Role of dextral strike-slip faulting in the distribution of Aegean extension since Miocene times inferred from receiver function analysis

Agathe Faucher *[1]; Christel Tiberi[1]; Frederic Gueydan[1]; Alexandrine Gesret[2]*

[1] Géosciences Montpellier, UMR 5243CNRS, Université de Montpellier, Rue Eugène Bataillon, 34095 Montpellier, France.

[2] Mines ParisTech,PSL - Research University, Centre de Géosciences, 35 Rue St Honoré, F-77300 Fontainebleau, France

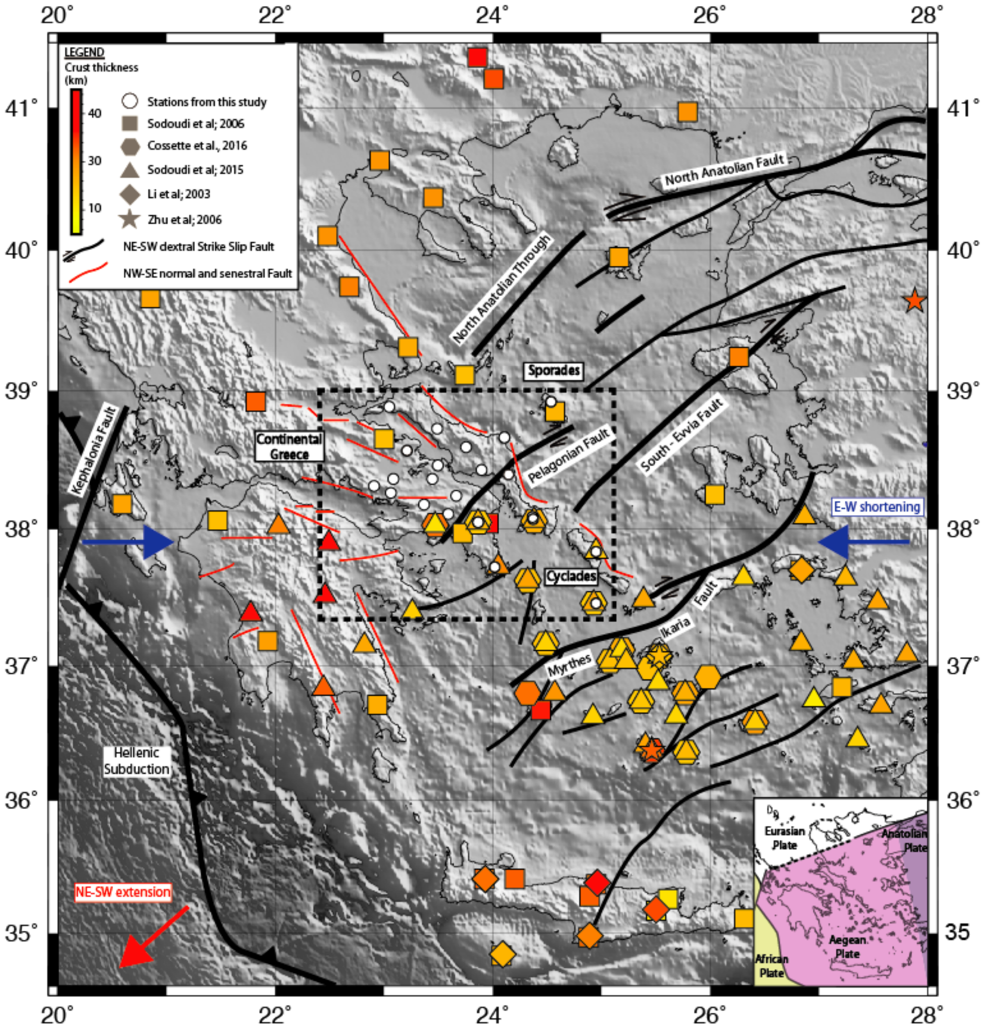


Fig.1. Simplified tectonic map with different faults. NW-SE normal faults in red lines and dextral strike-slip in black lines. Blue arrows: E-W Anatolian extrusion shortening and red arrow: NE-SW roll-back extension. Moho depth from receiver function from Cossette et al. (2016); Li et al. (2003); Sodoudi et al. (2015,2006); Zhu et al. (2006). Inset: Current distribution of tectonic plates around Aegean.

➢ Tectonics of the Aegean plate and questions (Fig.1)

- Aegean plate deformed by NE-SW subduction roll-back extension and E-W Anatolian extrusion shortening (respectively red and blue arrow Fig. 1)
- Associated structures are characterized by

  > Miocene NW-SE normal faults for roll-back extension

  > Supposed Miocene **NE-SW dextral strike-slip faults** (Pelagonian and Myrthes-Ikaria faults – Kokkalas & Ayden, 2013) and Plio-Quaternary North Anatolian fault for Anatolian extrusion (Fig. 1)

⇒ Thus, potential coeval activity between NW-SE normal faults and **NE-SW dextral strike-slip faults** since Miocene.

→ Do extrusion-related structures (NE-SW dextral faults) interact with subduction-related faults (NW-SE normal faults) ?

- Miocene is also marked by the progressive curvation of Hellenic trench favoring extension rate variations and block rotation in the Aegean domain.

  > Extension rate variations visible in the contrasting topography between Continental Greece and the Cyclades. Airy isostasic equilibrium implies a 1.7km Moho accommodation in depth.

⇒ Thus, a lateral gradient in amount of finite strain should lead to different crustal thinnings

→ How crustal thickness varies and accommodates this differential extension rate ?

→ How NW-SE normal faults and **NE-SW dextral strike-slip faults** interact with this differential extension rate since Miocene ?

➢ Key questions and methods

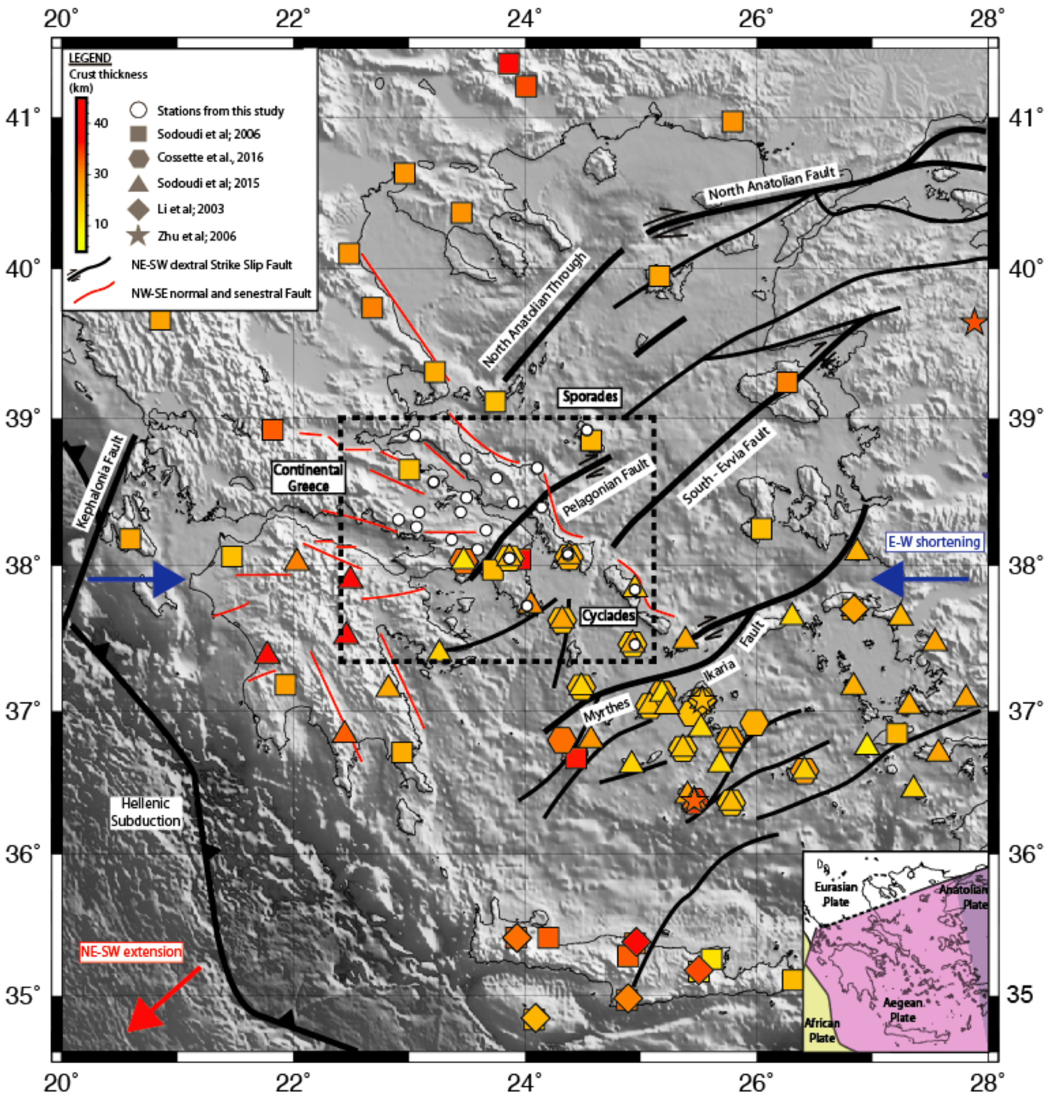


Fig.1. Simplified tectonic map with differents faults. NW-SE normal faults in red lines and dextral strike-slip in black lines. Blue arrow: E-W Anatolian extrusion shortening and red arrow: NE-SW roll-back extension. Moho depth from receiver function from Cossette et al. 2016; Li et al., 2003; Sodoudi et al., 2015,2006; Zhu et al., 2006. Inset: Current distribution of plate tectonic around Aegean.

→ Do extrusion-related structures (NE-SW dextral faults) interact with subduction-related faults (NW-SE normal) ?
→ How crustal thickness varies and accommodates this differential extension rate ?
→ How NW-SE normal faults and NE-SW dextral strike-slip faults interact with this differential extension rate since Miocene ?

Focus on a transitional zone marked by large topographic variations and exhibiting normal faults and **NE-SW dextral strike-slip faults** (**Pelagonian and South Evvia faults**) between Continental Greece, the Cyclades and the Sporades

❑ *To answer theses questions we:*

➢ Use receiver function analysis ➢ Characterize an associated strike and dip for some stations	→	Precisely deduce the Moho depth and geometry
➢ Study both the radial and transverse component	→	Determine each fault role on the crustal thickness.
➢ Interpret our results with previously existing data in the Aegean domain	→	Good constraint on Moho long wave-length variations to discuss NE-SW Myrthes-Ikaria fault (Cyclades) and the Sporades.

➢ Method

- ❑ Moho depth

a. Signal treatment : rotation in RZT – Iterative deconvolution
b. Moho depth determination from the calculation of Ps PpPs and PpSs + PsPs theoretical arrival time by Zhu & Kanamori (2000) inversion (Fig.2 a & c)

- ❑ Strike and Dip

Dipping interface direction corresponds to the backazimuth associated with Ps polarity change in transverse component (Fig.2b) and strike corresponds to this value + 90° (Fig.2d)

a. Use an exhaustive search in strike-dip domain
b. Modeling theoretical receiver functions associated with all strike/dip couples
c. Calculation of the difference in time arrival between $strike_{mod}$ /dip_{mod} and $strike_{obs}$/dip_{obs}
d. Smaller difference help to find the best strike/dip couple solution

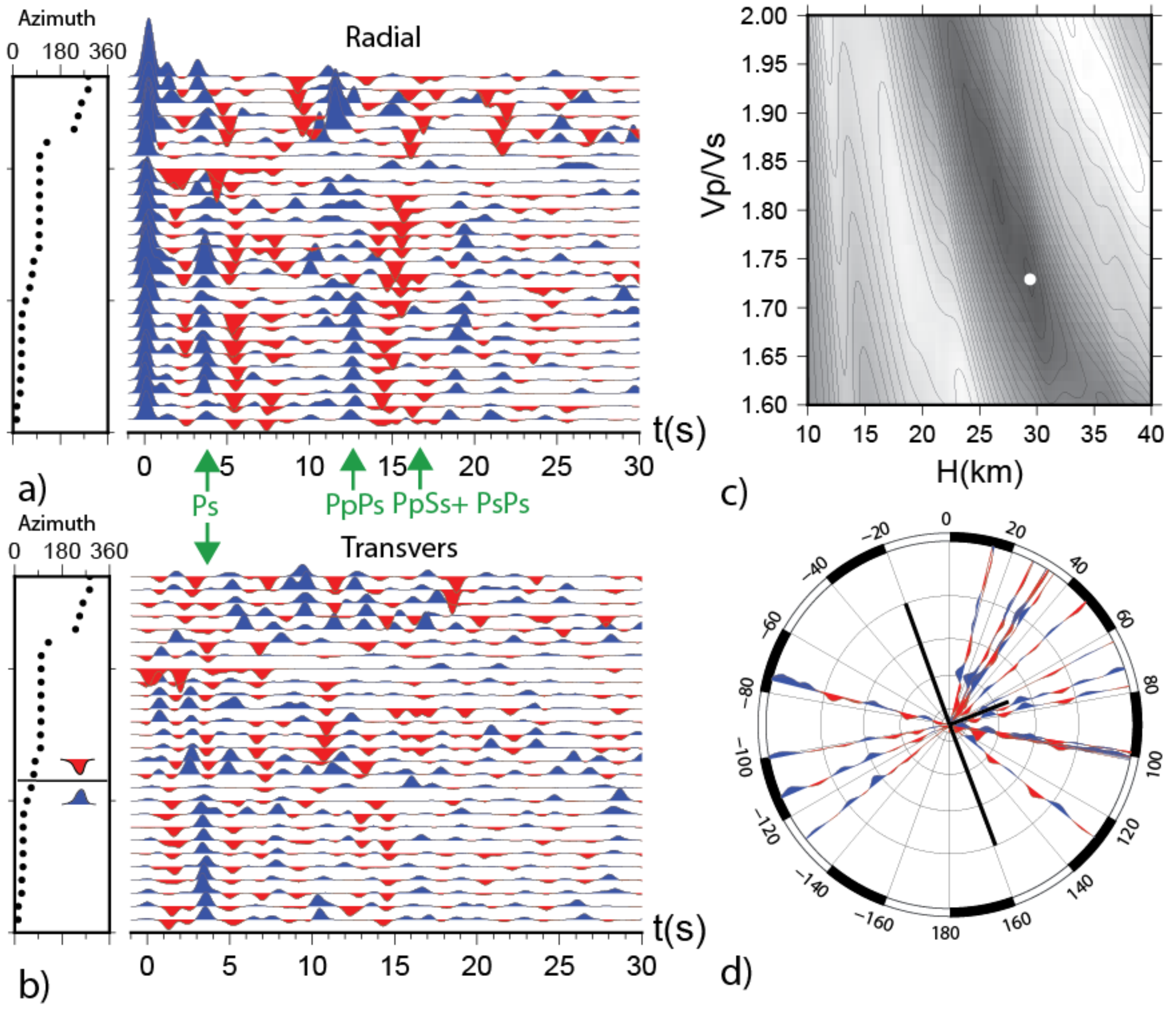


Fig.2. Receiver Function method. a) Radial component of receiver function. b) Transverse component of receiver function. c) Zhu & Kanamori inversion results. H: Moho depth, white point: best solution of H-Vp/Vs couple. d) Receiver functions arrange in function of their backazimuth. Change in Ps polarity represent dip direction.

➢ Transition between Continental Greece and Cyclades: The Pelagonian and South Evvia dextral strike-slip faults

- 24 MEDUSA stations selected (Fig.3)
- Moho depth between 22 and 29.4 km with mean value at 26km
- Error value between 0.72 (S029) and 7.3 (S020) with mean value at 1.7km → Good quality of seismic data

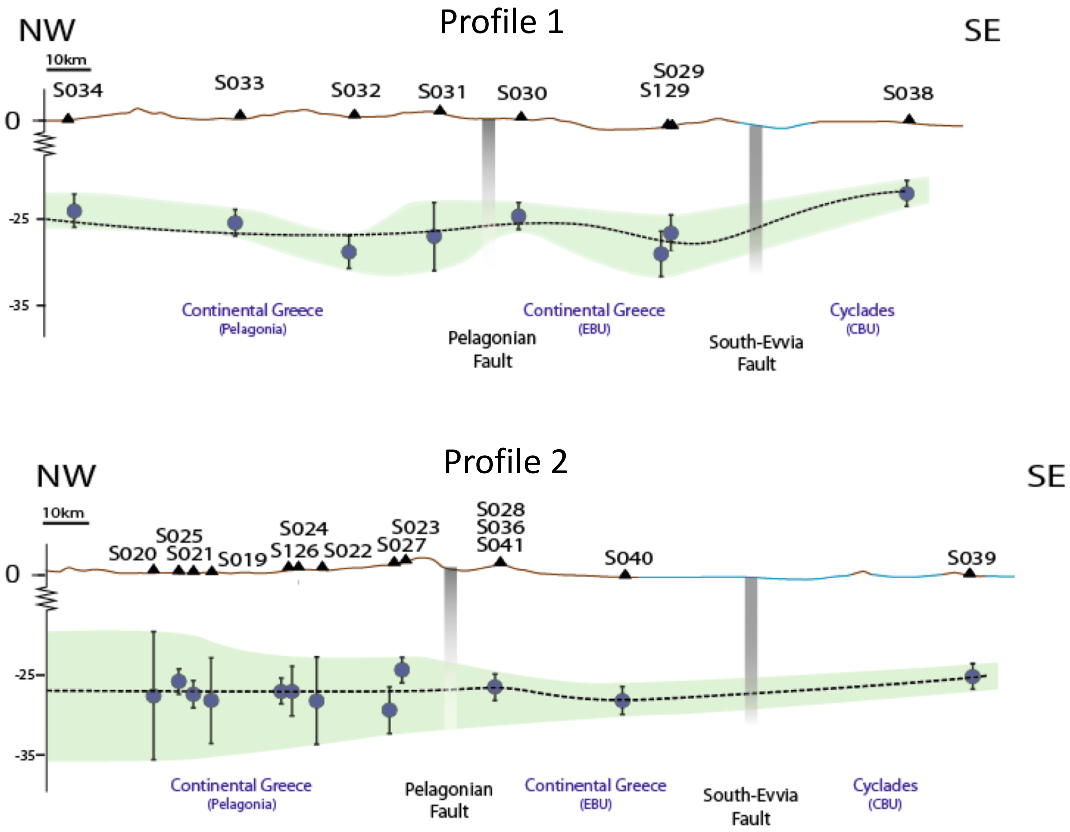


Fig.4. Moho depth along two profiles, see Fig.3.left. Profile 1 is located underneath Evvia Island. Profile 2 is located underneath Attica. In topographic profile, brown: land, blue: ocean. Shaded grey bars: Dextral strike-slip faults

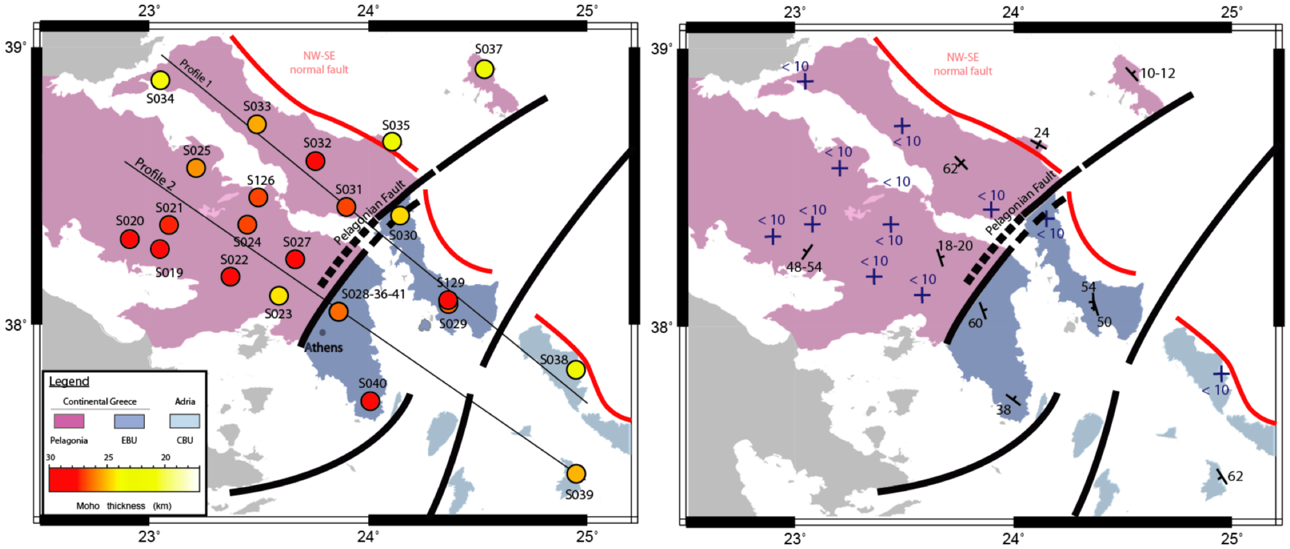


Fig.3. Aegean Map with results. Black lines: dextral strike-slip faults, red lines: NW-SE normal faults. Right: Moho depth values from Zhu & Kanamori (2000) inversion, with the location of profiles 1 & 2. Left: strike/dip values.

Profile 1 : (Fig.4)
- 2km thinning underneath Pelagonian strike-slip fault and **5km underneath the transition between Continental Greece (S029-129) and Cyclades (S038) underneath South-Evvia strike-slip fault**
- Moho variations are observed, but from error bars + dip_{max} of 10°, a sub-horizontal Moho can be deduced underneath Continental Greece (Fig.4 profile 1, dashed line in Pelagonian part) → mean value at 26km

Profile 2: (Fig.4)
- No large Moho variation consistent with low dip angle.
- Sub-horizontal Moho underneath Continental Greece with a mean depth of 27.2km
- High dip angle underneath EBU part of Continental Greece (Fig.3, right)
- **Thinning of 3km between S040 and S039 underneath the transition between Continental Greece and Cyclades underneath South-Evvia fault.**

➢ Transition between Continental Greece and Cyclades: The Pelagonian and South Evvia dextral strike-slip faults

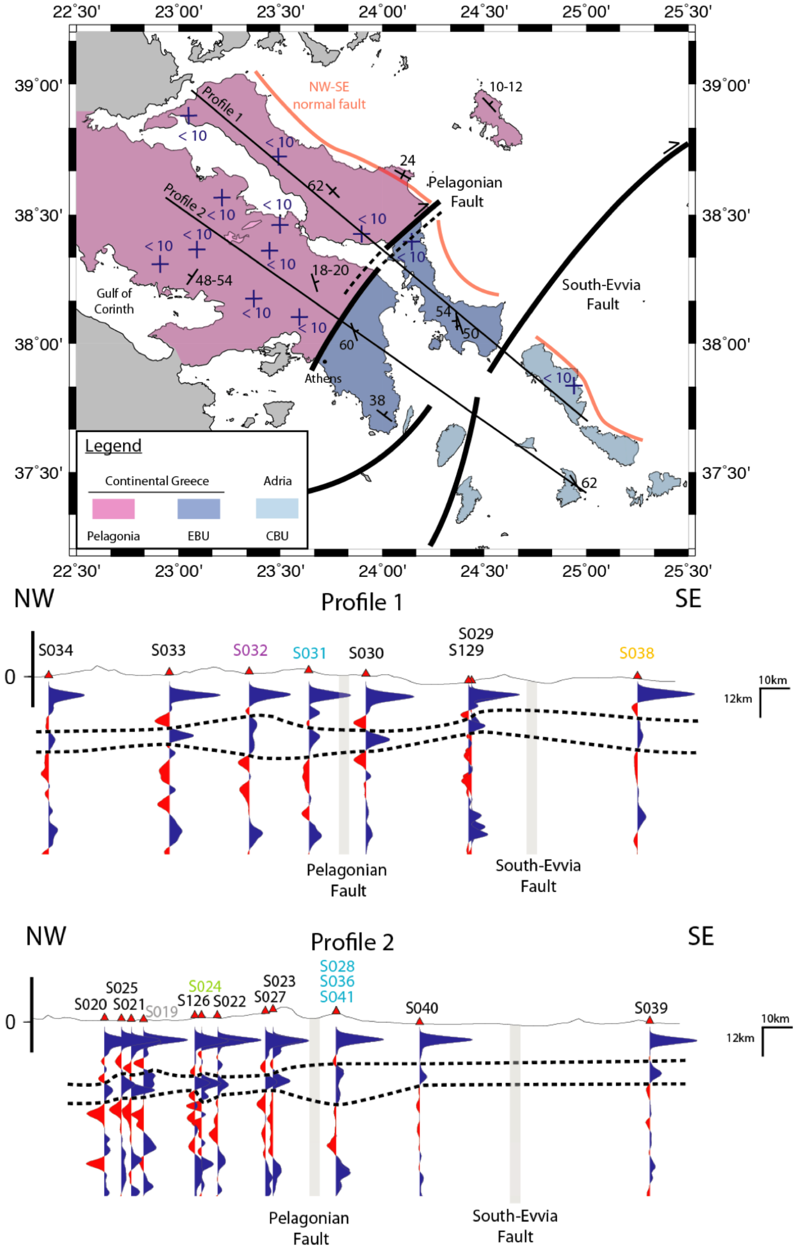


Fig.5. Top: strike/dip values with location of profiles 1 & 2. Black lines: dextral strike-slip faults, red lines: NW-SE normal faults. Bottom: Complexity of the signal on Ps wave delimitated by dashed lines. Shaded grey bars: Dextral strike-slip faults

Complexity of the signal

❑ *Why ?*

The complexity of the signal could be an indicator of a change in Moho geometry, lateral seismic velocity modifications, the presence of tectonic discontinuities (faults) or anisotropy

Analysing complex signal of MEDUSA stations allows to investigate the potential effects of Pelagonian and South Evvia faults on the Ps signature.

→ No complexity = Clear and narrow positive Ps pick around 3-5s

→ Complexity = Wider or doubled Ps pick

❑ Station displaying signal complexity (dashed lines – Fig.5):

- Continental Greece (Pelagonian + EBU parts):

. S019 - S024 : Poor signal quality → local change in physical properties or deep interface

. S032 : associated with a high value of dip (62°), supposed to be caused by Moho depth change

. **S031 and S028/36/41 : not related to depth Moho change since dip value <10°, but could be caused by their proximity with the Pelagonian fault**

- Cyclades:

. **S038: no dip high value but located between South Evvia fault and a NW-SE normal fault, both could caused this signal complexity.**

➢ Transition between Continental Greece and the Sporades: NW-SE normal faults

- Sub-horizontal Moho consistent with strike/dip study (Fig.6 & 7)
- **Large step in Moho depth (around 6km) between S032 and S035 close to NW-SE normal fault** (Fig.7)
- Moho mean value at 23km underneath Sporades (*but only based on 2 stations*)

NW-SE normal fault located above Moho step between Continental Greece and the Sporades.

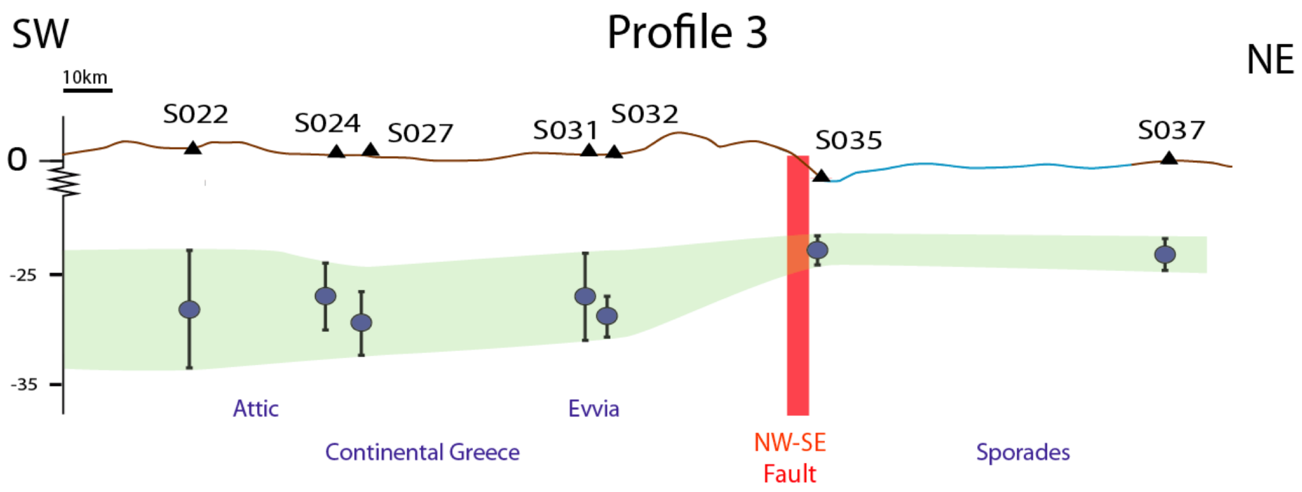


Fig.7. Profile 3 is located underneath Attica and Evvia island. In topographic profile brown: land, blue: ocean. Red line: NW-SE normal fault

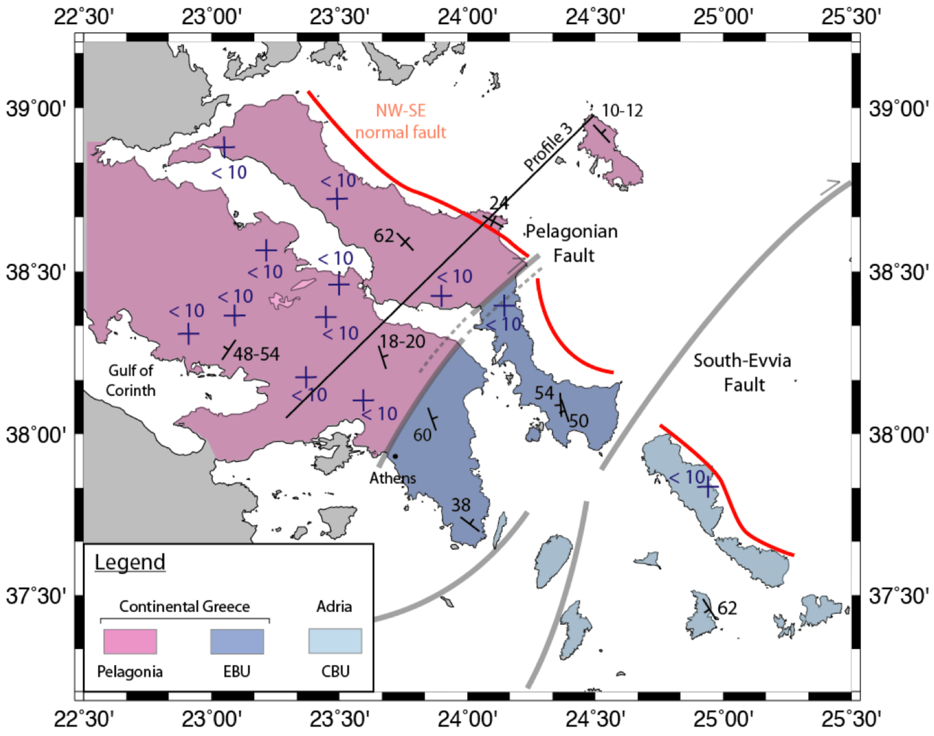
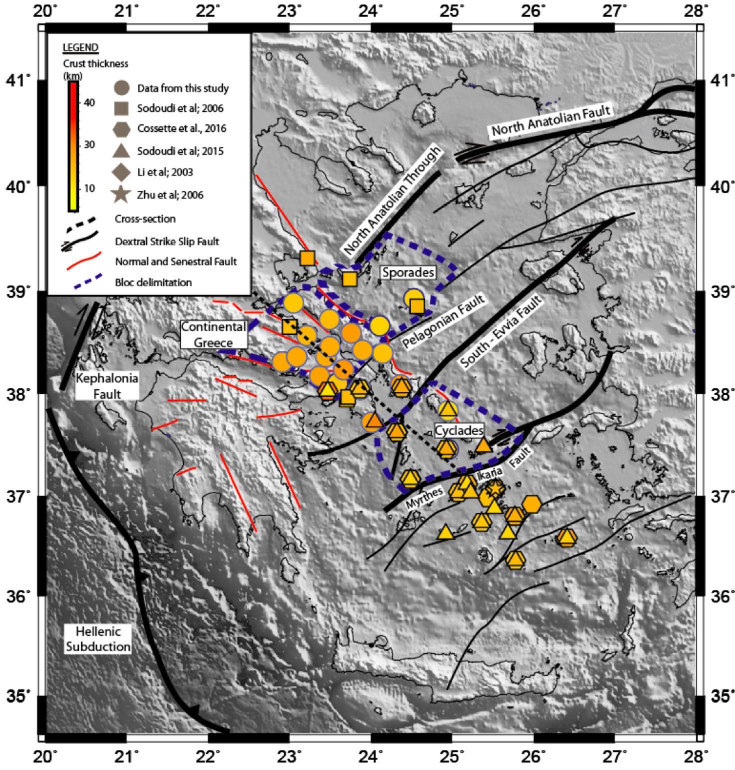


Fig.6. Top: strike/dip values with the location of profile 3. Black lines: dextral strike-slip faults, red lines: NW-SE normal faults

Pelagonian and South-Evvia dextral strike-slip faults and NW-SE normal faults are located underneath Moho steps between respectively Continental Greece & Cyclades and Continental Greece & Sporades. They delimitated these 3 domains associated with different extension rates.
=> Dextral strike-slip and NW-SE normal faults **accommodate differential extension rates.**

➢ Discussion (1) - Results summary and compilation with data from literature



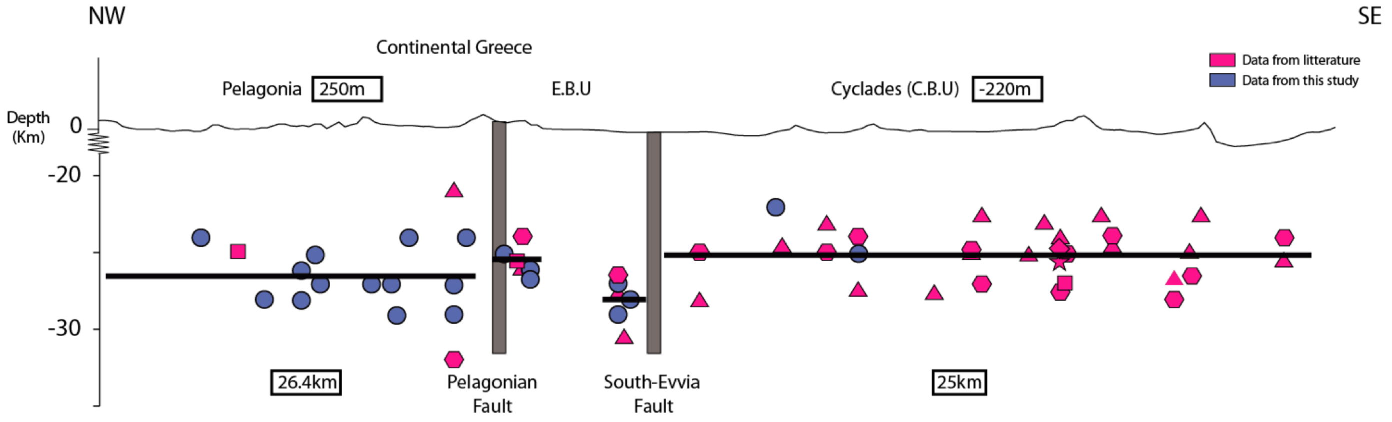


Fig.8. Left: Simplified tectonic map with different faults. NW-SE normal faults in red line and dextral strike-slip in black line. Moho depth from receiver function from Cossette et al. (2016); Li et al. (2003); Sodoudi et al. (2015,2006); Zhu et al. (2006), circles represent results from this study. Blue dashed lines represent blocks delimitation: Continental Greece in NW – the Cyclades in SW and the Sporades in N. Right: Depth Moho cross-section with dextral strike-slip faults in grey along dashed line on the left map.

- Moho variations delimit 3 different blocks with 3 different Moho depths (from this study + literature data - Fig.8): Continental Greece (26.4km) – Cyclades (25km) – Sporades (*24km ?)*
- Taking into account the uncertainty in receiver function and topographic mean value, Continental Greece and Cyclades could be considered in isostasic equilibrium because:
  . Expected value of moho depth difference between Continental Greece and Cyclades based on topography variation = 1.7km
  . Real value deduced from receiver function (from this study + literature data - Fig.8 left) = **1.4 km**
- Moho geometry (thickness + strike/dip) is impacted by **Pelagonian & South-Evvia dextral strike-slips** and NW-SE normal faults
- Both **dextral strike-slips** and NW-SE normal faults delimitate the 3 blocks
- EBU represents a deformed transitional zone above the Moho step between Continental Greece and Cyclades.

In Miocene, the coeval activity of dextral strike-slip and NW-SE normal faults allows delimiting blocks with different extensions. Thus, both kinds of structures accommodate the different extension rates caused by the Hellenic trench curvature.

➢ Discussion (2)

❑ To go further…

- The south limit of the Cyclades blocks could be represented by Miocene crustal Myrthes–Ikaria fault (Kokkalas & Aydin, 2013)
- Currently, Pelagonian and Myrthes-Ikaria faults don't seem active (no seismic activity in Quaternary) contrary to South-Evvia fault.
- Moreover, South-Evvia fault seems to accommodate the largest Moho step (5km vs 2km for Pelagonian fault) supposing high activity in South-Evvia fault.

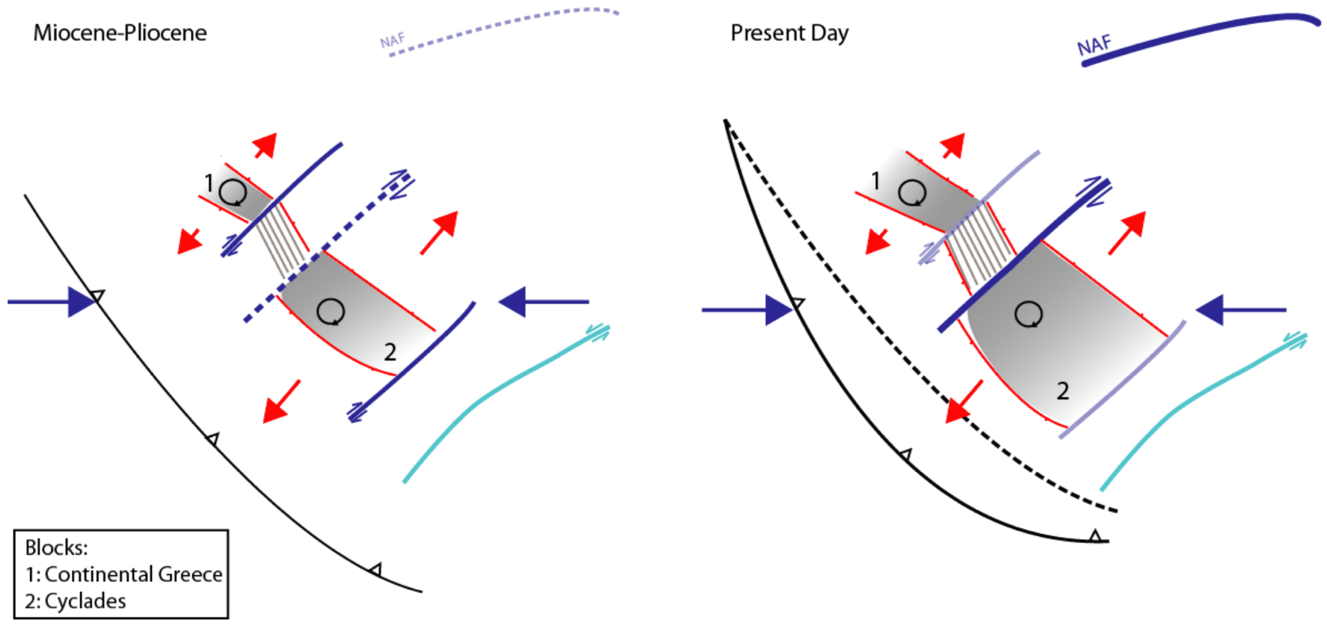


Fig.9: Sketch of differential extension accommodated by dextral strike-slip (blue lines) and normal faults (red lines) **for Continental Greece and Cyclades**. Blue arrows: westward Anatolian extrusion shortening, red arrows: roll-back extension (size of arrows represent extension rates). Dark circles represent blocks rotation. NAF: North Anatolian dextral strike-slip fault. Left: Dashed lines represent future faults. Right: light blue lines represent faults of lower activity, dashed line: the old position of the trench.

❑ …We suppose (Fig. 9):

A/ NE-SW dextral strike-slip faults (as Myrthes-Ikaria - Kokkalas & Aydin (2013) or Pelagonian) were active during Miocene coeval with NE-SW normal faults (Papanikolaou & Royden, 2007) and both delimitated blocks with differences in extension (Fig. 9 right).

B/ Dextral strike-slip faults do not accommodate the same amount of extension and could either be active or not at the same period. We suppose that South-Evvia was created shortly after the Pelagonian fault which will accommodate more extension following strain migration between the two (Fig. 9 left).

May be the formation of North Anatolian dextral strike-slip fault in Plio-Quaternary shows a northward migration of strain. This migration, could happen between Miocene and present times and could produce the surrender of some NE-SW dextral strike-slip faults to the benefit of stronger NE-SW dextral strike-slip faults as the North Anatolian and South-Evvia faults.

=> This hypothesis could explain the current limited dextral strike-slip faults activity in the Aegean domain compared to a large amount of NE-SW dextral strike-slip faults (Sakellariou & Tsampouraki-Kraounaki, 2019).

References

Cossette, É., Audet, P., Schneider, D., & Grasemann, B. (2016). Structure and anisotropy of the crust in the Cyclades, Greece, using receiver functions constrained by in situ rock textural data. *Journal of Geophysical Research: Solid Earth*, *121*(4), 2661-2678.

Li, X., Bock, G., Vafidis, A., Kind, R., Harjes, H. P., Hanka, W., ... & Yuan, X. (2003). Receiver function study of the Hellenic subduction zone: imaging crustal thickness variations and the oceanic Moho of the descending African lithosphere. *Geophysical Journal International*, *155*(2), 733-748.

Papanikolaou, D.J., Royden, L.H. (2007). Disruption of the Hellenic arc: Late Miocene extensional detachment faults and steep Pliocene-Quaternary normal faults-Or what happened at Corinth?: DISRUPTION OF THE HELLENIC ARC. *Tectonics,* 26. https://doi.org/10.1029/2006TC002007

Kokkalas, S., Aydin, A. (2013). Is there a link between faulting and magmatism in the south-central Aegean Sea?. *Geol. Mag.*, 150, 193–224. https://doi.org/10.1017/S0016756812000453

Sakellariou, D., Tsampouraki-Kraounaki, K. (2019). Plio-Quaternary Extension and Strike-Slip Tectonics in the Aegean, in: Transform Plate Boundaries and Fracture Zones. Elsevier, 339–374. https://doi.org/10.1016/B978-0-12-812064-4.00014-1

Sodoudi, F., Brüstle, A., Meier, T., Kind, R., & Friederich, W. (2015). Receiver function images of the Hellenic subduction zone and comparison to microseismicity.

Sodoudi, F., Kind, R., Hatzfeld, D., Priestley, K., Hanka, W., Wylegalla, K., ... & Bohnhoff, M. (2006). Lithospheric structure of the Aegean obtained from P and S receiver functions. *Journal of Geophysical Research: Solid Earth*, *111*(B12).

Zhu, L., Mitchell, B. J., Akyol, N., Cemen, I., & Kekovali, K. (2006). Crustal thickness variations in the Aegean region and implications for the extension of continental crust. *Journal of Geophysical Research: Solid Earth*, *111*(B1).

Zhu, L., & Kanamori, H. (2000). Moho depth variation in southern California from teleseismic receiver functions. *Journal of Geophysical Research: Solid Earth*, 105(B2), 2969-2980.

Contact

Agathe Faucher *[1]; Christel Tiberi[1]; Frederic Gueydan[1]; Alexandrine Gesret[2]*

[1] Géosciences Montpellier, UMR 5243CNRS, Université de Montpellier, Rue Eugène Bataillon, 34095 Montpellier, France.

[2] Mines ParisTech,PSL - Research University, Centre de Géosciences, 35 Rue St Honoré, F-77300 Fontainebleau, France.

Principal contact: agathe.faucher@umontpellier.fr