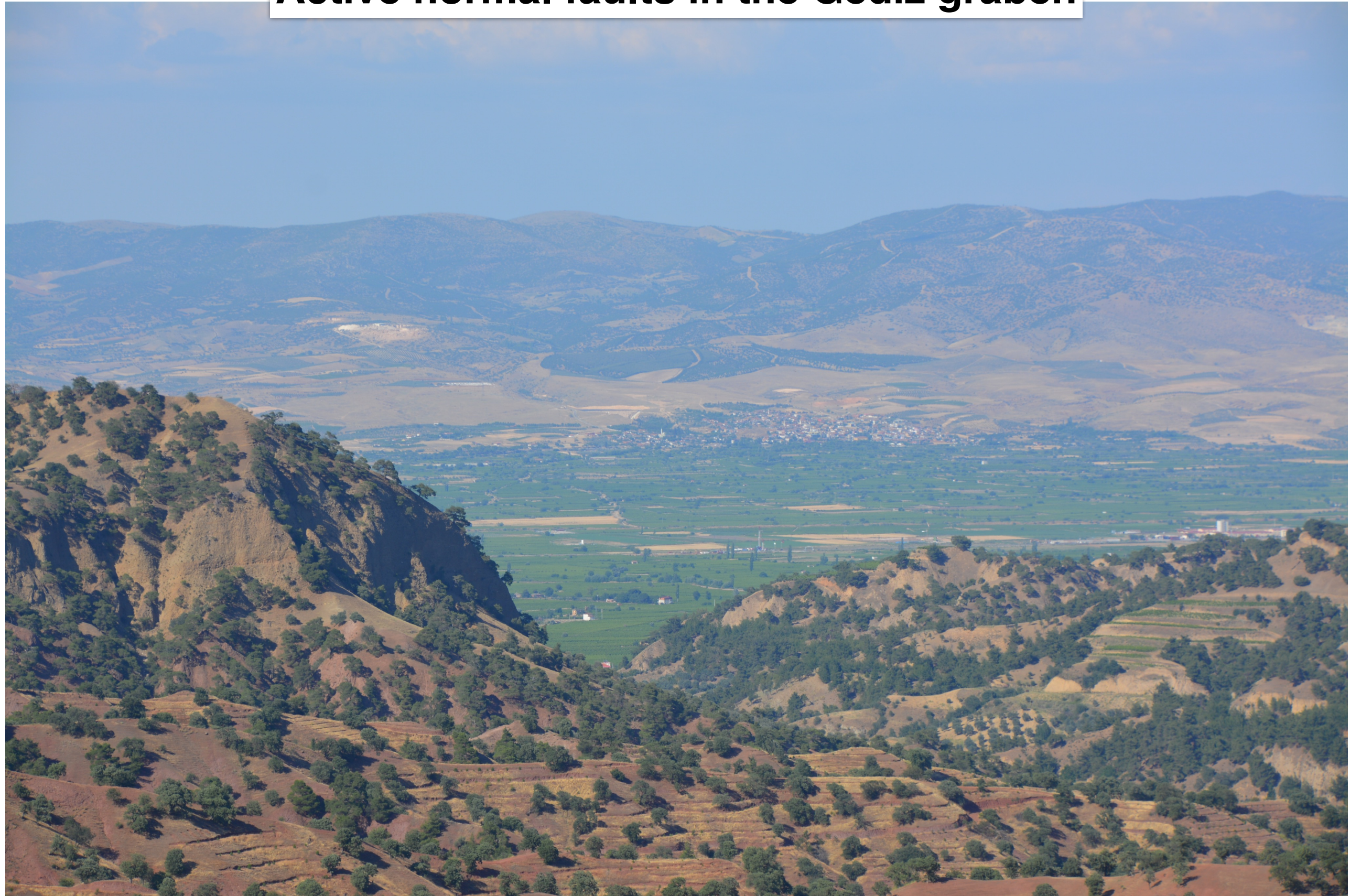
Active normal faults in the Büyük Menderes graben



Active normal faults in the Simav graben



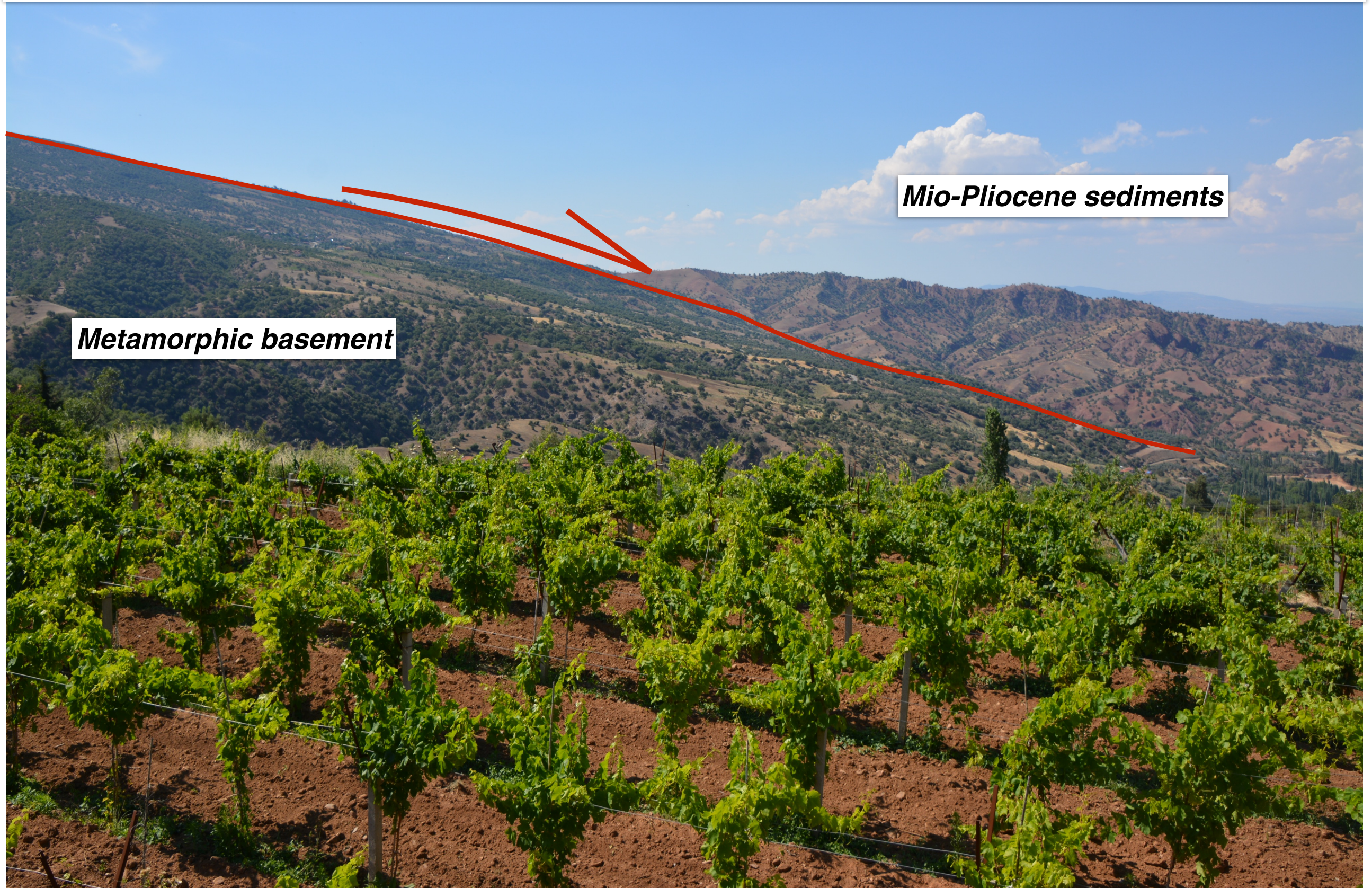
Active normal faults in the Gediz graben

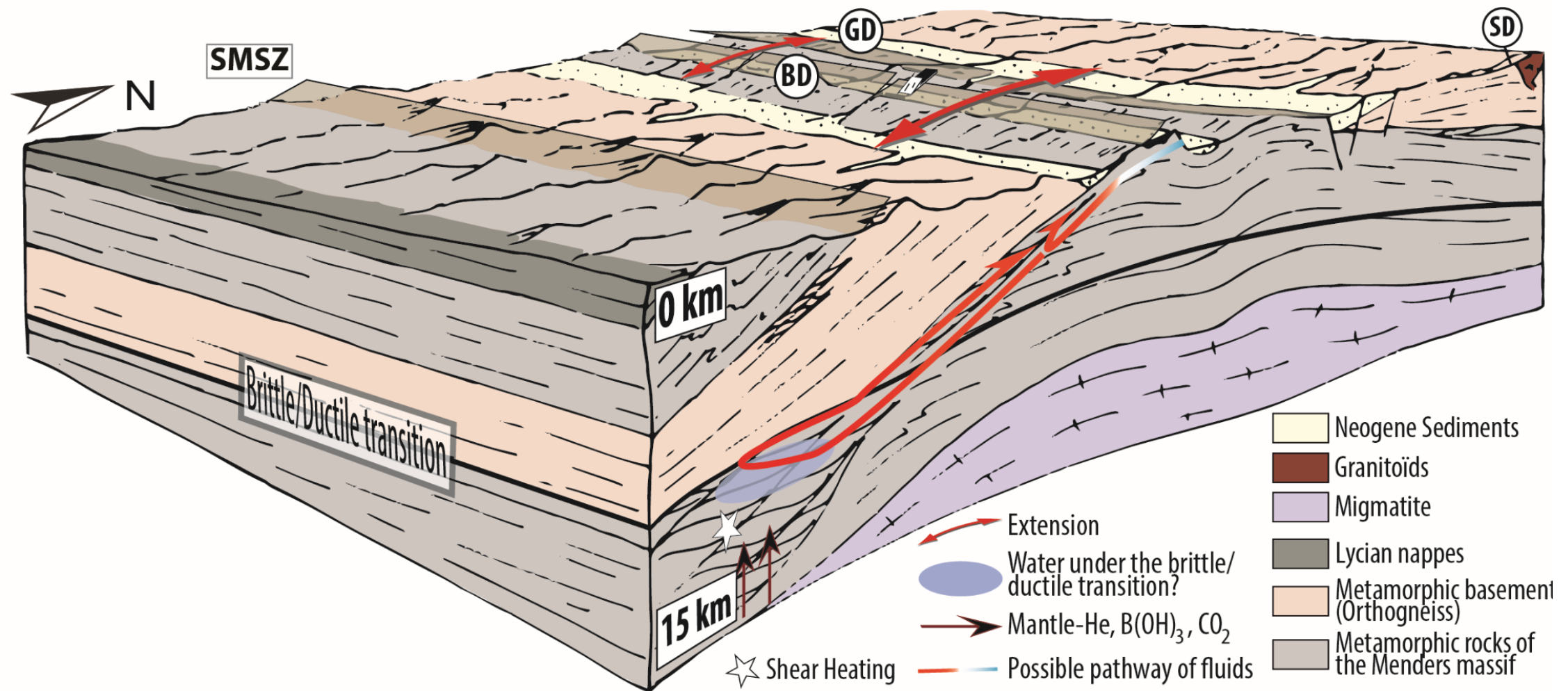


Low-angle normal faults (detachment) in the Gediz-Alasehir graben



Low-angle normal faults (detachment) in the Gediz-Alasehir graben





Large-scale detachments and steep normal faults control the circulation of geothermal waters.

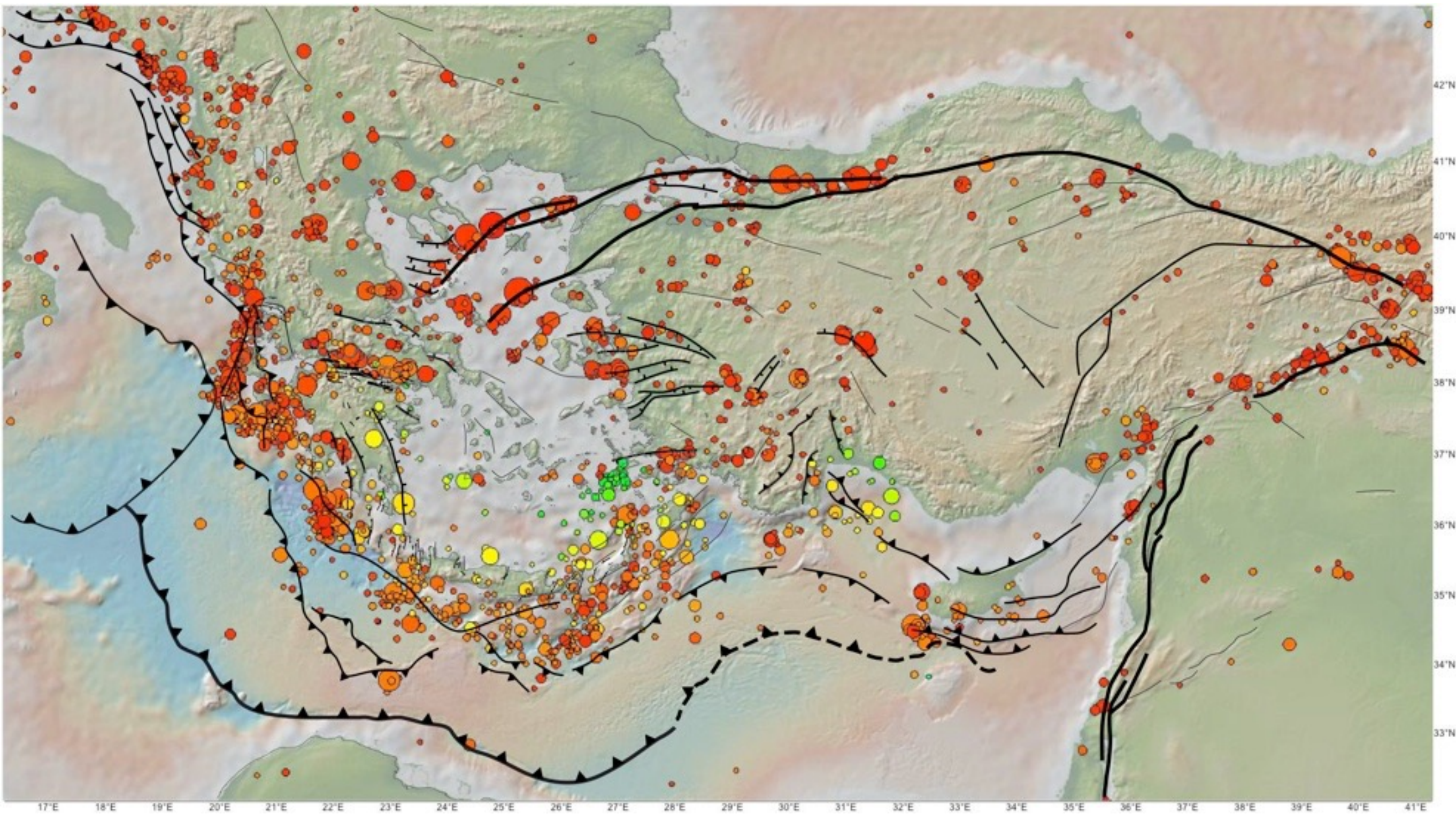
The abnormal geothermal gradient is responsible for the formation of geothermal reservoirs

The abnormal geothermal gradient is the results of subduction dynamics (slab retreat and slab tear)

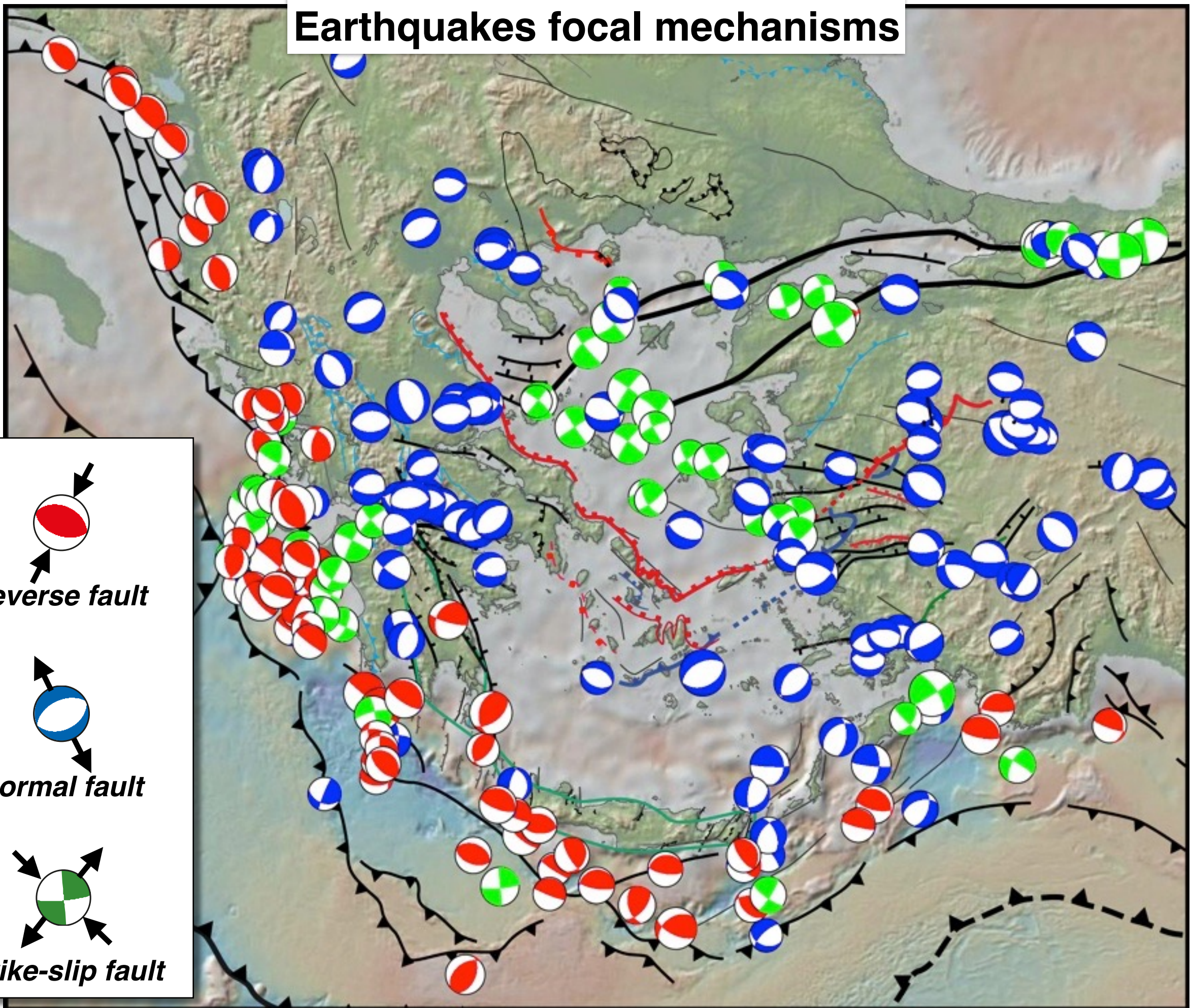
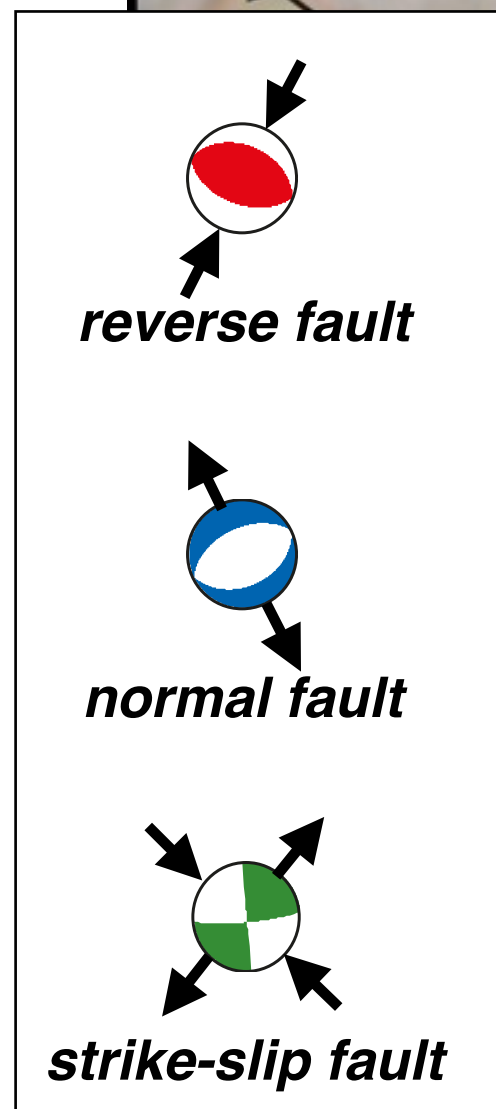
A scenic landscape photograph of a coastal region. In the foreground, there is a dense field of low-lying bushes with numerous small, bright red berries. The middle ground features a calm, blue bay or cove, bordered by steep, rocky cliffs. The cliffs are covered in sparse, dry vegetation. In the background, the sea extends to the horizon under a clear, light blue sky. The overall scene suggests a Mediterranean or Aegean coastal environment.

*3. Active
Mediterranean tectonics:
the Aegean region*

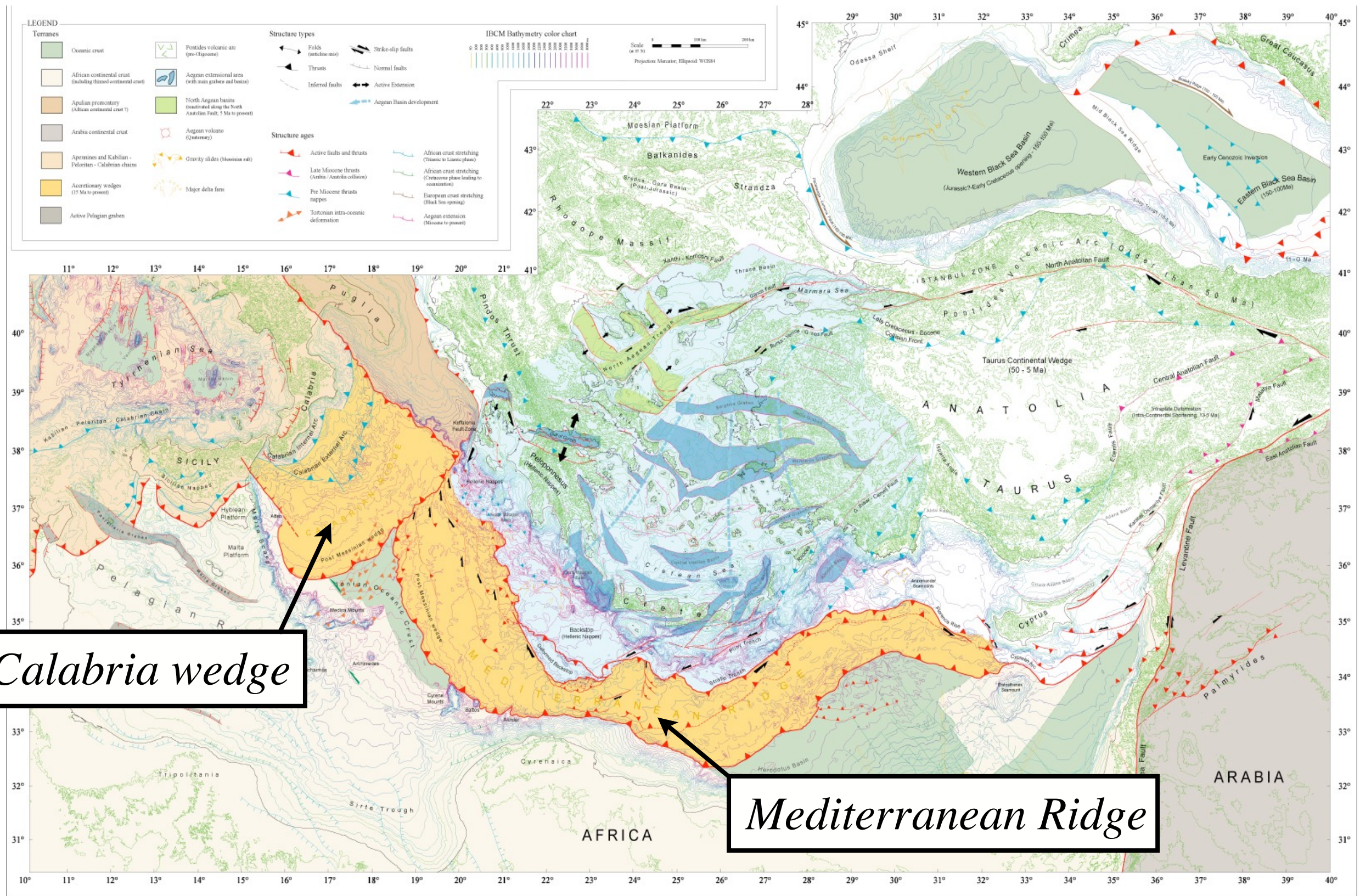
Seismicity



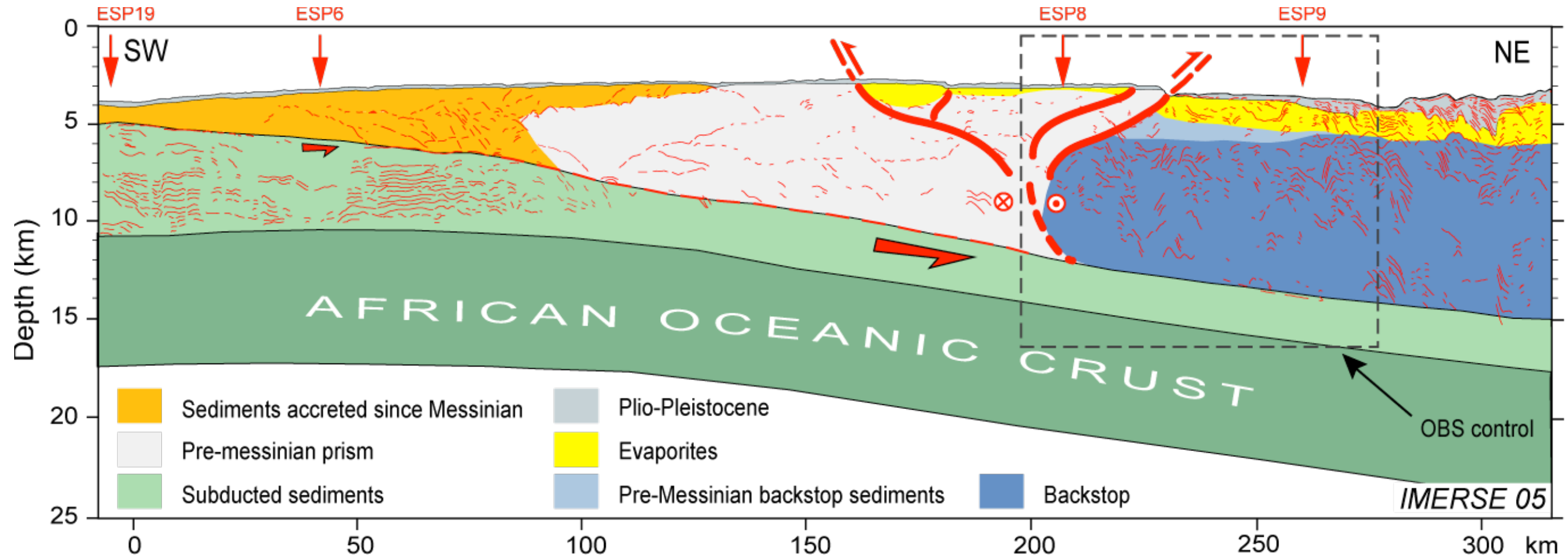
Earthquakes focal mechanisms



Two active or recent accretionary wedges

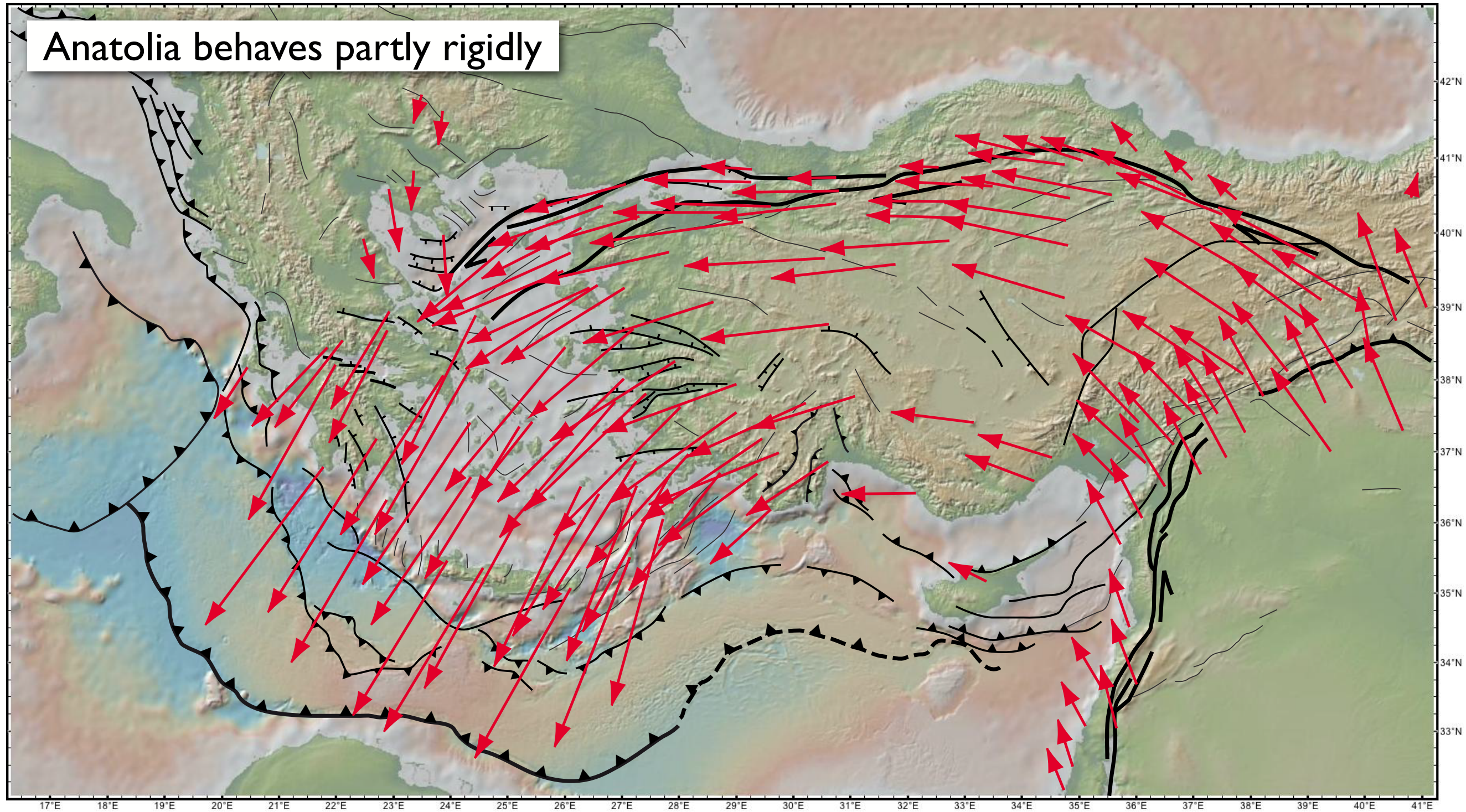


The Mediterranean Ridge accretionary wedge



GPS velocity field (*fixed Eurasia*)

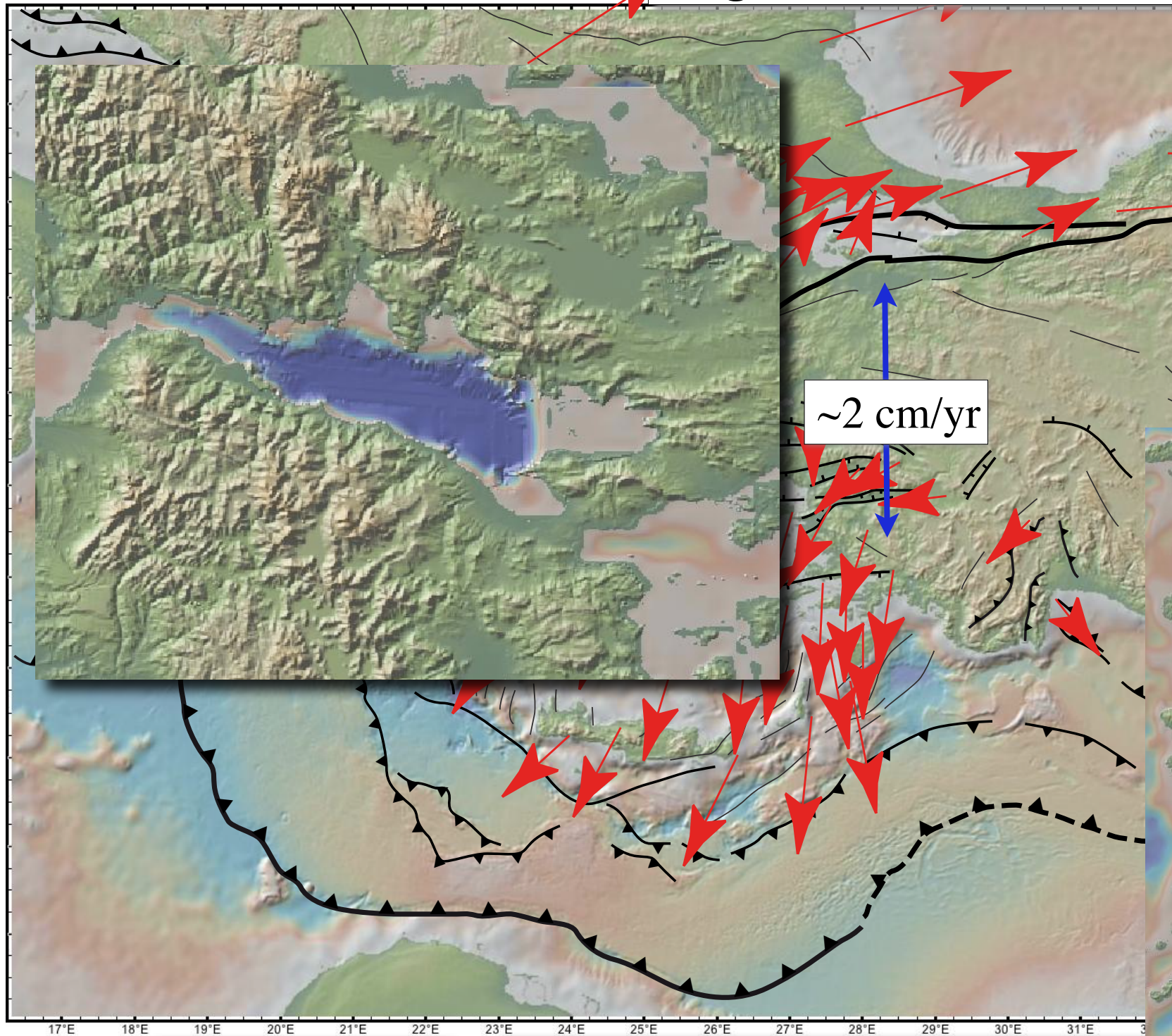
Anatolia behaves partly rigidly



Reilinger et al., 2009

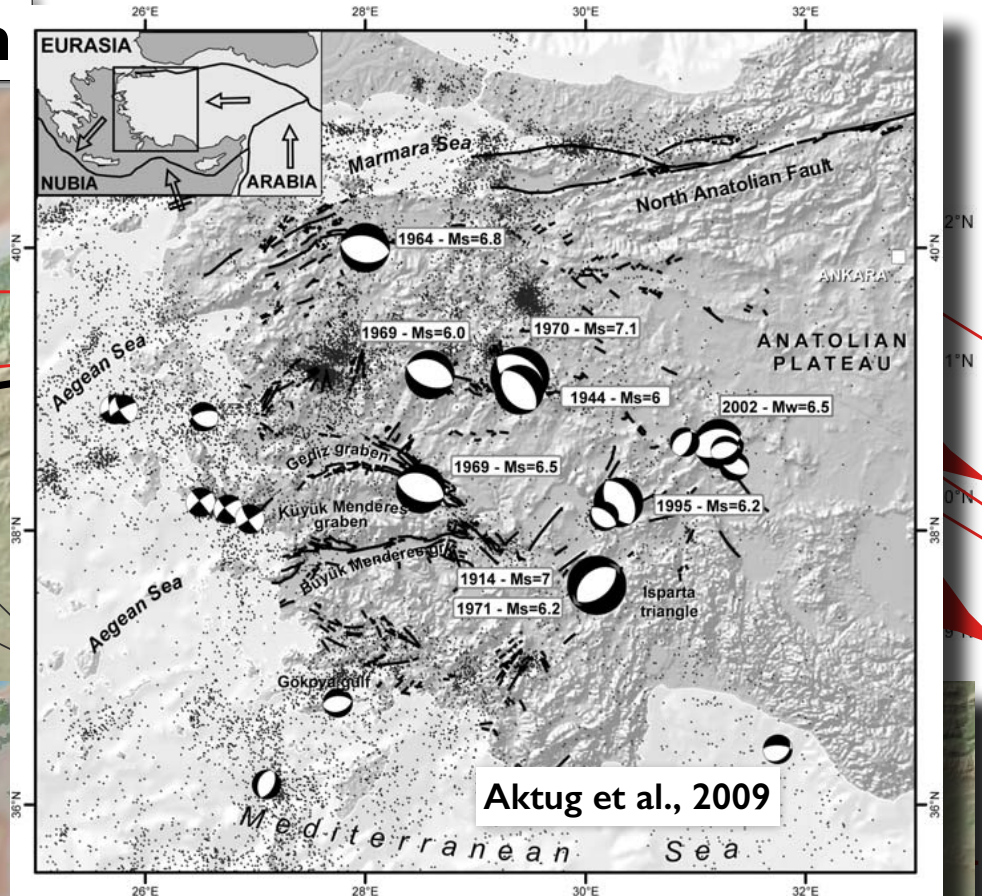
GPS velocity field (*fixed Anatolia*)

Aegean active extension



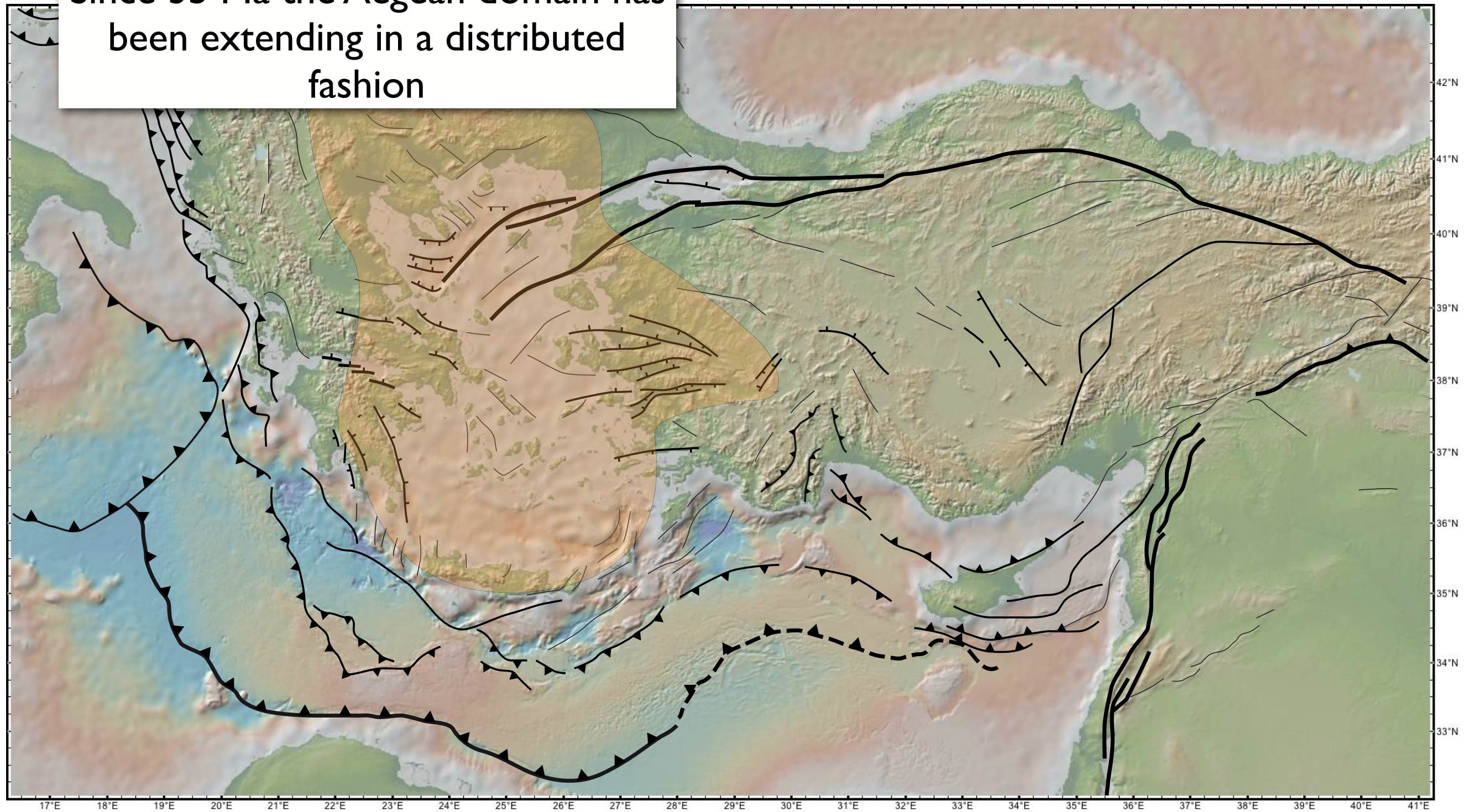
McClusky et al., 2000

**An extensional component in the
Aegean,
older than the NAF, ~30-35 Ma**



Aktug et al., 2009

Since 35 Ma the Aegean domain has
been extending in a distributed
fashion



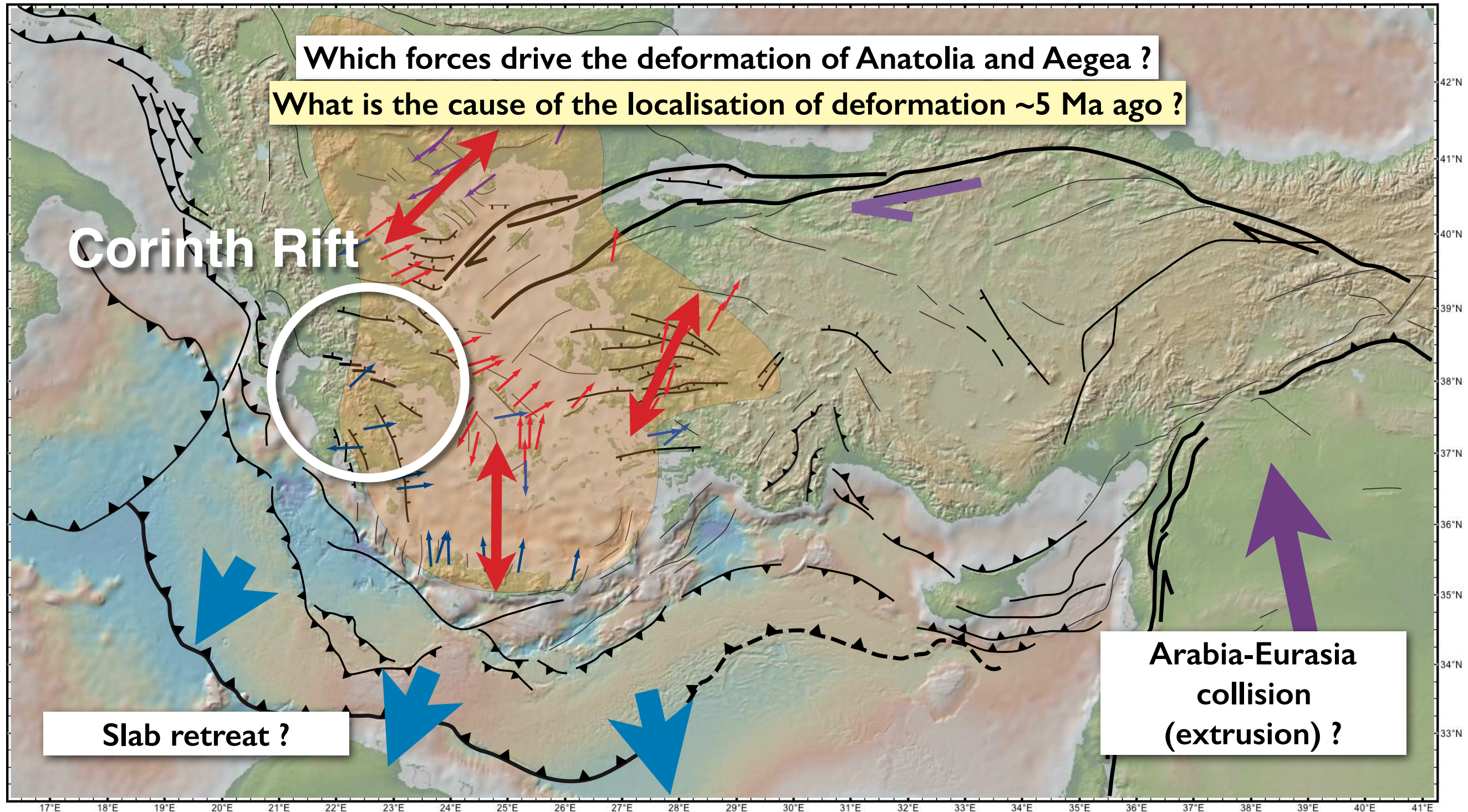
Which forces drive the deformation of Anatolia and Aegea ?

What is the cause of the localisation of deformation ~5 Ma ago ?

Corinth Rift

Arabia-Eurasia
collision
(extrusion) ?

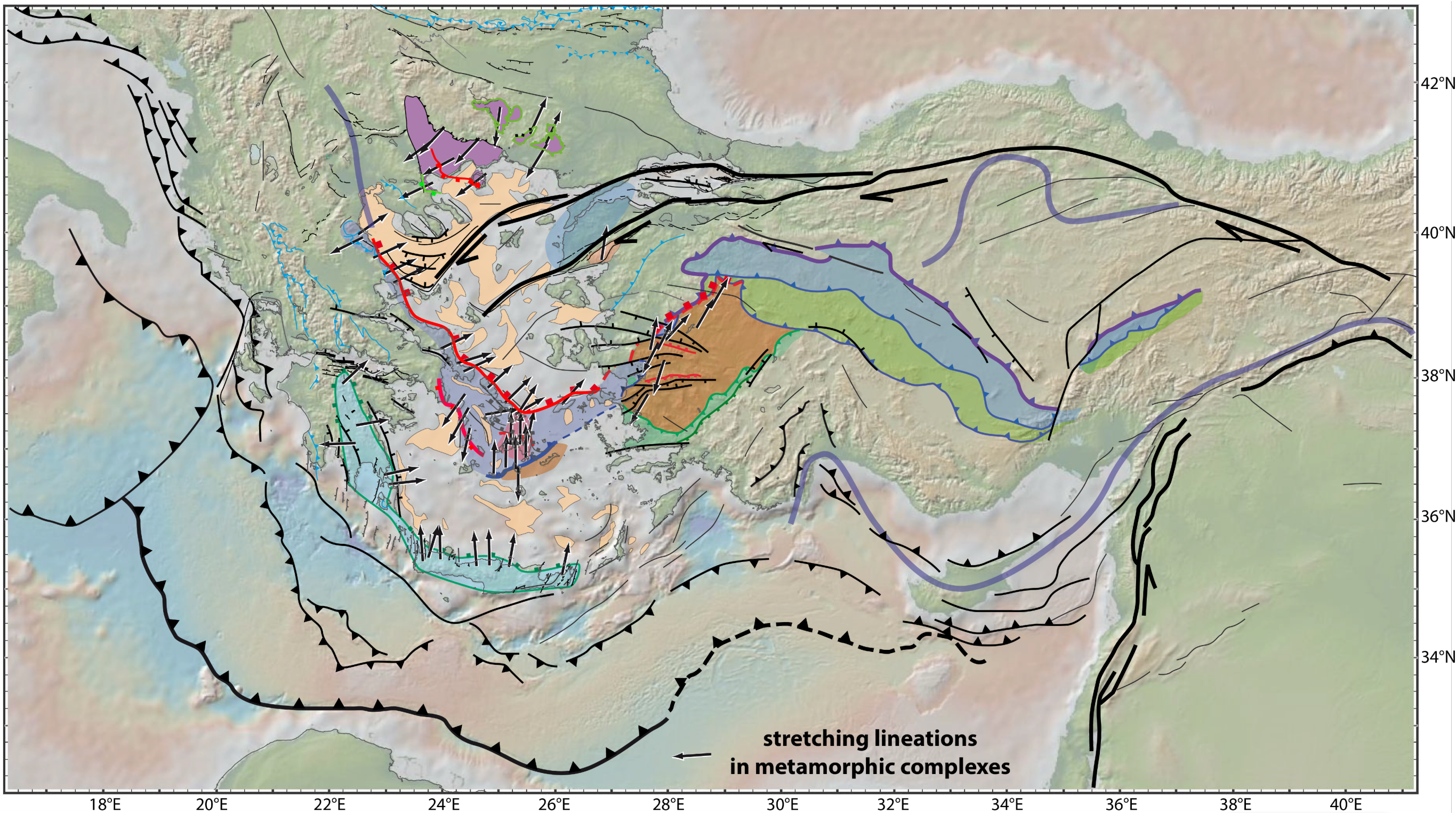
Slab retreat ?



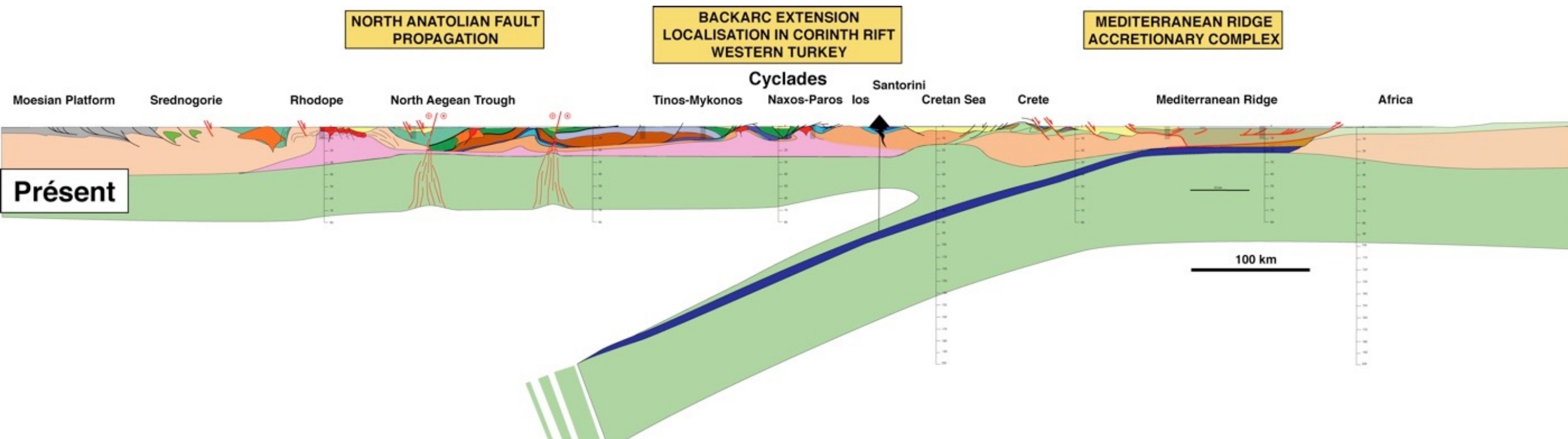
A scenic landscape photograph of a coastal region. In the foreground, there are dense, low-lying bushes with numerous small, bright red flowers. The middle ground features a calm, turquoise bay nestled between rugged, rocky hills. The hills are covered in sparse, dry vegetation. The sea extends to the horizon under a clear, light blue sky. The overall scene is bright and sunny, with a clear view of the coastline and the Aegean Sea.

*4. Long-term
Mediterranean tectonics:
the Aegean region*

Exhumed metamorphic units

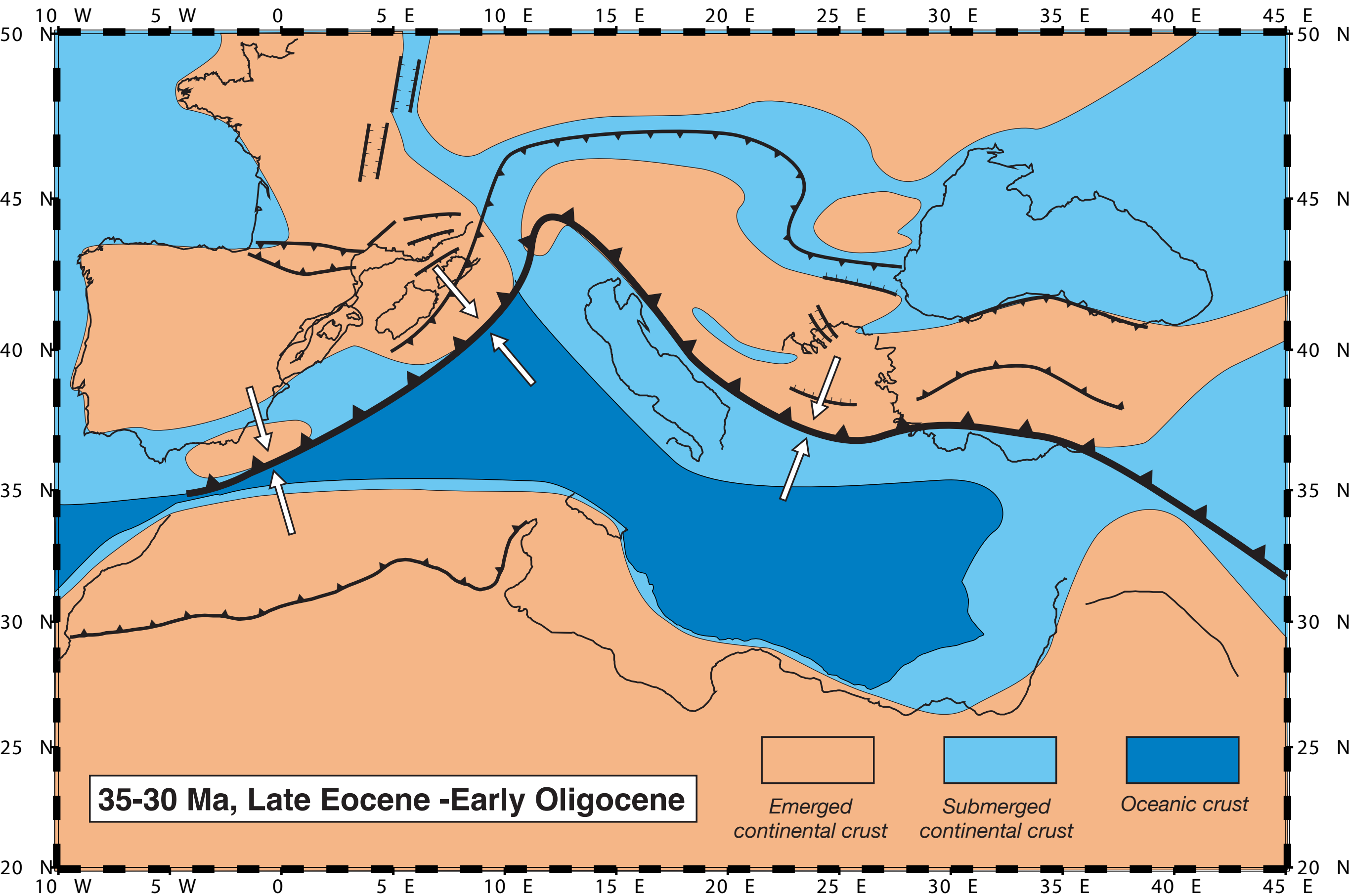


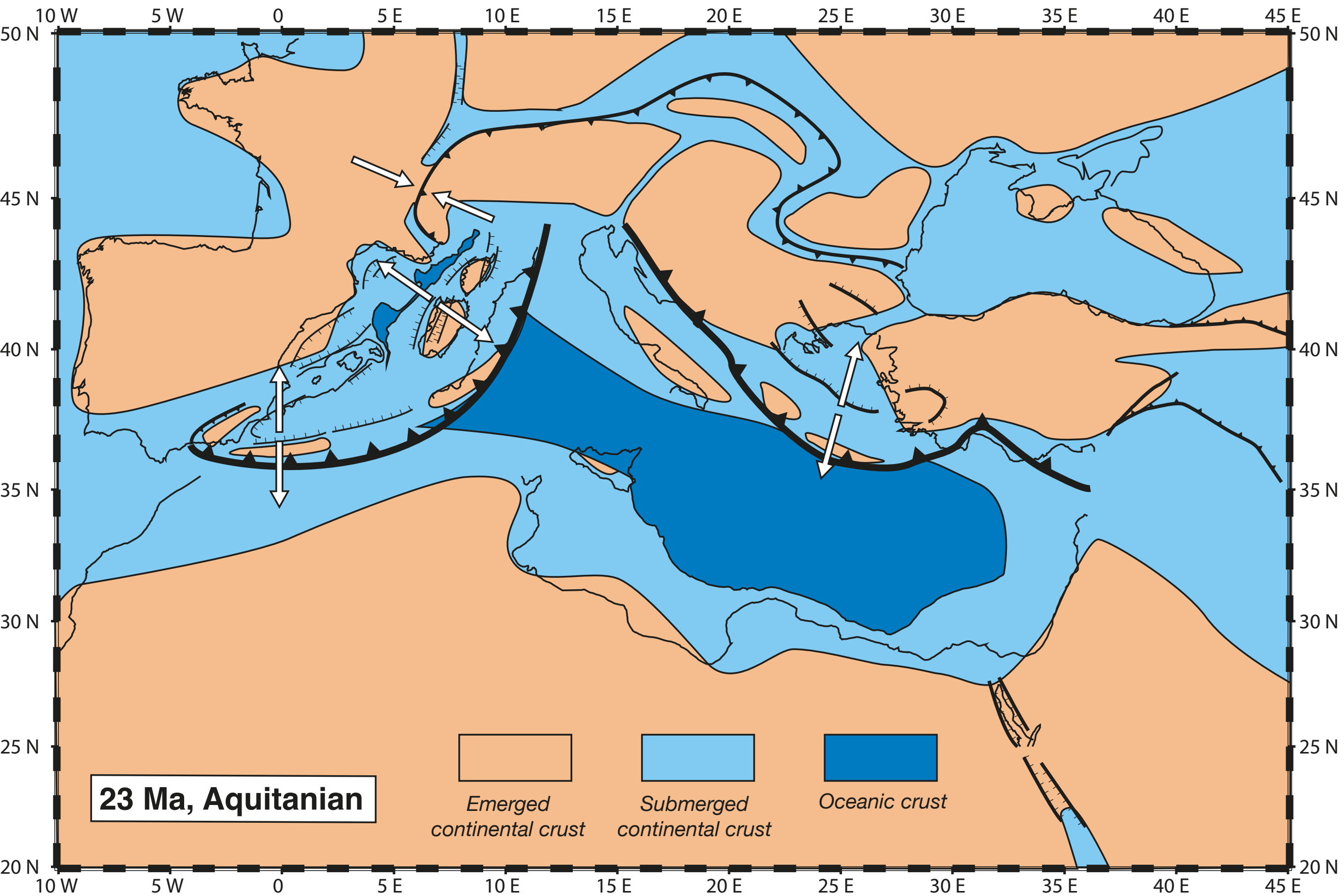
A N-S lithospheric section



The present structure of the Aegean region results from the succession of two episodes:

- (1) *a subduction episode with collision of continental blocs and crustal thickening,*
- (2) *an episode of extension and crustal thinning associated with slab retreat*



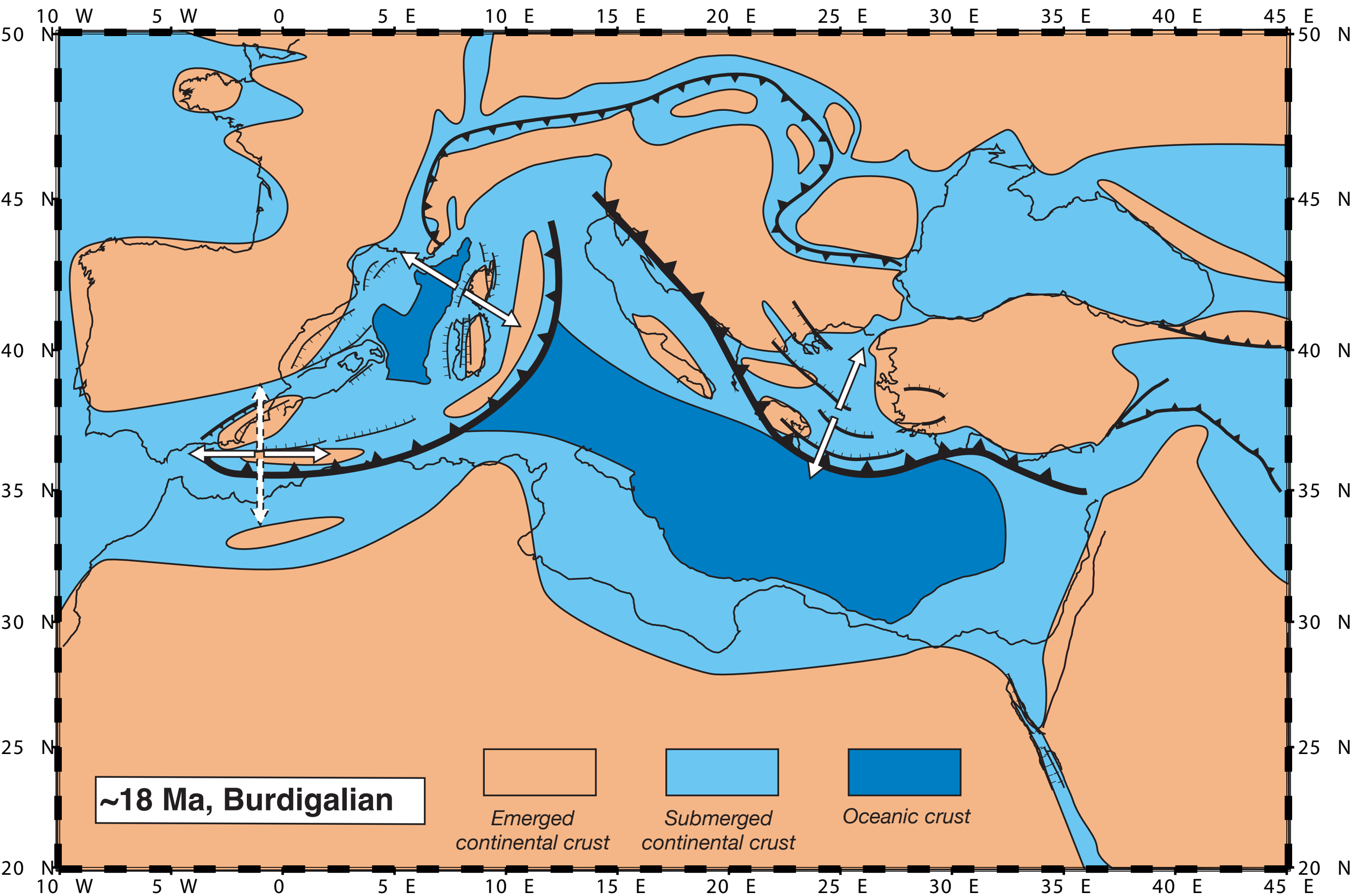


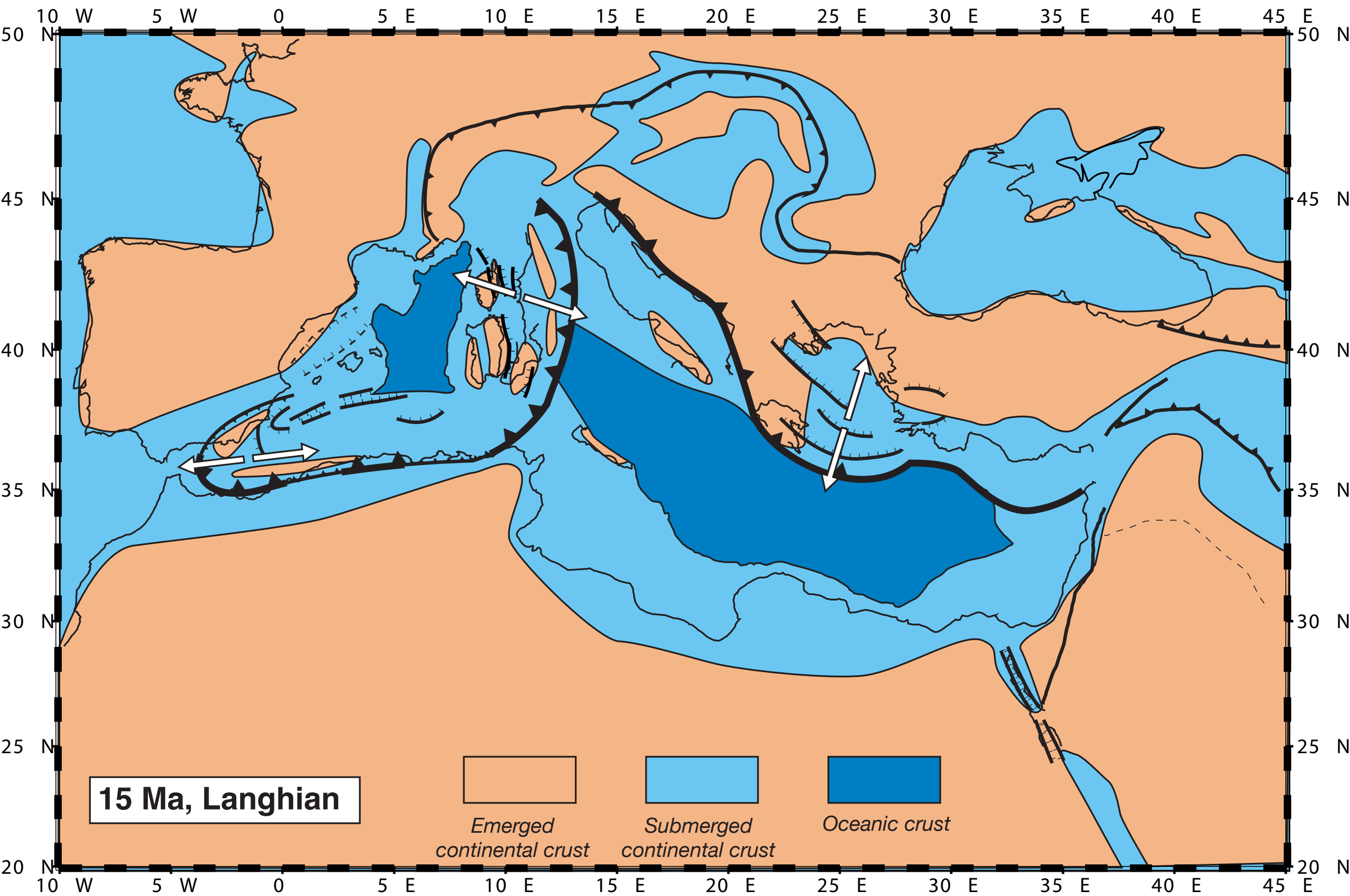
23 Ma, Aquitanian

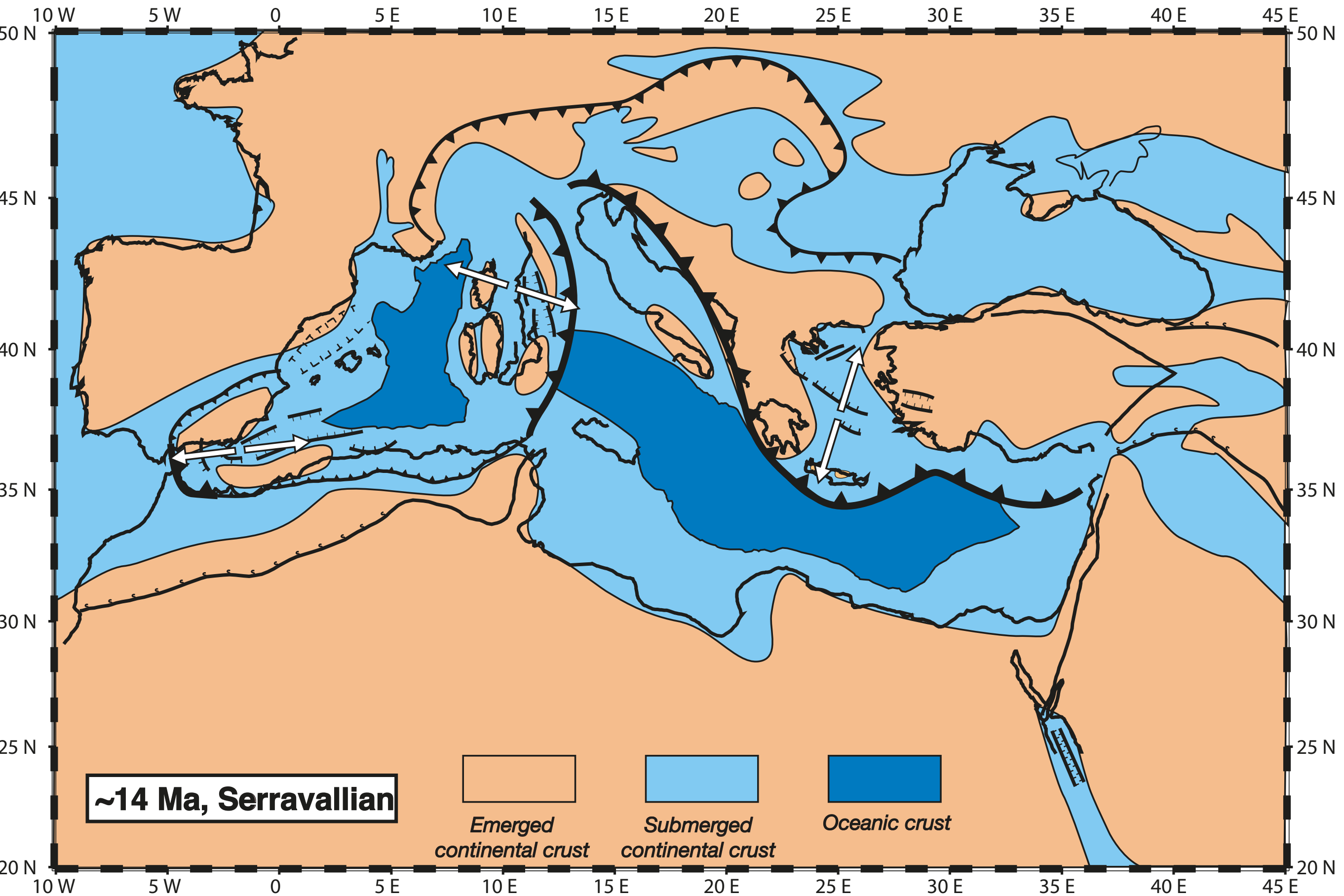
*Emerged
continental crust*

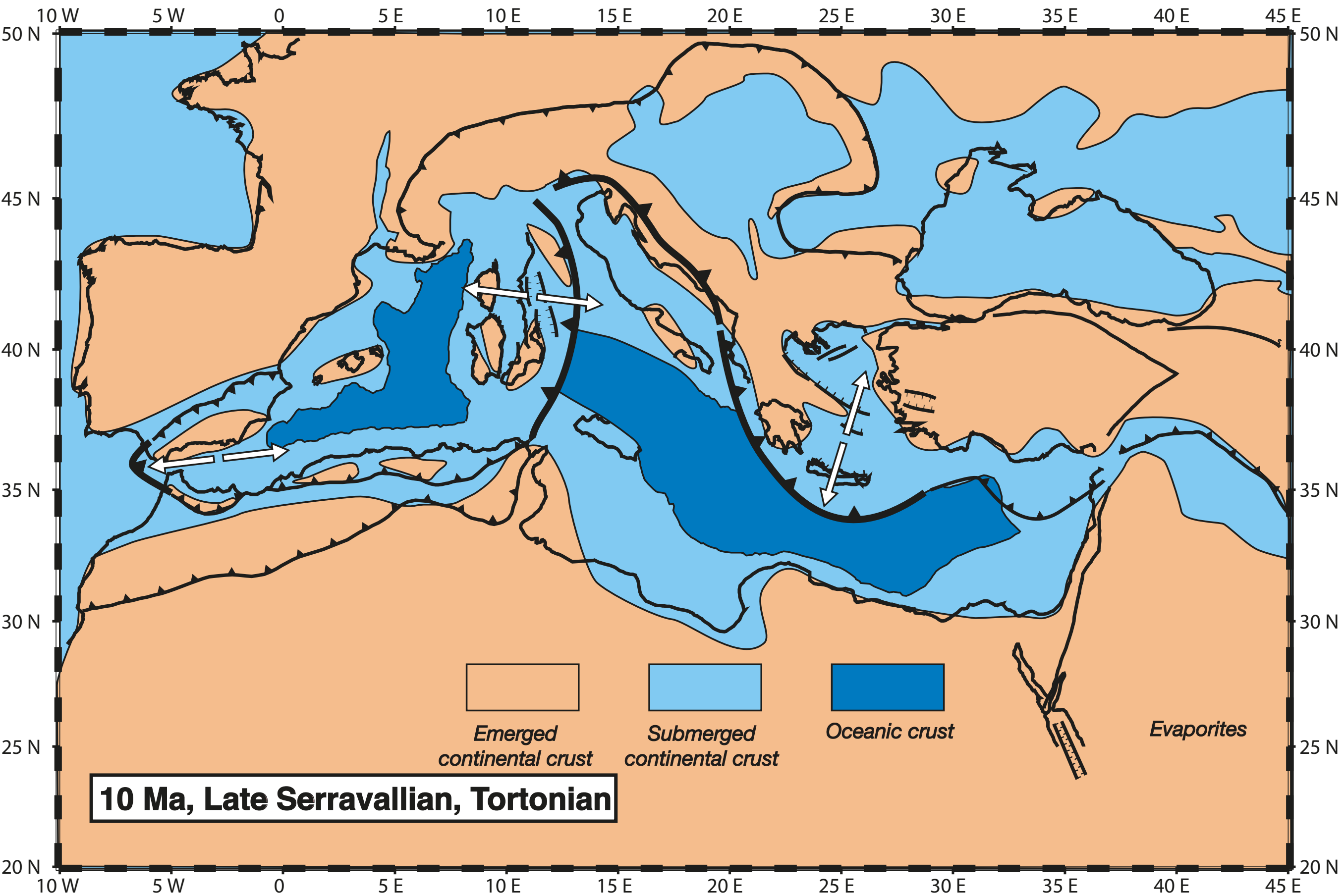
*Submerged
continental crust*

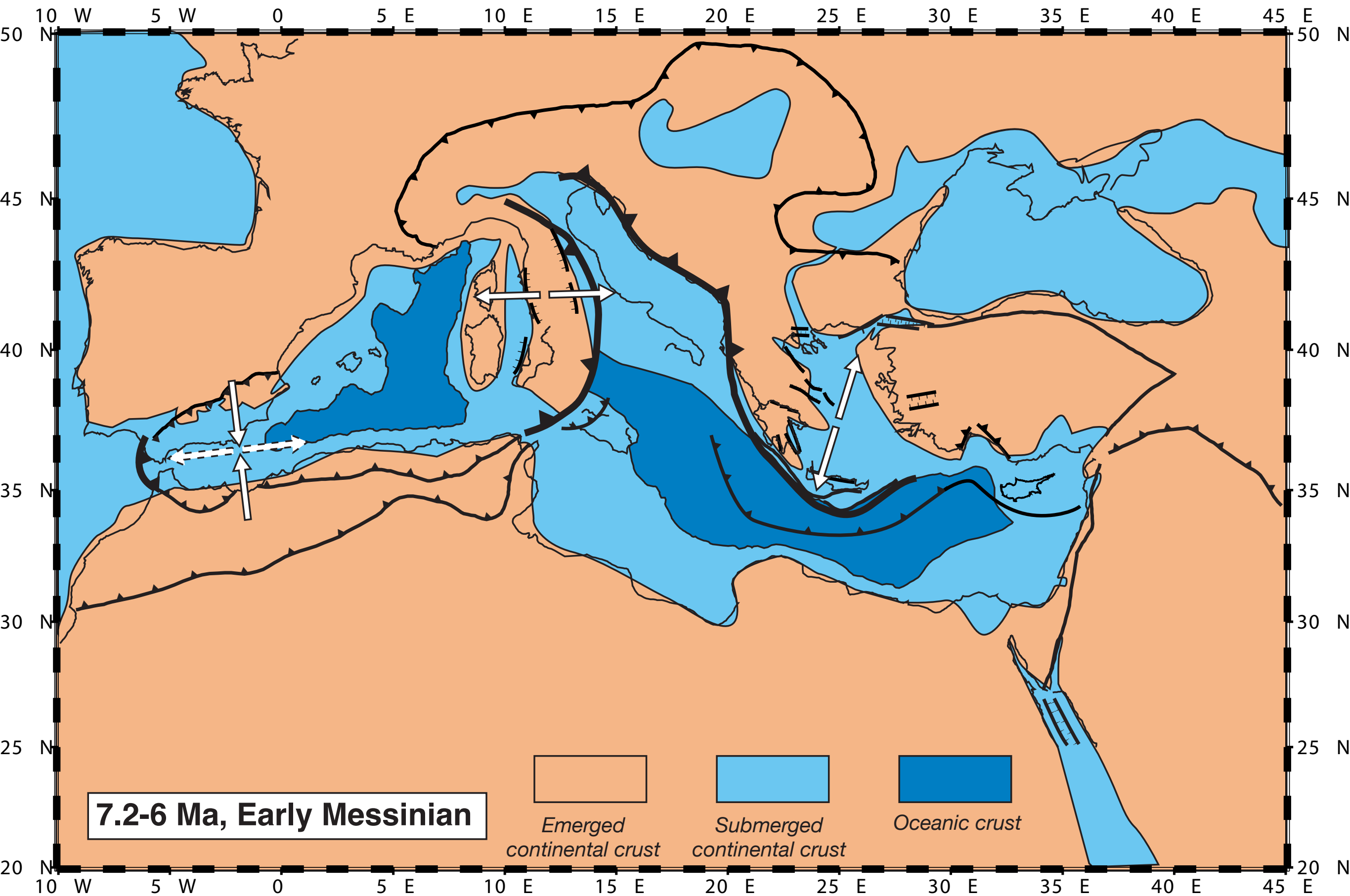
Oceanic crust

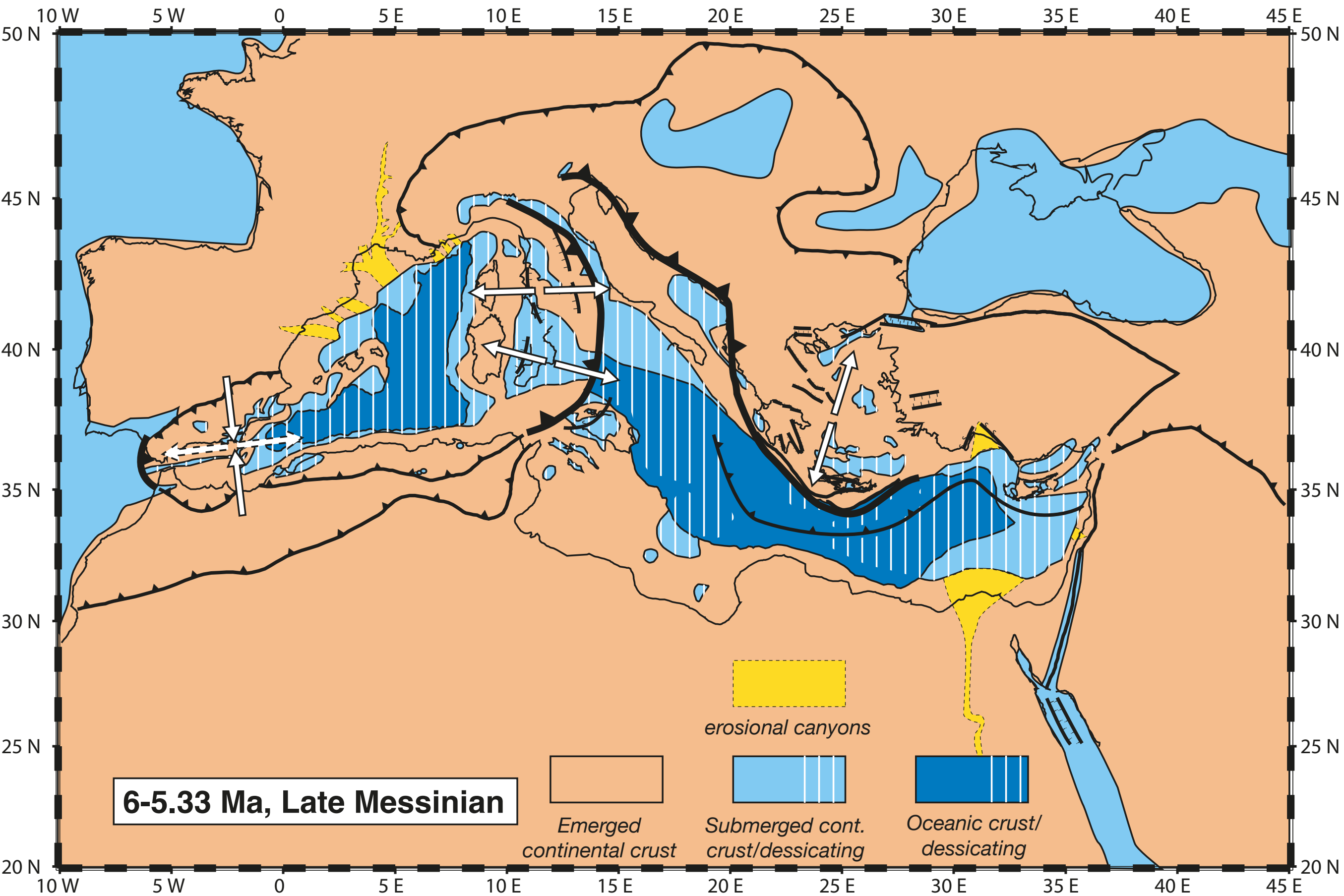




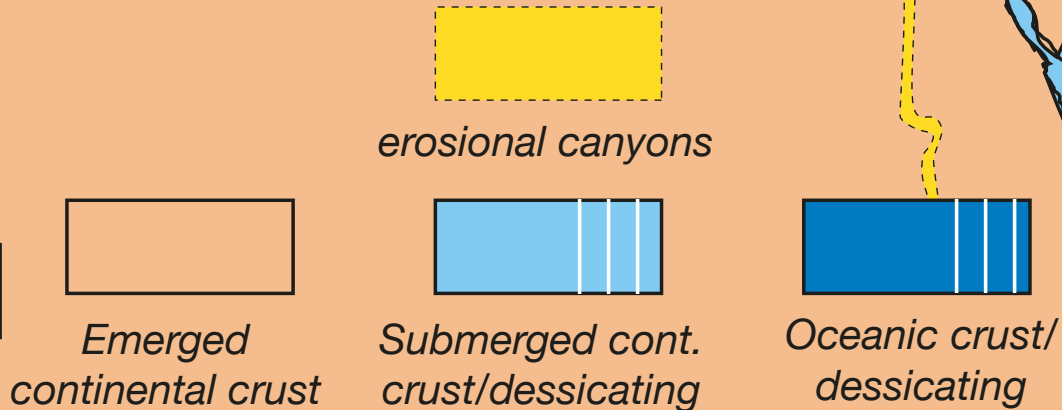


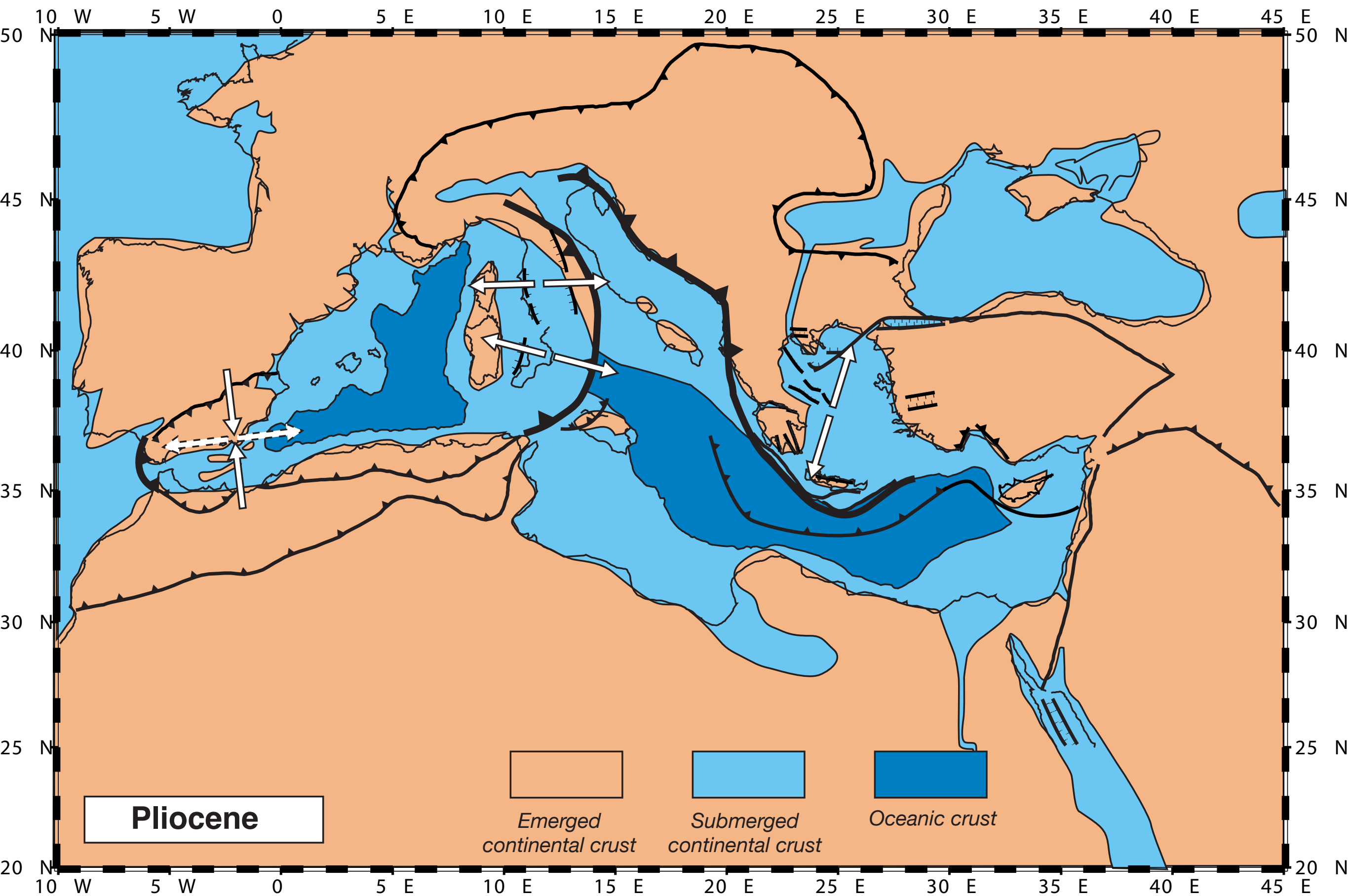


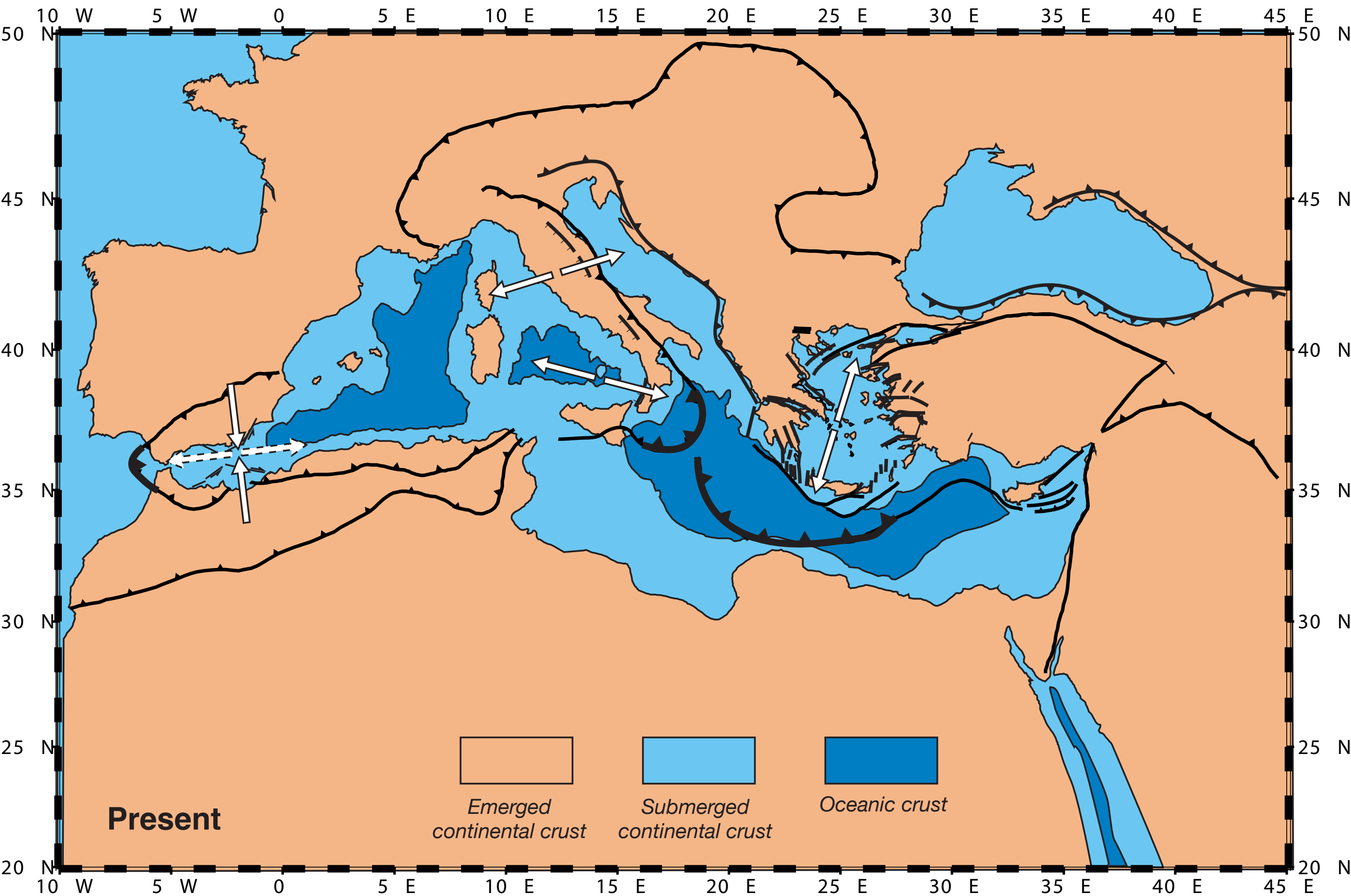


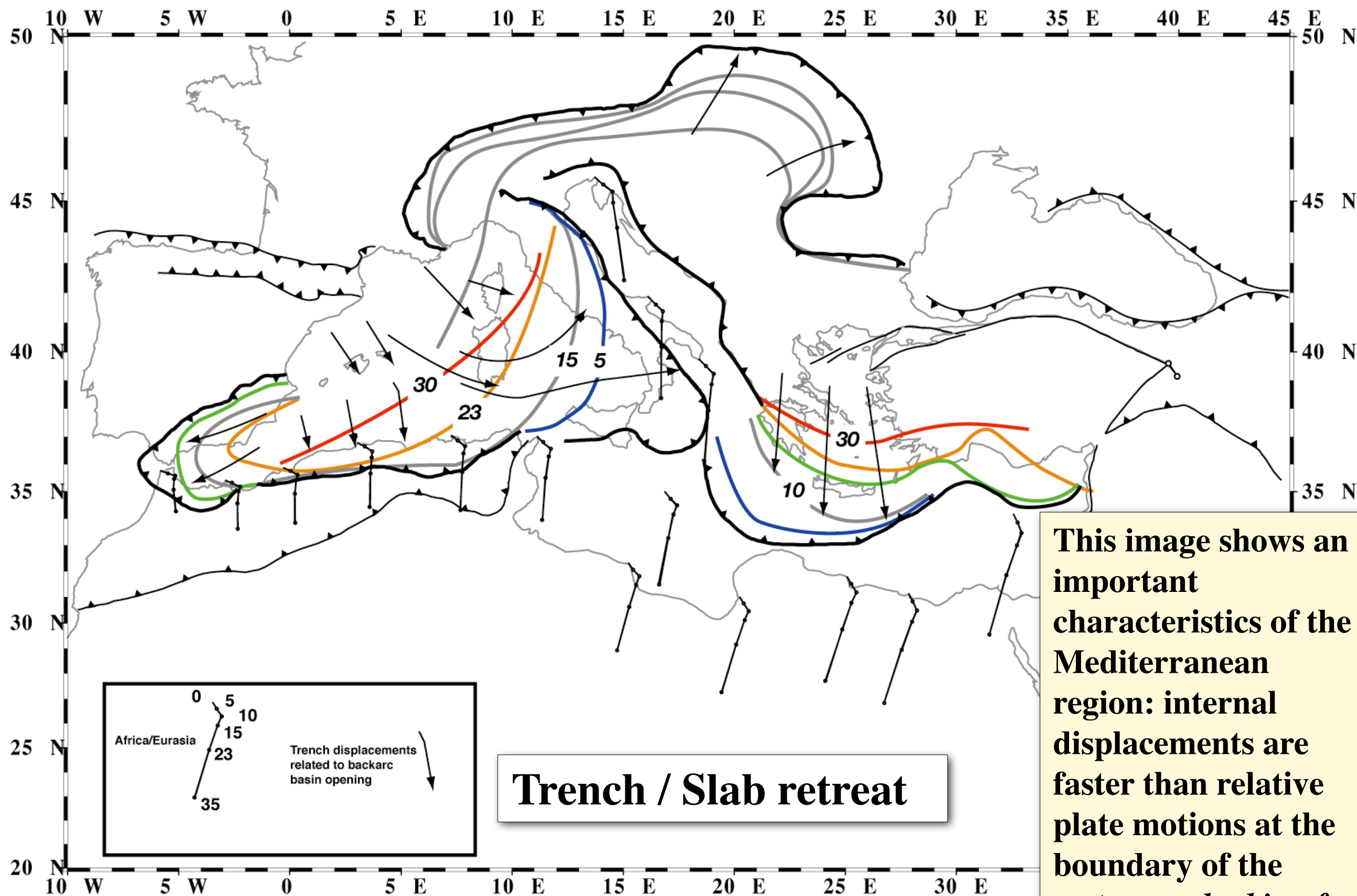


6-5.33 Ma, Late Messinian





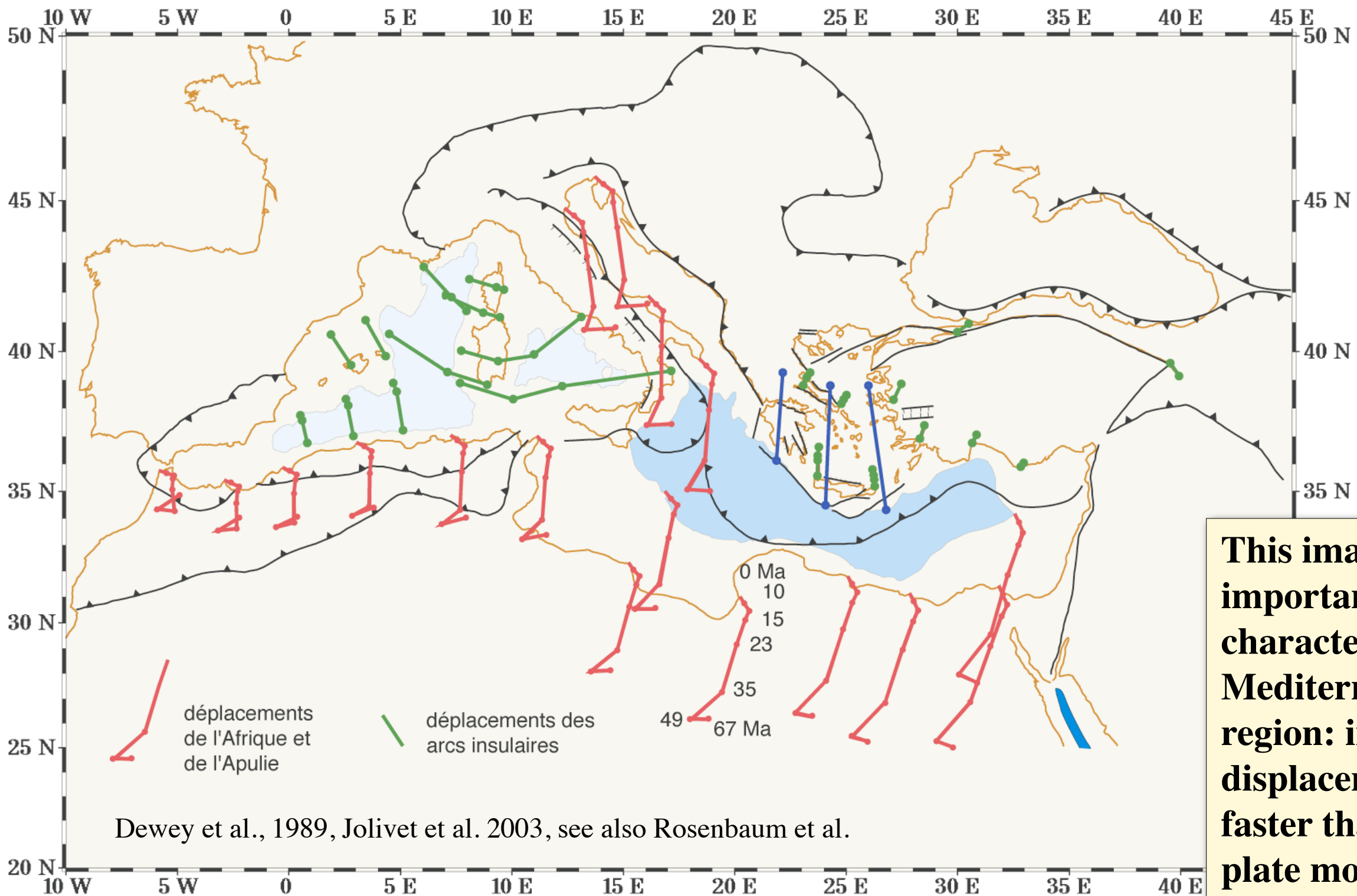




Trench / Slab retreat

This image shows an important characteristics of the Mediterranean region: internal displacements are faster than relative plate motions at the boundary of the system ... *looking for an internal engine*

Displacements since 70 Ma (*Eurasia fixed*)

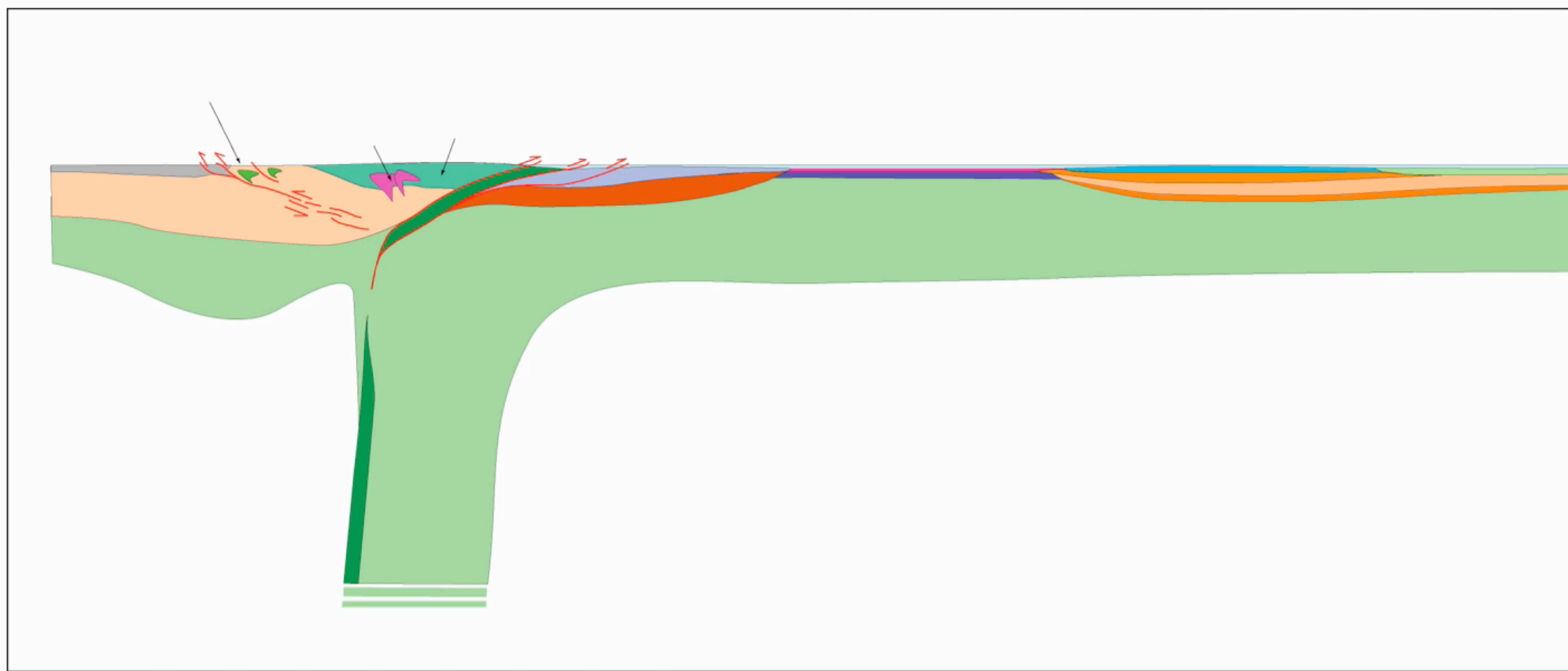


This image shows an important characteristics of the Mediterranean region: internal displacements are faster than relative plate motions at the boundary of the system ... *looking for an internal engine*

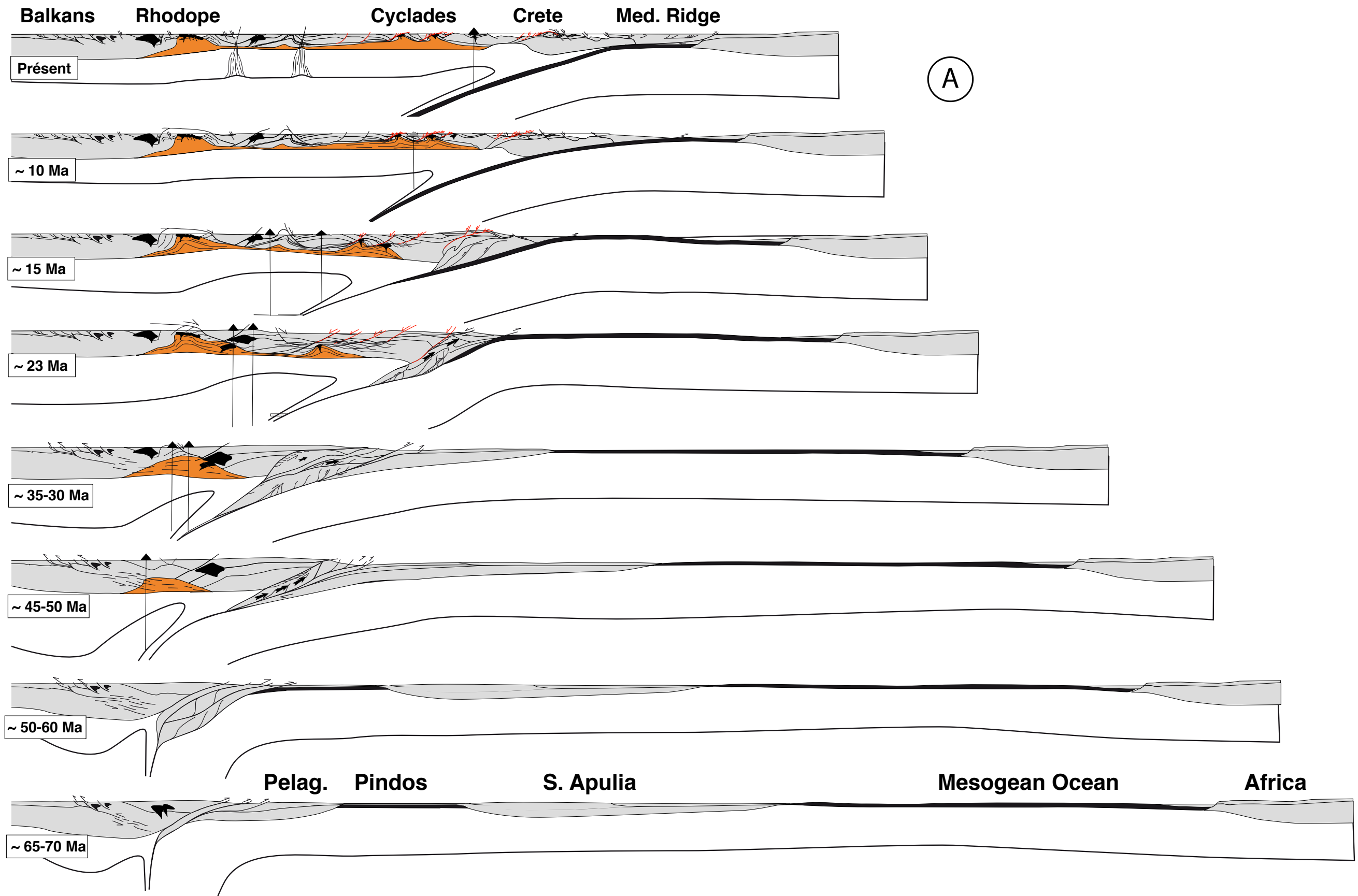


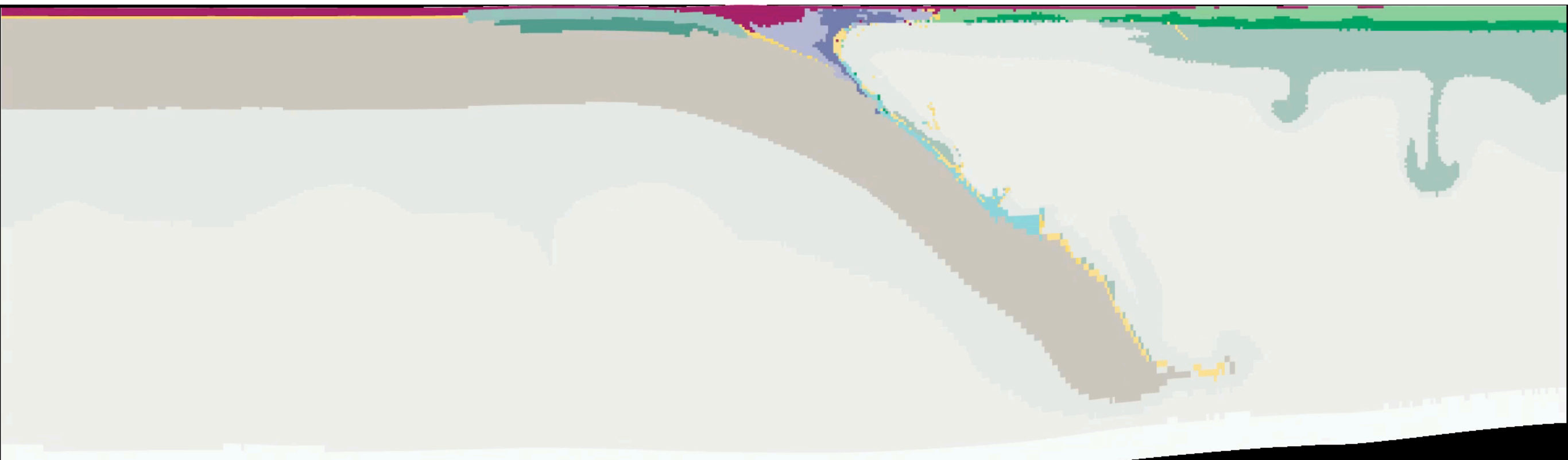
4.3.

*Geodynamic synthesis of the
Aegean region*

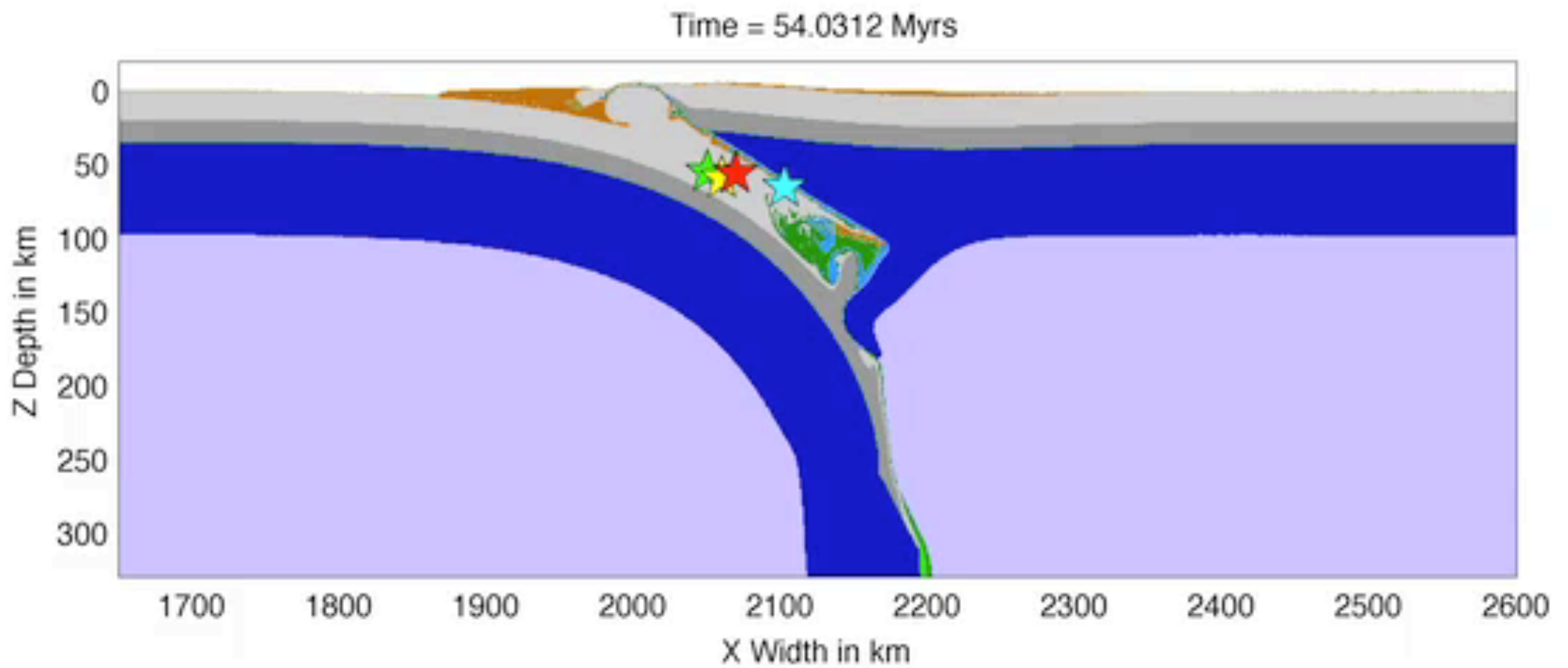


65-70 Ma

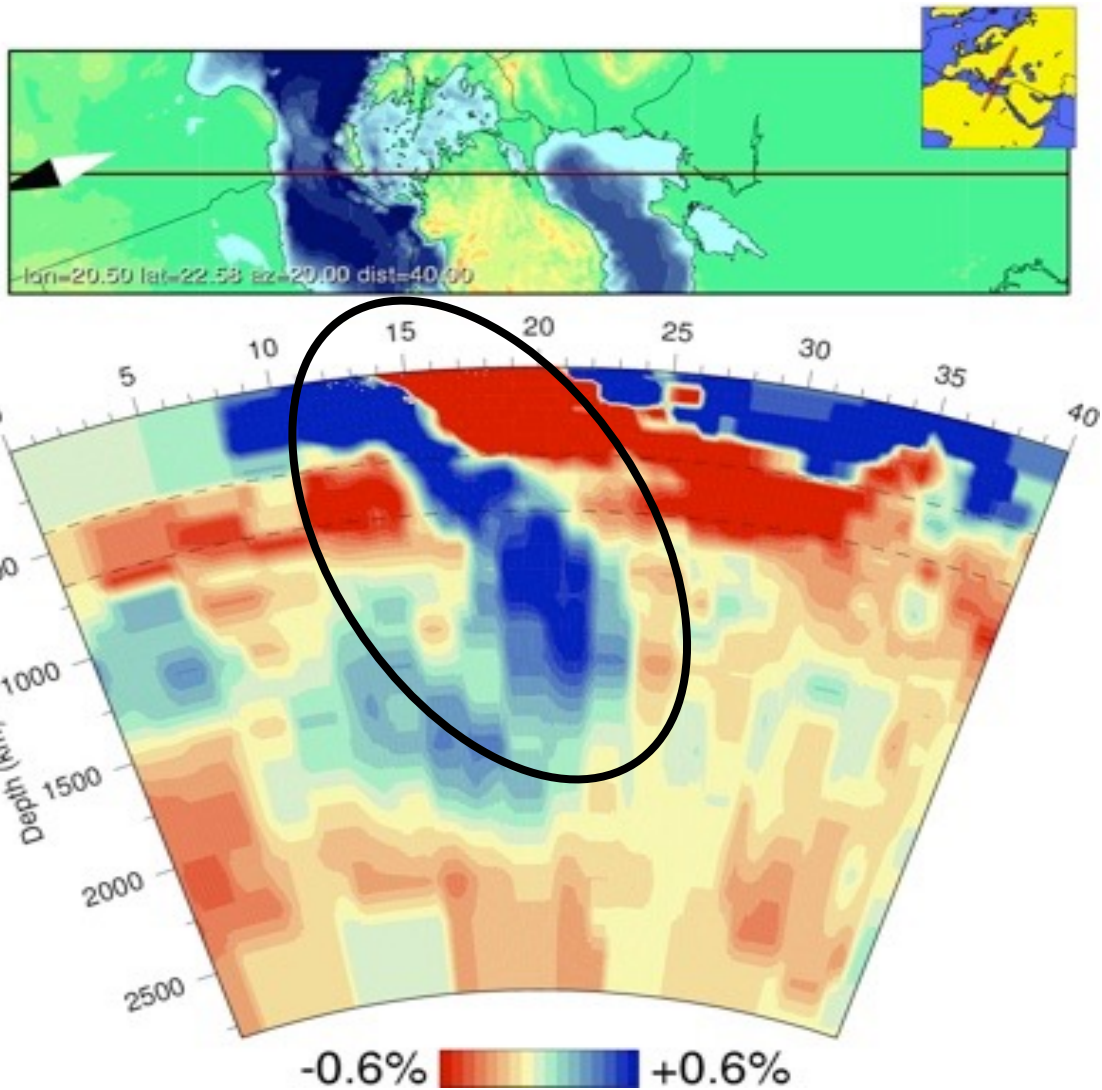




Tirel et al., 2013



Duretz *et al.*, 2012



Convergence ~ 800 km

+

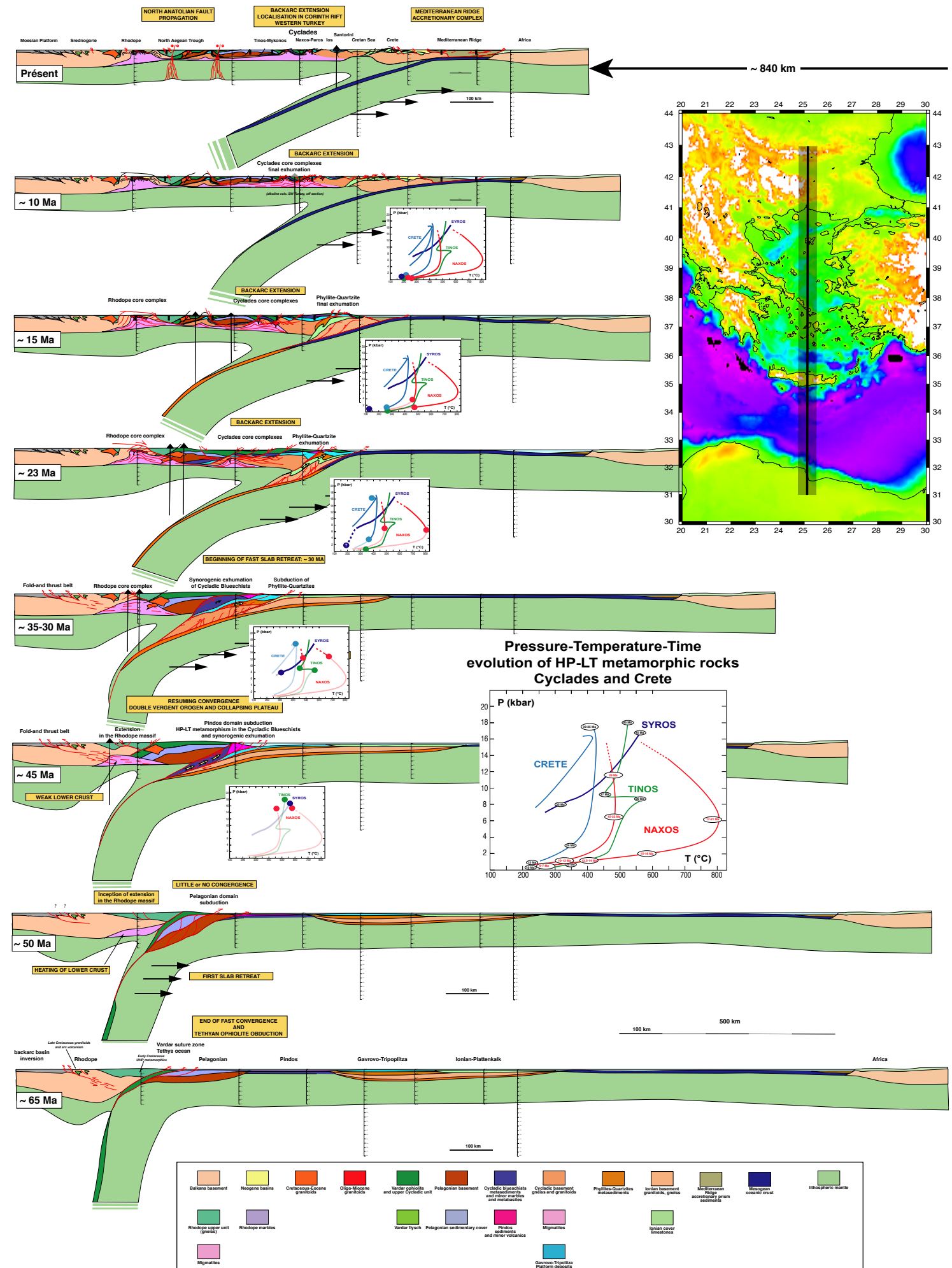
slab retreat ~ 700 km
(500 km since 30 Ma)

=

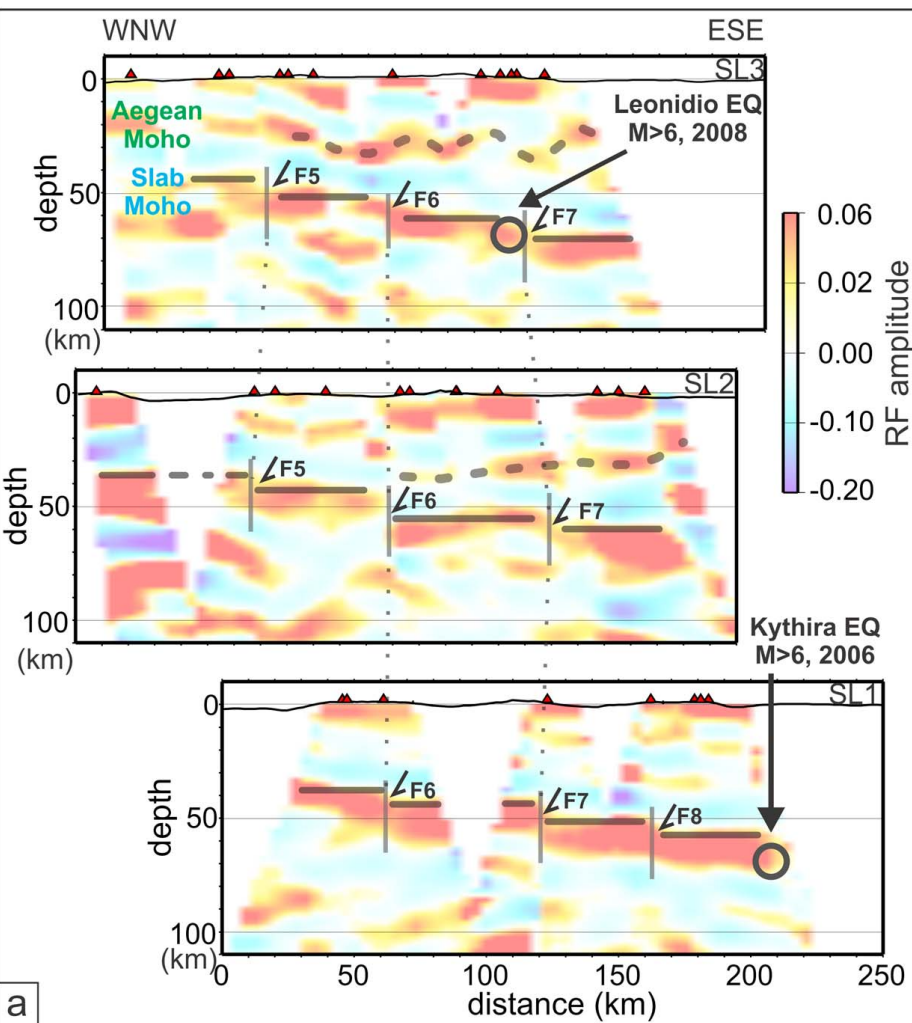
subduction ~ 1500 km

since 65 Ma

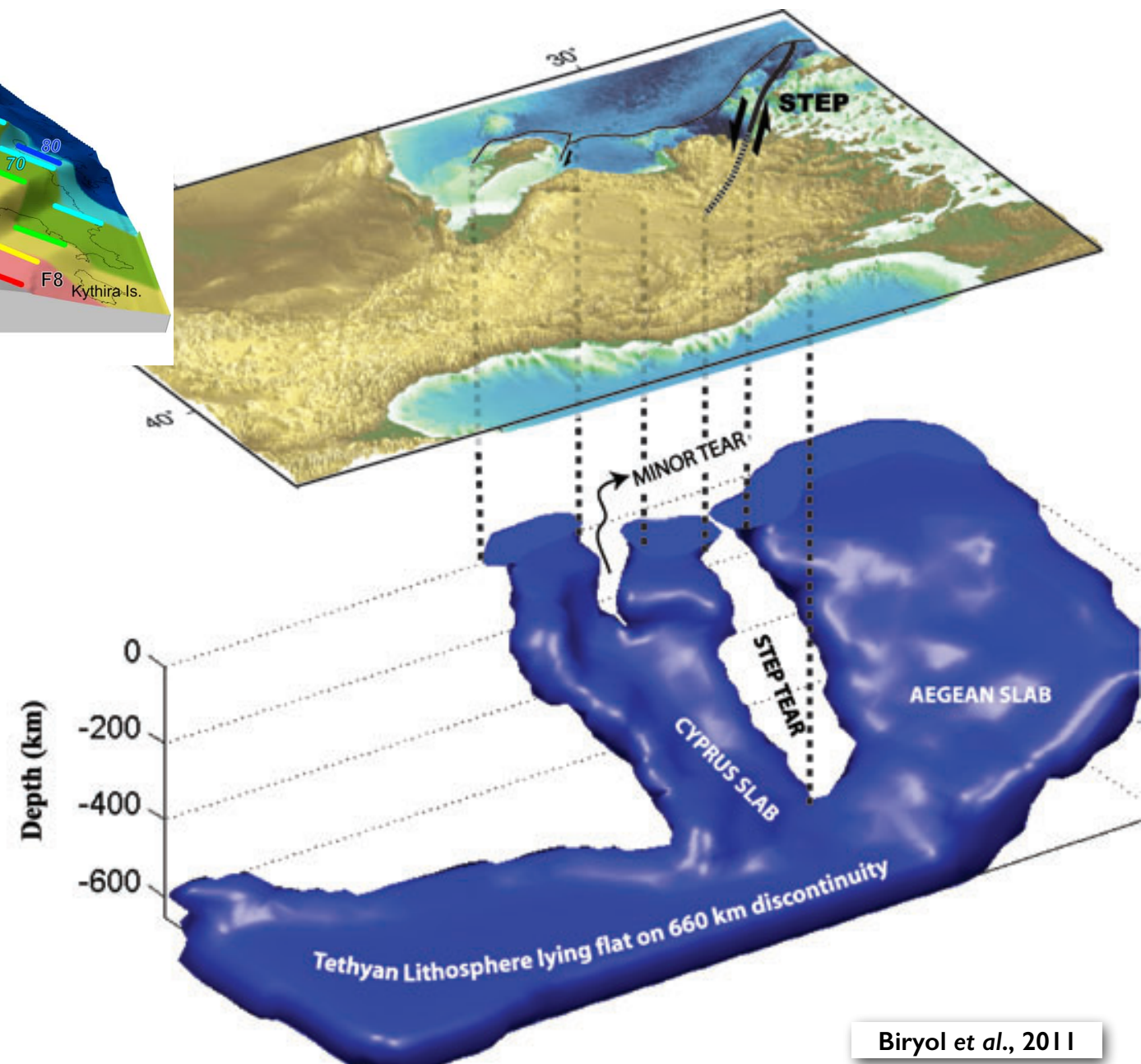
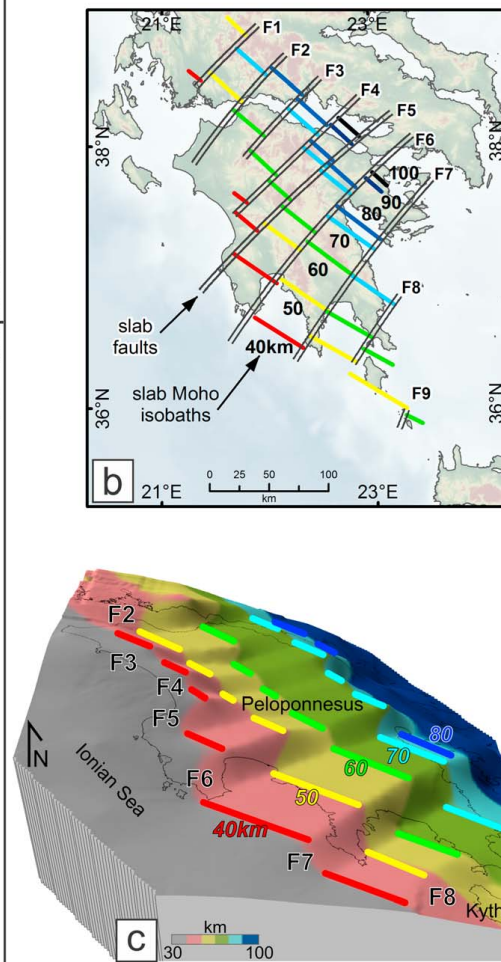
Jolivet and Brun, 2010



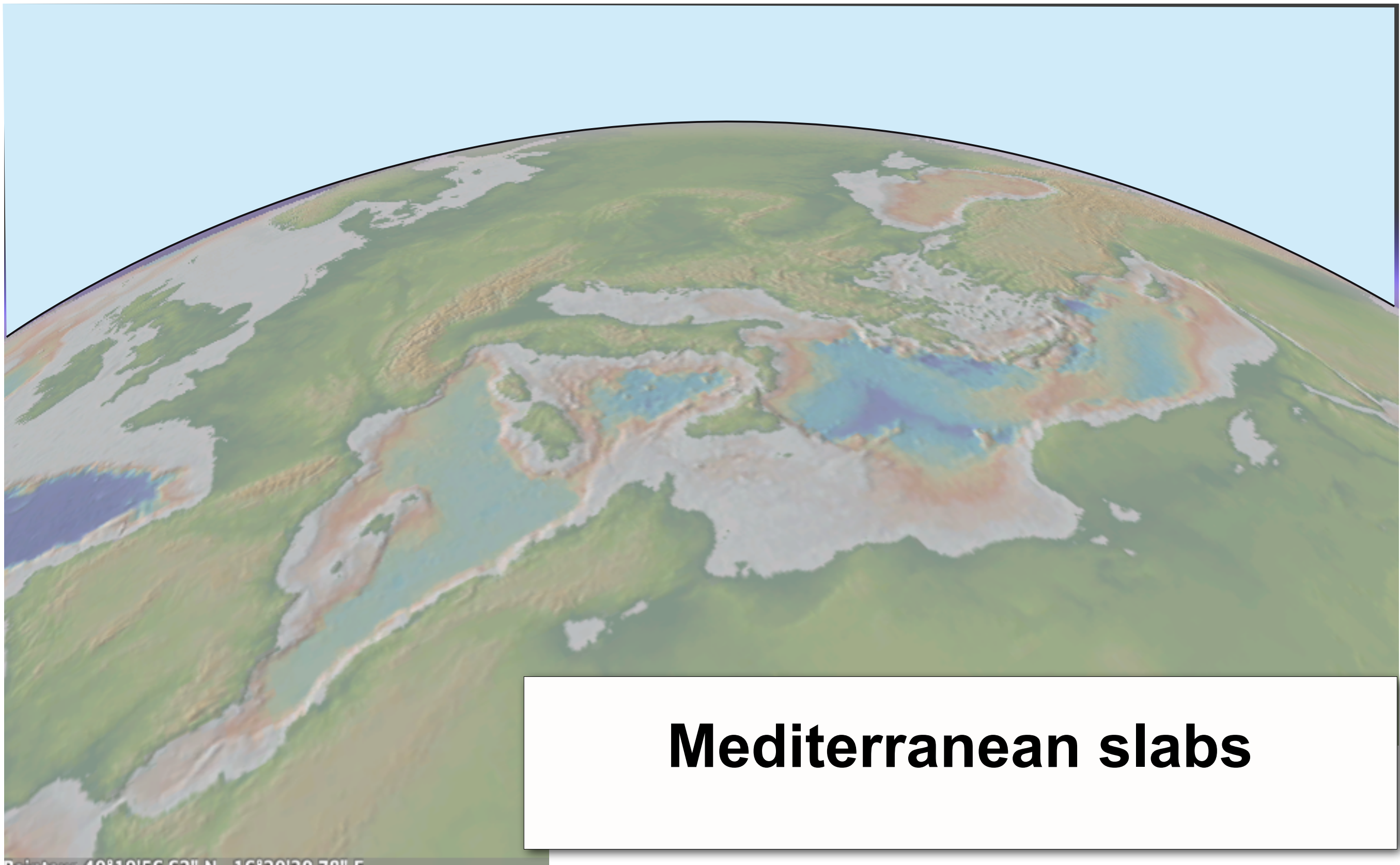
The subducting slab is not a single piece
it is also instead strongly deformed
and torn into several pieces



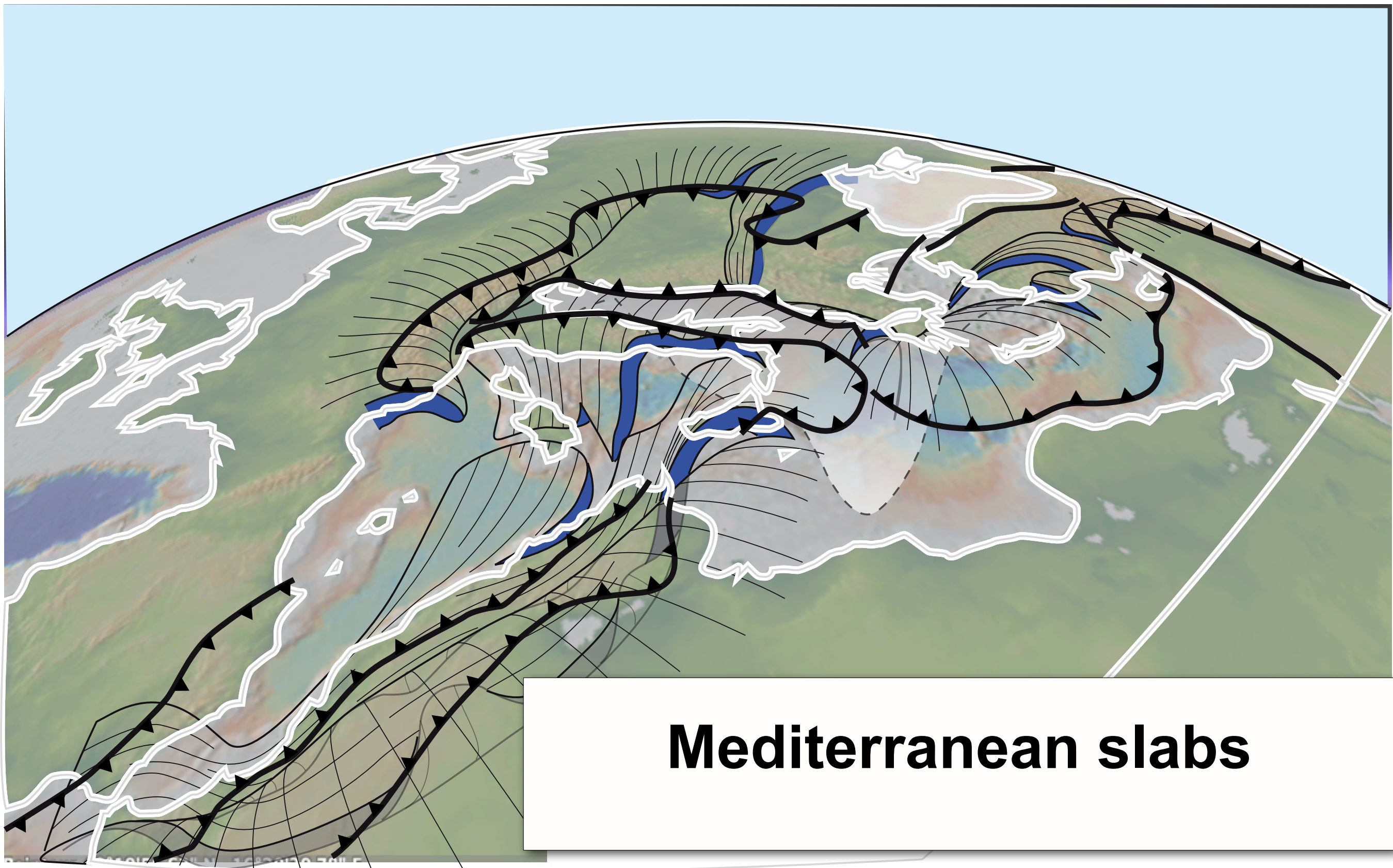
Sachpazi et al., 2016

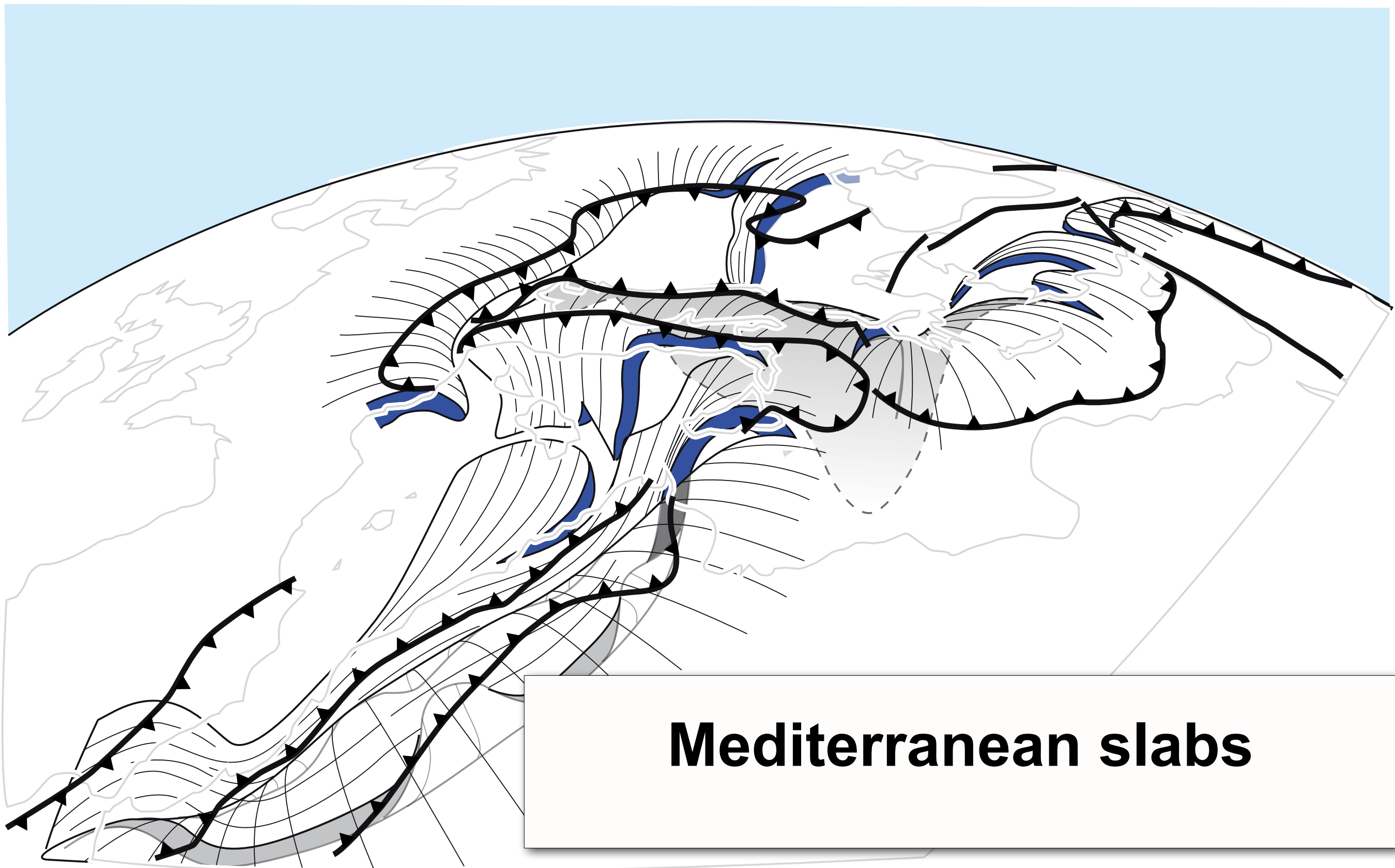


Biryol et al., 2011



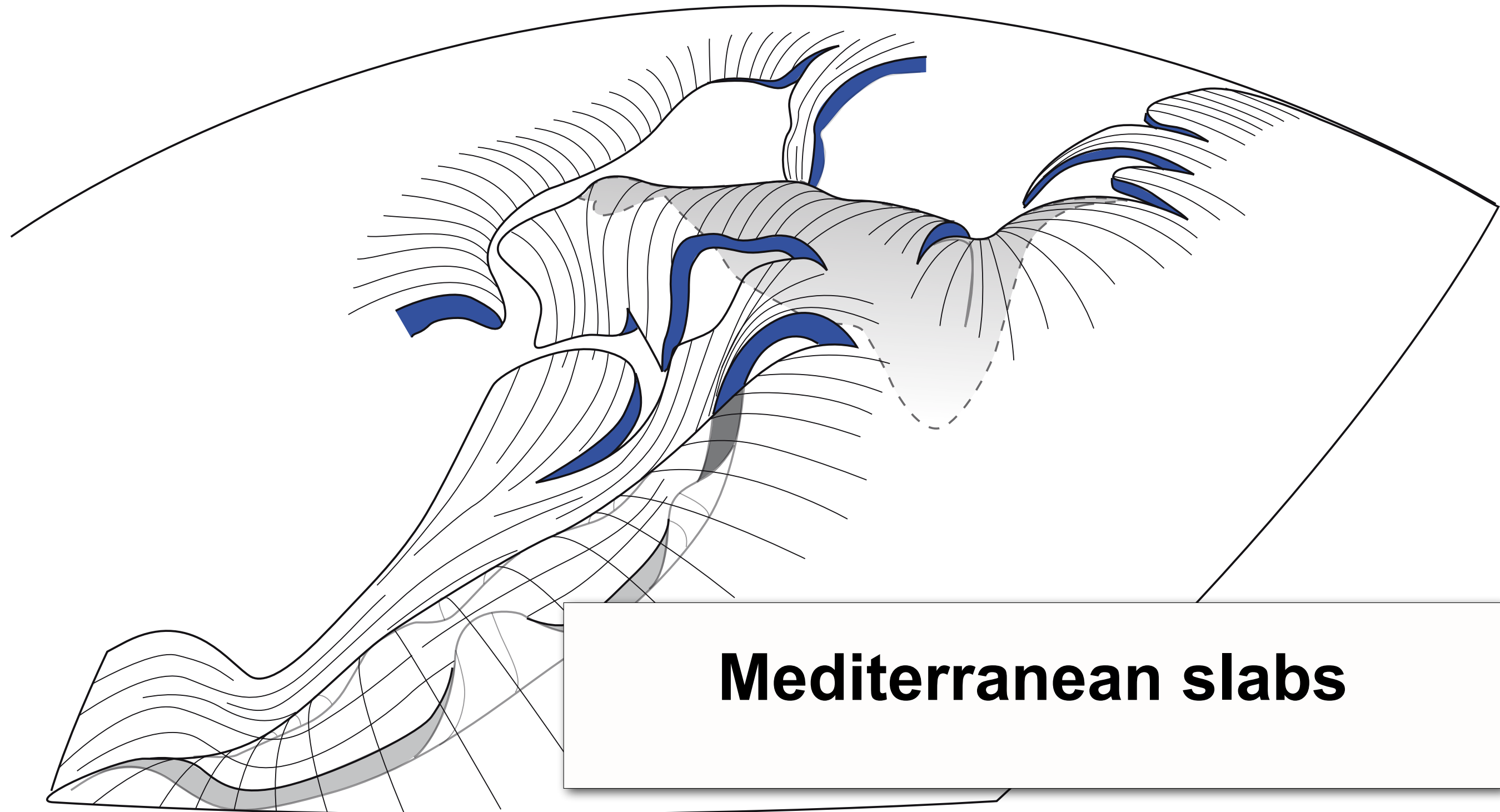
Mediterranean slabs





Mediterranean slabs

a complex geometry inherited from 35 Ma of slab retreat



Mediterranean slabs

MERCI !

