

Multiscale dynamics of a normal fault system:

The western rift of Corinth

Pascal Bernard, IPGP

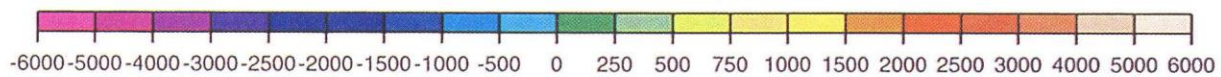
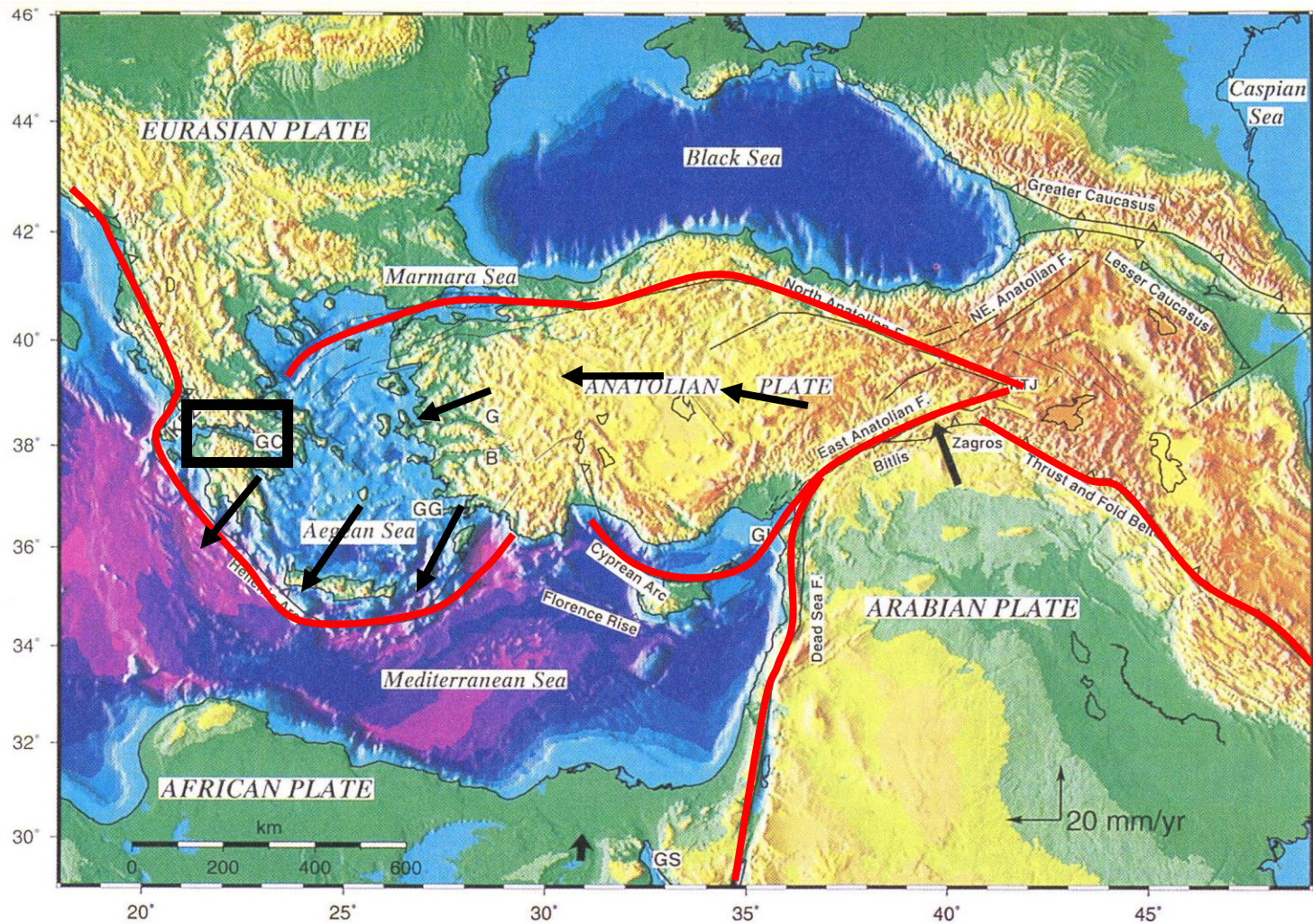
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Hubert-Ferrari (Univ. Liège), Ch. Beck (ISTerre), A. Canitano (IPGP), M. Godano
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P. Papadimitriou (Univ. Athens), N. Voulgaris (Univ. Athens), J. Zahradnik (Charles Univ.)
... et al. == CRL team*

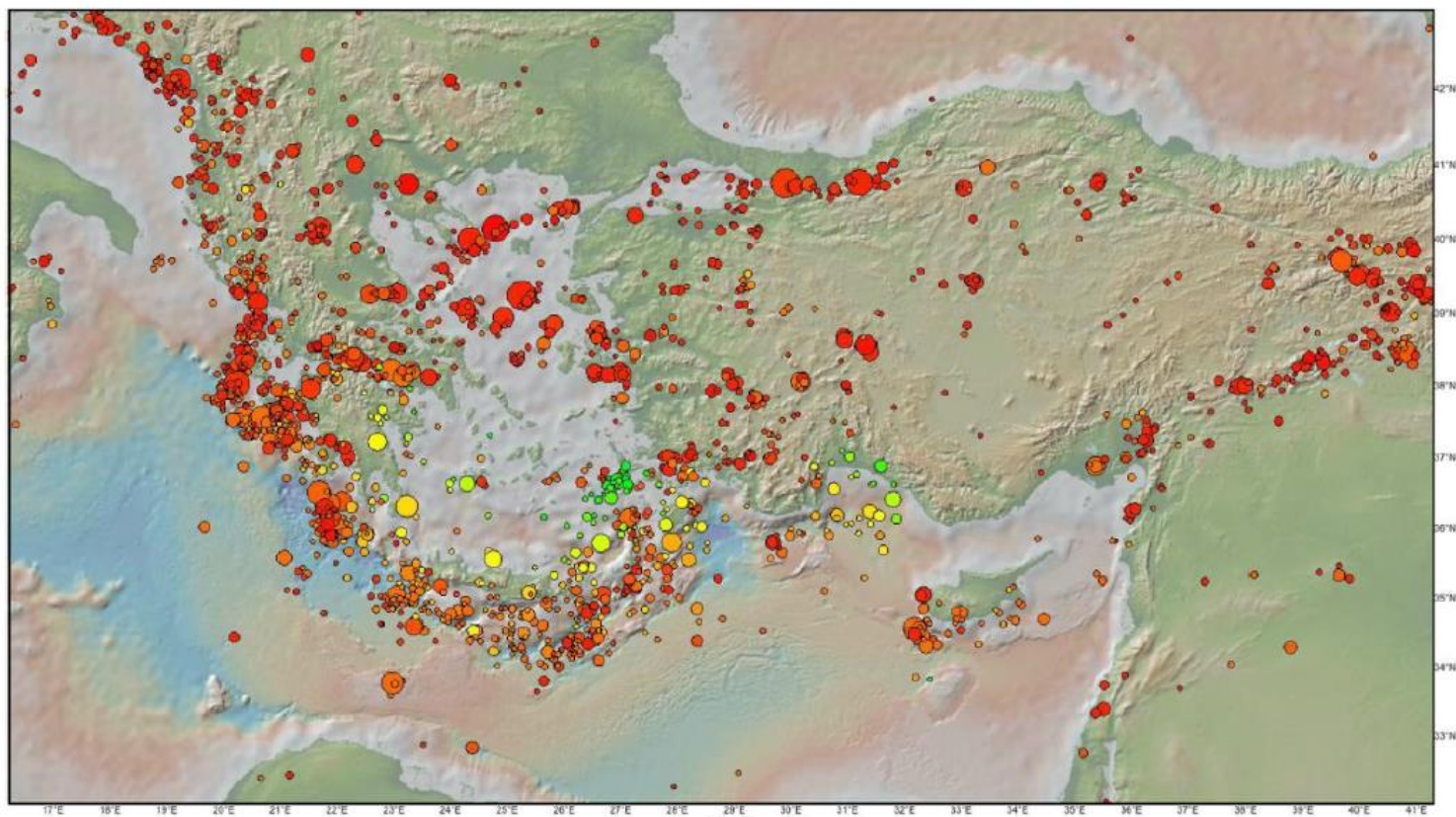
Corinth Rift Laboratory (CRL): <http://www.crlab.eu>

EC projects: ... CORSEIS, 3HAZ, REAKT

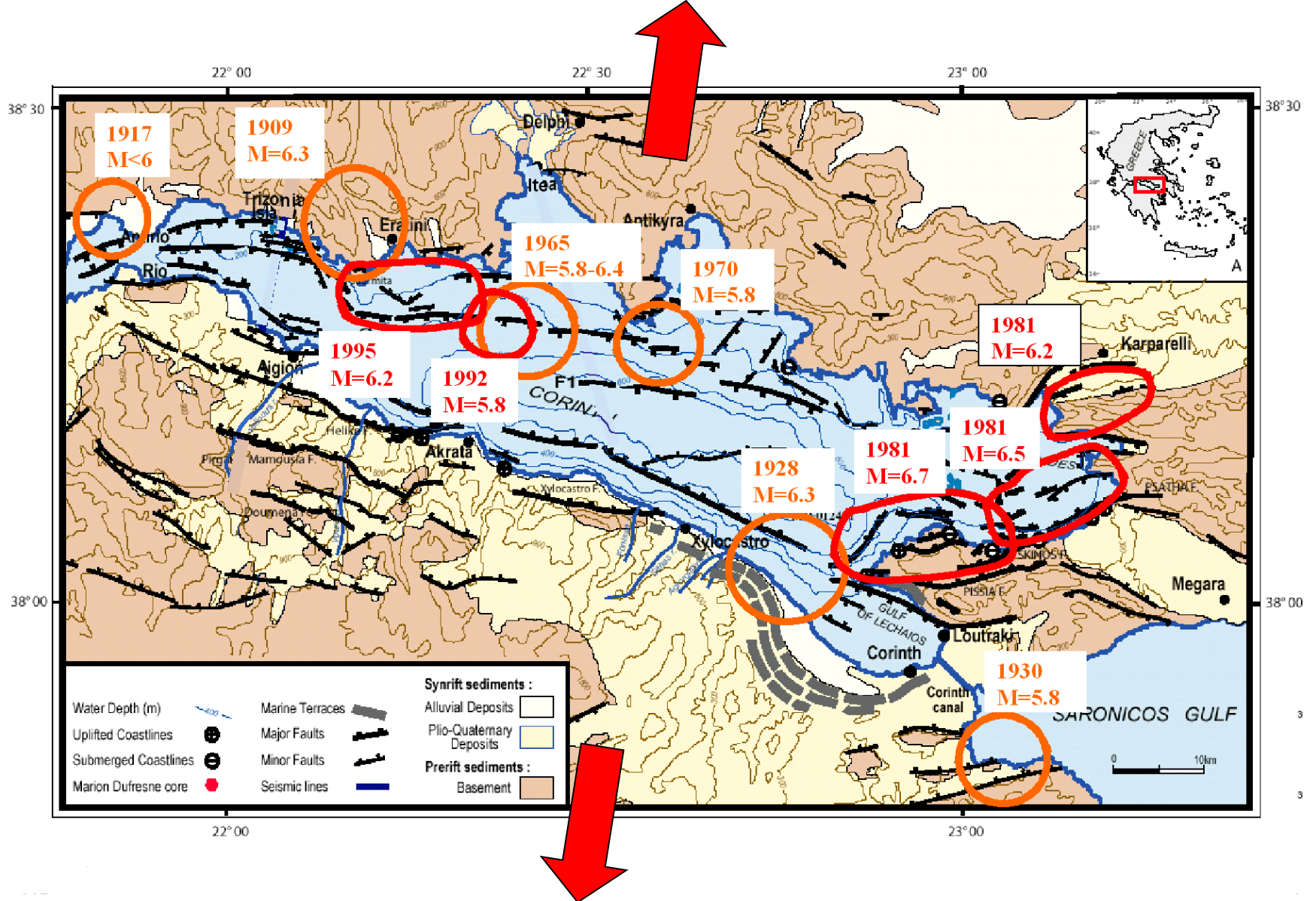
ANR SISCOR







USGS-NEIC
1970+
M>4.5



Seismicity: Ambraseys & Jackson (1990); Papazachos & Papazachou (1997)

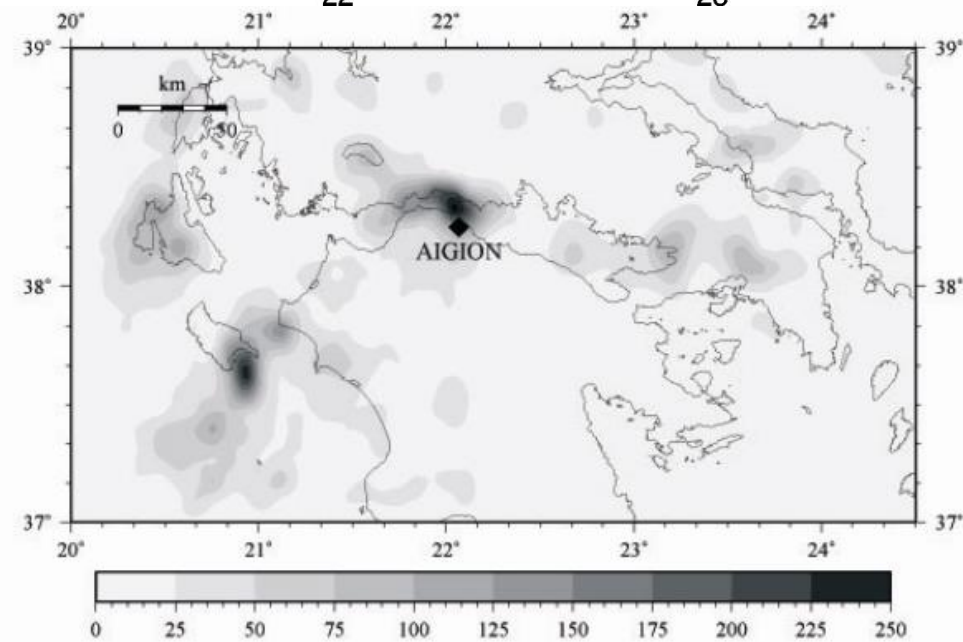
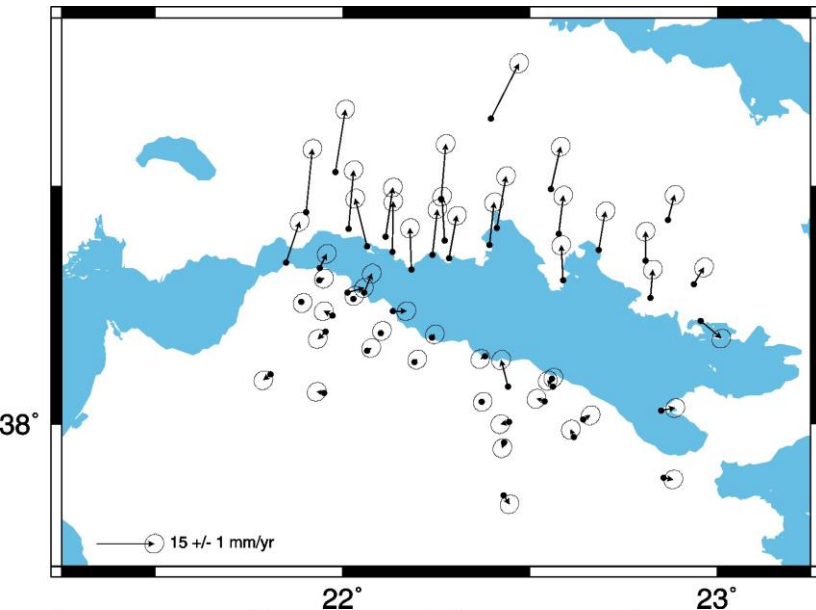
Tectonic map: Moretti et al. , 2005



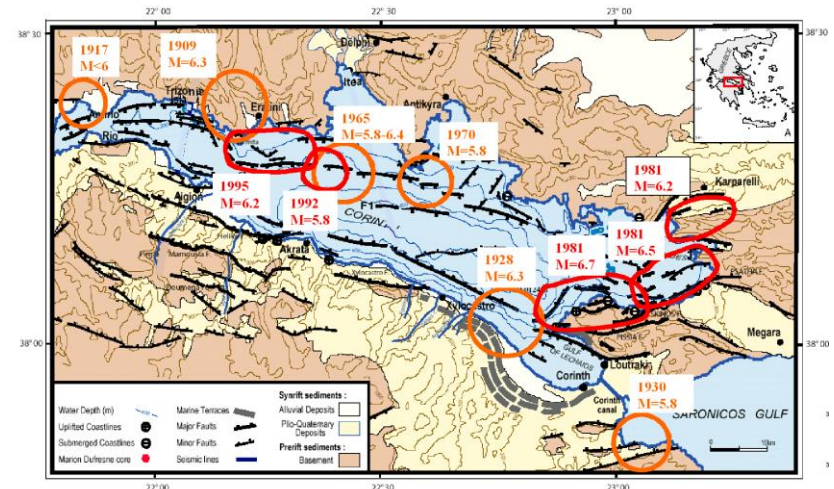
N

HELIKE FAULT

GPS , Avalone et al., 2004



Seismicity and deformation; the general context

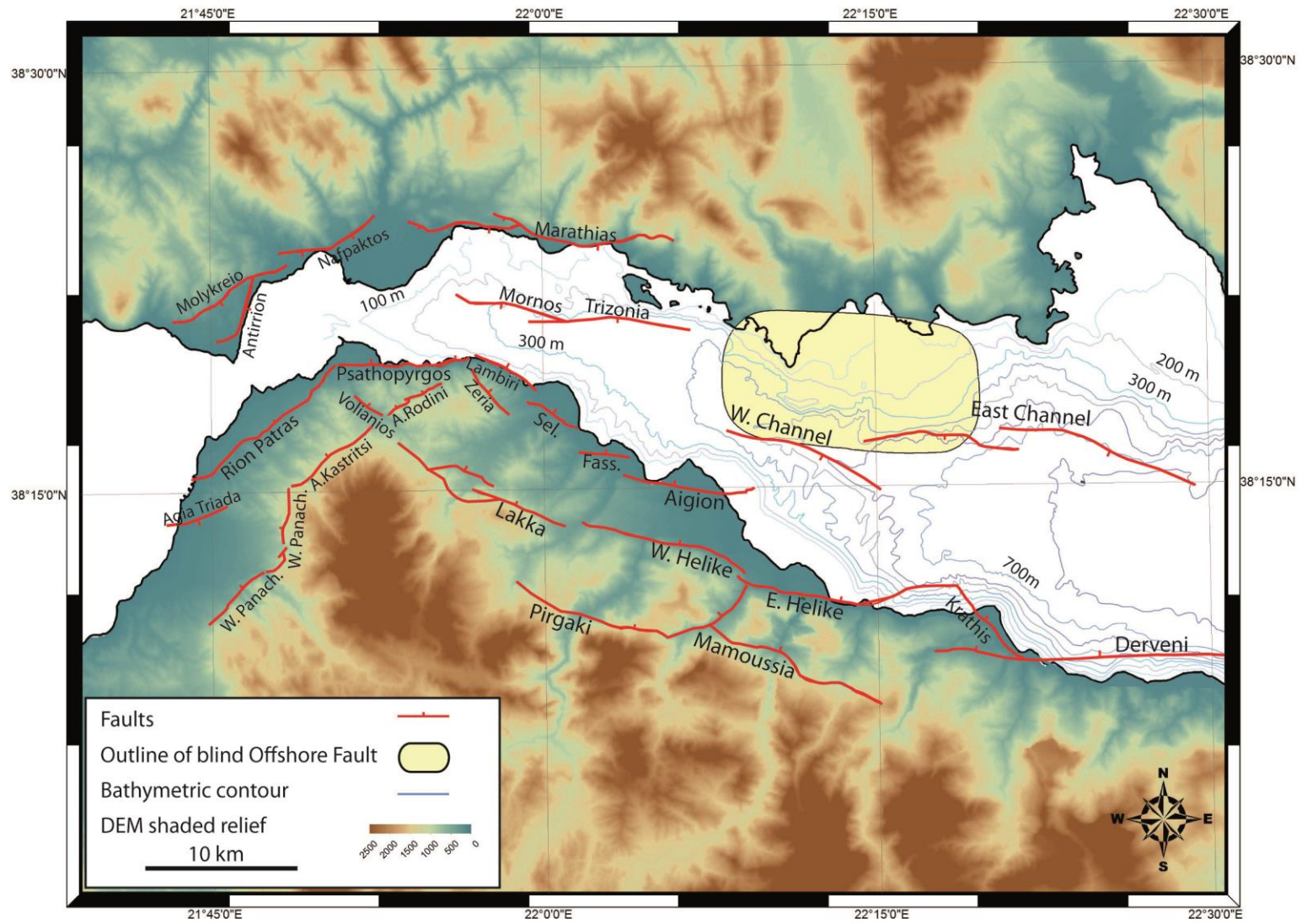


- en-echelon large normal fault system dipping north
- younger, western rift : higher strain rate and higher microseismicity rate
- Large earthquakes in the whole rift
- seismic strain << GPS strain

Catalogue NOA

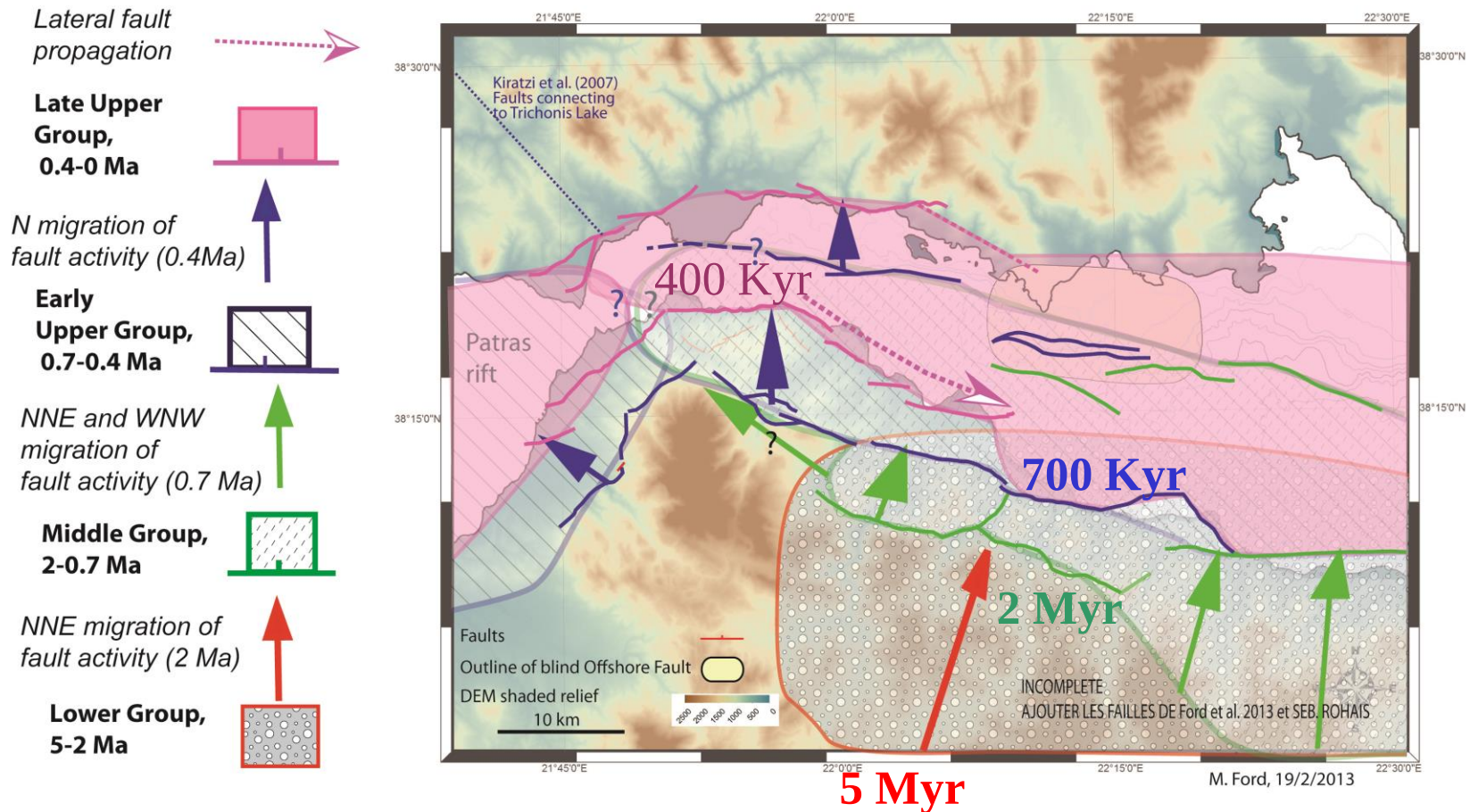
Bourouis & Cornet, 2010

Main faults in the western rift of Corinth



Ford, Meyer, 2012 - SISCOR

Evolution of Fault system and depocentre migration

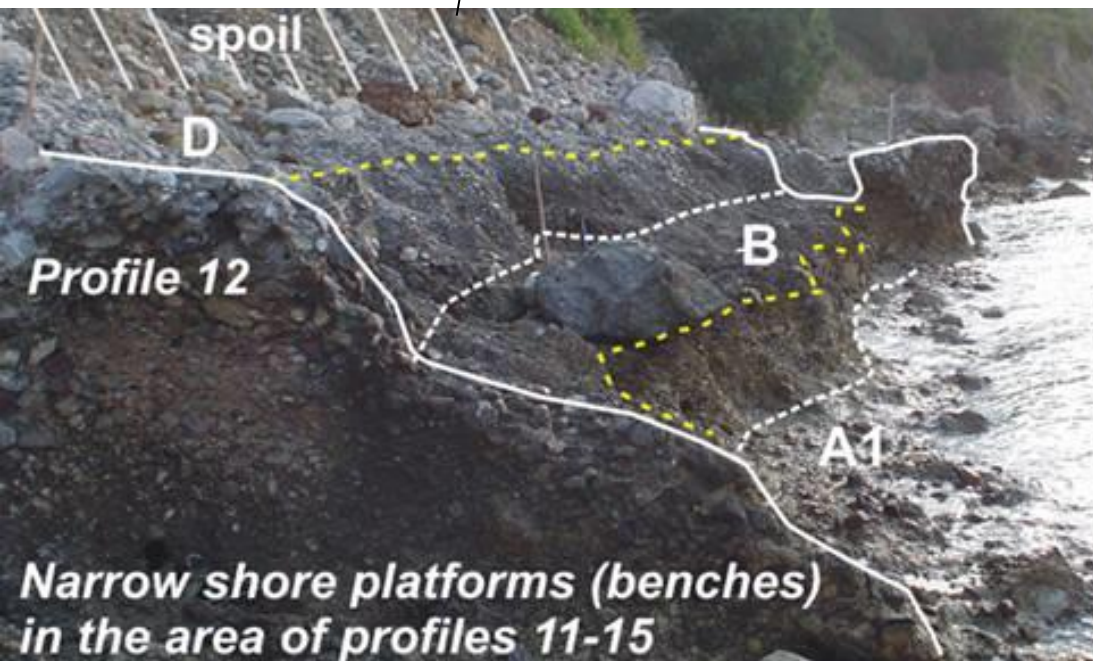


Ford et al. 2013

**Complex inherited geometrical structure with
Expected present mechanical and seismic interplay of old and new faults**

Paleoseismicity (trenching on faults)

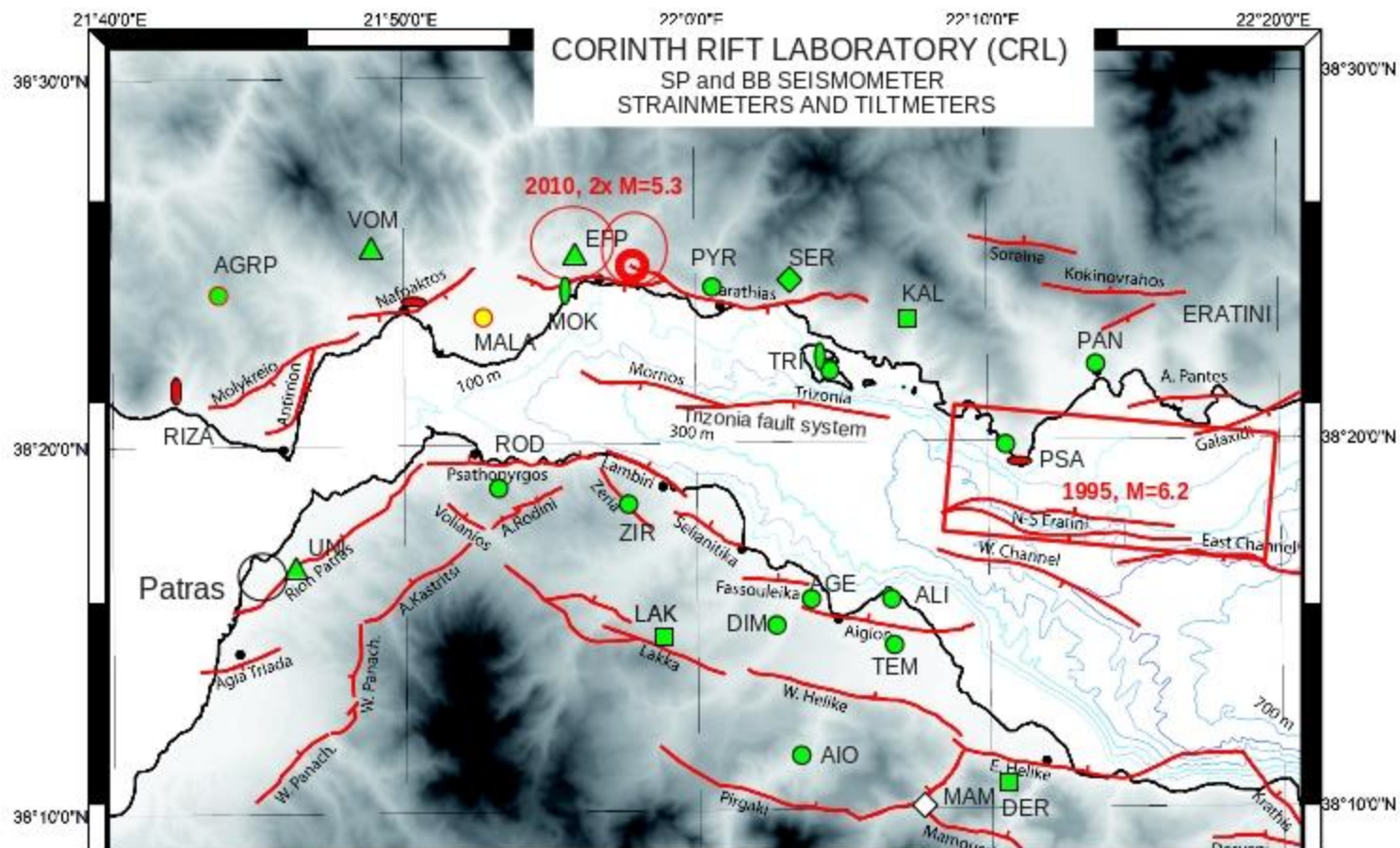
Uplifted terraces : uplift rates



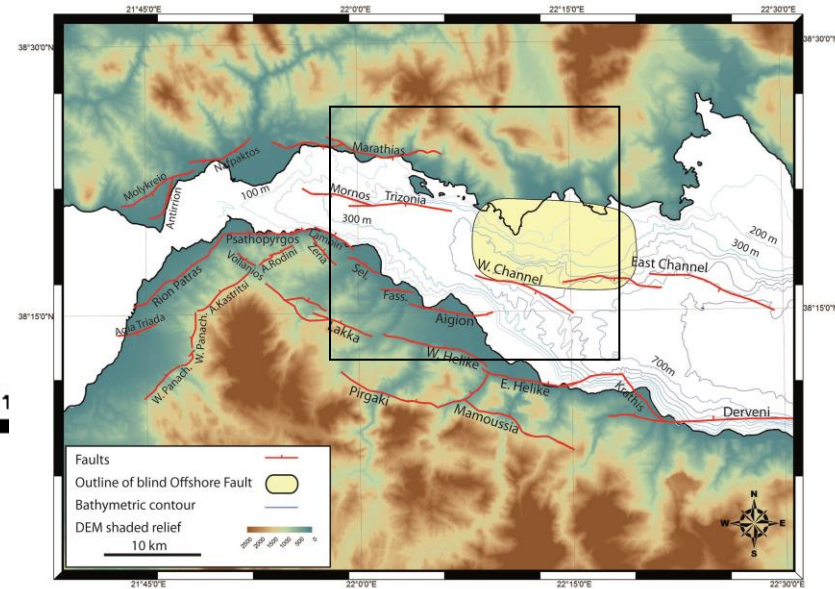
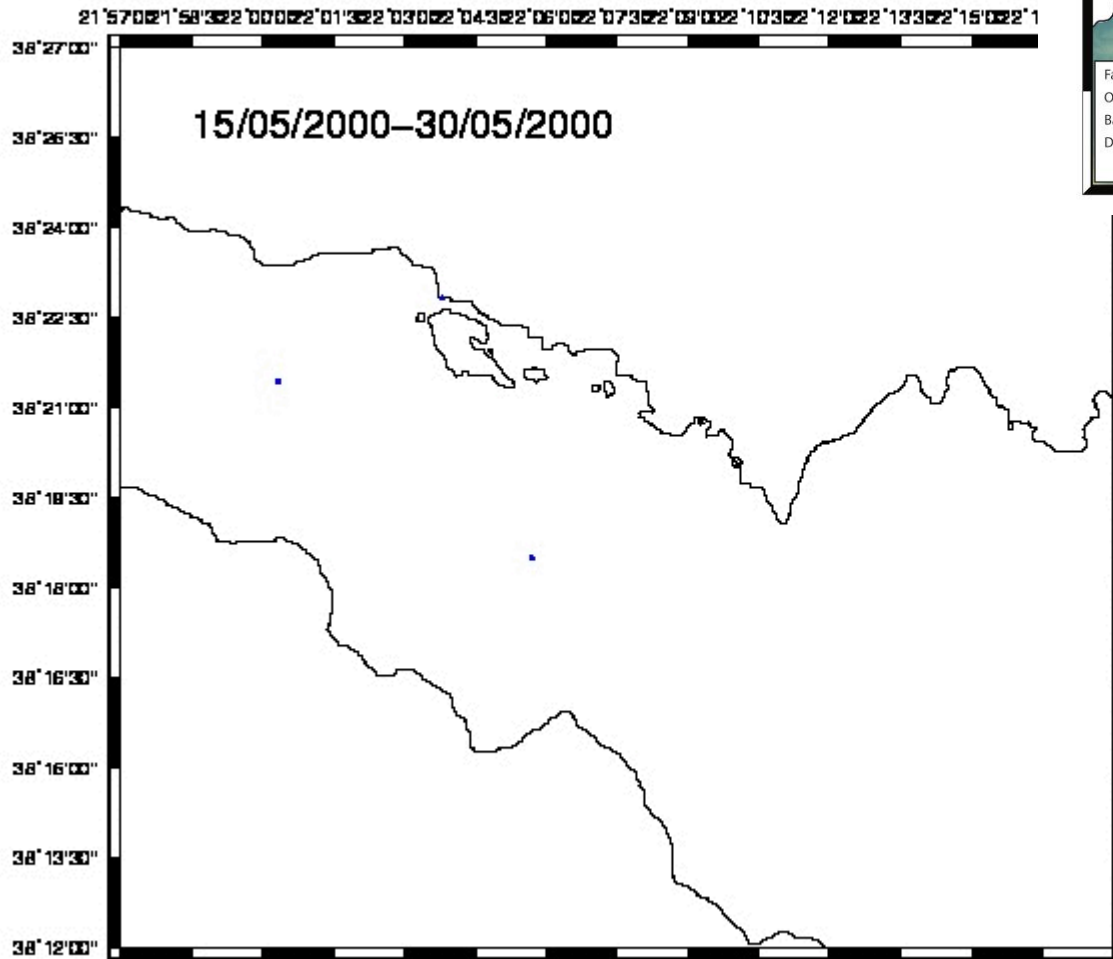
Uplifted paleoshoreline:

5 rapid uplift (50 cm) episodes
(coseismic?) in 2000 years

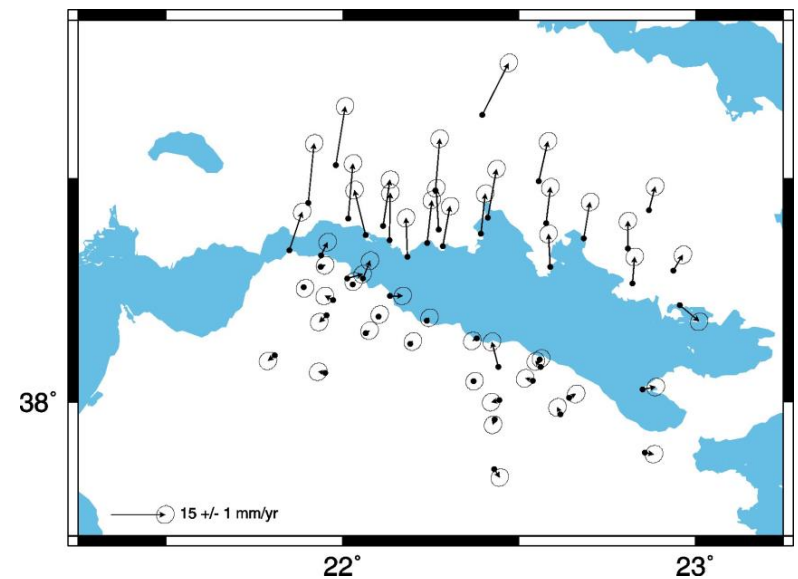
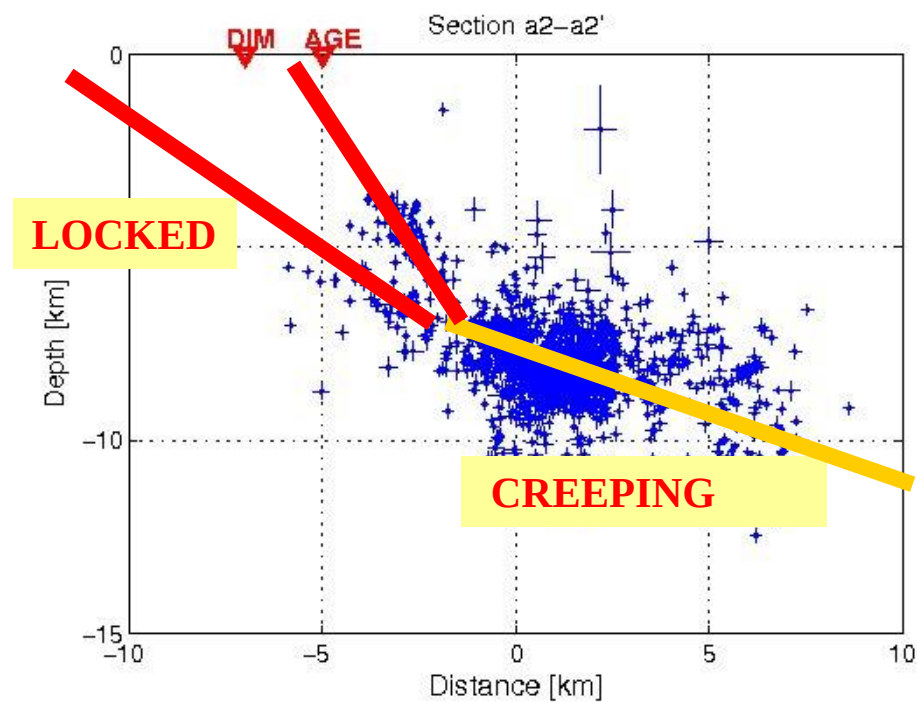
Palyvos, Pantosti
2007



■ Seismicity 2000-2007



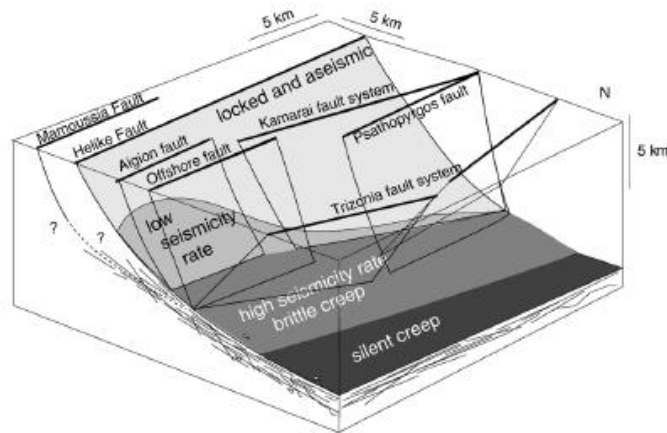
Which faults
are activated?



Avalone et al., 2004

Rigo et al. 1996

Bernard et al. 2007



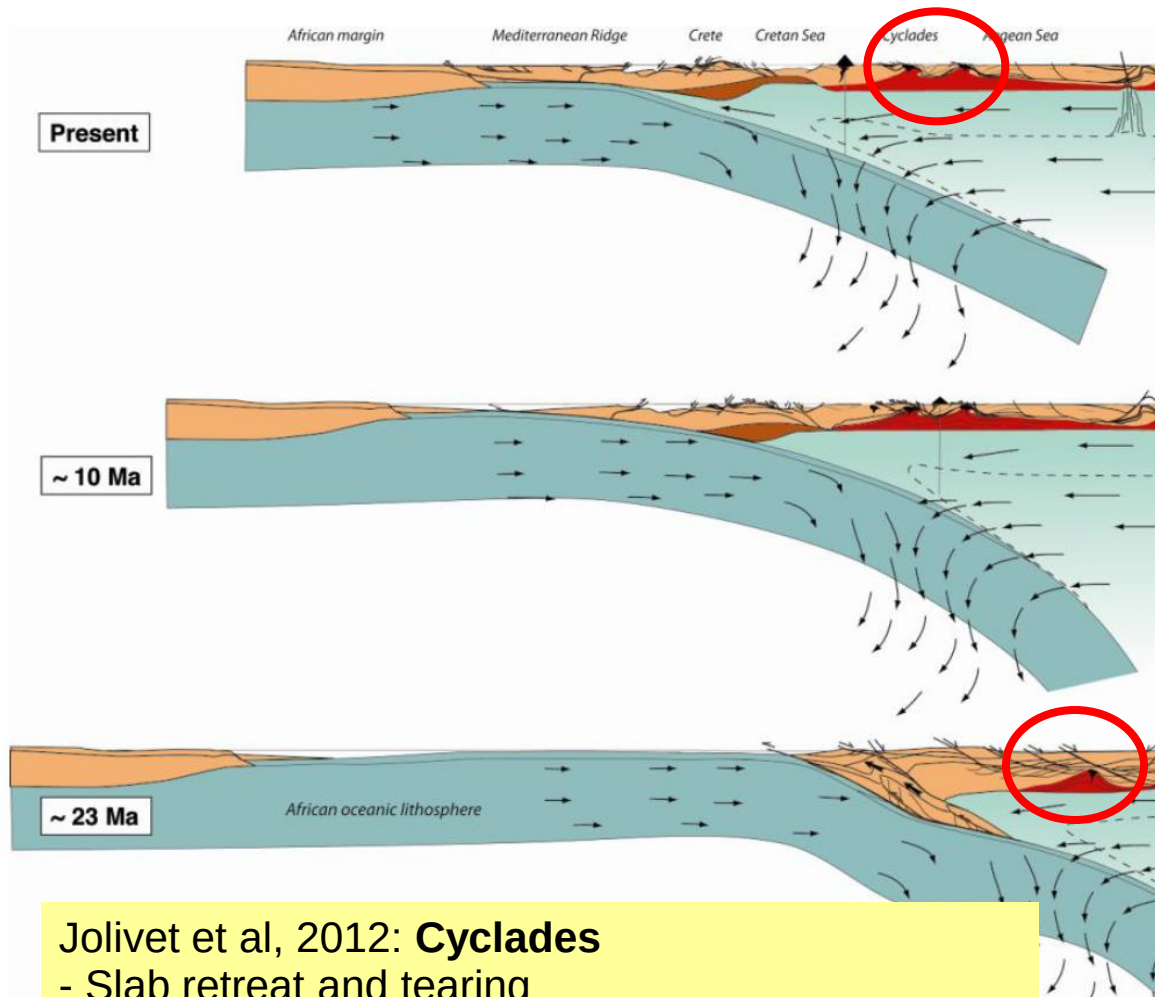
Normal faults rooting on a major detachment:

- low angle dip of microseismicity
- NS localized gradient of strain rate from GPS

Aegean tectonics – large scale extension

5012

LECOMTE ET AL.: KINEMATICS OF MYKONOS DETACHMENT

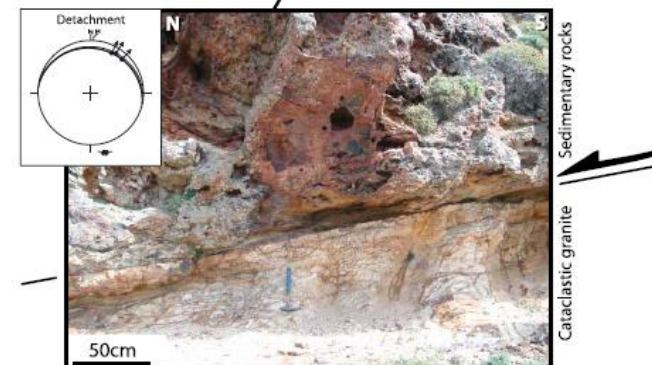
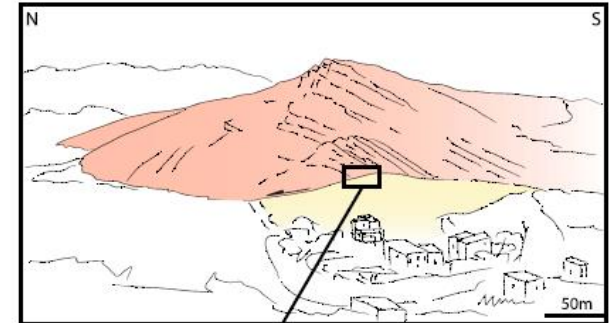


Jolivet et al, 2012: **Cyclades**

- Slab retreat and tearing
- Crustal scale detachment
- Exhumation of core complex, from 8-15 km depth

Western Corinth rift:

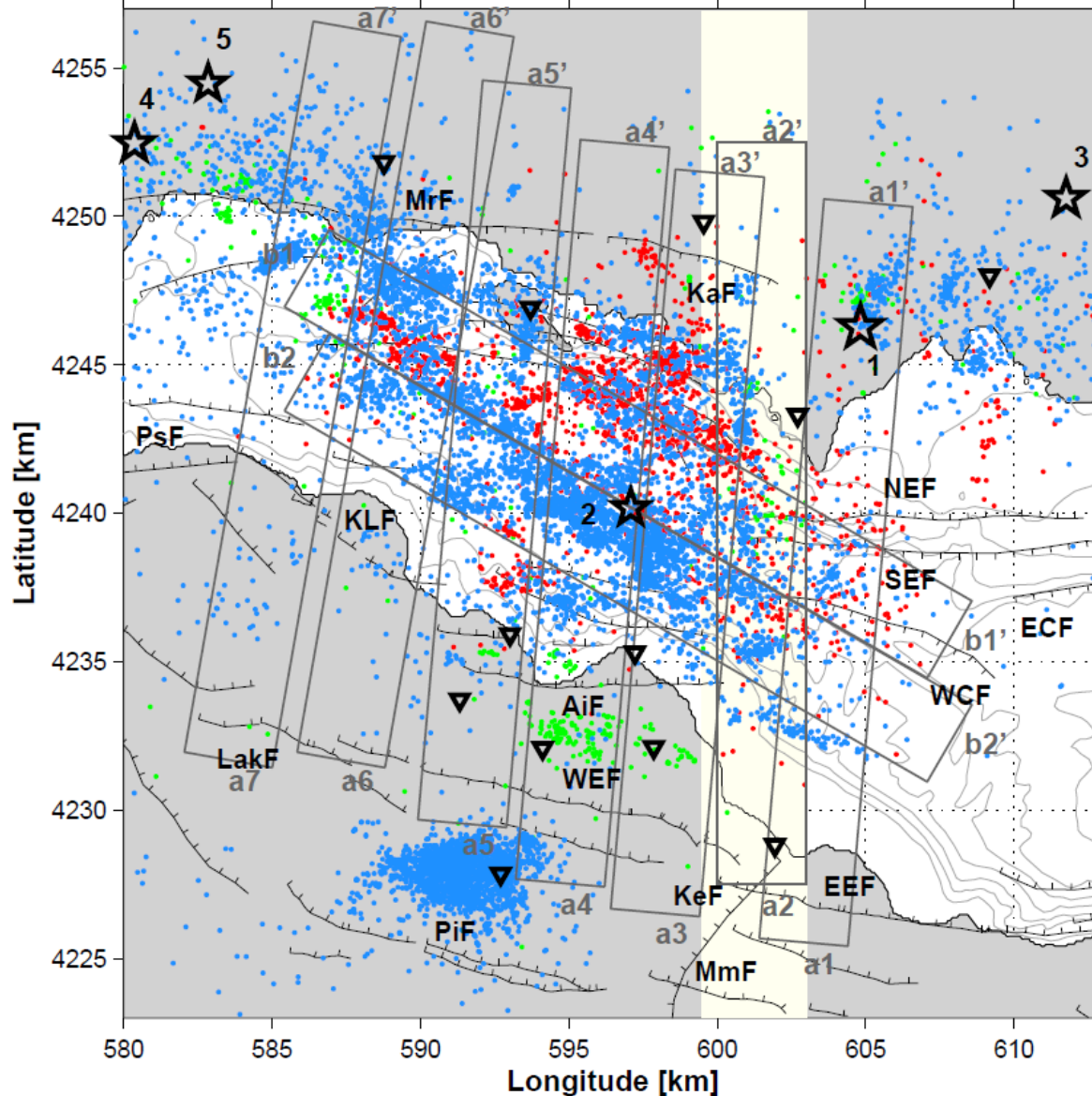
similar to early stage of Cyclade detachment?



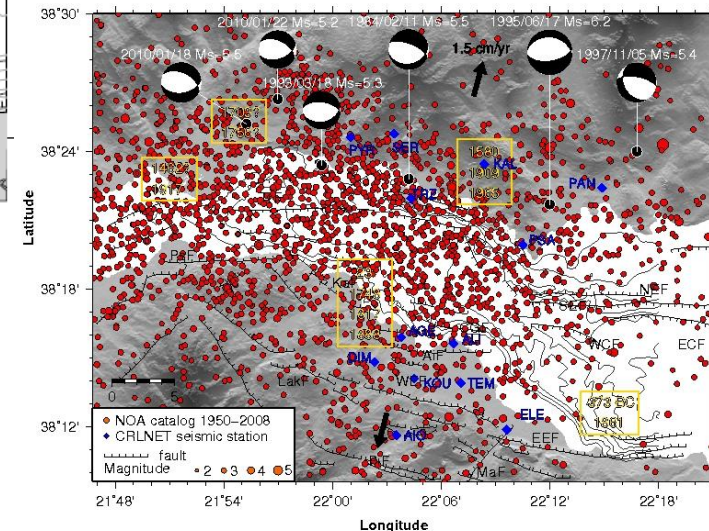
LeComte et al. 2010
Cyclades:
Mykonos detachment

Double-difference relocation, Lambotte et al.(2013)

- NW trend of micro-seismicity:
at the root of the recent fault
system
- strong segmentation
- isolated clusters



NOA locations since 1975

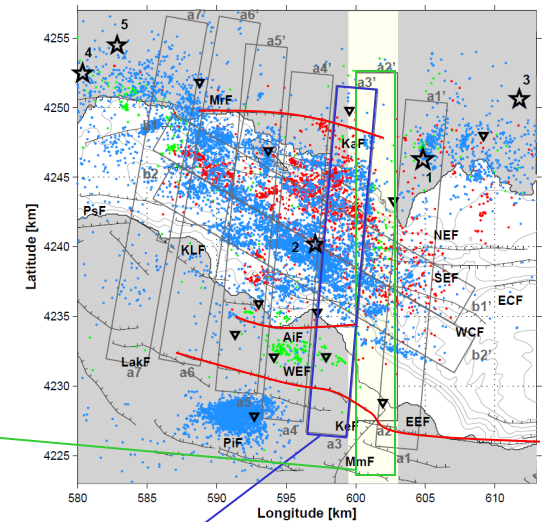
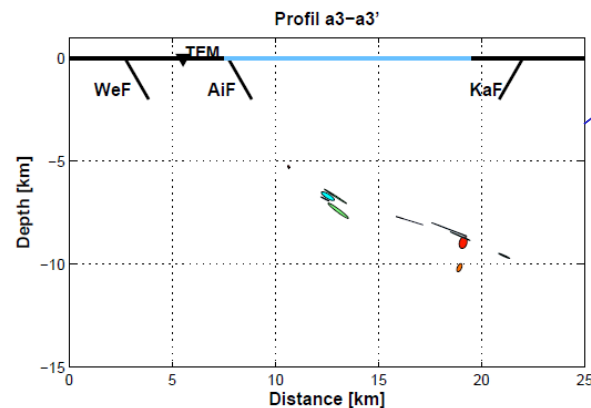
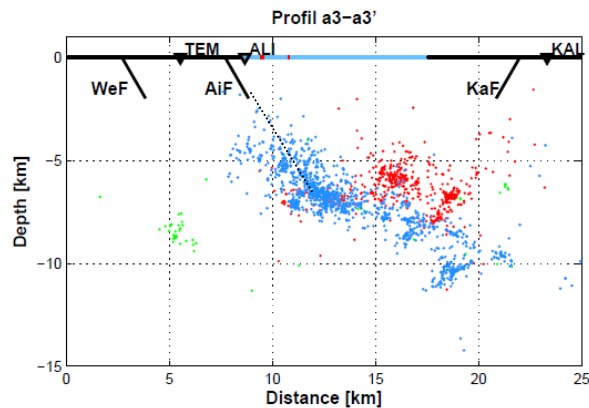
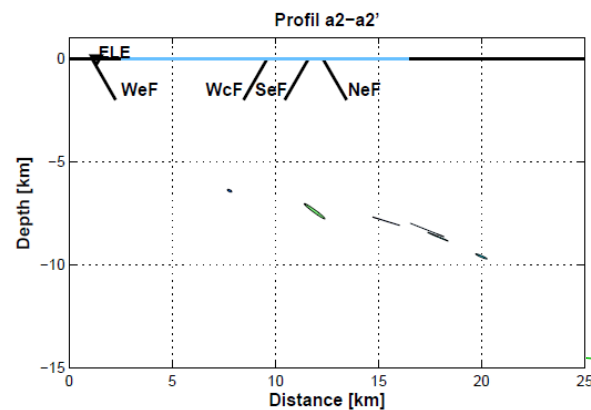
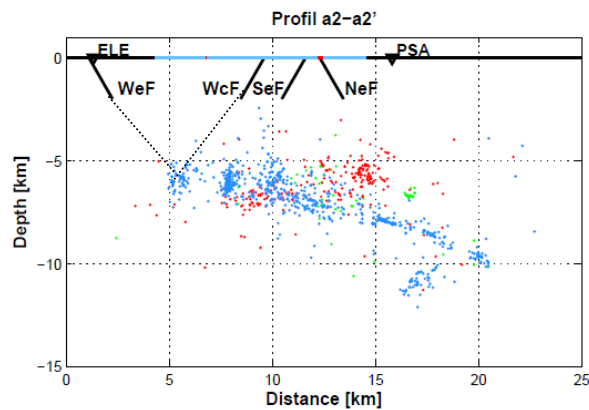


Blue: 2001-2007

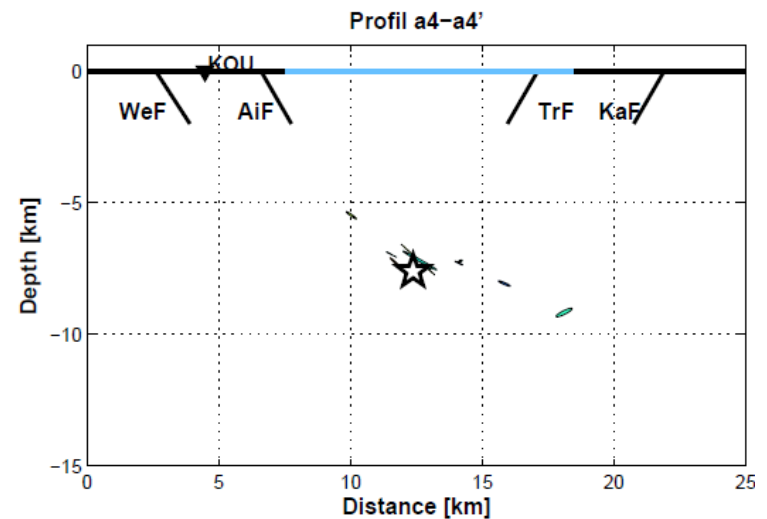
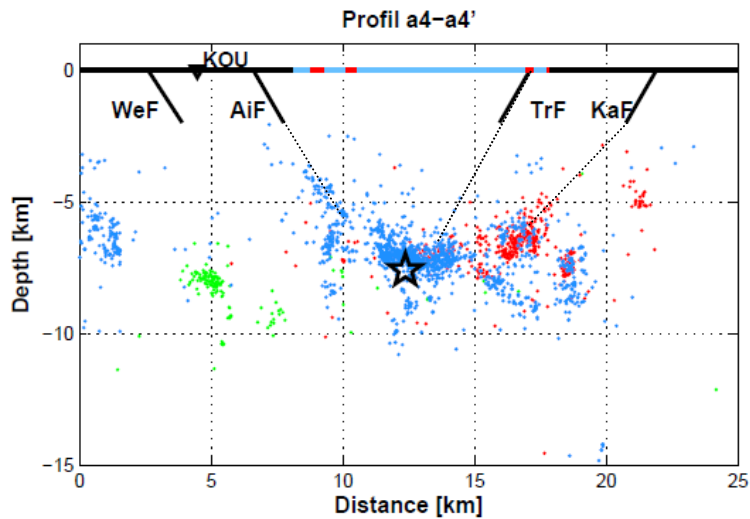
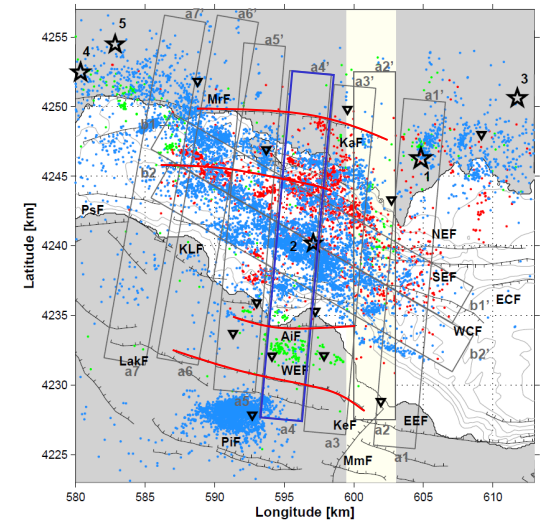
Red: Aftershocks 1995

Green: July 1991

- Aigion et Helike faults
- antithetic faults (Kalithea)
- low dip seismogenic layer , dipping north but:
1995 aftershocks are shallower (red)
Some multiplets have larger dip
Active structures below the layer



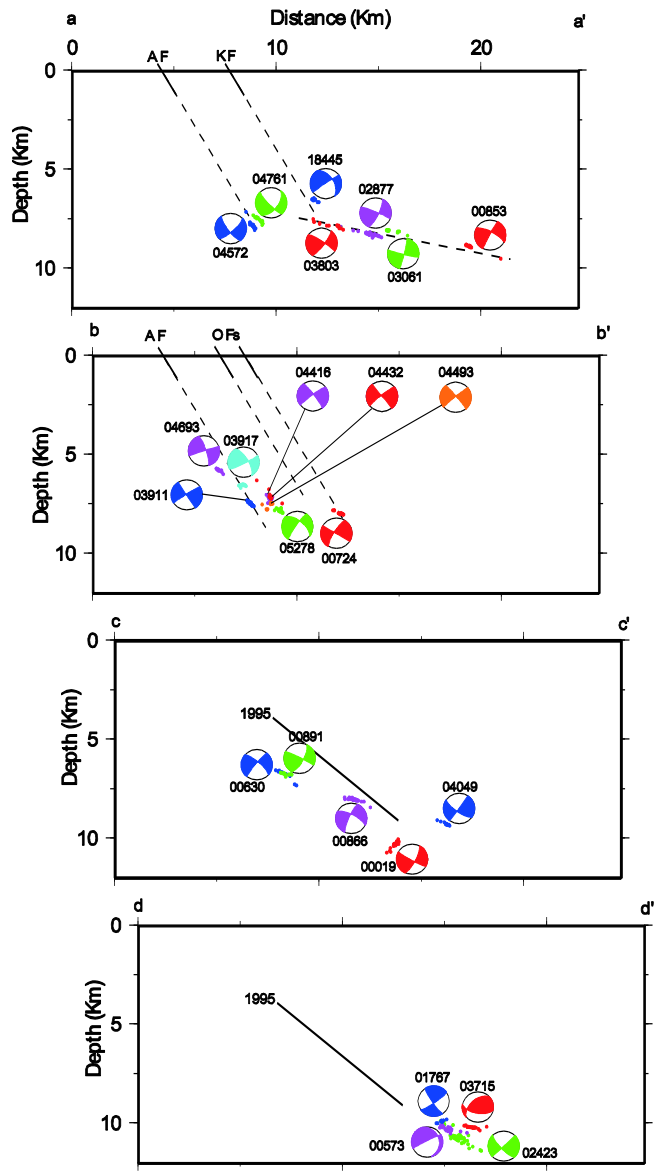
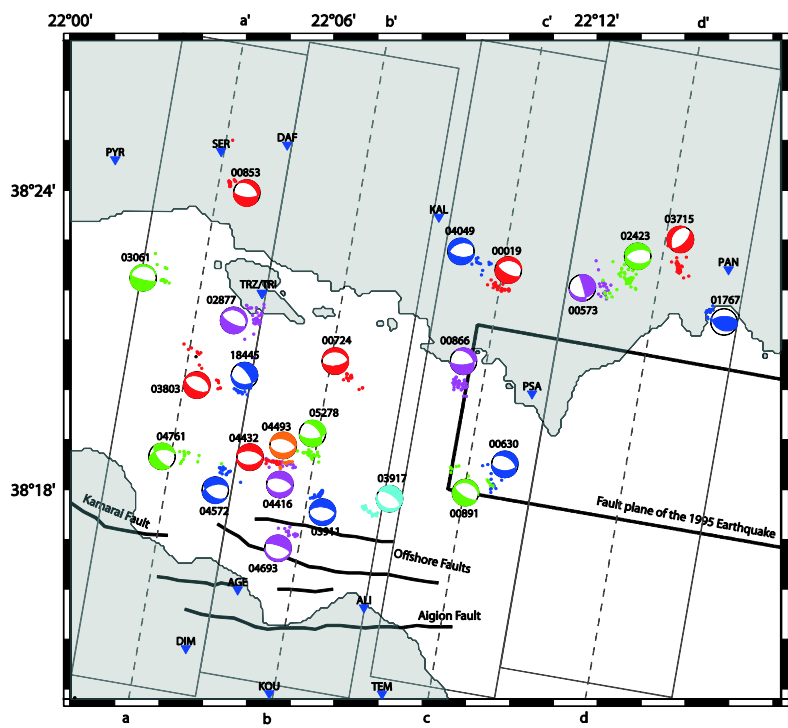
- Aigion fault: activity at 3 km, partial creep?
- West Helike Fault : silent
- Trizonia fault, antithetic: silent
- Kalithea fault: deep activity?
- + complex structure of the seismogenic « layer »



Multiplets:

Normal fault mechanisms, dip 20-50° in the low dip angle seismic layer (10-15°)

Hence: Heterogeneous structuration of the brittle layer

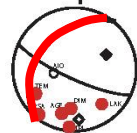
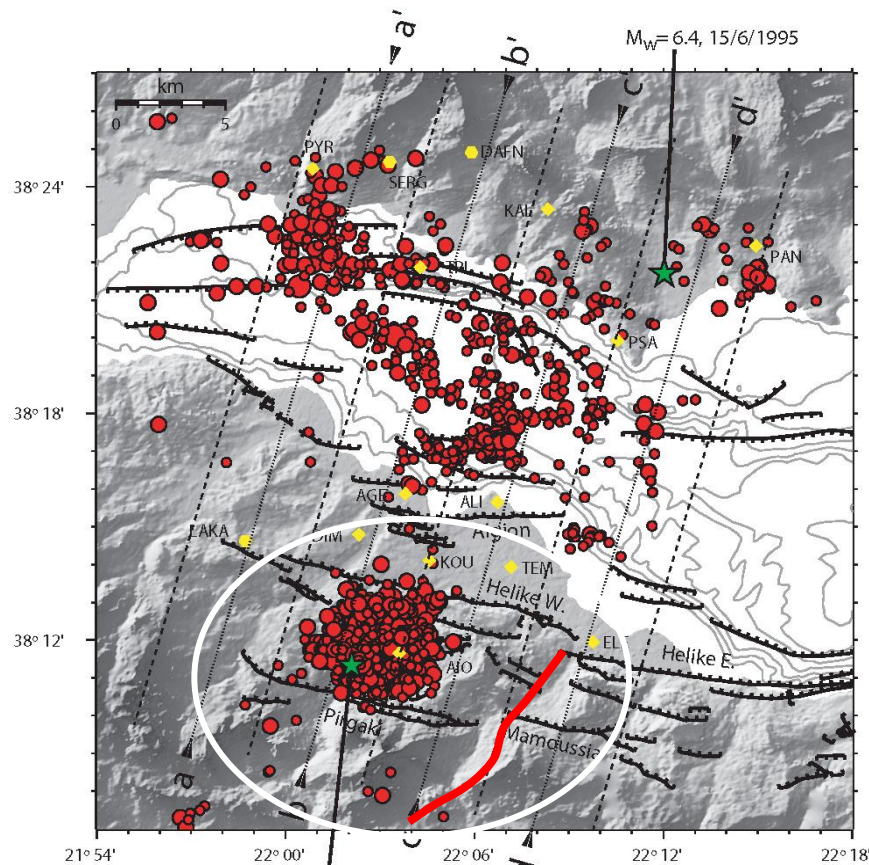


Short term spatio-temporal interaction

Seismic swarms

2001, 2002, 2004

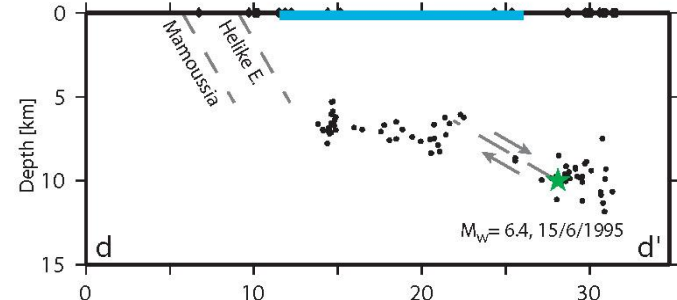
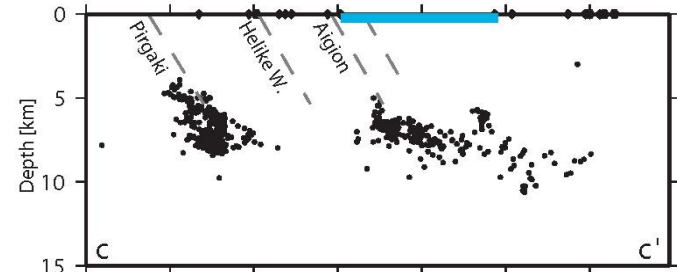
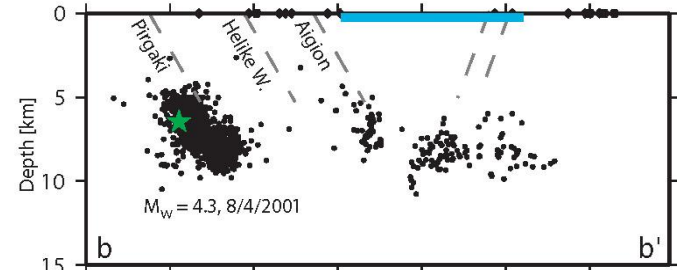
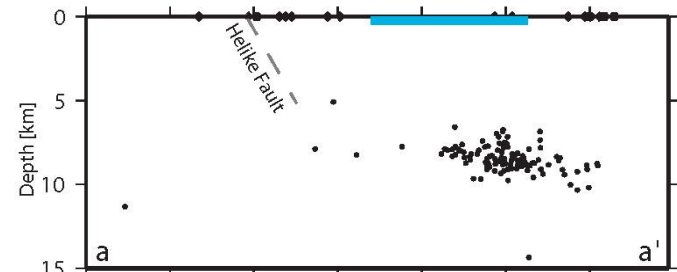
Re-activation of an ancient fault, dip 45° NW 2001 seismic swarm - 3 months - $M_{\max}=4.2$



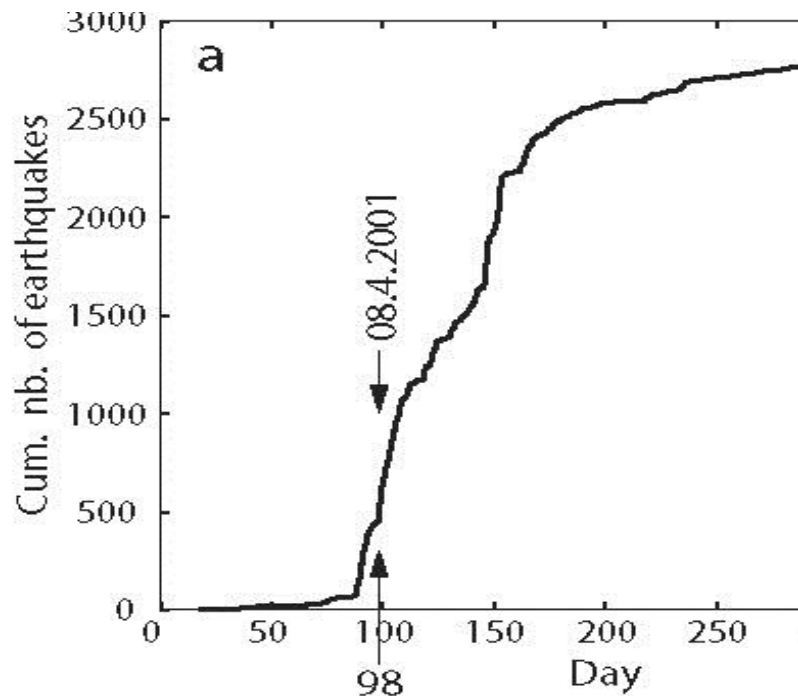
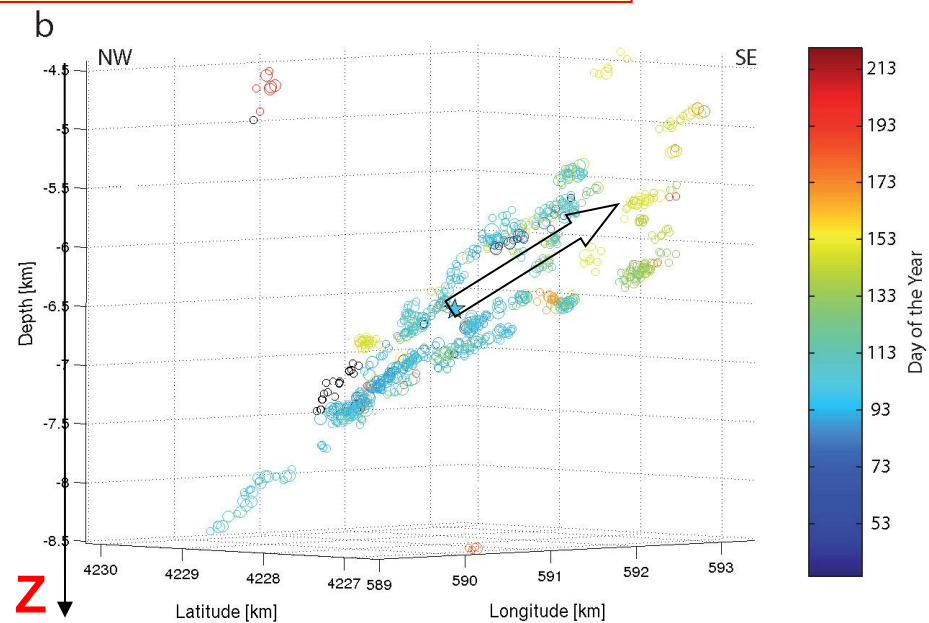
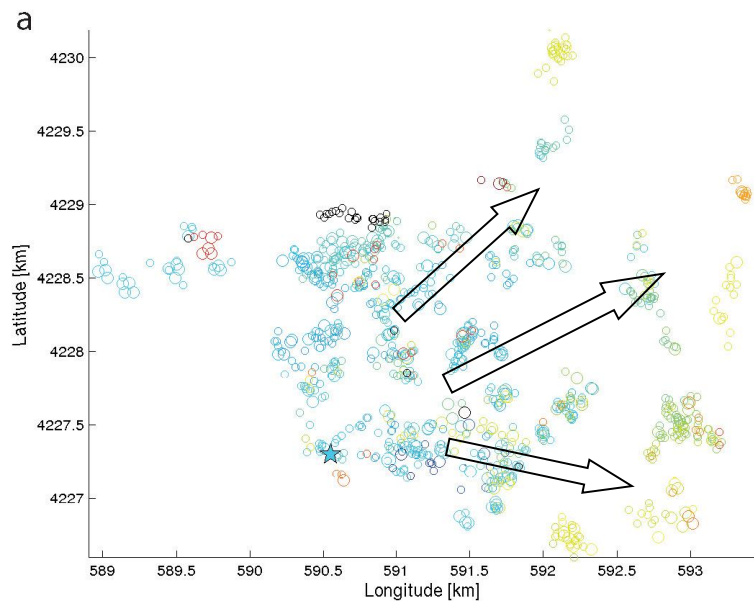
Kerinitis fault

$M_W = 4.3$, 8/4/2001

M_W : • 1-2 • 2-3 • 3-4 • 4-5



2001 seismic swarm: relocated multiplets



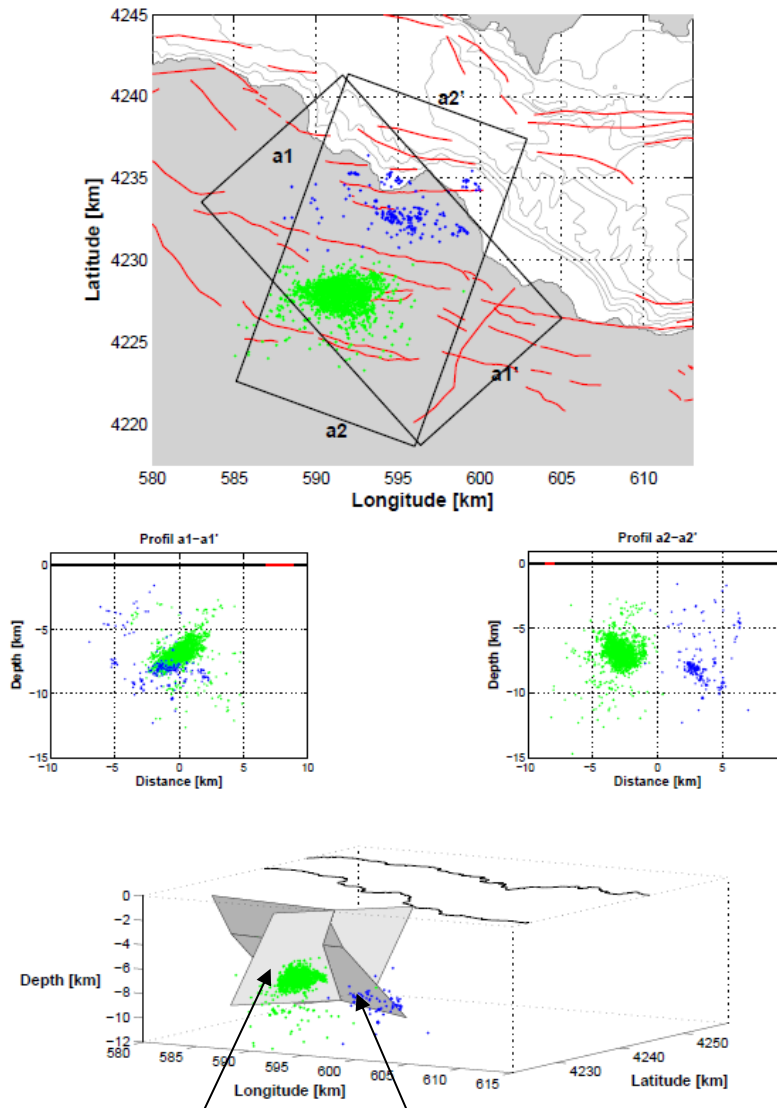
3 – 4 months:

**Upward migration on the
Kerinitis fault, 20-30 m/day
pore pressure pulse?**

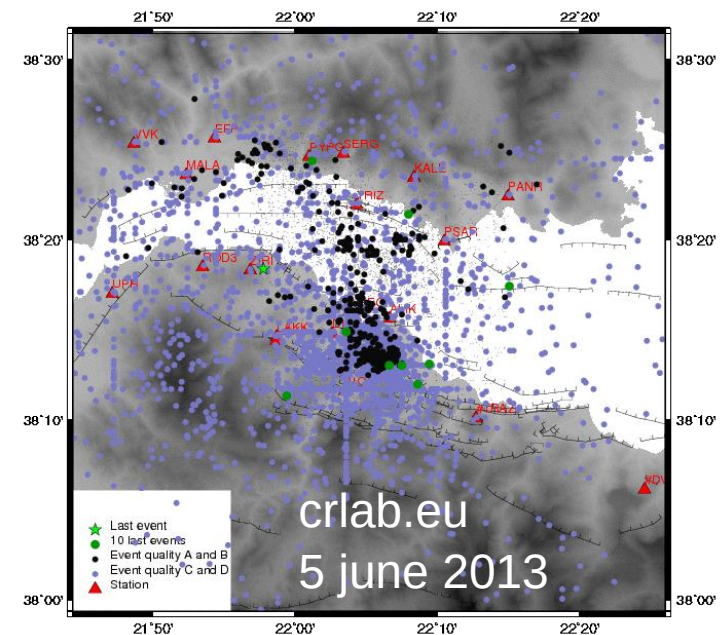
- Diffusivity $0.1 \text{ m}^2/\text{s}$
- Hydraulic conductivity 10^{-5} m/s
- Permeability $7 \cdot 10^{-13} \text{ m}^2$

+ coupled slow slip ?

The 2001 swarm (green)
migration on Kerinitis fault
stopped when reaching
the intersection with Helike
fault (blue swarm in 1995)

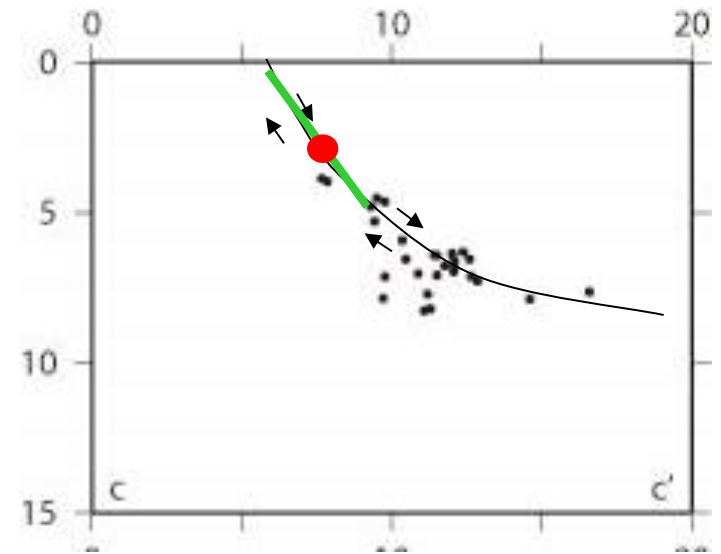
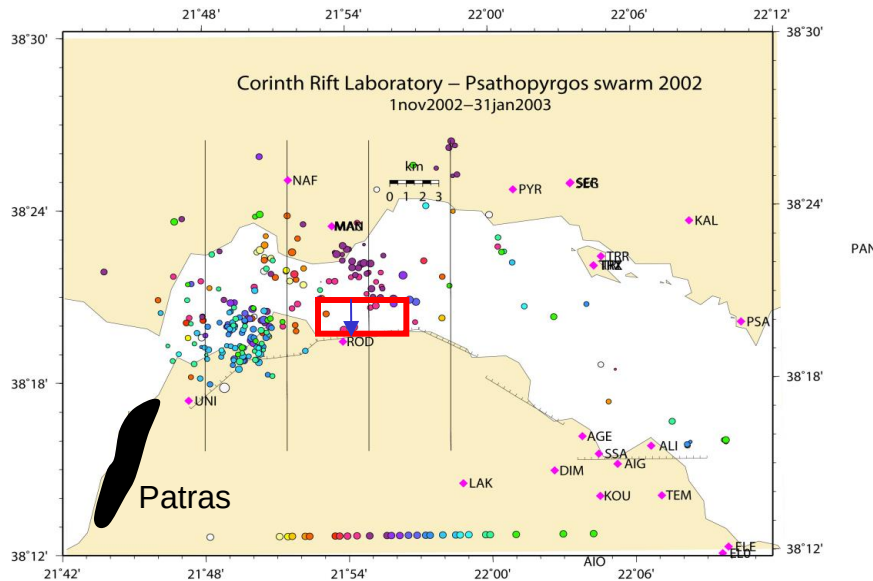


Kerinitis fault Helike fault

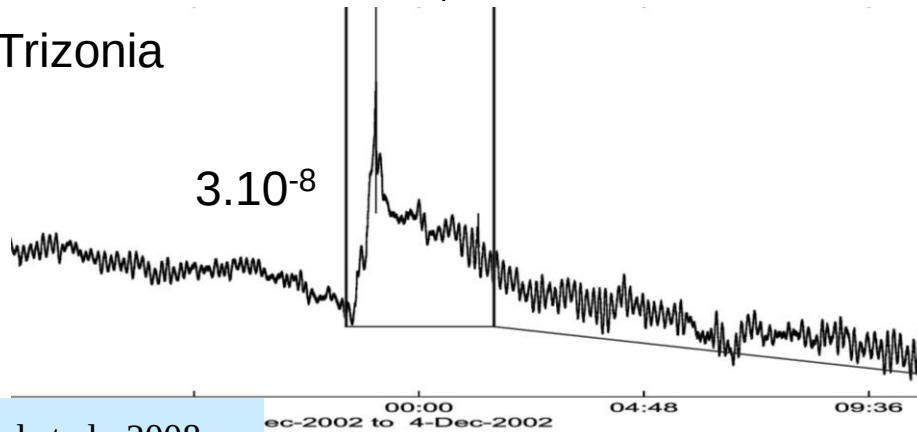


The May-June 2013 swarm
activates the same area

2002 : seismic swarm and transient creep on the Psathopyrgos fault



Borehole strainmeter,
Trizonia



Aseismic slip, 30 minutes on
Psathopyrgos fault :

□ $u=10$ cm – M_w equiv =5

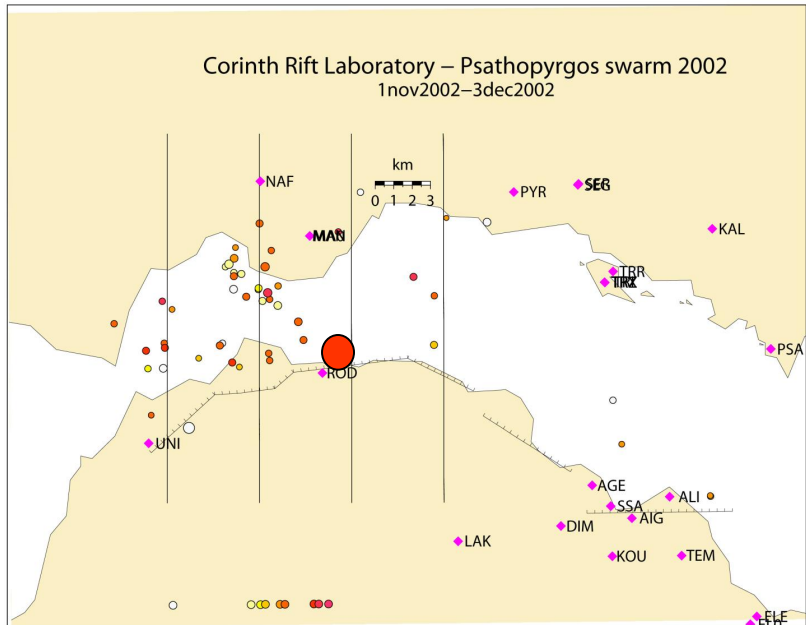
Strain peak:

$M=3.5$ earthquake,

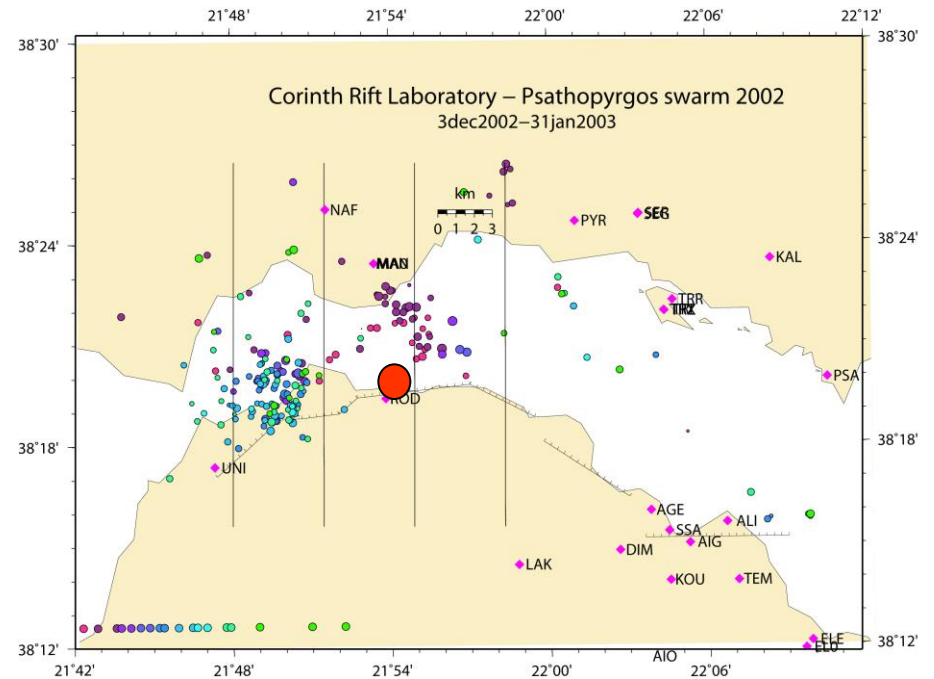
very shallow depth 2.5 km

2002 swarm before and after 3 dec. shallow earthquake

Before 3rd dec event



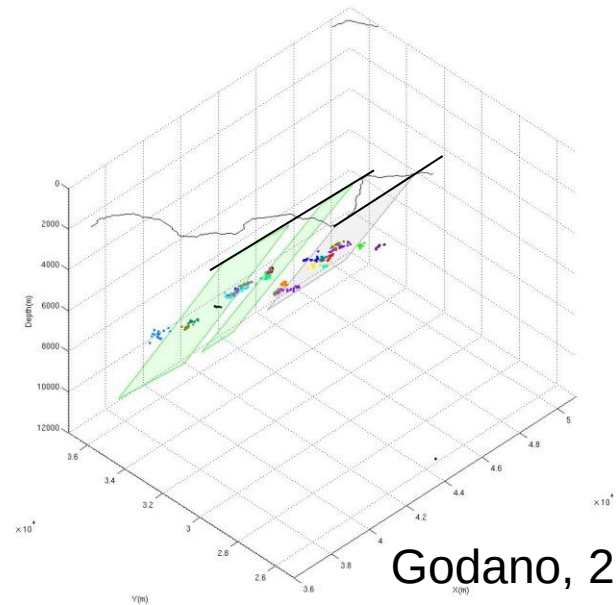
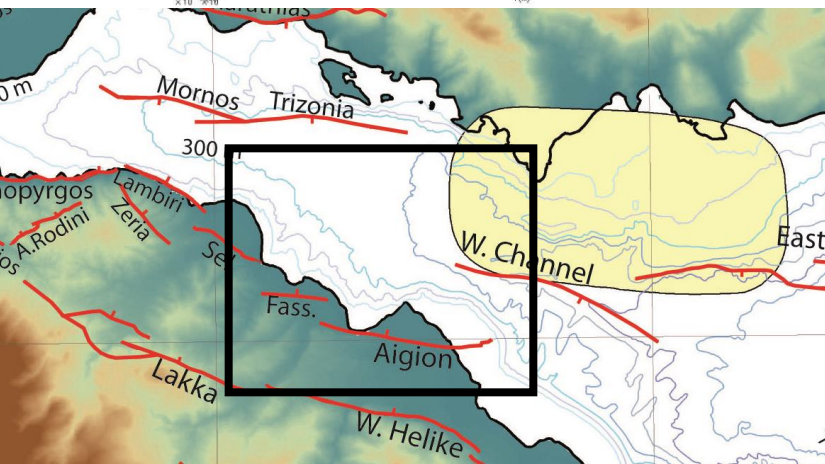
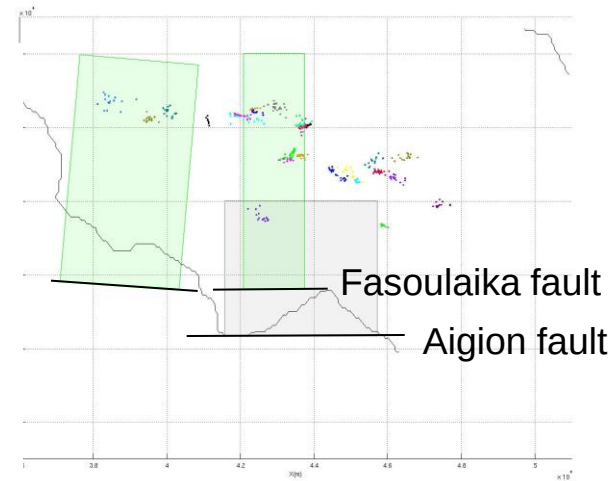
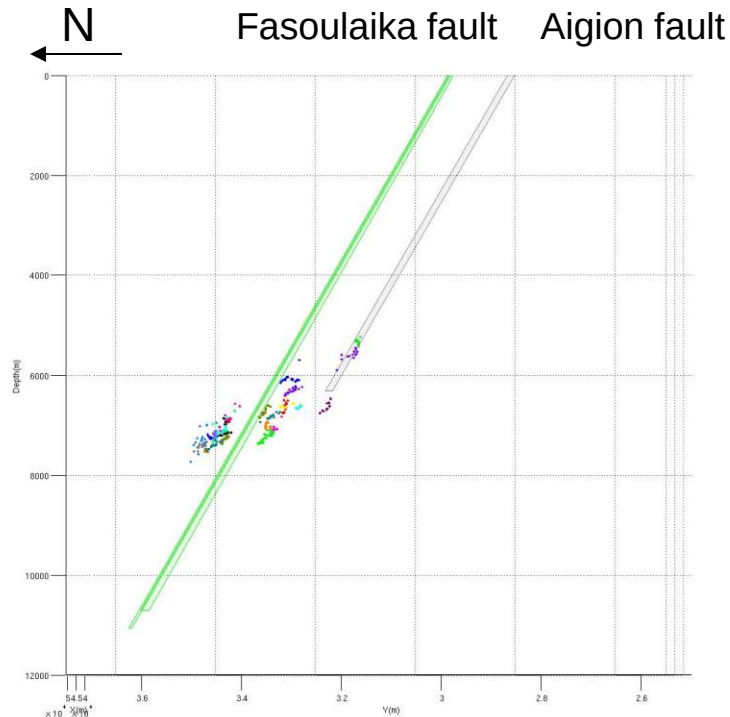
After 3rd dec event



Migration velocity 100 m to 1 km/day

2004 seismic swarm :

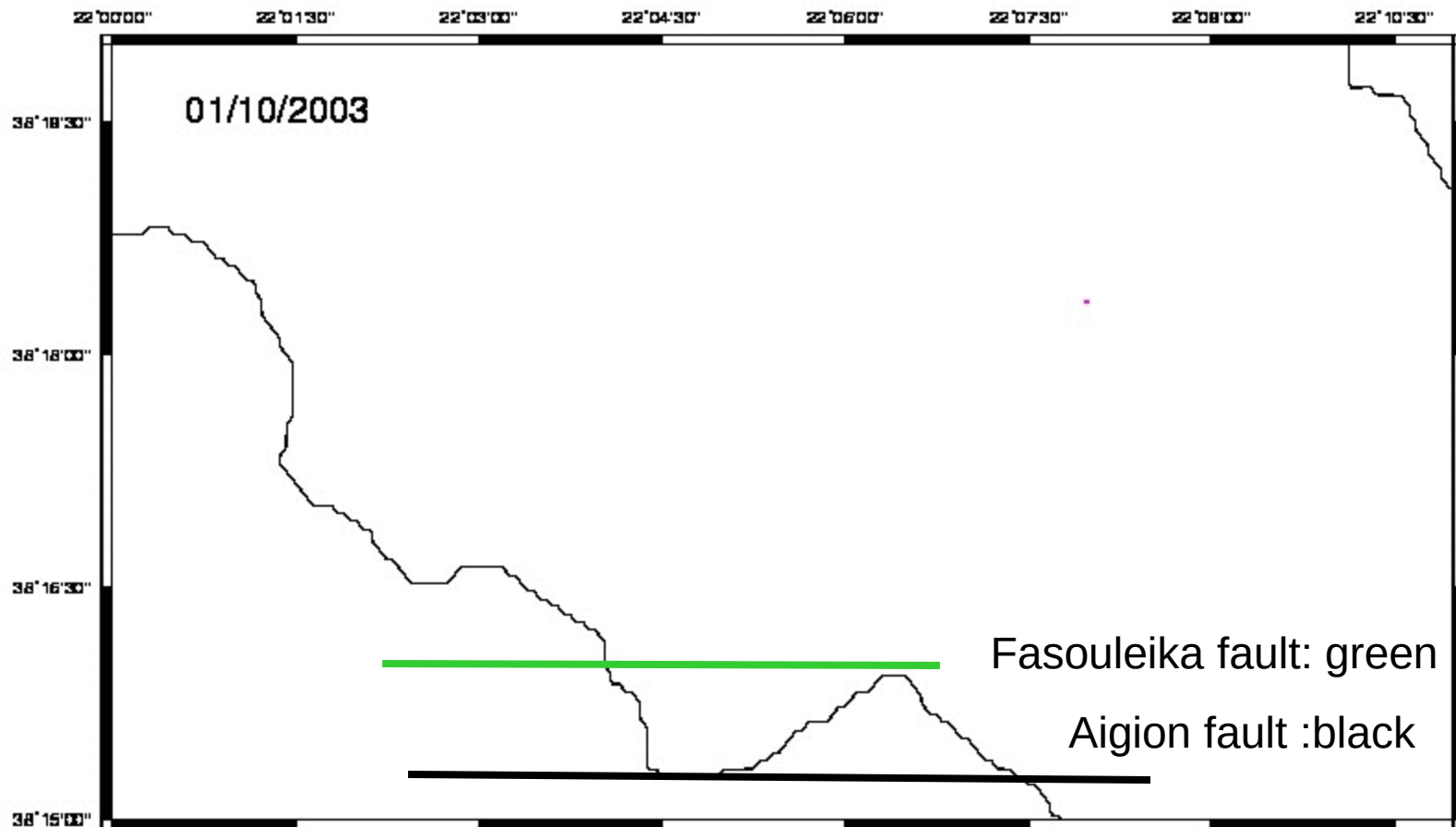
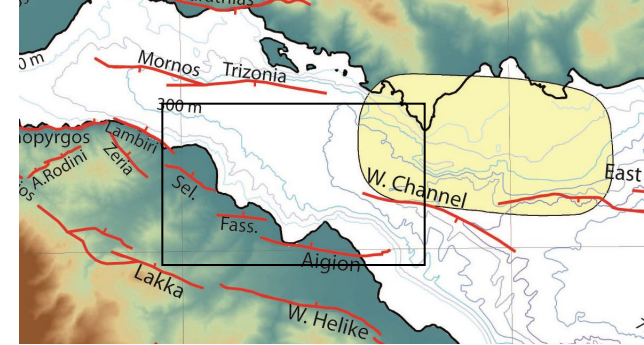
jumping from the Aigion fault to the Fasouleika fault



Godano, 2013

2004 seismic swarm :

jumping from the Aigion fault to the Fasouleika fault

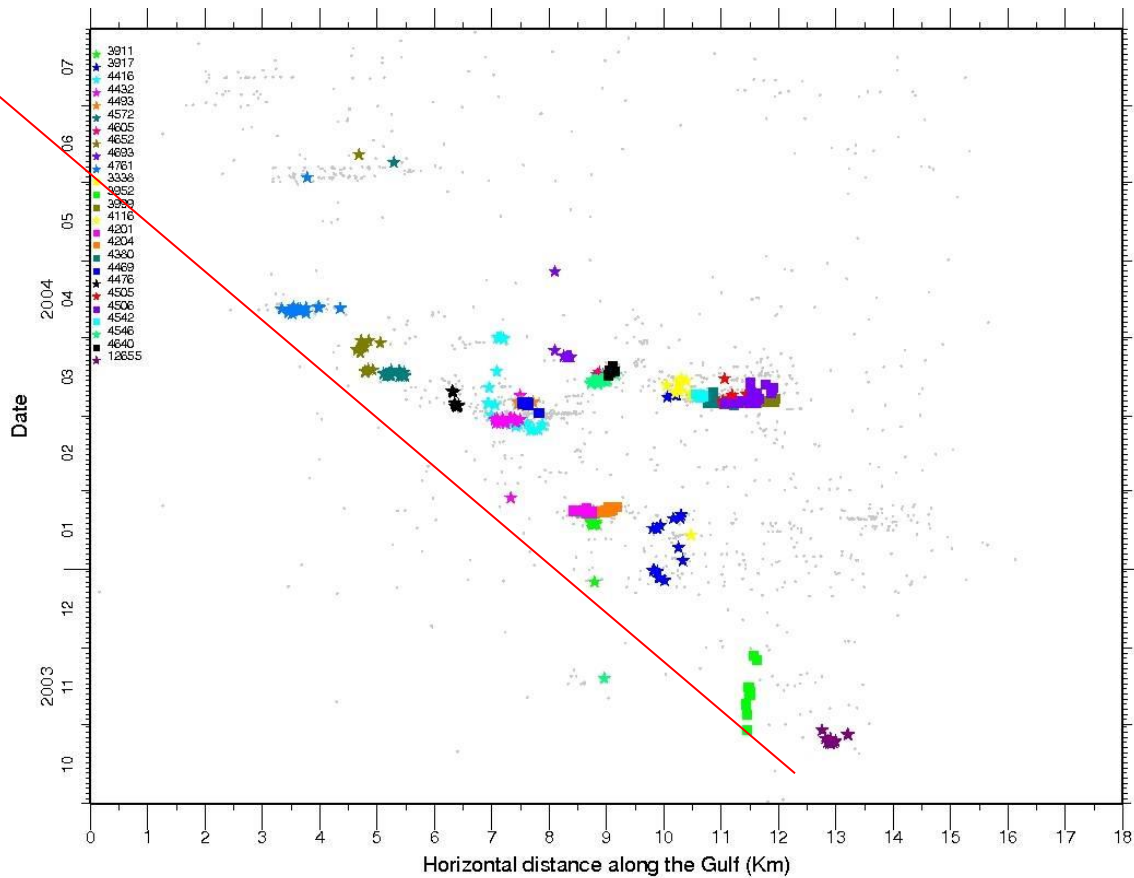


Godano, 2013

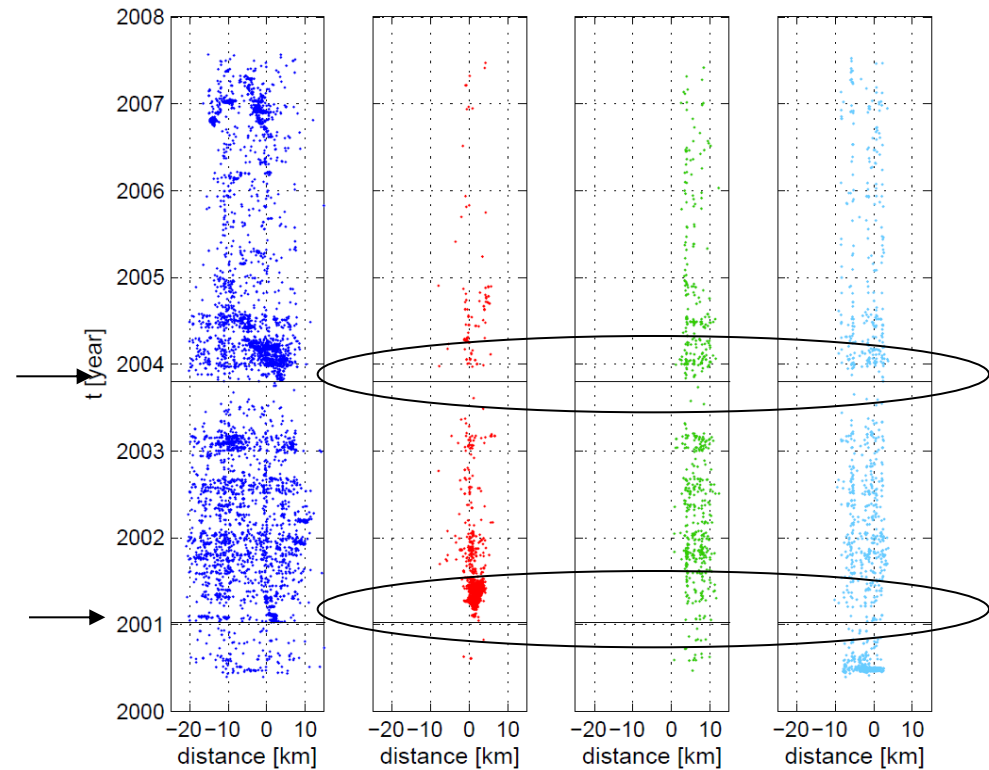
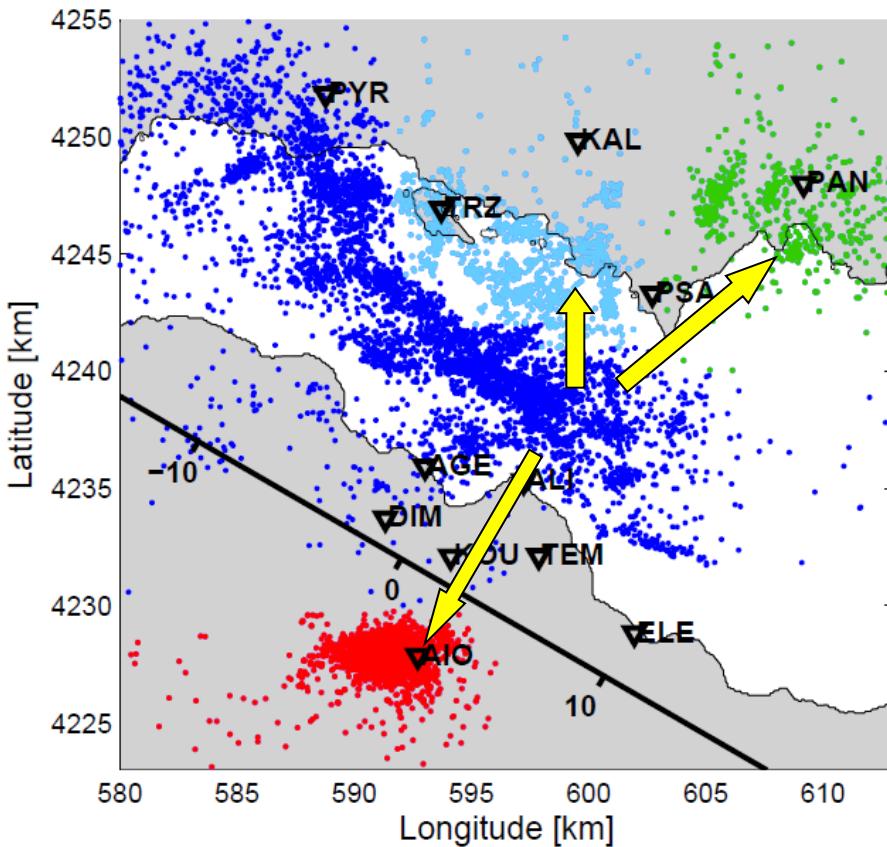
2004 swarm

Start at the eastern end of Aigion fault

diffusion 10 km, 200 days : 50m /day



Microseismic swarms of 2001 and 2004:
Diffusion from the rift axis outwards (NE and SW)

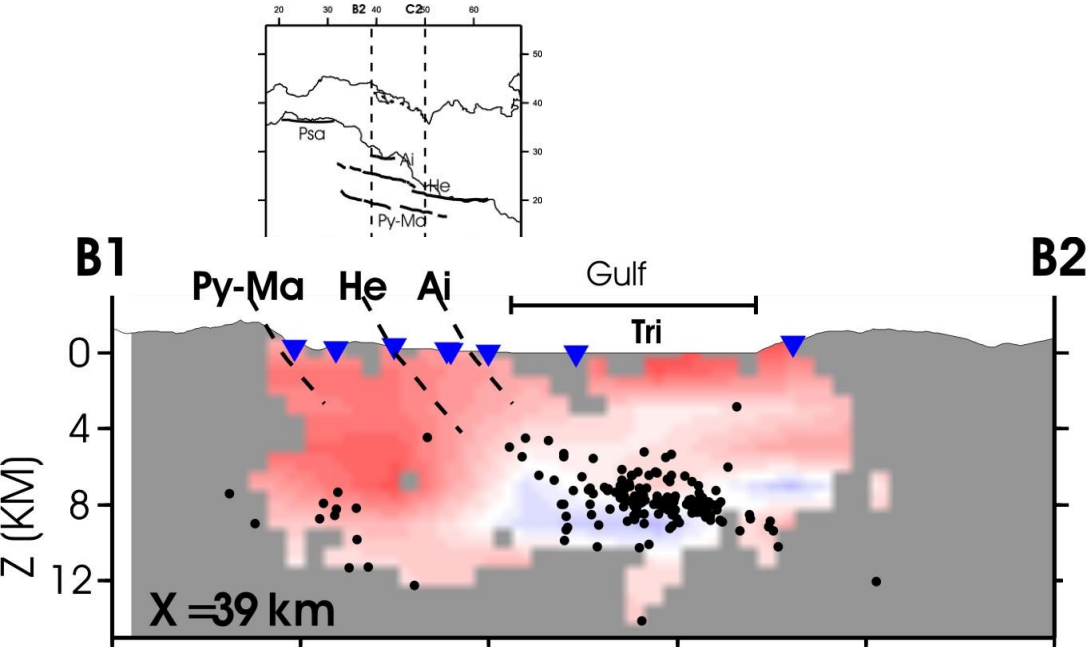


Lambotte et al. 2013

Fluids may come from the subduction 50 km below

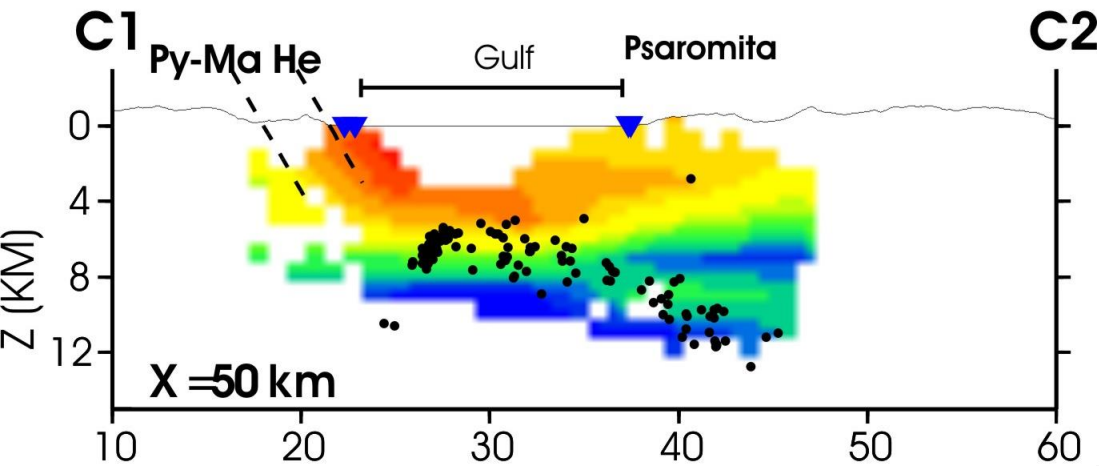
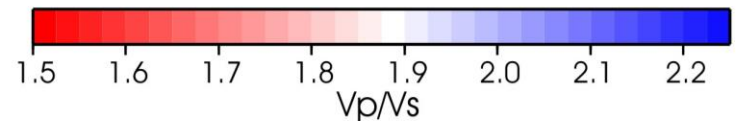
Corinth Tomography: Evidence for fluids

- Seismicity diffusion rate : 2001, 2002, 2004, ..
50 m to 1 km /day
- Source from the rift center

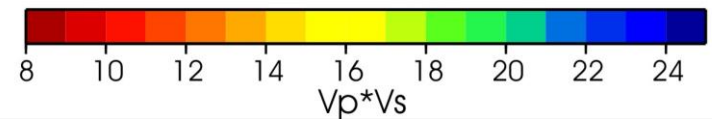


Latorre, 2004; Gautier et al. 2006

$V_p/V_s \Leftrightarrow$
Fluid saturated

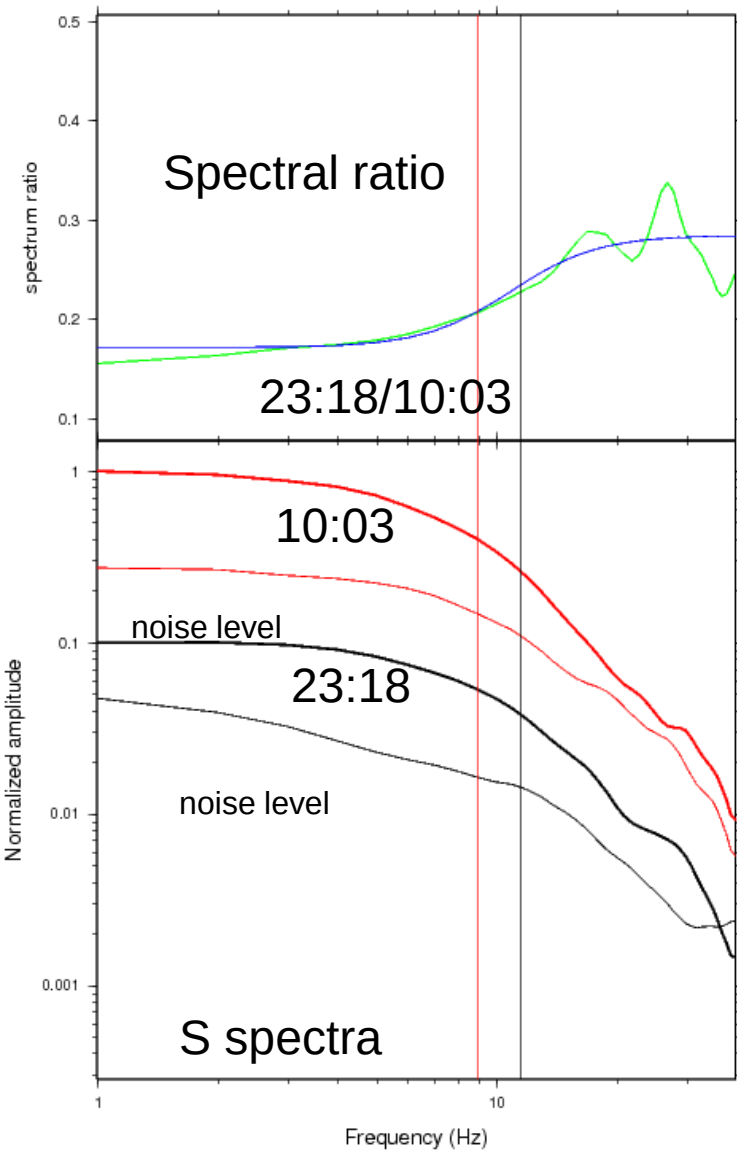


$V_p \cdot V_s \Leftrightarrow$
porosity/fracturation



Fitting S spectra and spectral ratio

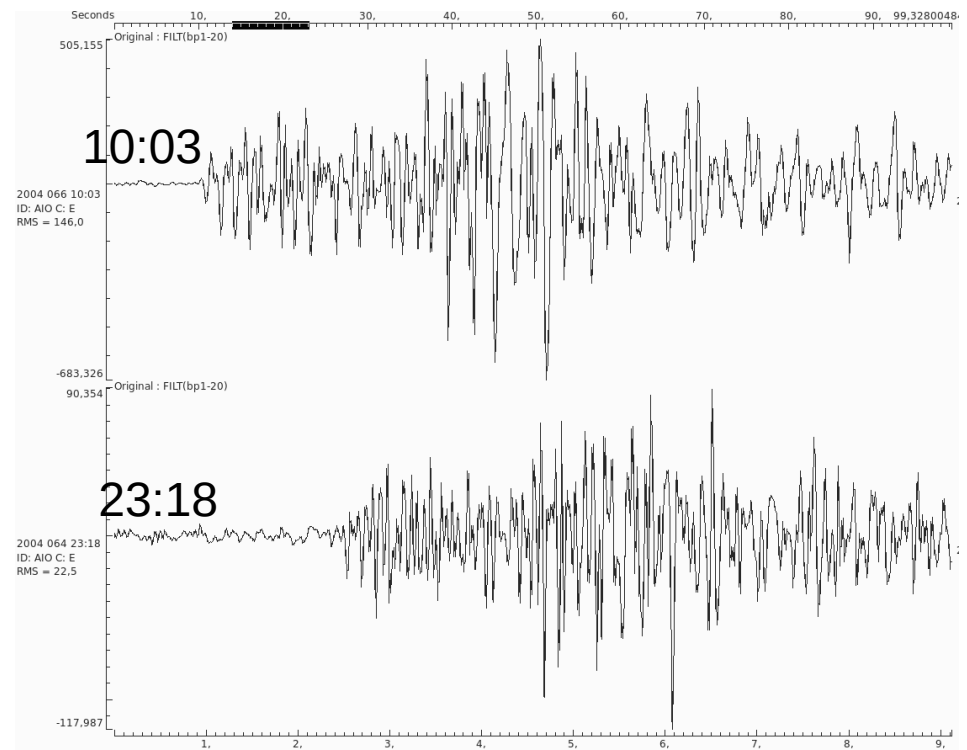
Assuming w-square model and constant attenuation Q



Spectra: trade-off between f_c and Q

spectral ratio: constrains f_c

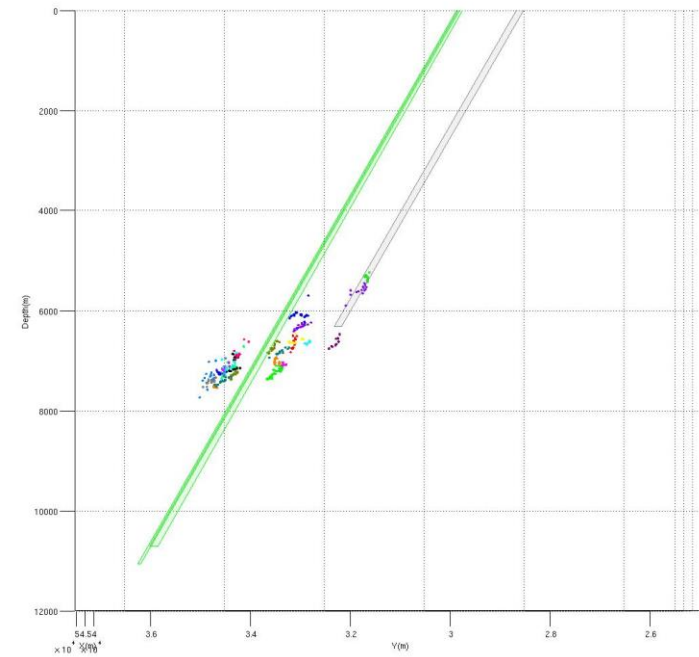
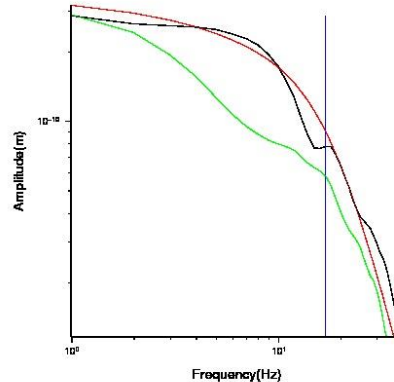
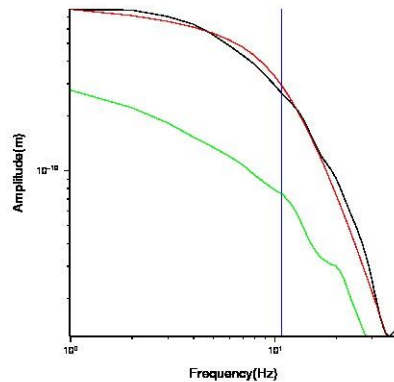
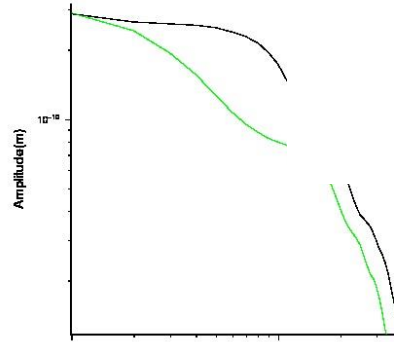
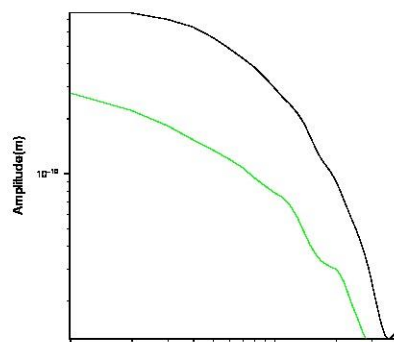
f_c min = 9Hz



Source dimension characterization in multiplets

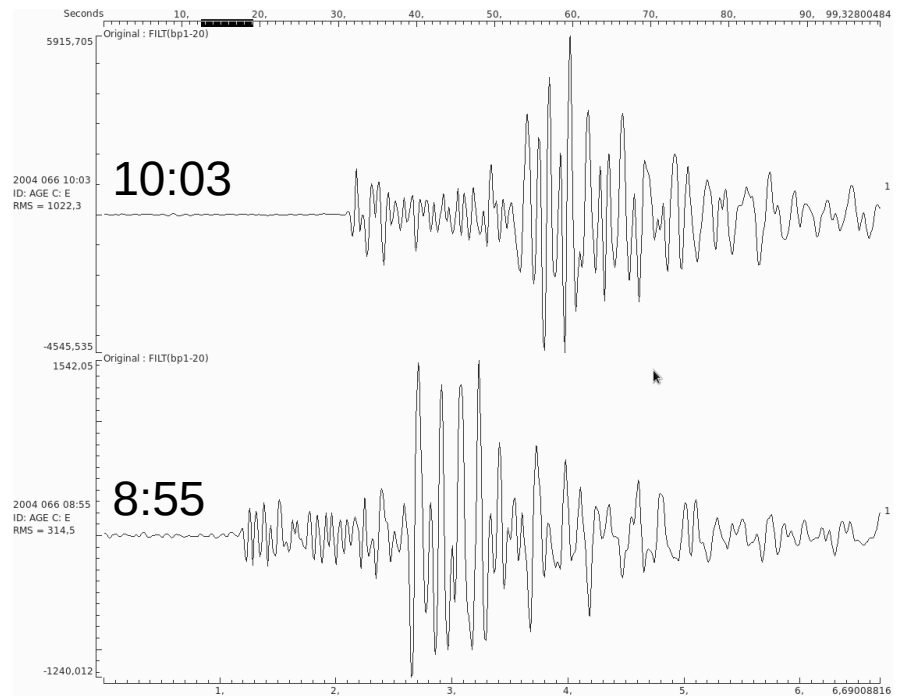
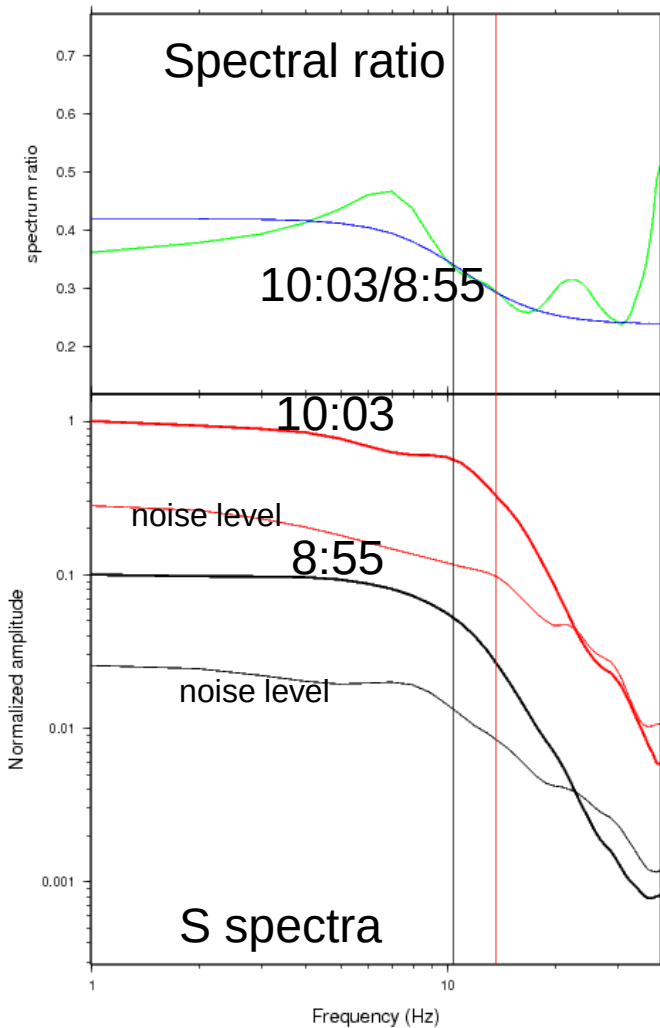
Seismic moment and corner frequencies

Fit to S spectra
with w-square



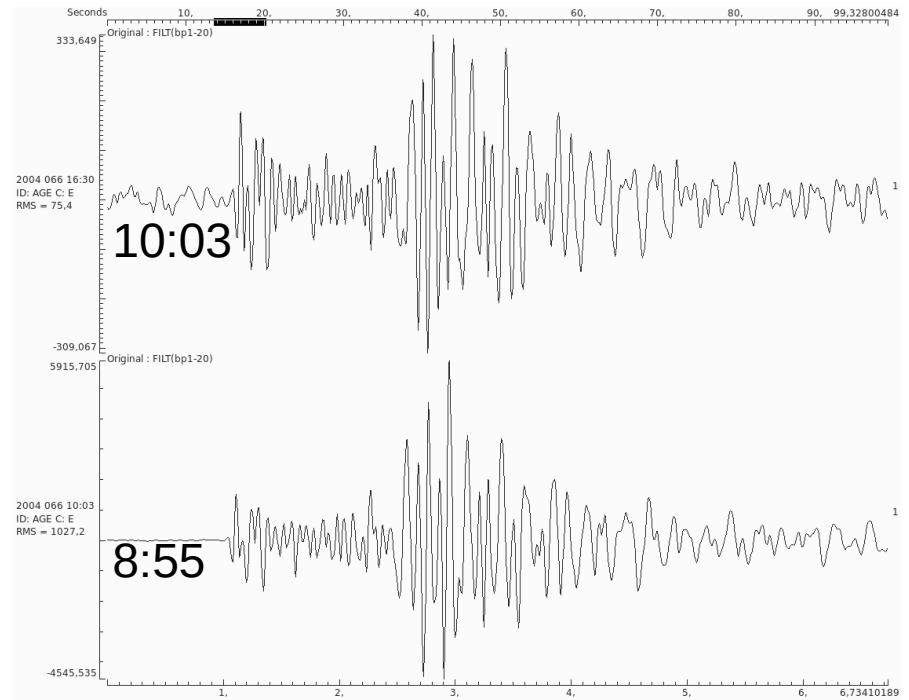
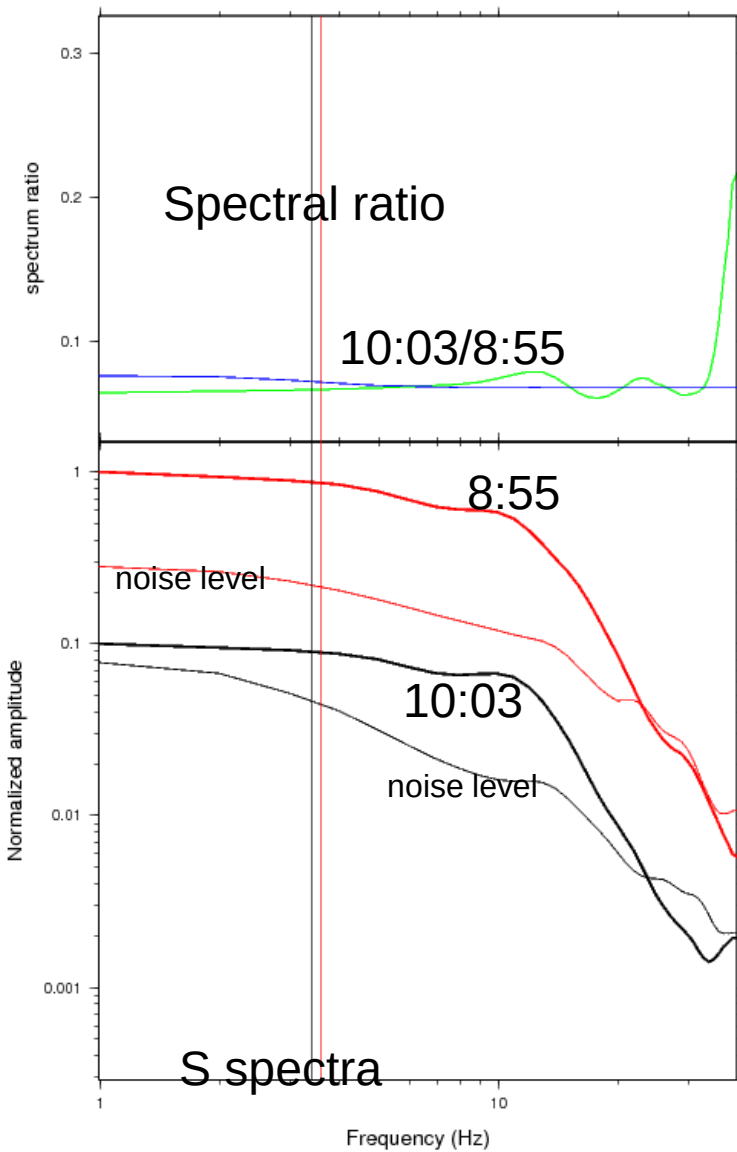
Target event with largest corner frequency
Hence larger stress drop

fc min=10 Hz



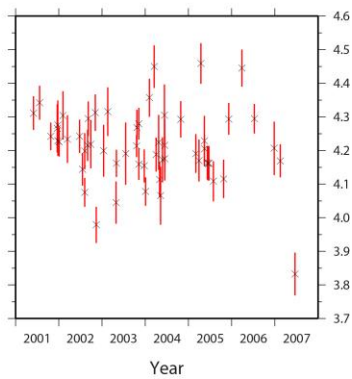
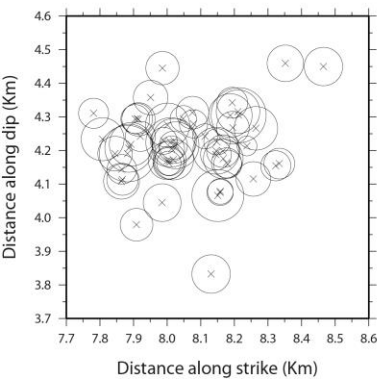
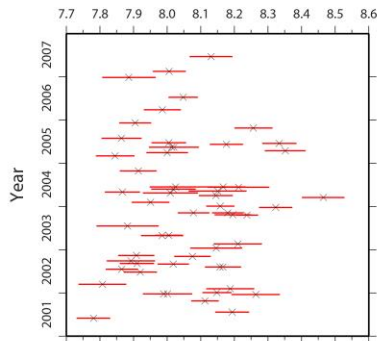
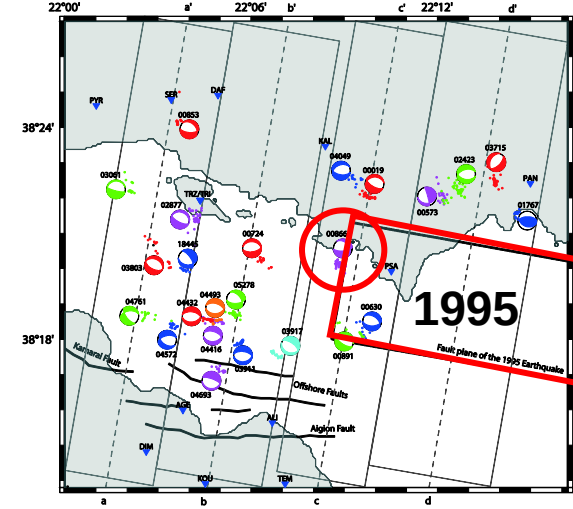
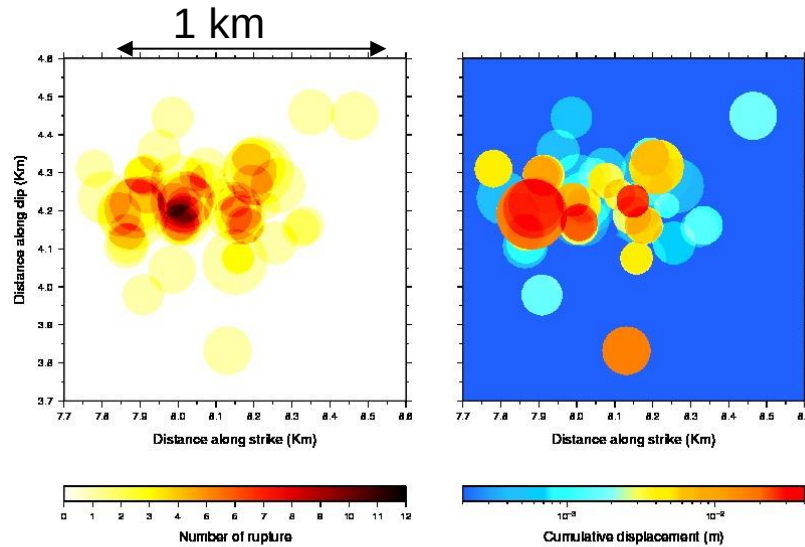
fc1=fc2

But poorly constrained

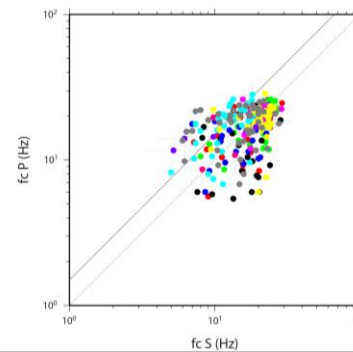


A « stable » multiplet on the « detachment »: interacting mechanical asperities

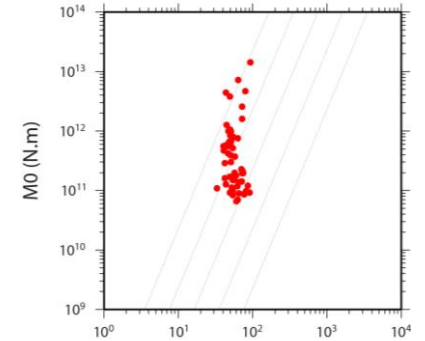
Godano
2013



fc(P) versus fc(S)



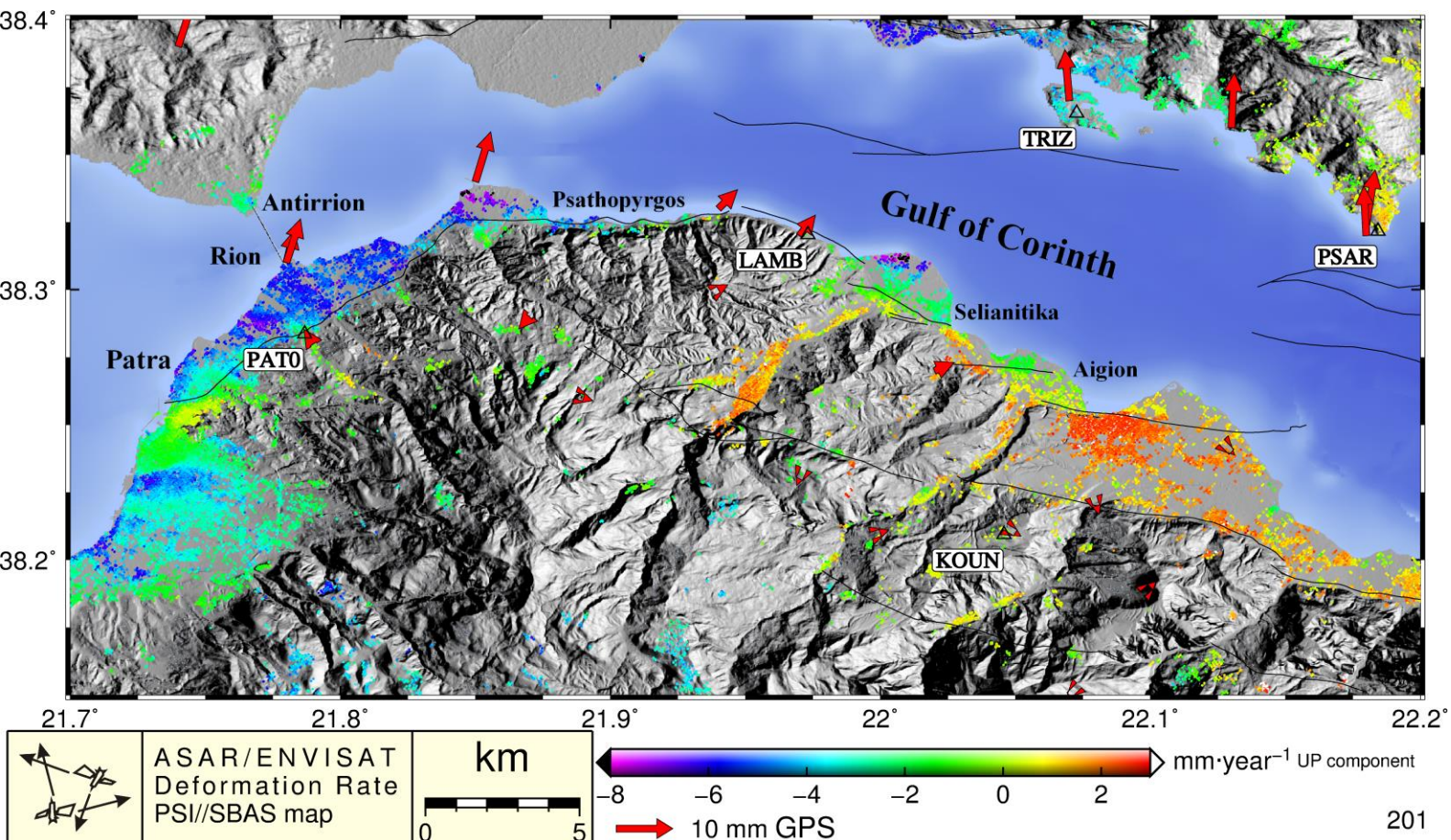
Mo versus fc(P)



Shallow aseismic creep on major faults from

GPS, InSAR, and strainmeters:

Psathopyrgos (transient creep), Rio-Patras, and Aigion faults

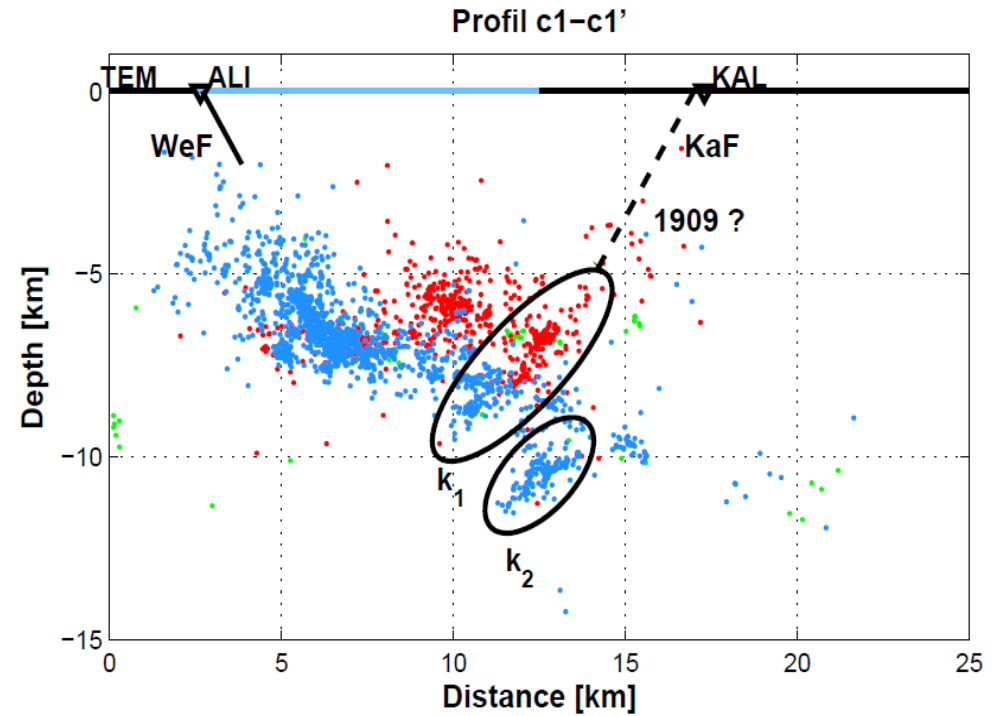
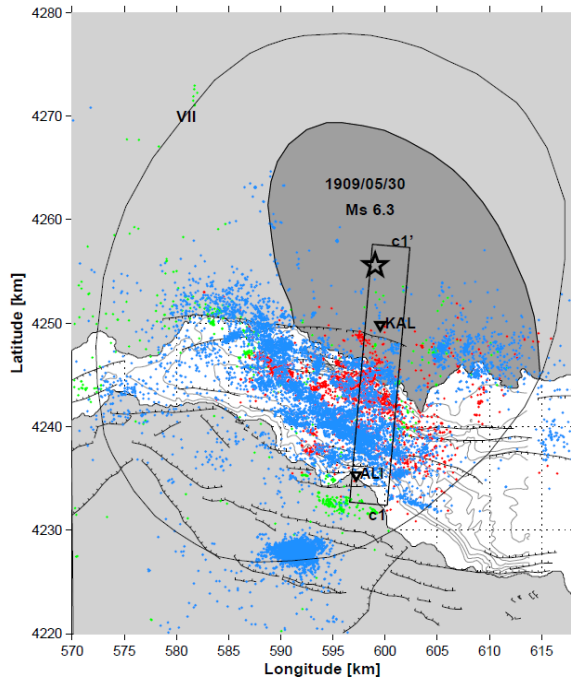


Moderate to large earthquakes :

1917, 2010, 1995

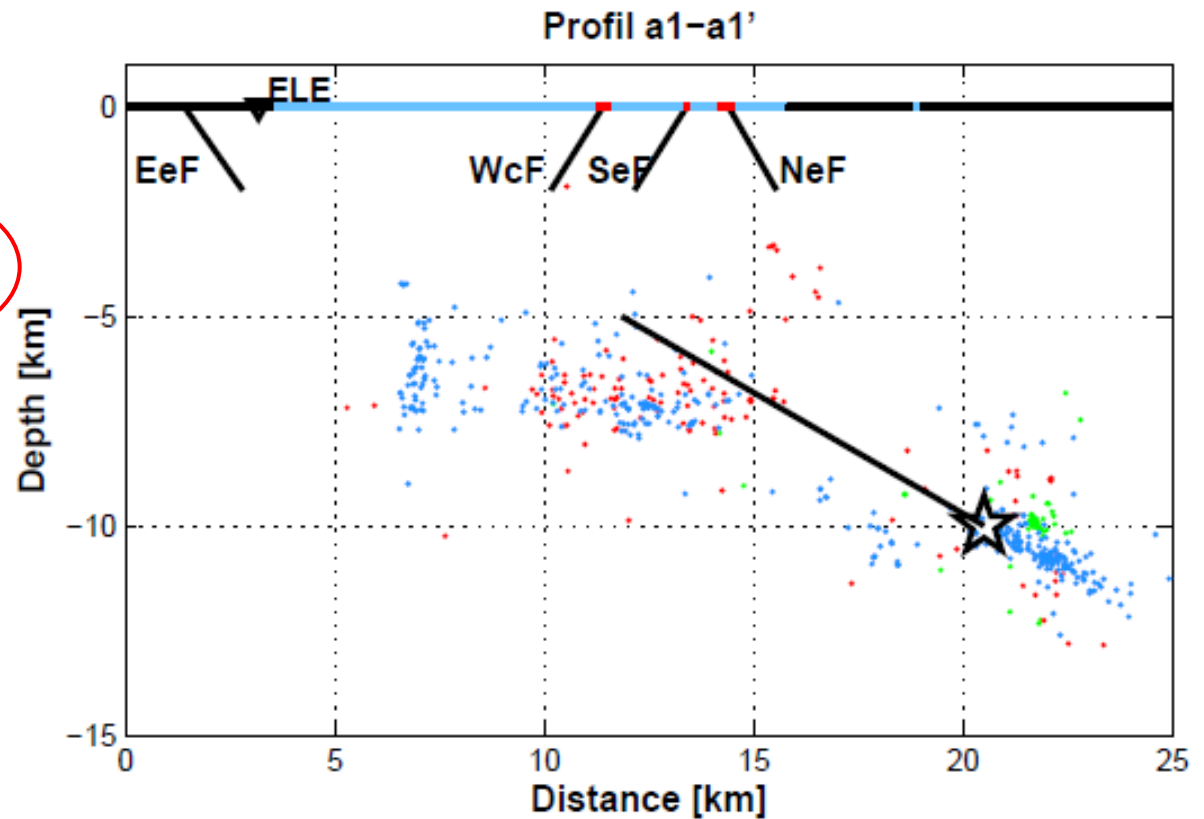
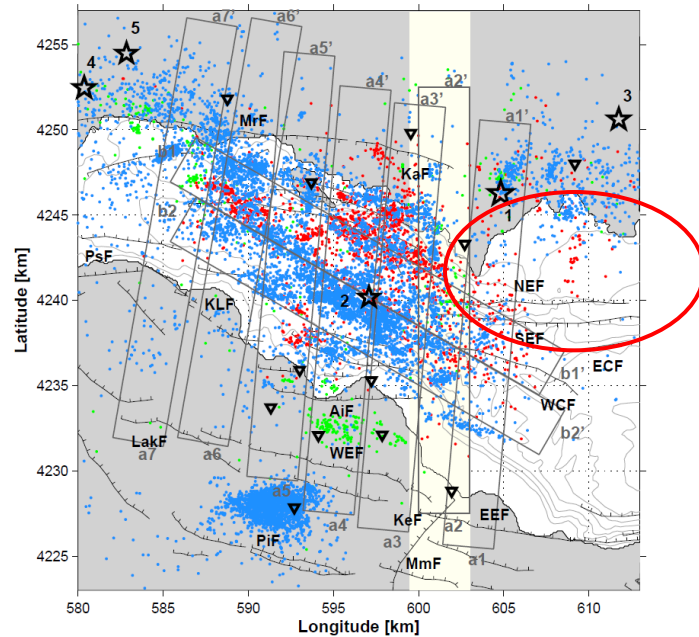
The Fokida Earthquake, 1909, $M = 6.-6.5$

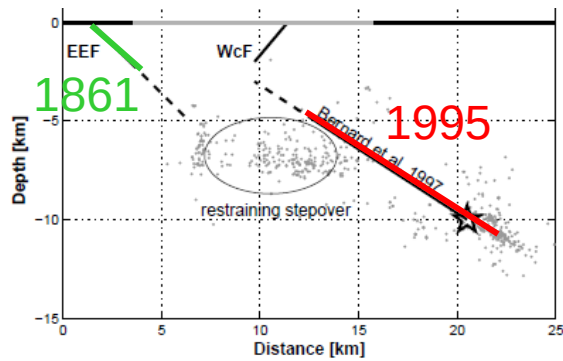
- on the Kalithea fault?



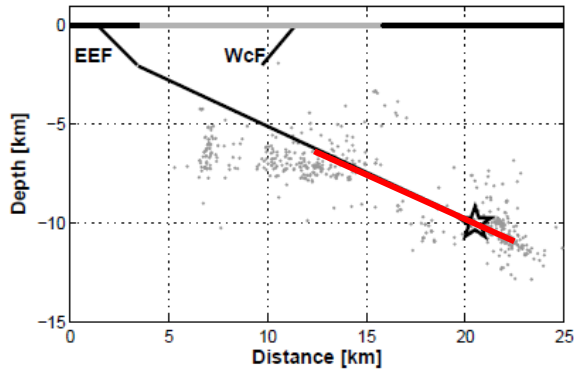
The Aigion Earthquake, 1995, M=6.2

An offshore fault, or the Helike fault?

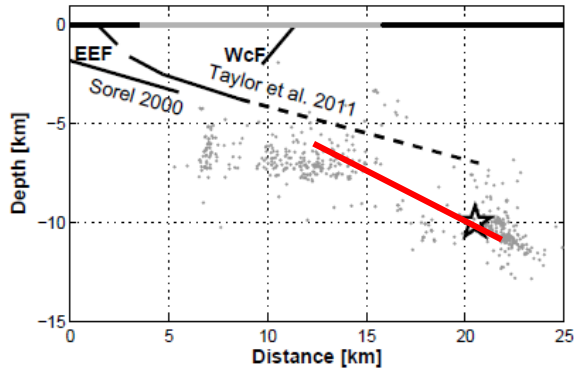




1995 EQ on an
Offshore fault

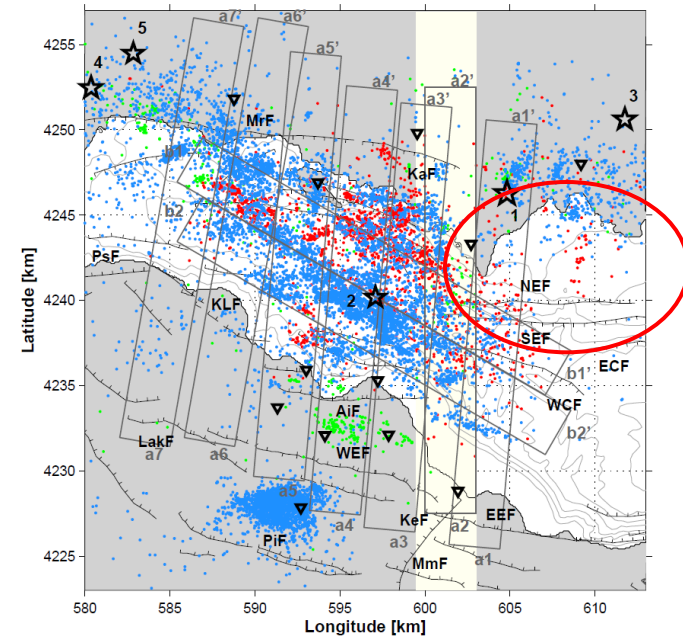


1995 EQ on the
East Helike fault



Detachment models

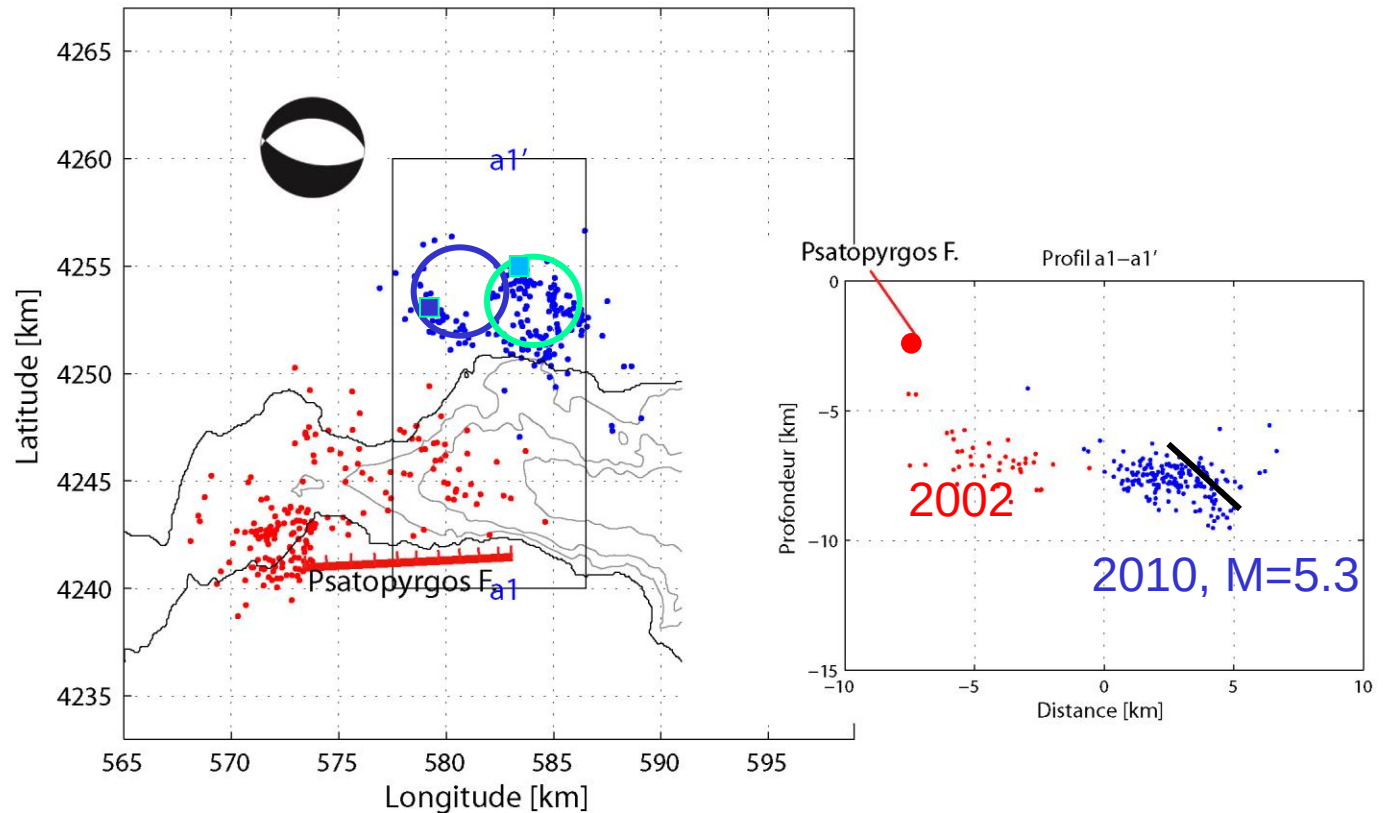
Sorel 2000, Taylor et al. 2011



Lambotte et al., 2013

Meyer, 2013

The Pyrgos 2010, doublet earthquakes, $M=5.3$
An offshore fault, or the Psathopyrgos fault?



1995 and 2010 earthquakes

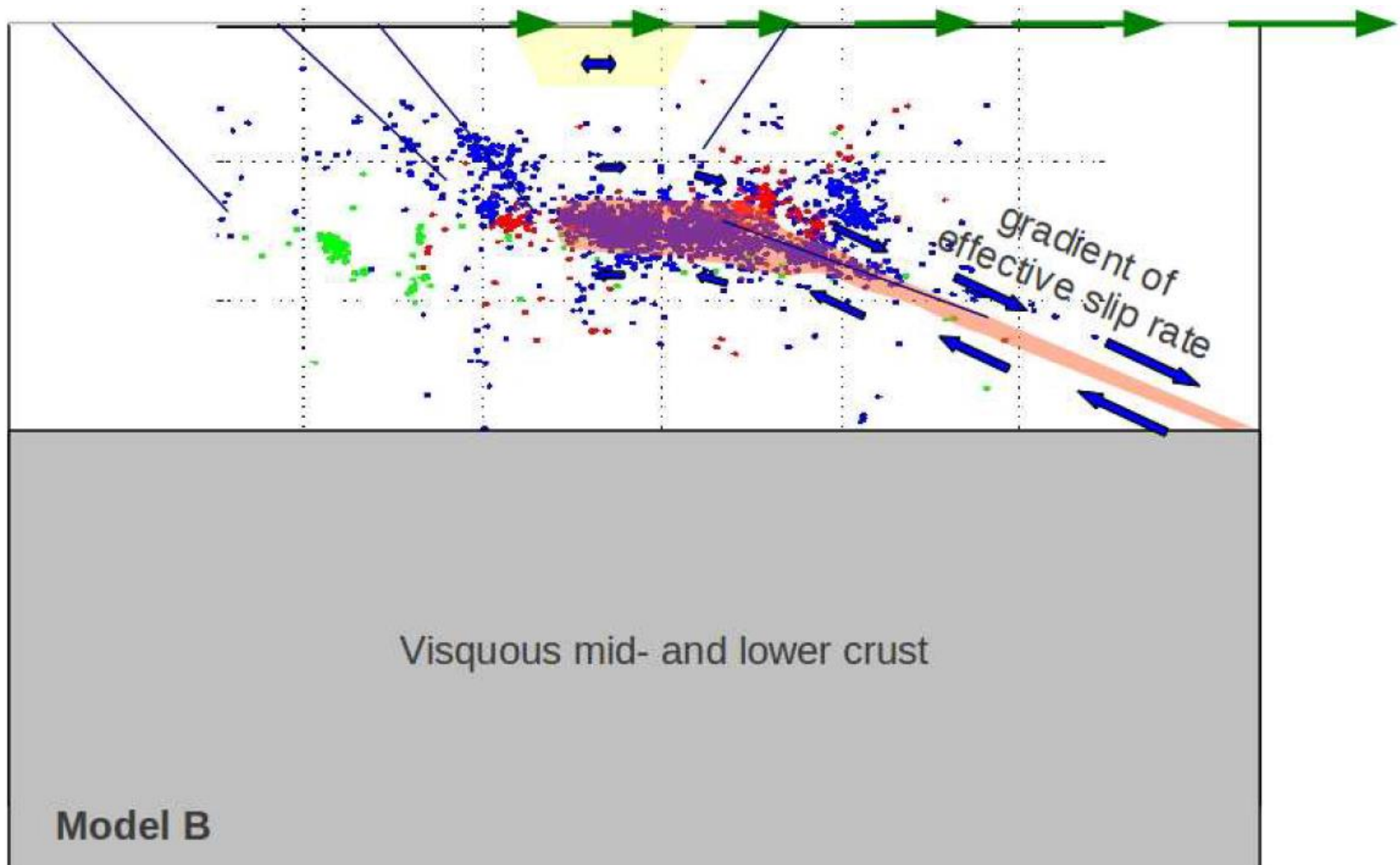
No continuity between deep, blind faults to the north and outcropping large faults to the south

Fine structure of the seismogenic zone:

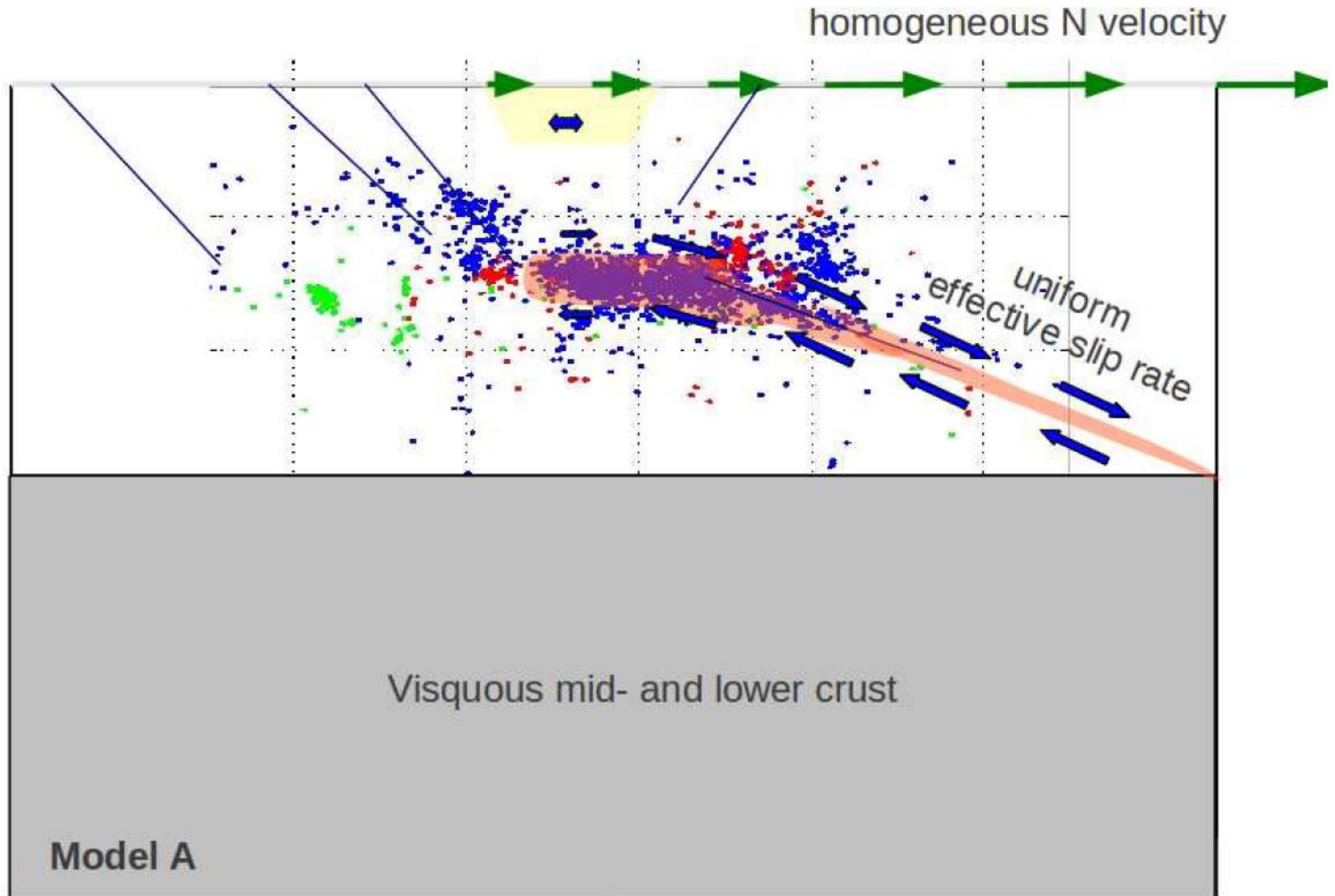
- Variable mechanisms – different from mean dip
- non planar structure
- Variable thickness (1 to 3 km)
- compressive step-over between south and blind north faults

Seismogenic layer: a thrust nappe from the western Hellenides?

Detachment model with constant opening rate (remote) and constant friction

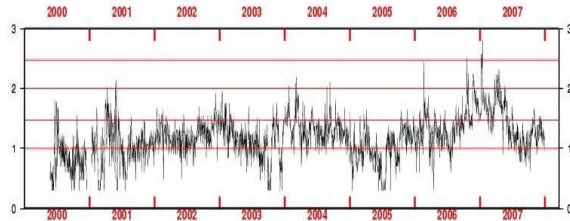


Detachment model with constant opening rate (remote) and decreasing friction



Stability of rift opening rate versus variability of micro-seismicity: different strain sources

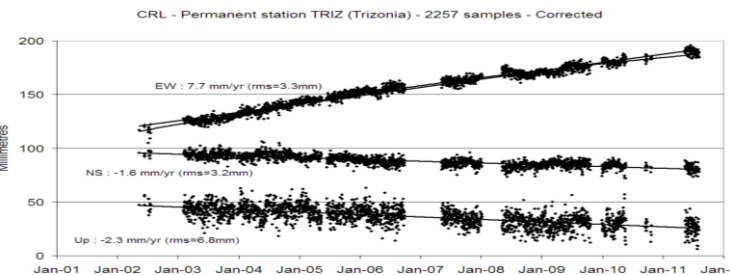
Log(seismicity rate) /day



Seismicity:
Fluctuating
stressing rate

contradiction

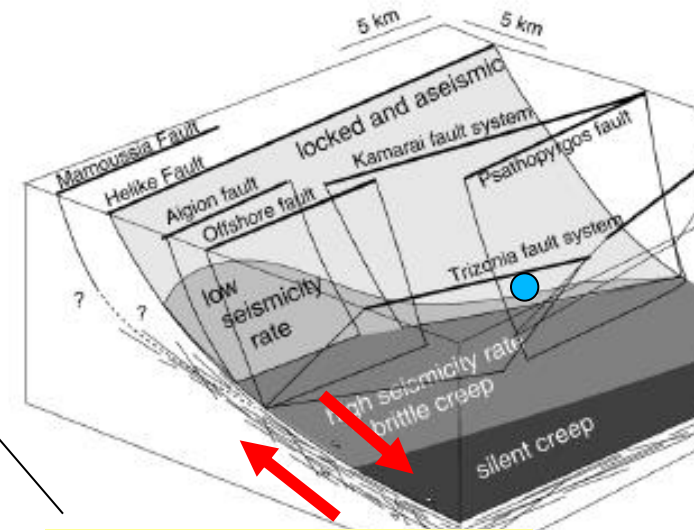
Displacement (N) (mm)



GPS:
constant
stressing rate

cGPS (TRI)

Brìole et al. 2013



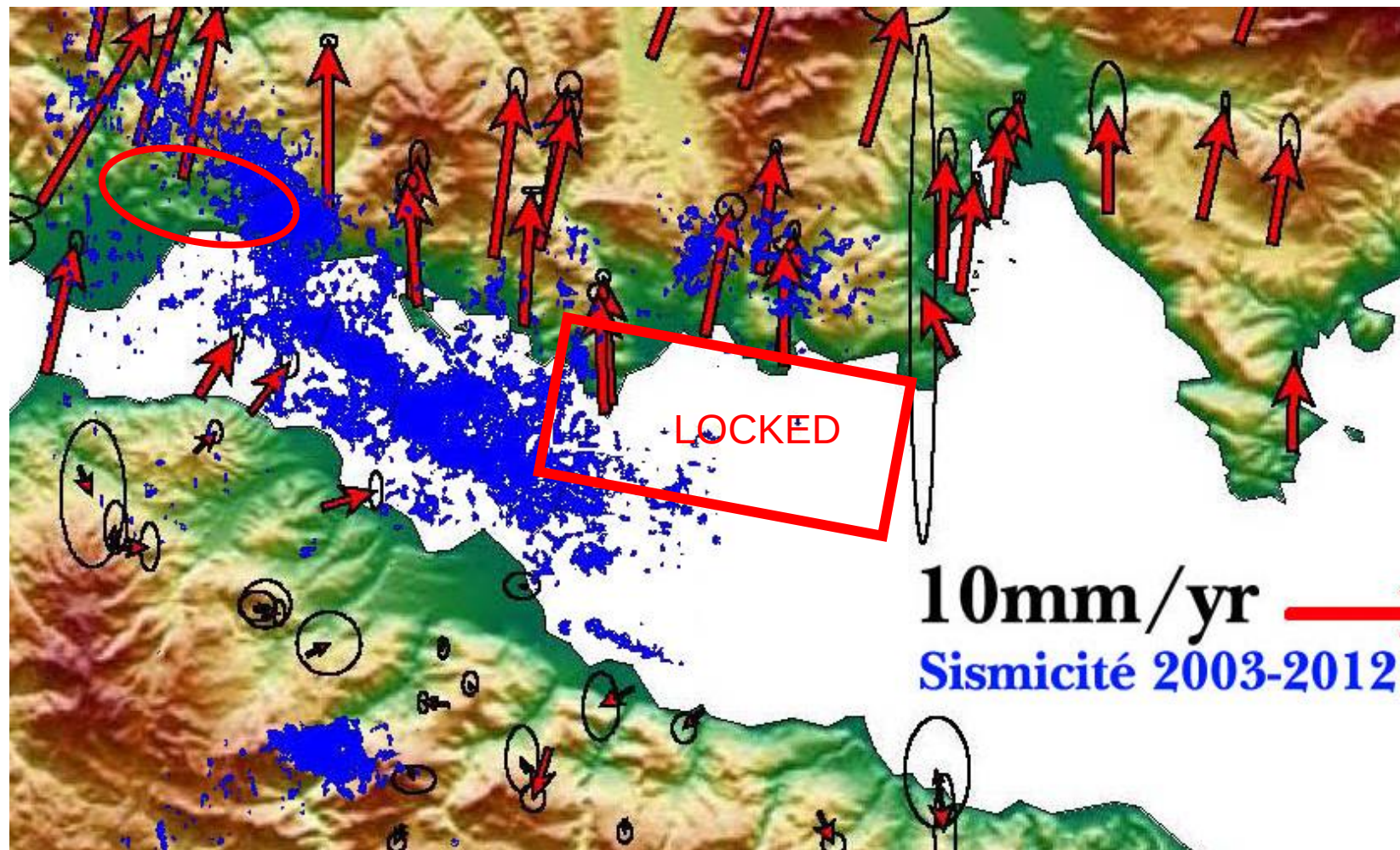
Shearing of the
« detachment »

The fluctuating micro-seismicity and the stationary GPS rate are unlikely to have the same source:

The main source of GPS rate may shearing of the seismic layer

Locked fault surfaces on 1995 and 2010 rupture zones :

Does not seem to affect GPS rates – deeper or shallower interseismic sources



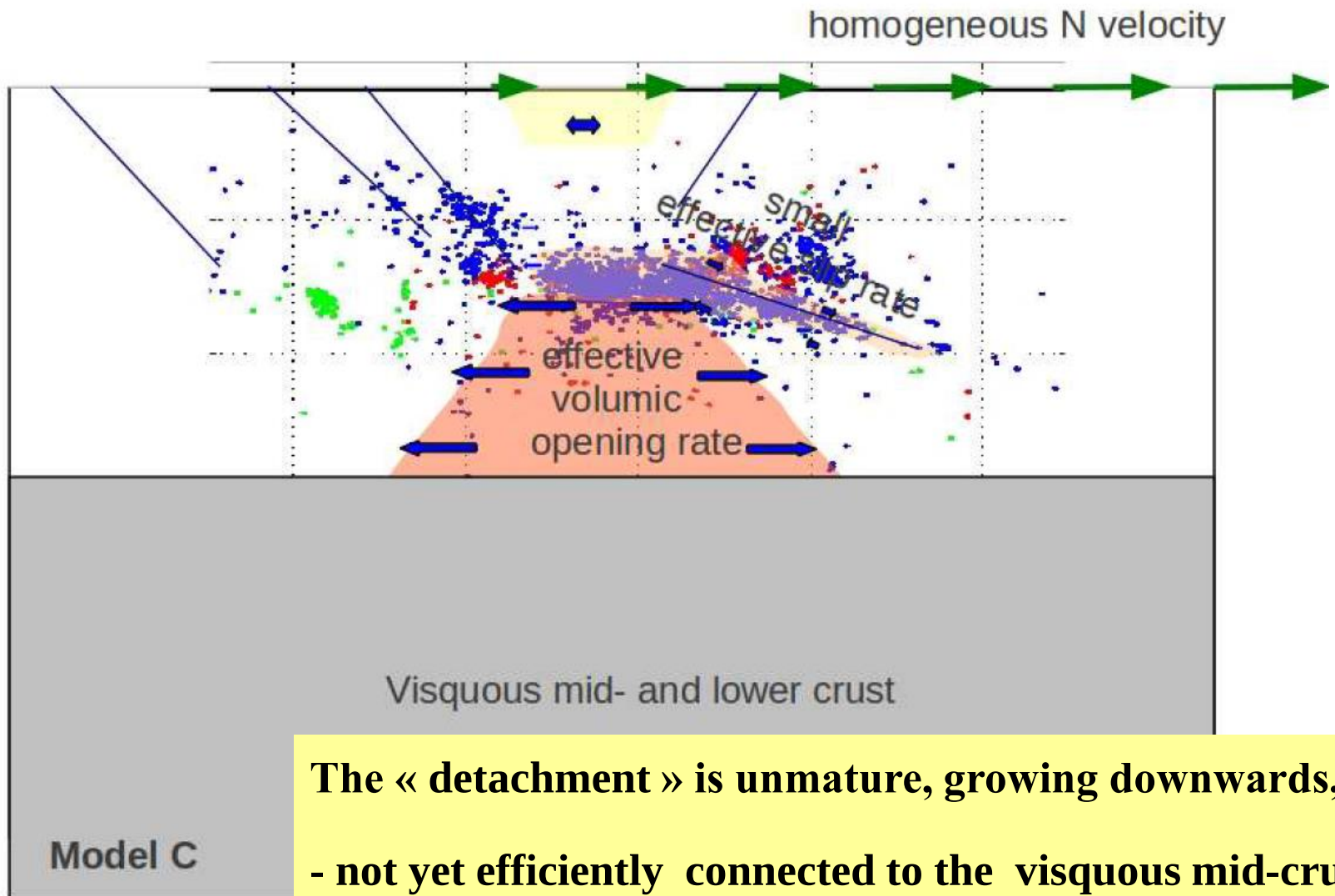
Detachment model:

- predicts correlation between GPS strain rate and seismicity

- predicts reduction and rotation of the velocity vectors near large locked asperities

... which is not observed ...

- hence, the main loading anelastic source is not within the thin seismogenic layer: the « detachment » is not expected to take much interseismic shear strain

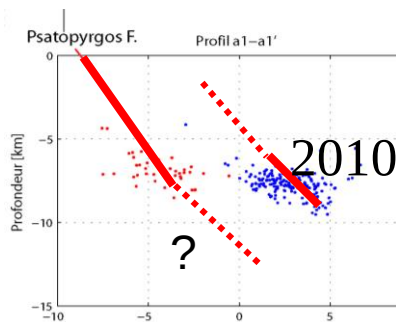
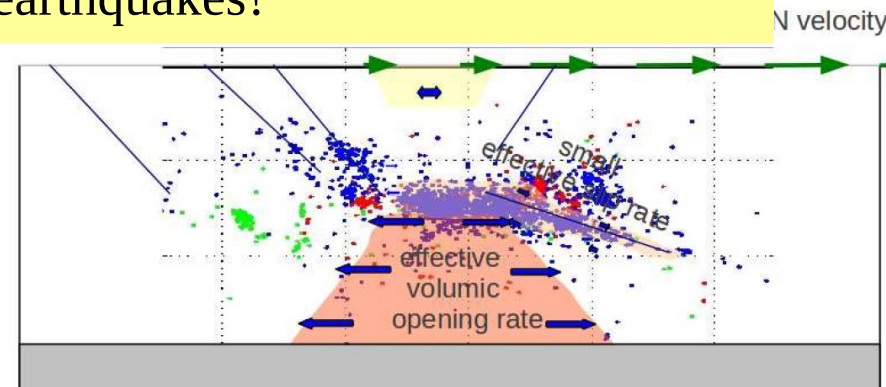
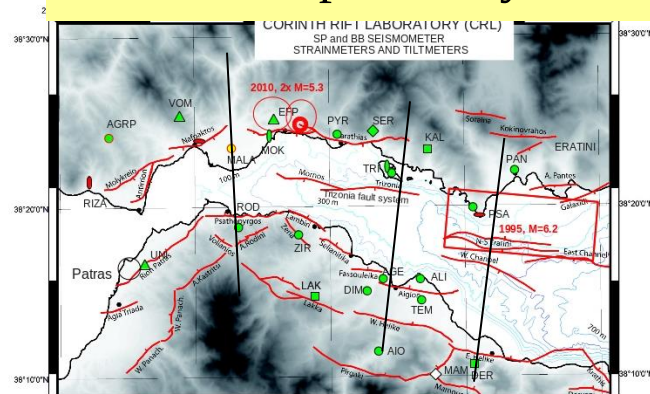


**The « detachment » is immature, growing downwards,
- not yet efficiently connected to the viscous mid-crust
- not the main guide for the western rift opening...**

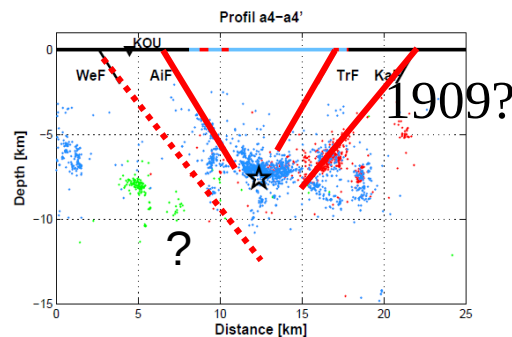
Consequence for seismic hazard:

- Strong vertical fault segmentation in addition to horizontal one
- Difficulties for dynamic upwards or downward cascade
- Hence also limitations in size of horizontal, intersegment connection

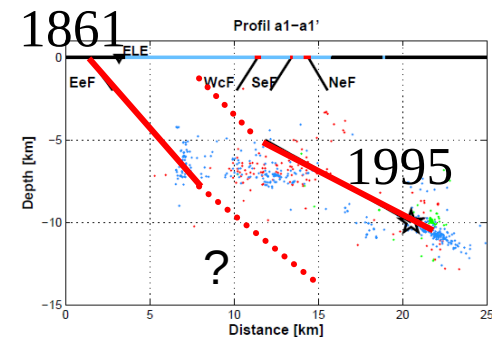
possibility of large M 7+ earthquakes?



Psathopyrgos fault



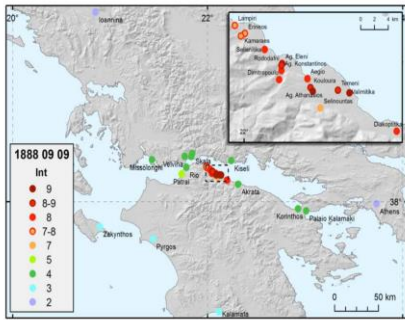
Lambiri/Algion f.
+ Antithetic faults



Helike East/offshore fault

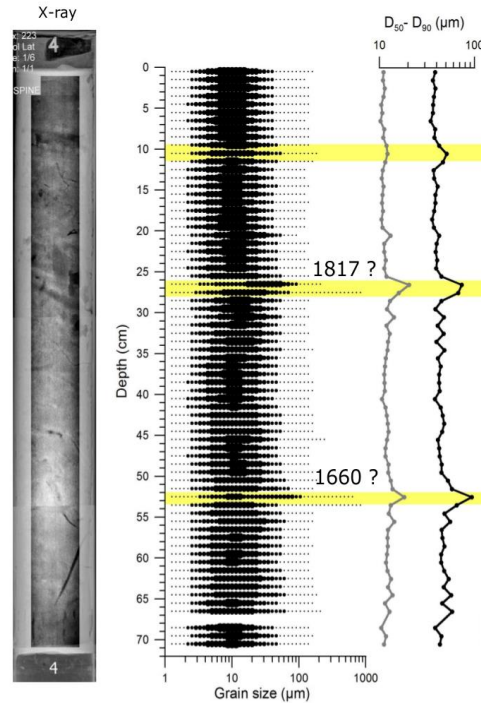
Past large earthquakes for fault activity and seismic hazard assesment:

Work in progress



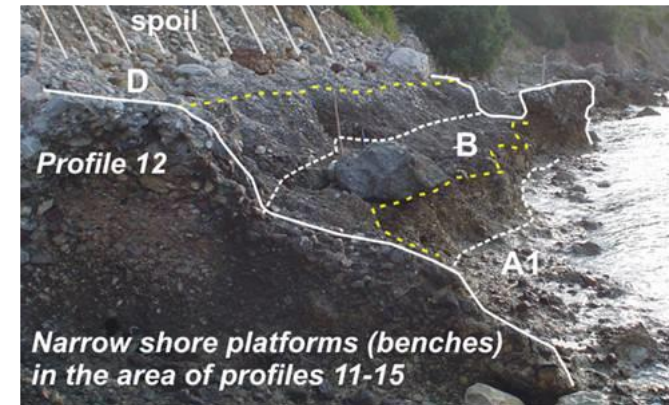
Intensity maps of historical earthquakes

Albini, 2013



Short gravity core – grain size variations

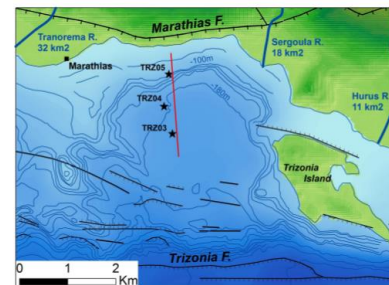
Beckers et al., 2013



Uplifted paleo-shorelines:

5 event, 0.5 m each
in 2000 years

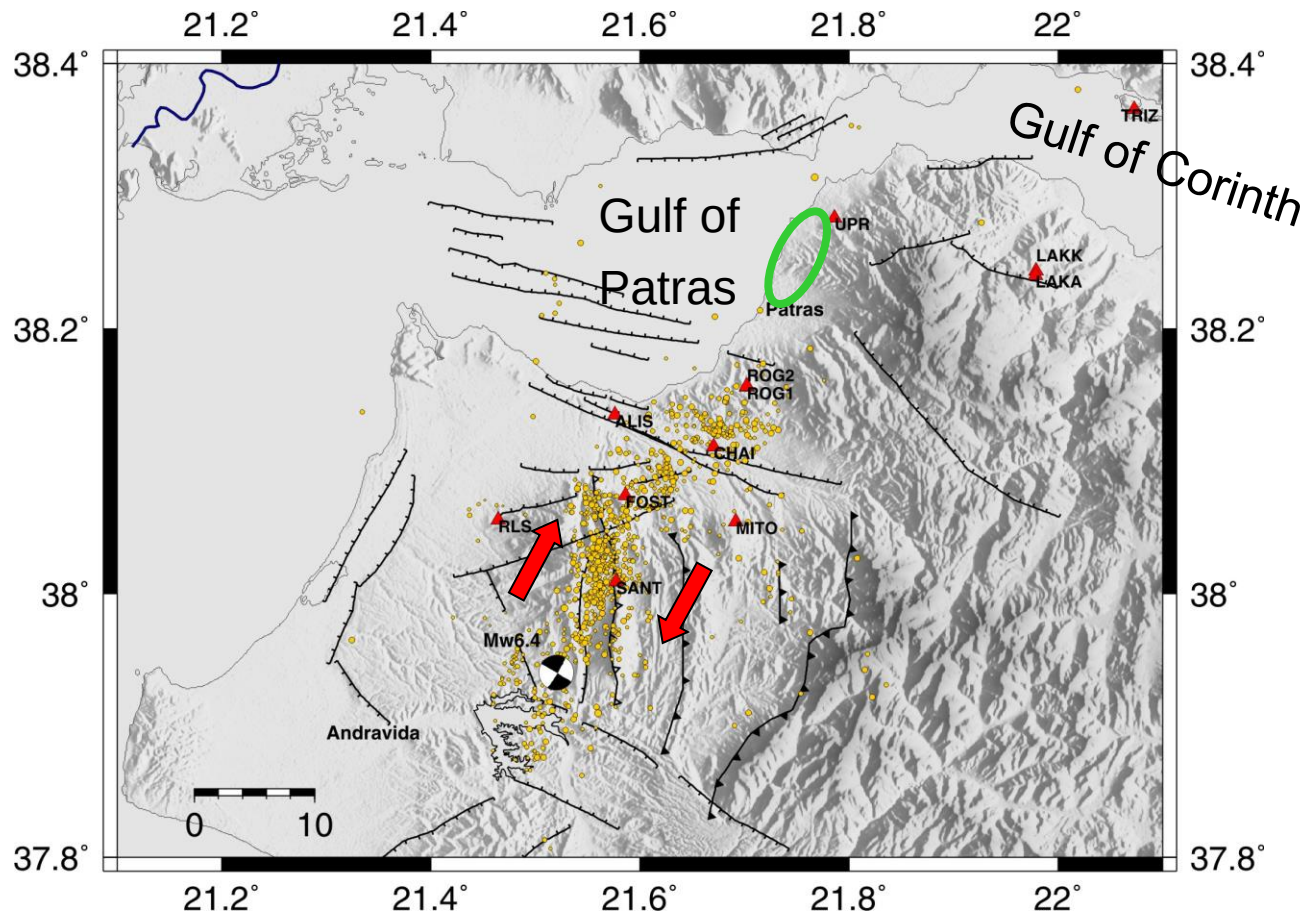
Palyvos et al. 2008



The western end of the Corinth rift:

the SW connection to the subduction

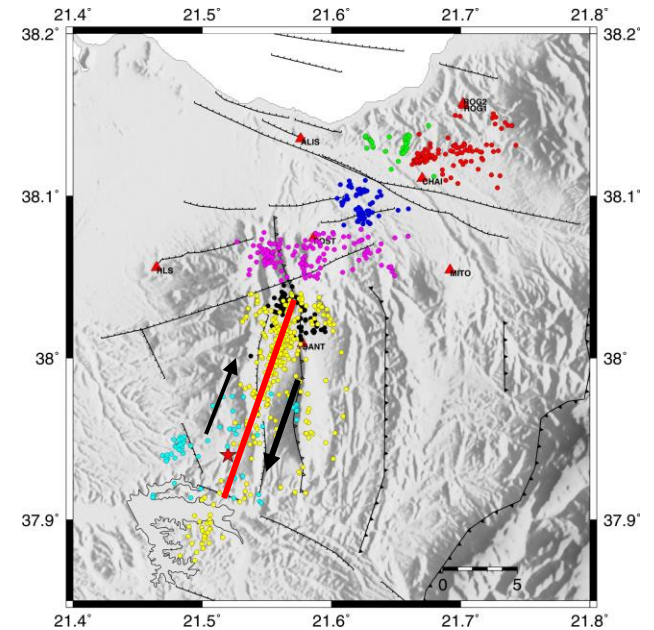
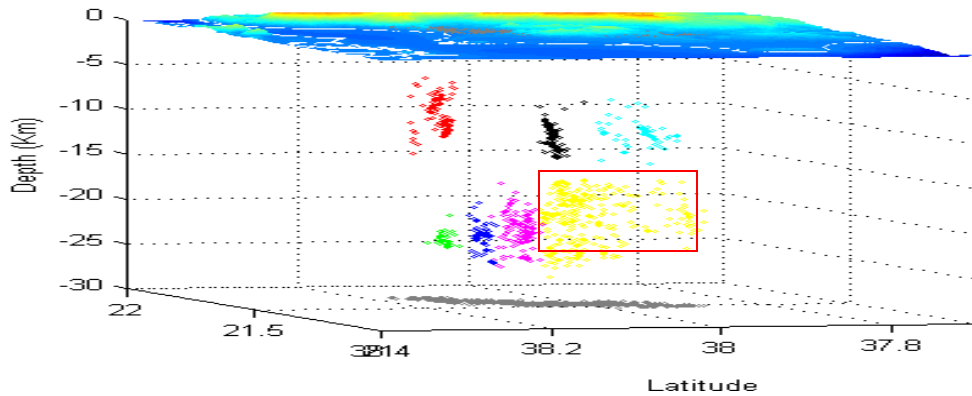
Insights from the M=6.2, Achaia-Ilia, 2008 earthquake



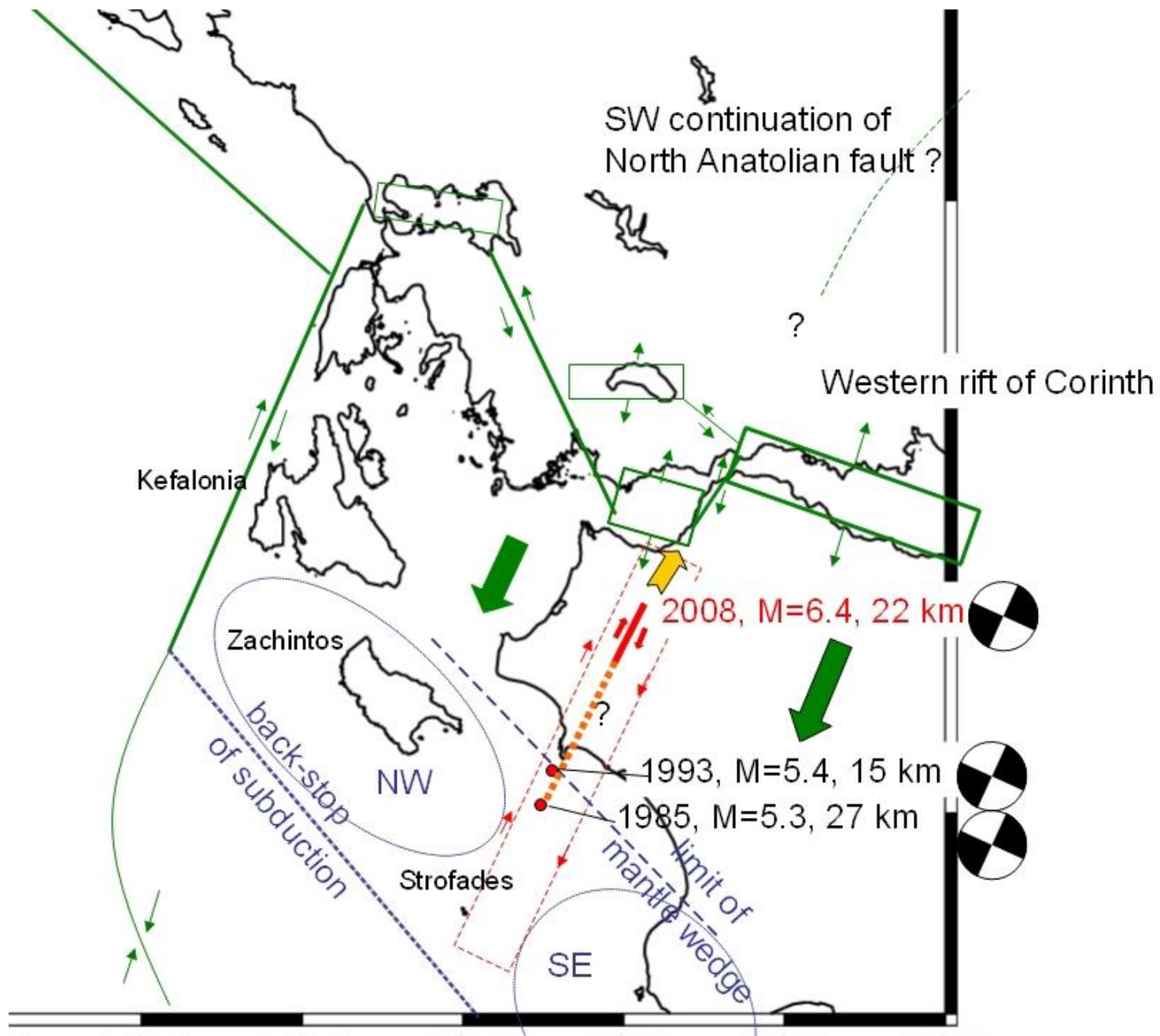
Serpetsidaki et al. 2013

The M=6.2, Achaia-Ilia (Andravida), 2008 earthquake

A deep strike slip event on
a unmature fault



Serpetsidaki et al. 2013



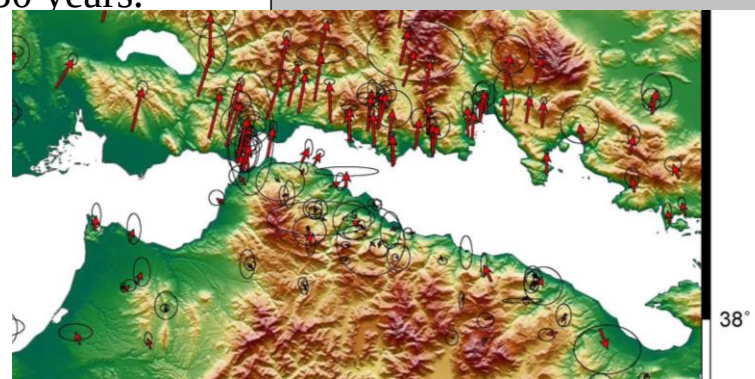
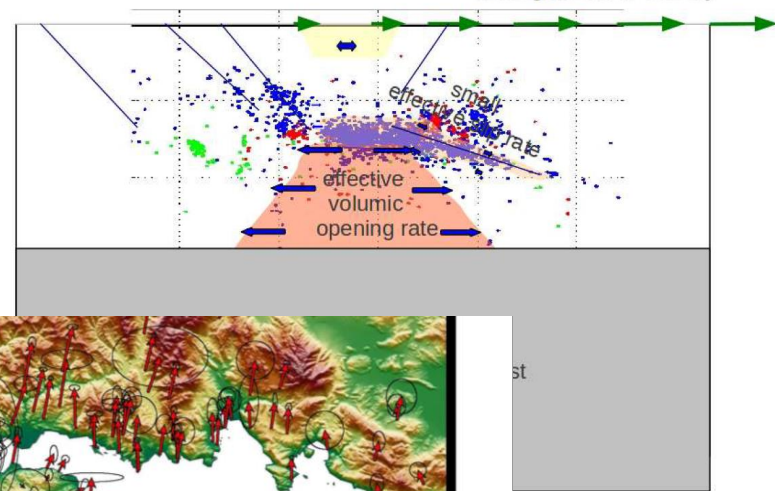
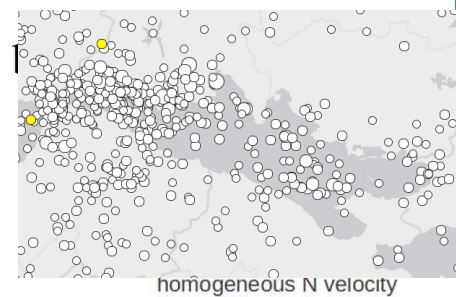
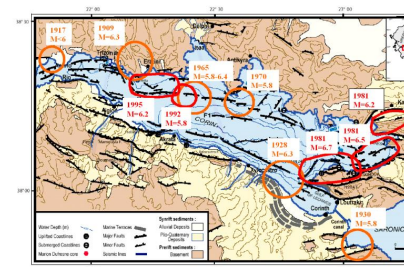
Seismicity of the Corinth Rift:

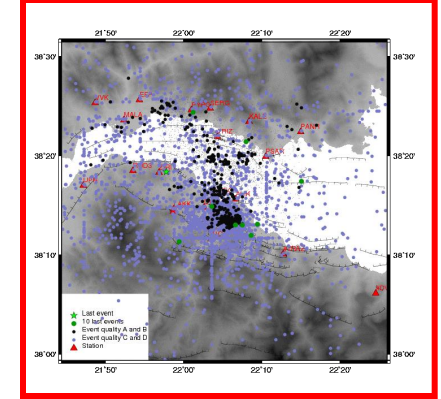
Normal faulting earthquakes (M 6-7), 5 to 10 per century in the whole rift

Western rift of Corinth:

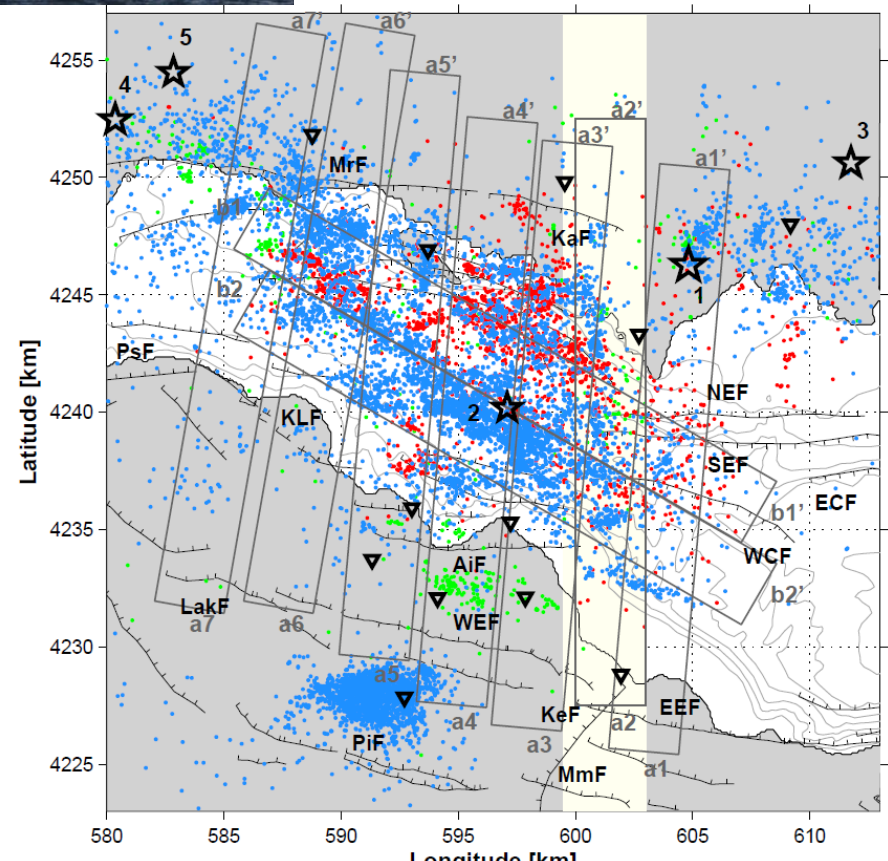
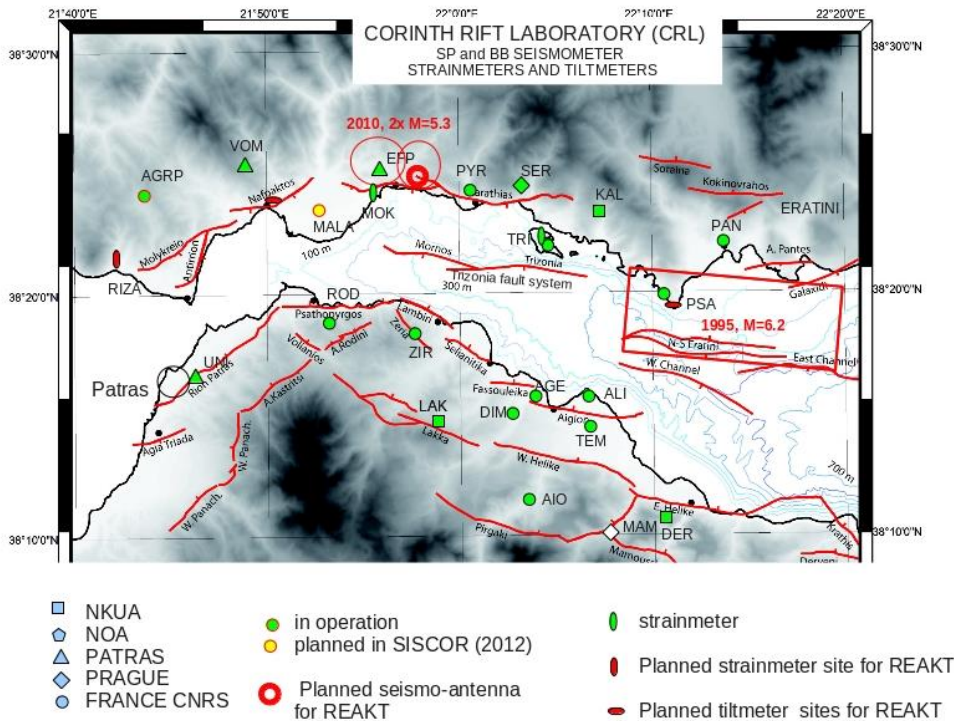
- high strain rate and high level of fluctuating microseismicity
- complex mechanical interaction between faults (old, new, deactivated, reactivated, ...)
- structural control with a brittle layer 1 to 2 km thick, around 7 to 9 km
- shallow steady/transient creep on major faults
- evidence for high pore pressure : influence/control, source?
- axial, « mode I » opening
- growing, immature detachment to the north
- More than 50% probability of a M>6 in the next 30 years.

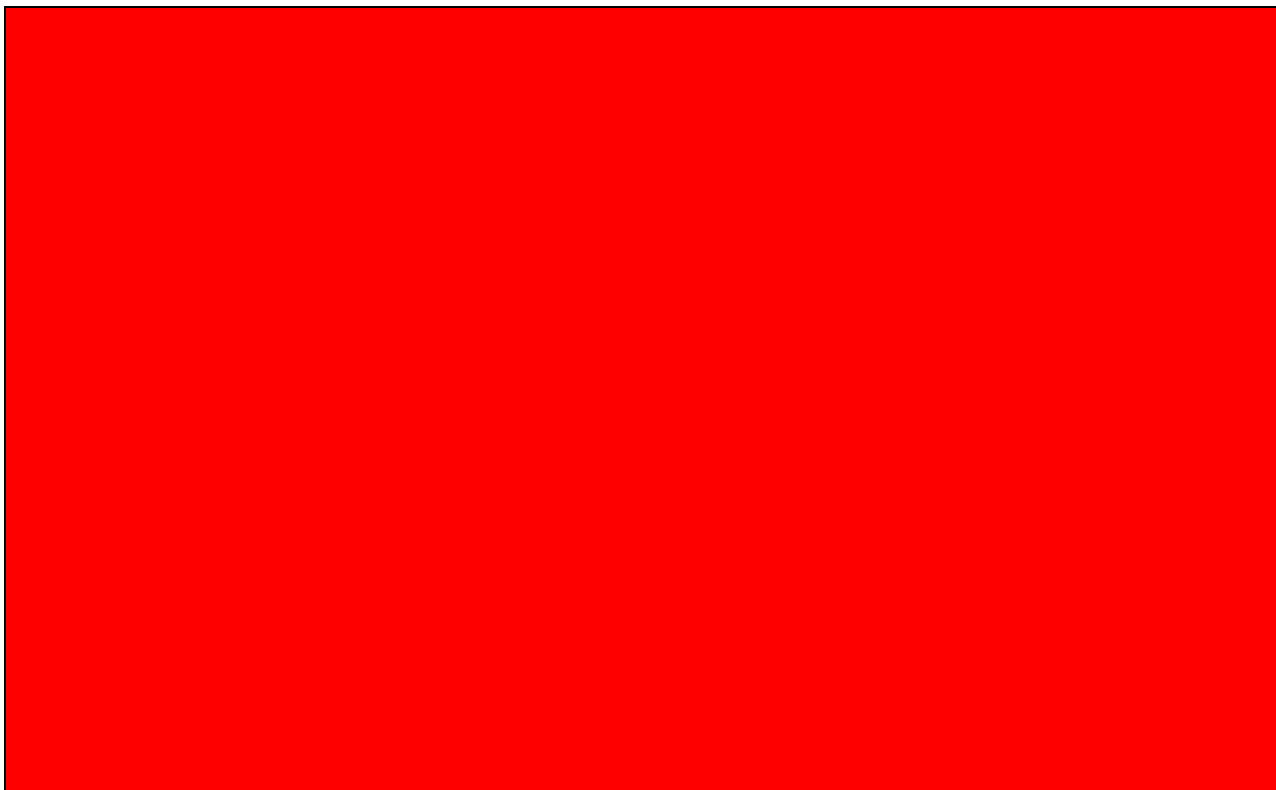
- Further west: continuity of the rifting
in the young Patras rift

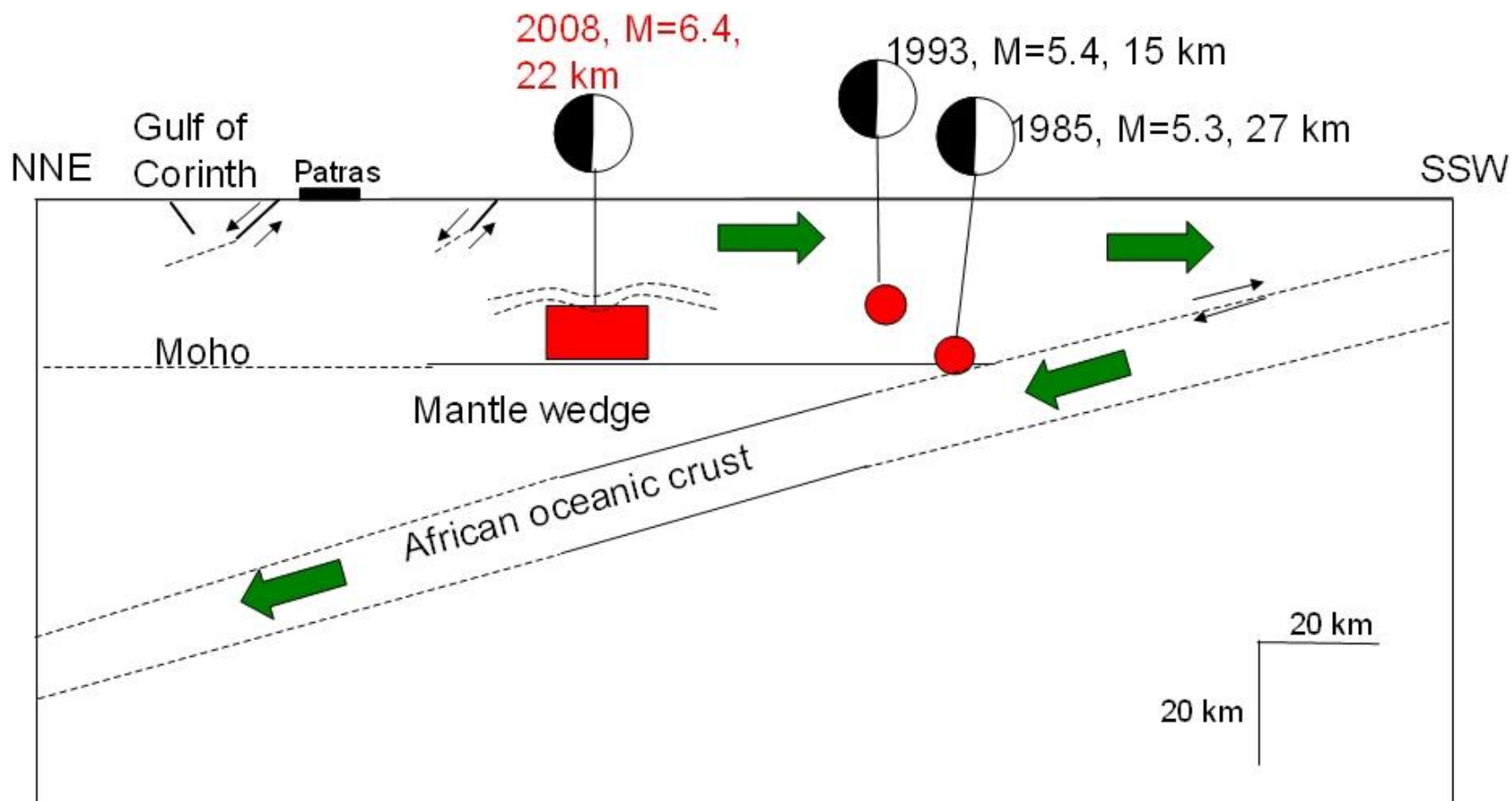




June-july 2013

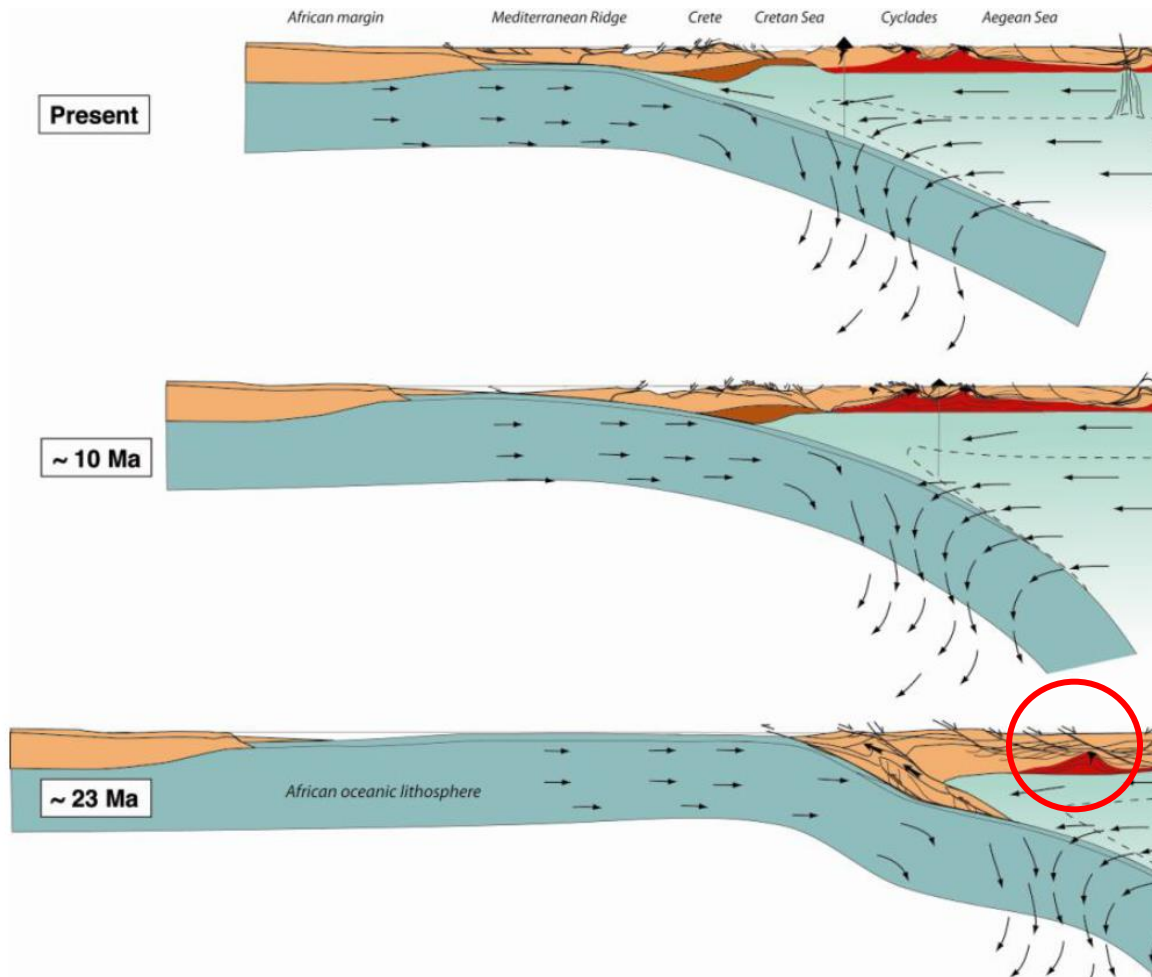






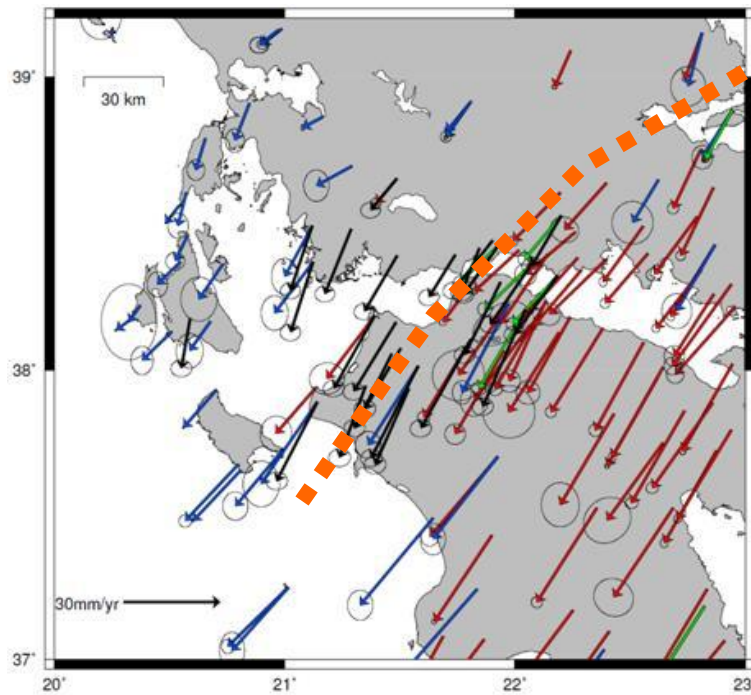
The western end of the Corinth rift:

The link to the subduction



The western end of the Corinth rift:

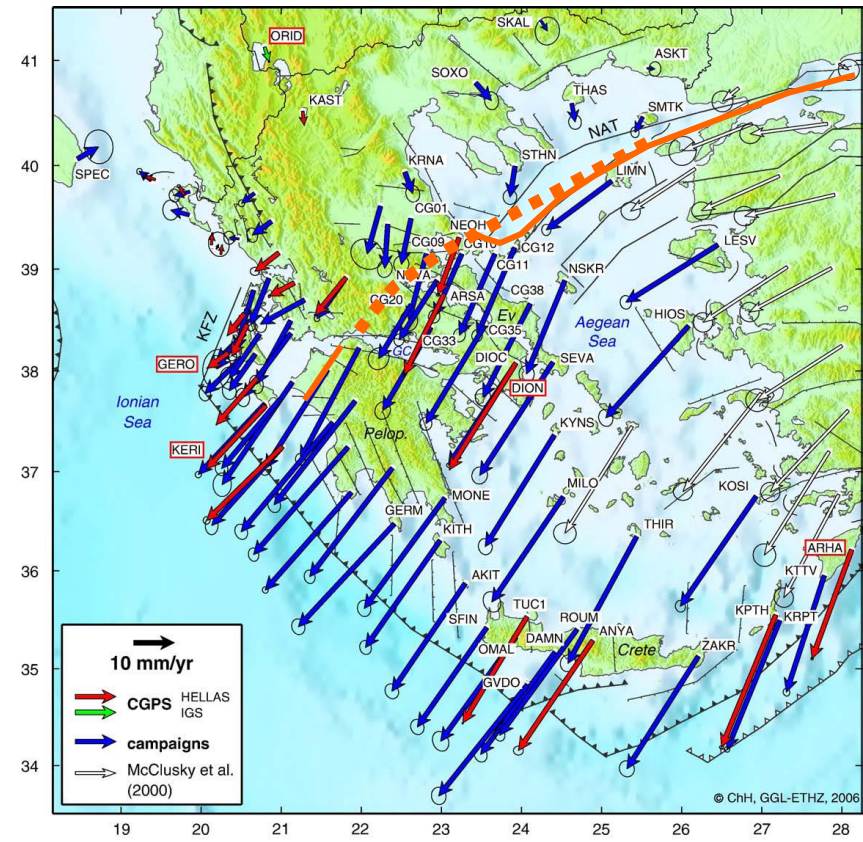
The link to the North Anatolian fault system



GPS :

Charara, 2010

Floyd et al., 2010



GPS 1993-2003

Hollenstein et al., 2008

The western end of the Corinth rift:

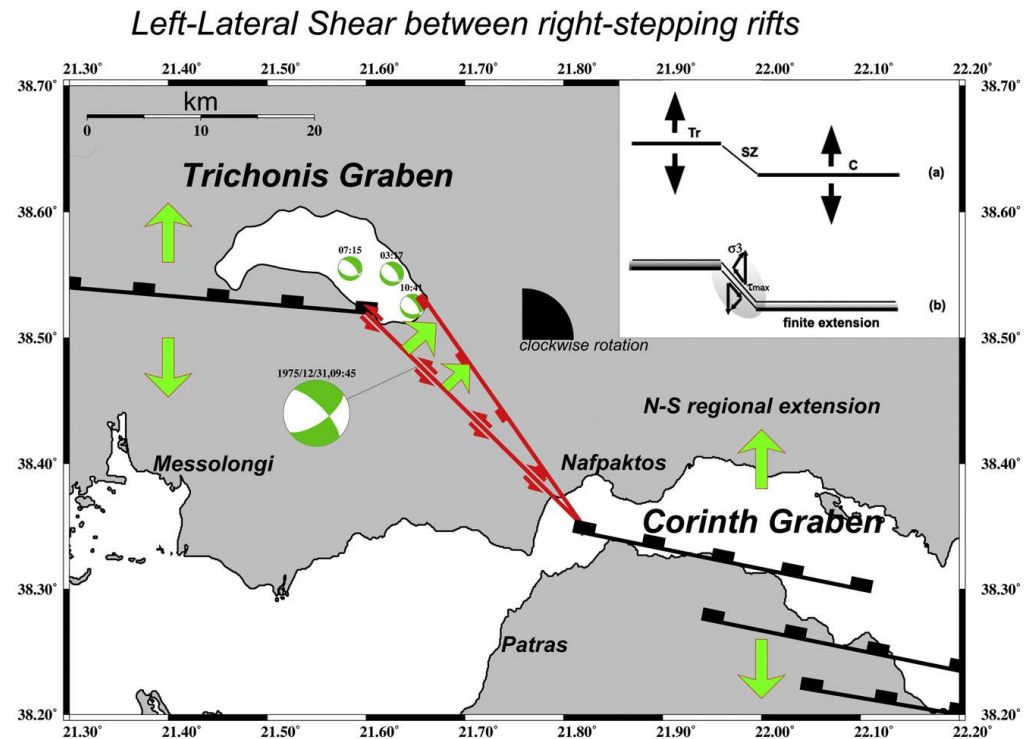
The NW connection to the Trichonis rift

Insights from the M=5, 2006 sequence

Seismicity:

1975: M=6.0

2007: swarm, M=5.0-5.2



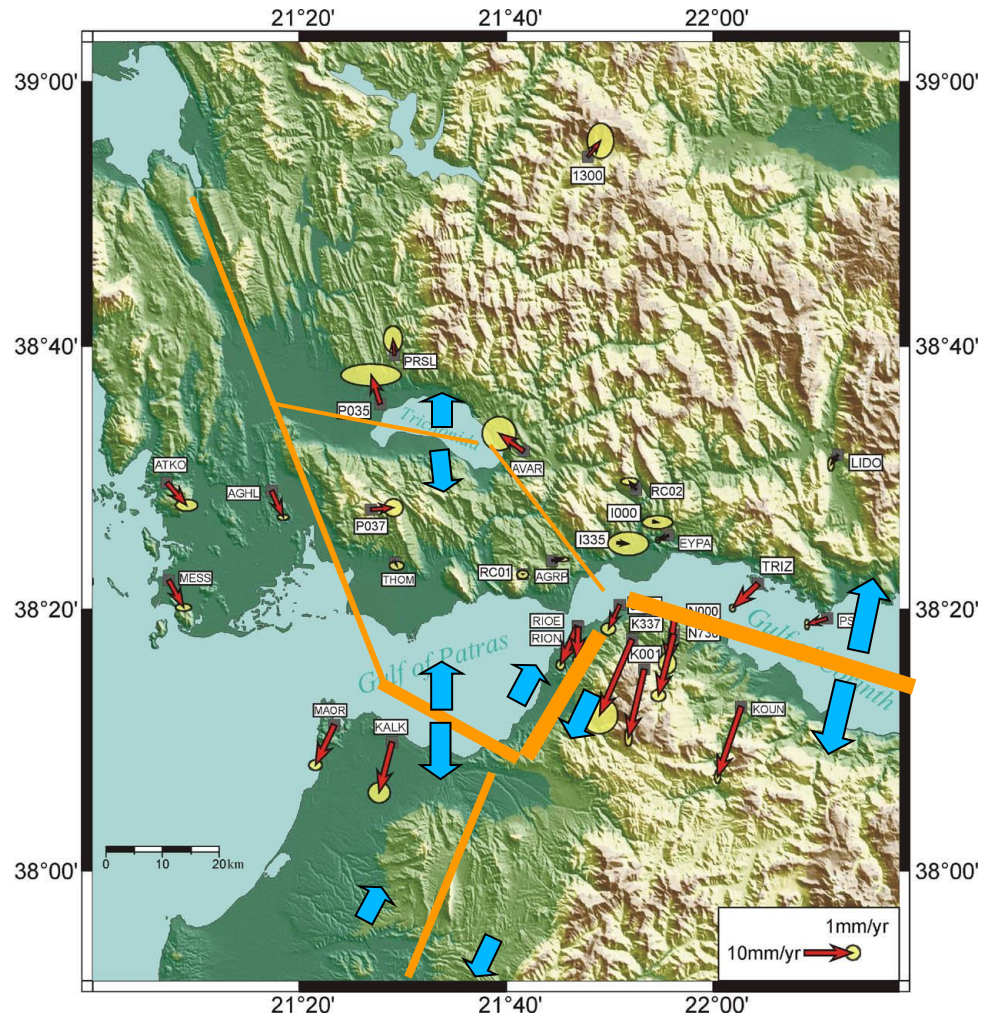
Seismicity:

Kiratzí et al., 2008

Faults:

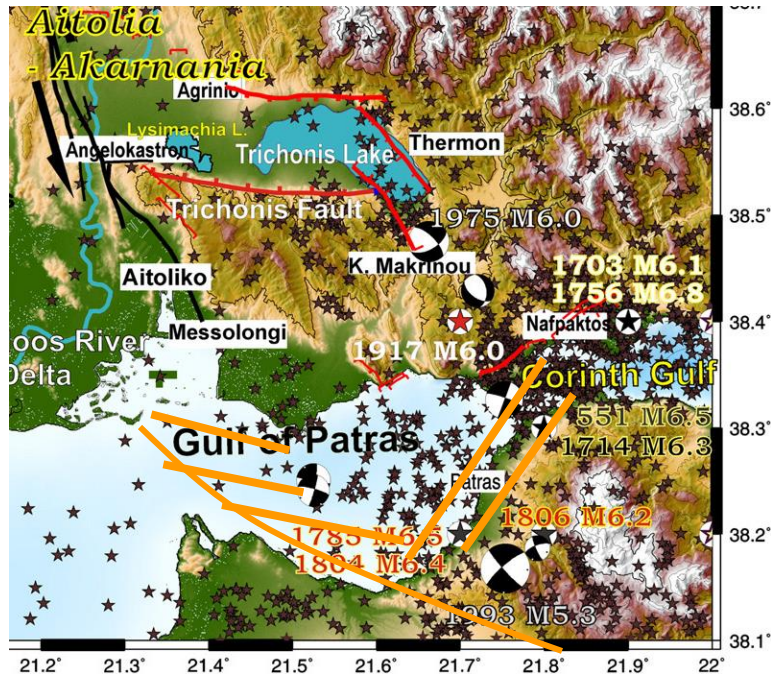
Doutsos et al., 1987; Lekkas & Papanikolaou, 1997; Goldworthy et al., 2002

The western end of the Corinth rift: clues from GPS....



The western end of the Corinth rift:

the western connection through the rift of Patras...



Kiratzi et al. 2008

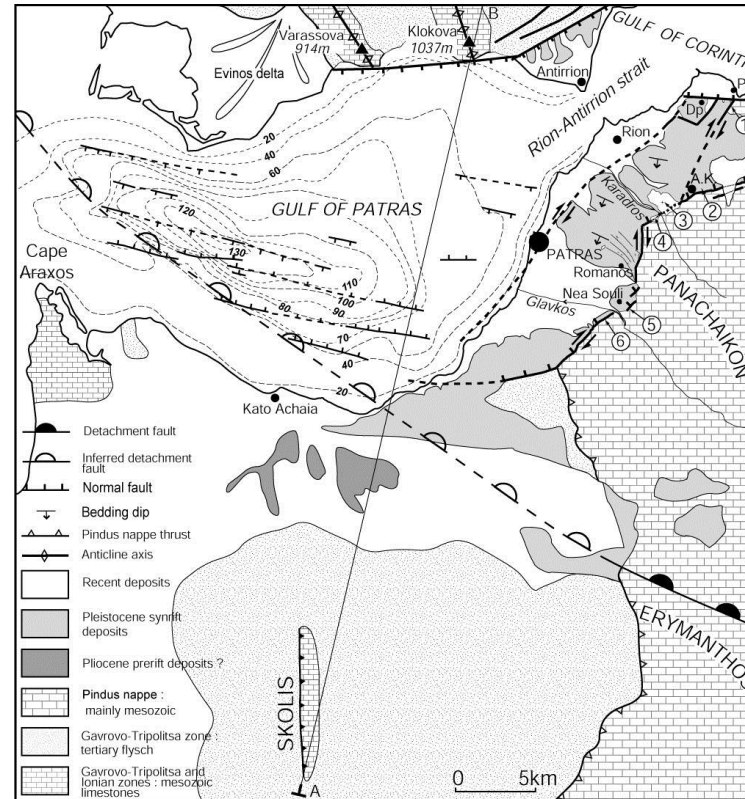
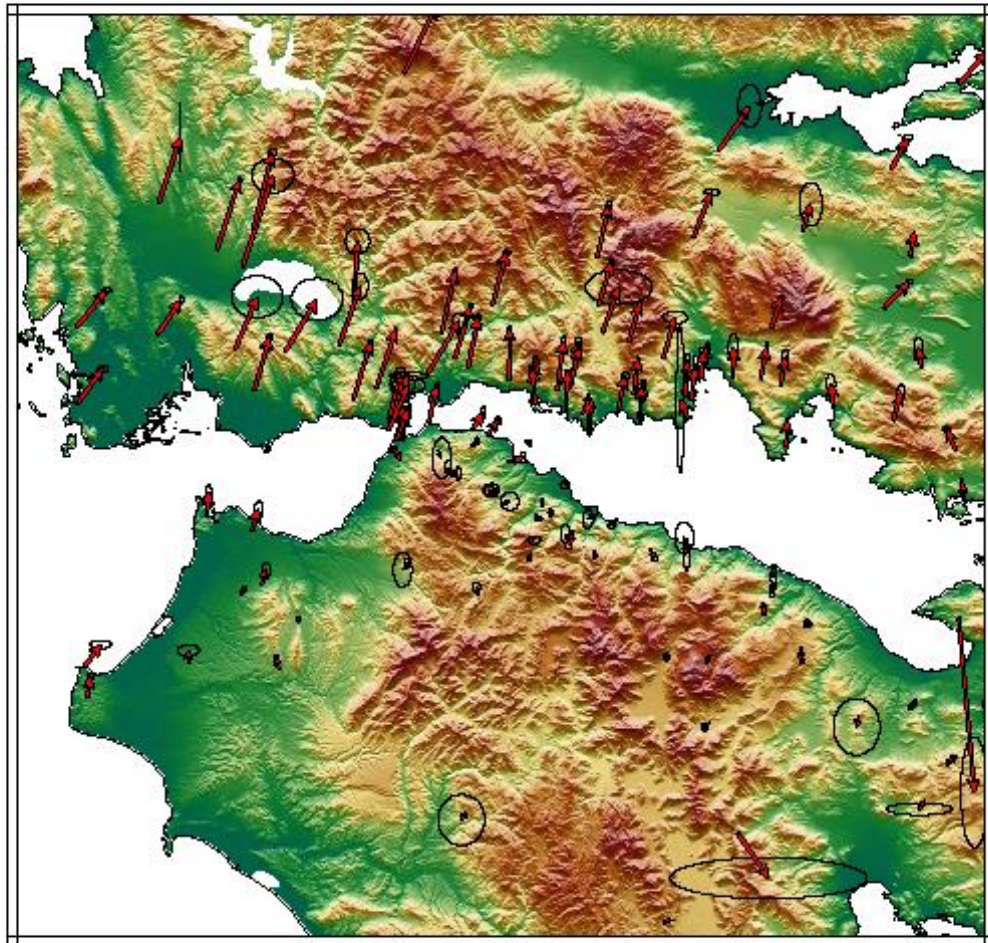
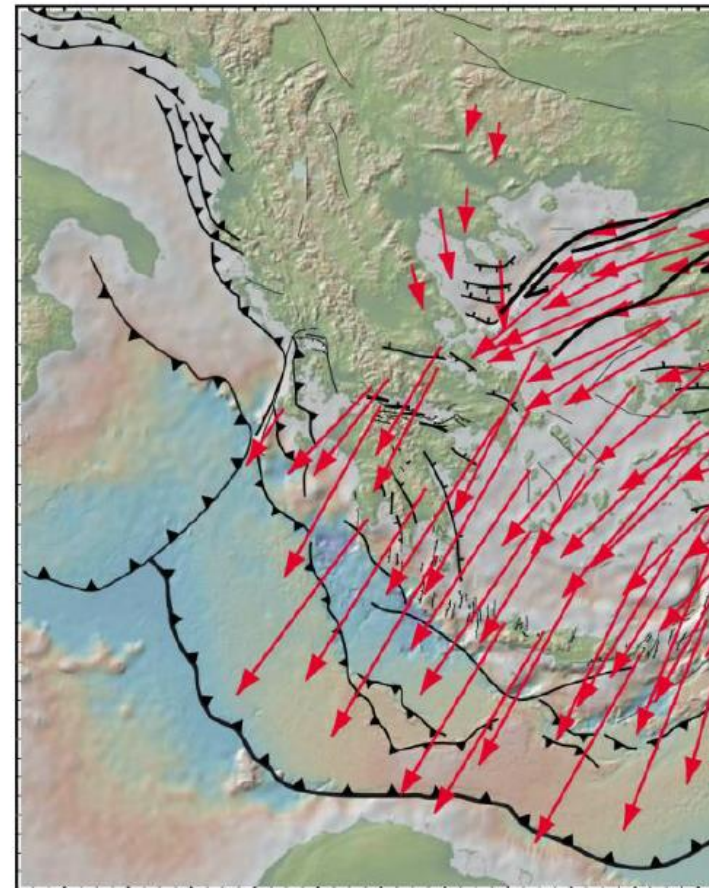


Fig.IV-10. Simplified geological map of the surroundings of the Gulf of Patras. Geology after British Petroleum (1971), Dufaure (1975), and personal data. Bathymetry after Ferentinos et al. (1985). Numbers 1 to 6 locate the areas described in the text. A-B: location of the section of Fig.III-69.

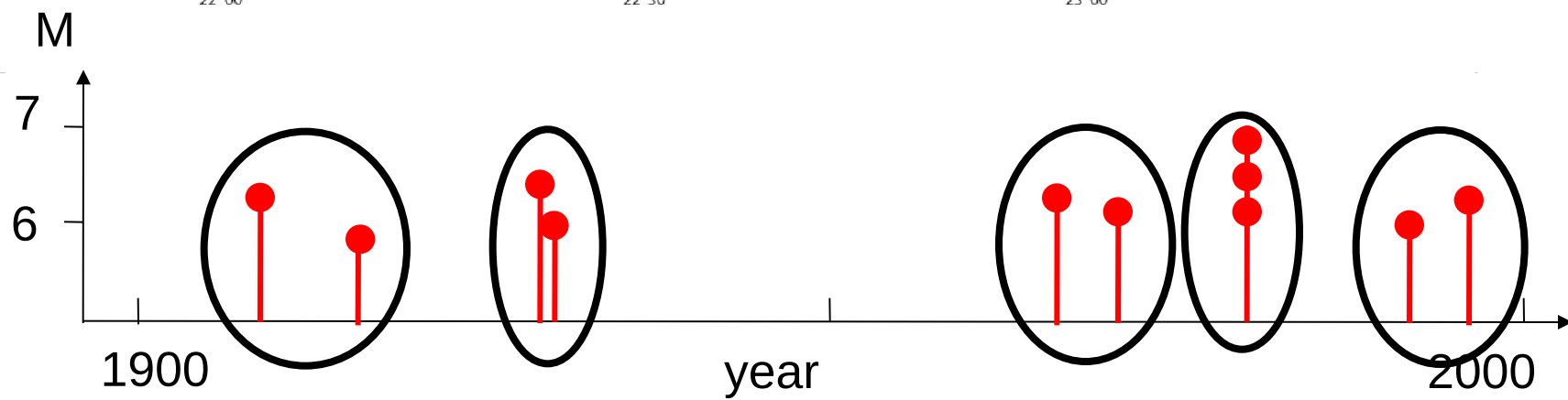
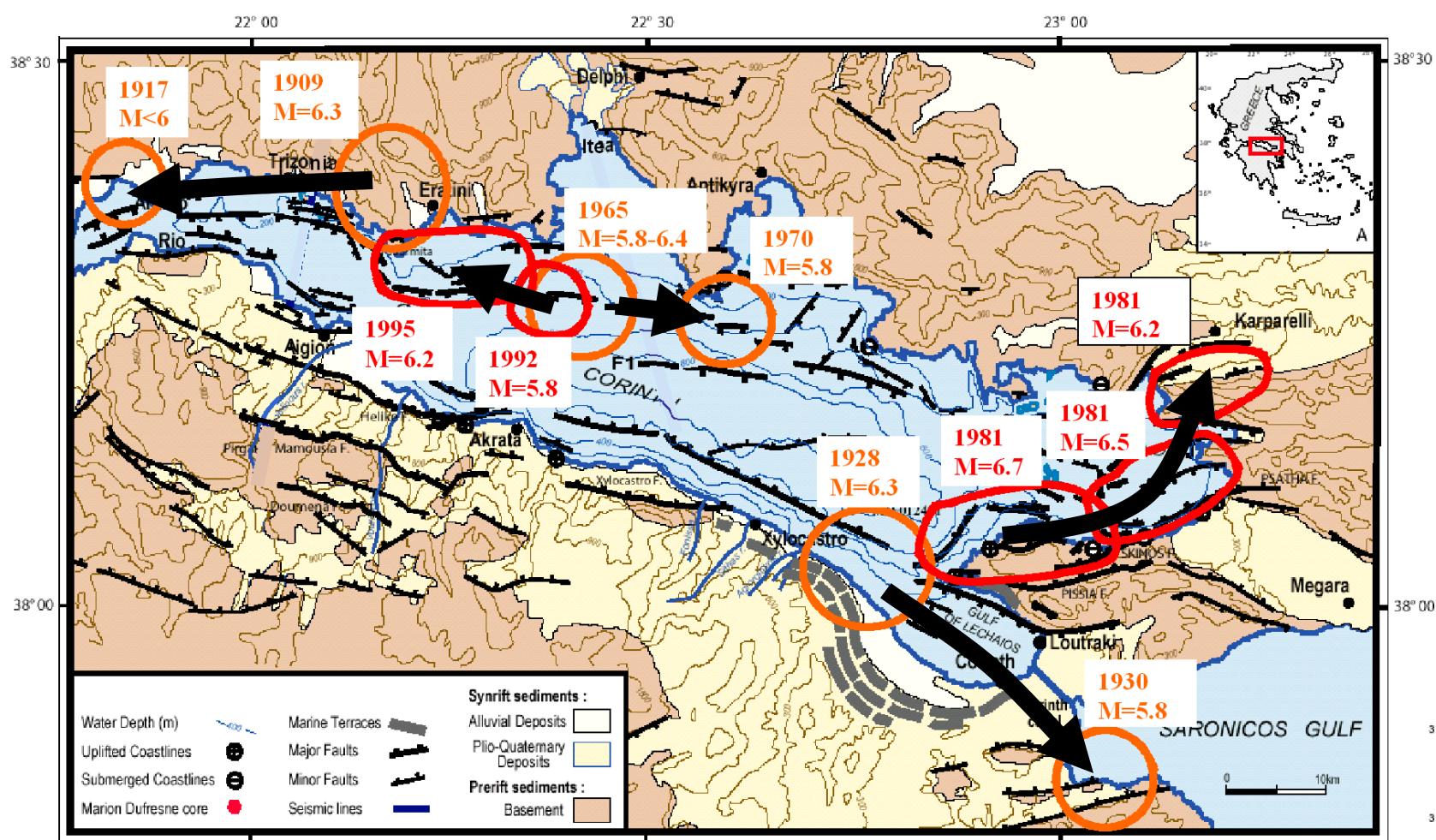
Flotté, 2005



GPS, Briole et al 2013



GPS d'après Reilinger
et al. (2010).



Quelles sont les zones bloquées:

Analyse temporelle

-GPS - sismicité: fluctuations différentes

- strainmeter:

les courtes crises n'ont pas de déformation marquée

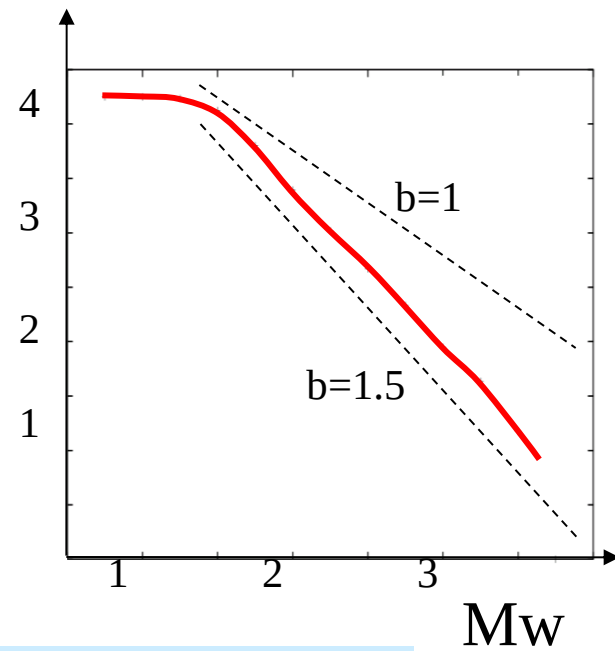
Donc l'activation sismique ne se produit pas sur la zone source de l'ouverture du rift.

Analyse spatiale:

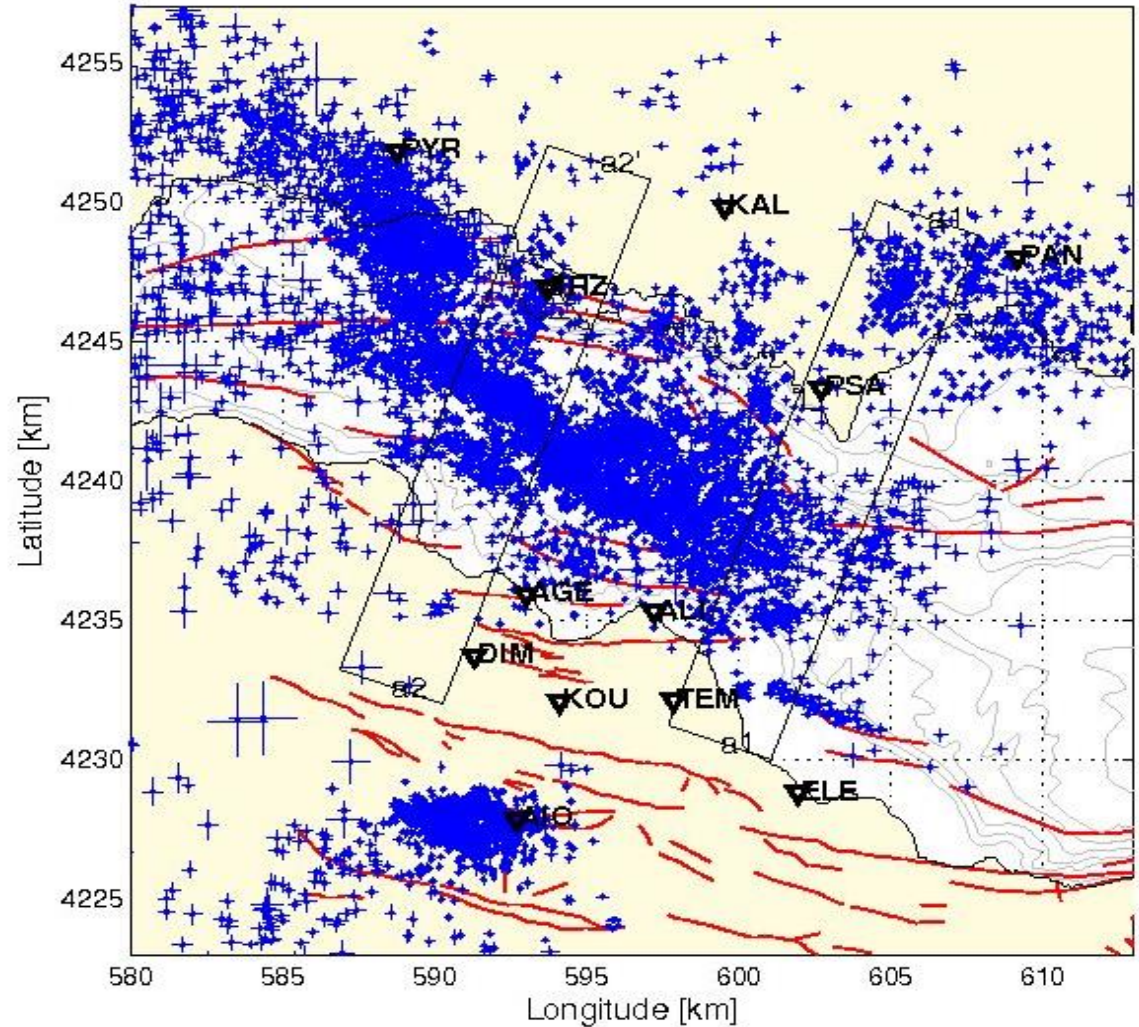
Les zones bloquées des asperités sismiques de 2010 et 1995 ne semblent pas le GPS

Seismicity 2000-2007

$\log(N)$



Pacchiani , 2006



Lambotte, 2008

Space clustering

Fault segments

1 km – 10 km

Time Clustering :

Pulsations

year-month-day

3 large crisis:

2001

2004

2007

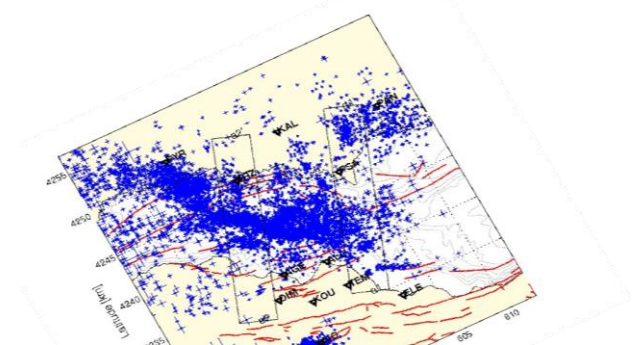
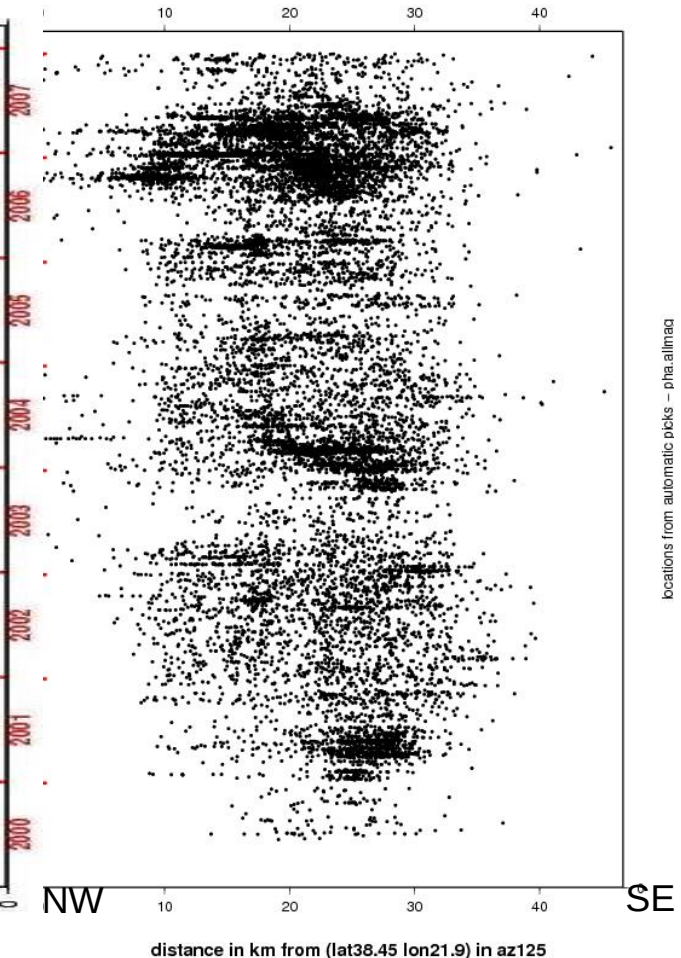
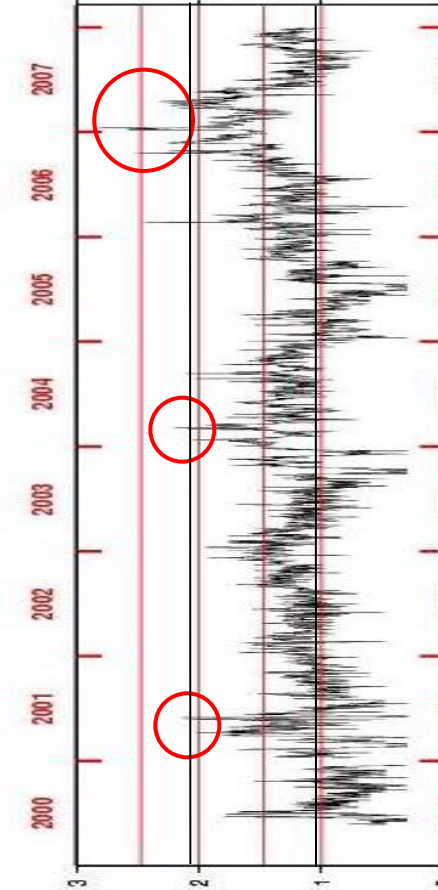
Time
(year)

seismicity rate
/day

2008

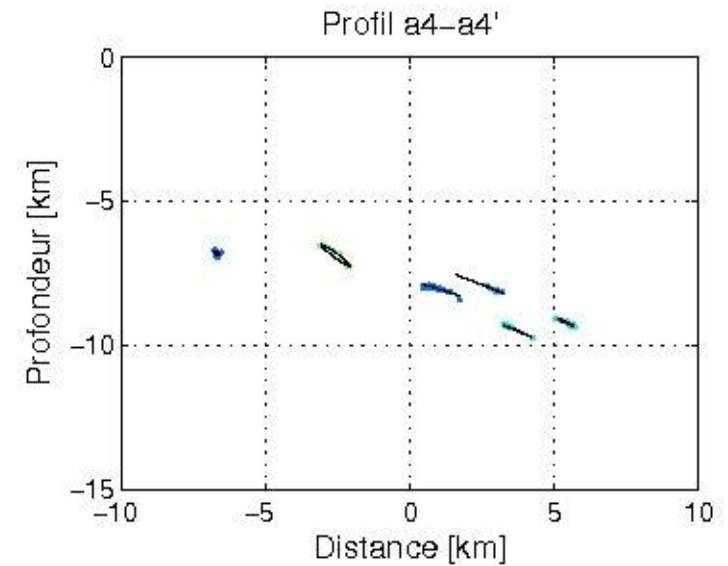
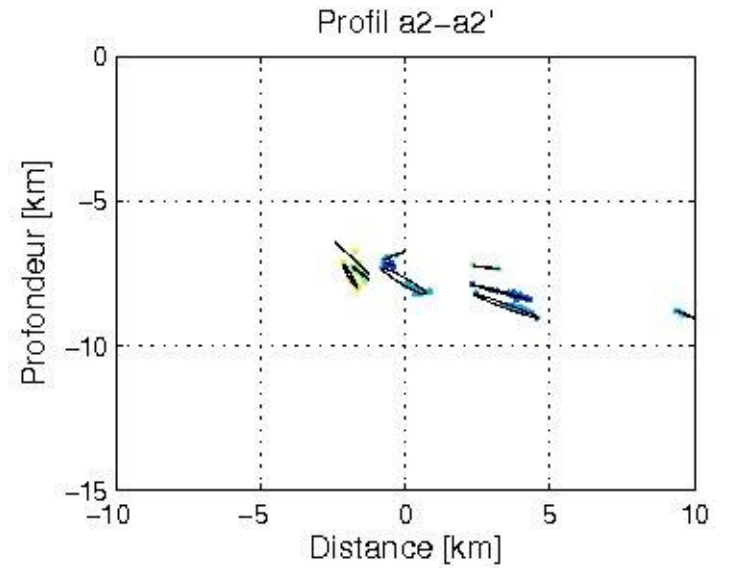
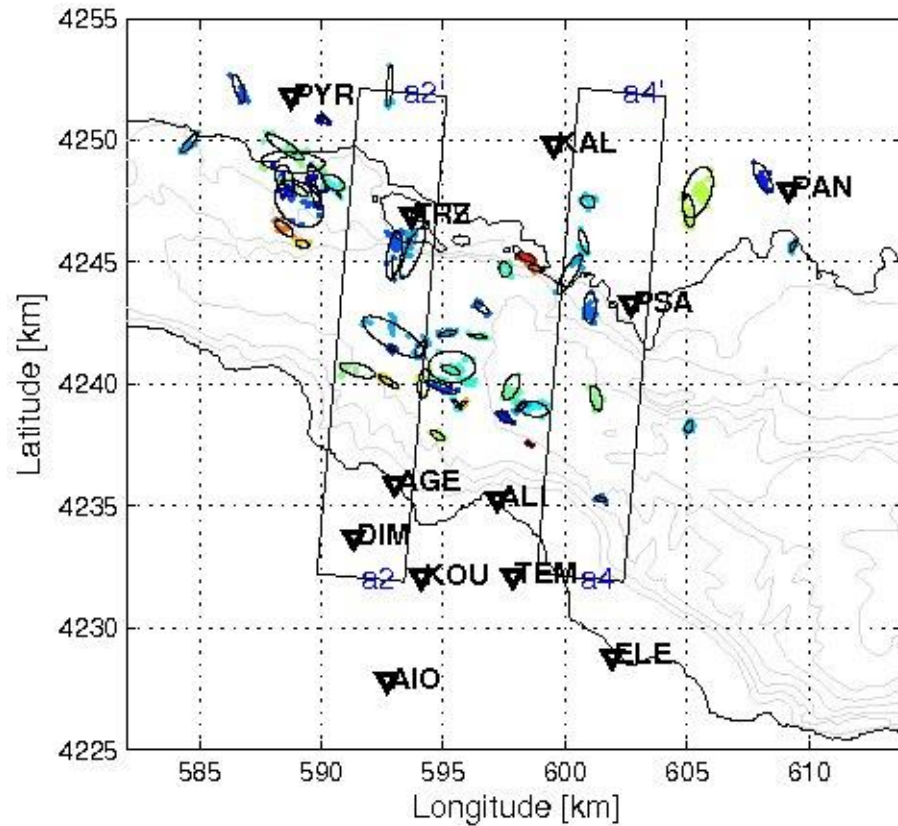
2000

1000 100 10



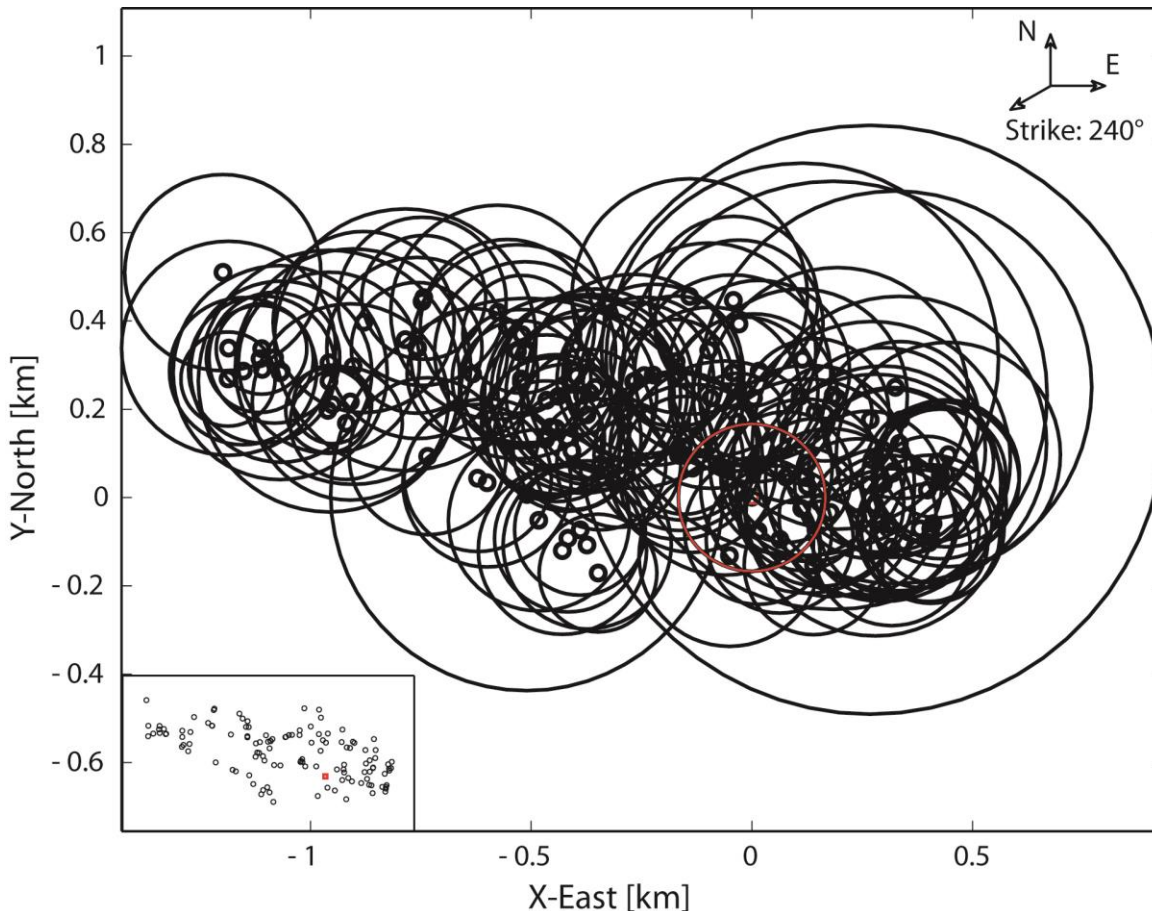
Multiplier fine structure:

Kilometric, north dipping fault segments



Lambotte et al 2009

spatial distribution of events in one multiplet



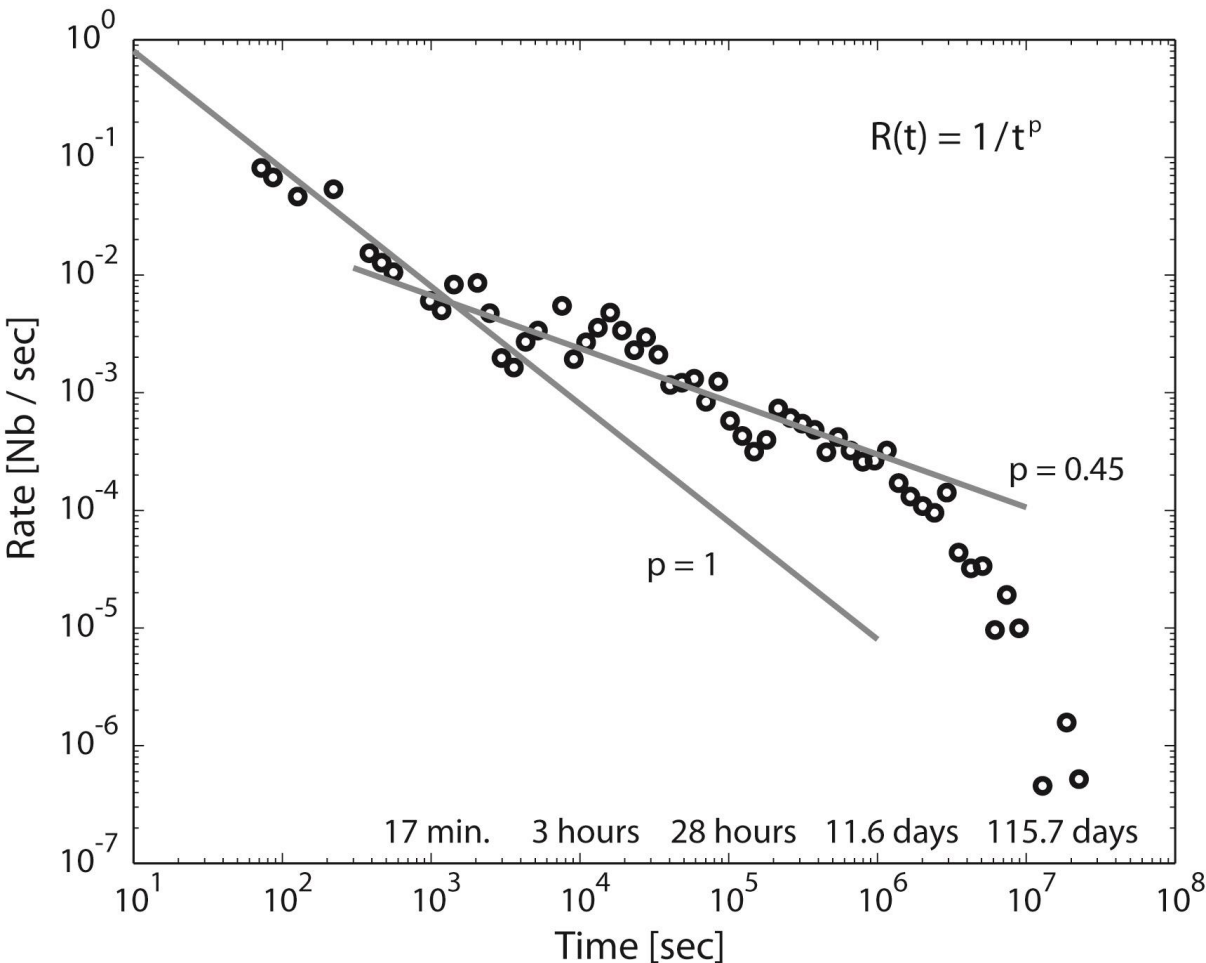
Multiple rupture of the same asperities

- Multiplet seismicity is forced/controlled by creep

- Creeping area must be larger than the seismic area

- Creep may be triggered/assisted by pore pressure

Decay rate stacked for all multiplets



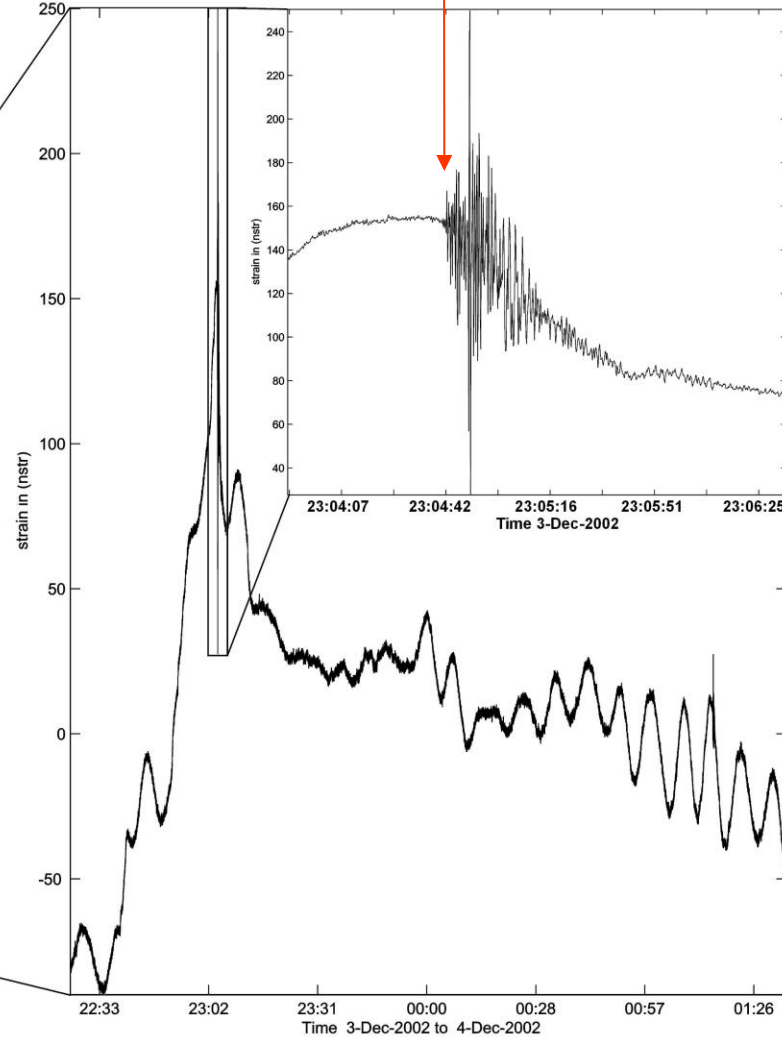
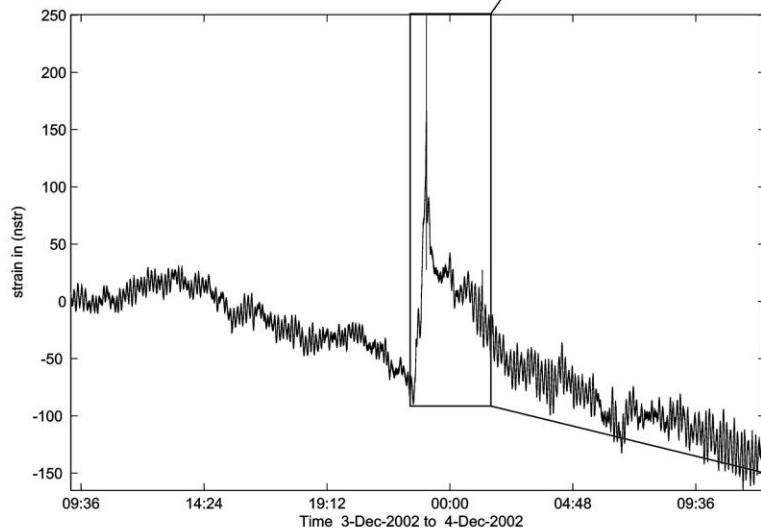
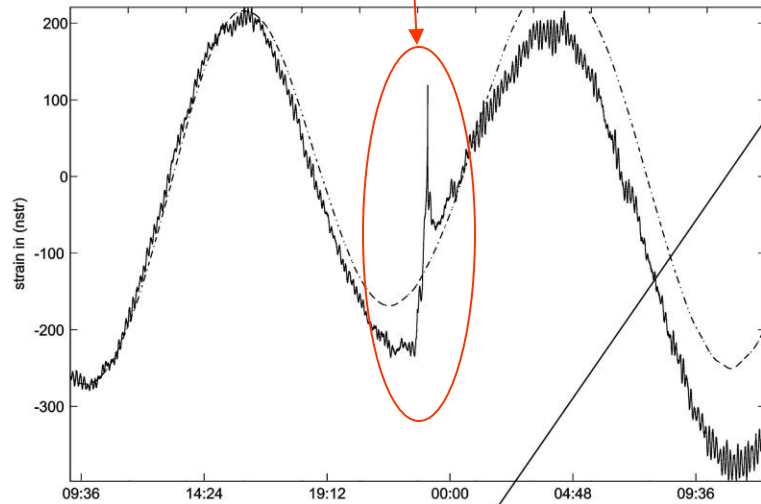
No standard Omori law:

persistent process
after 100 – 1000 s

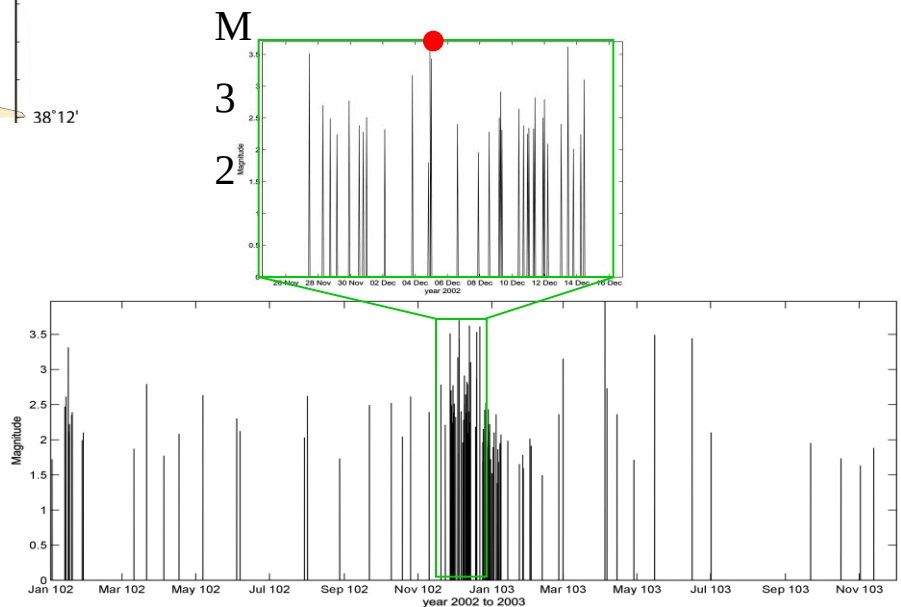
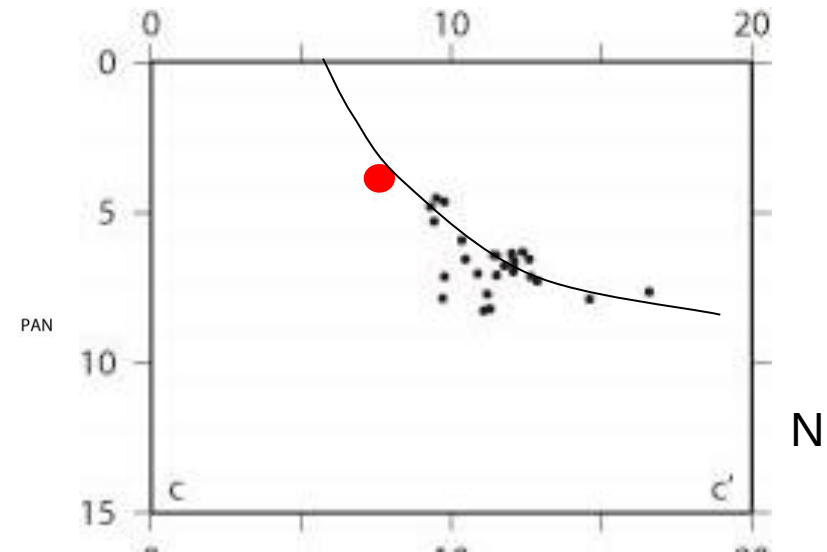
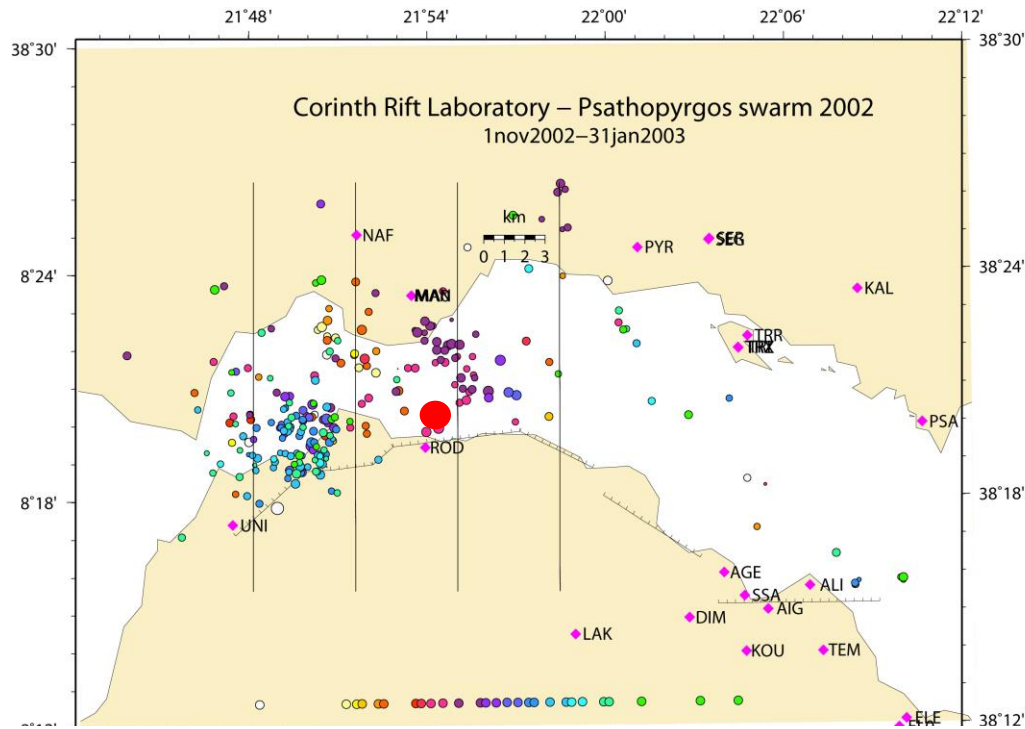
- Multiplet seismicity forced by creep
- Creep triggered by fluid flow

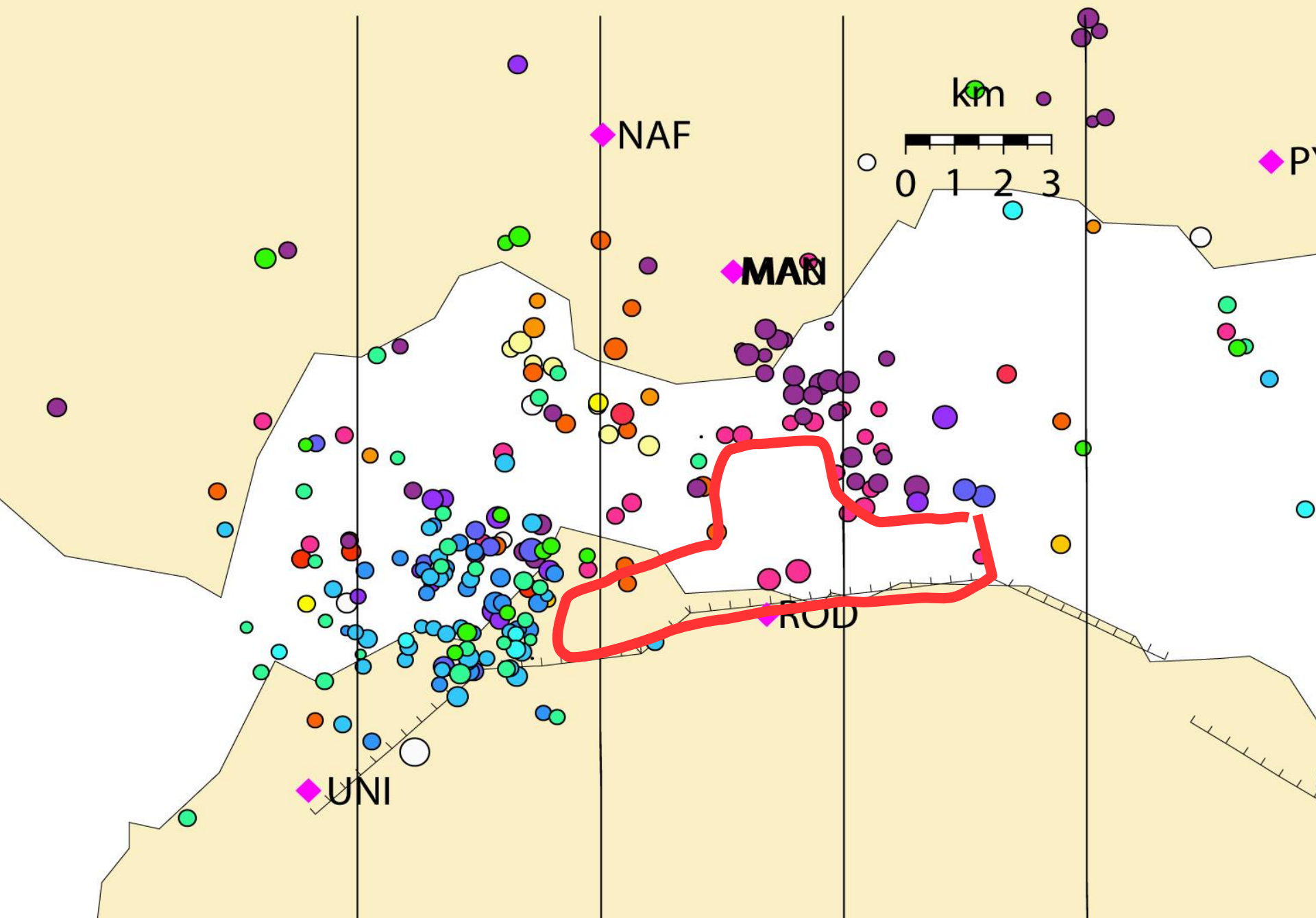
Transient strain

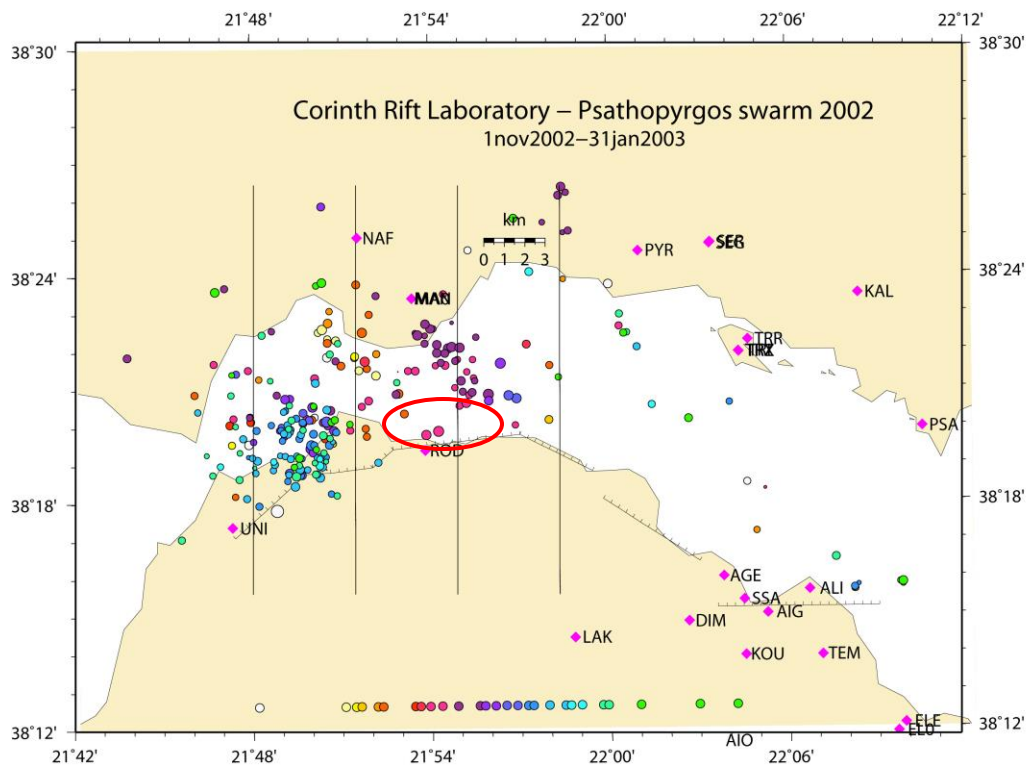
3 dec 2002 23:04 –
M=3.5



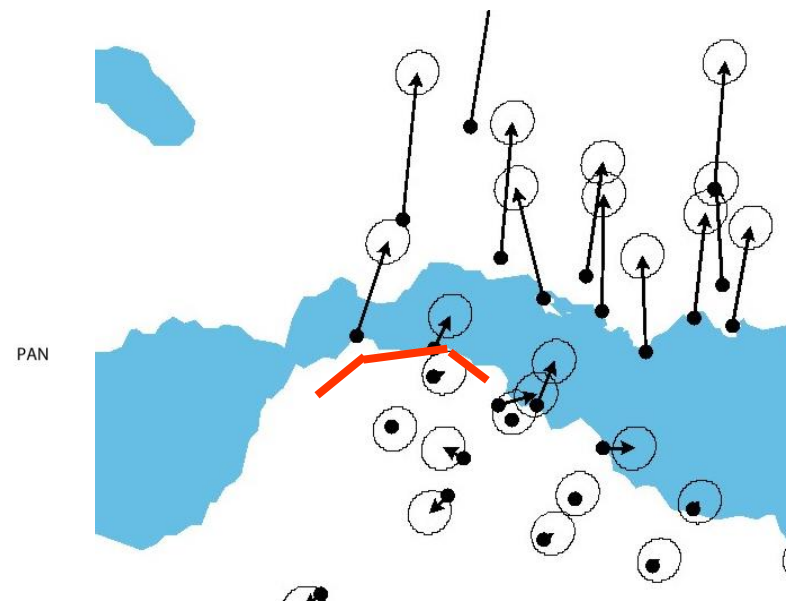
Psathopyrgos fault seismic swarm - Nov-dec 2002







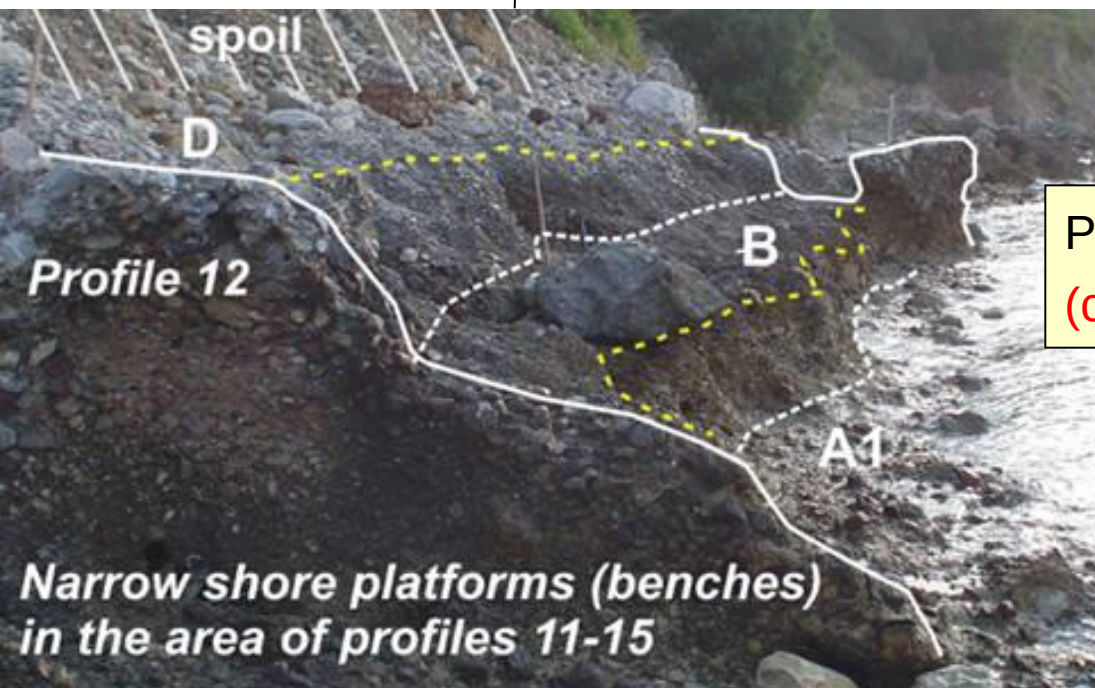
Nov 02 – jan 03:
Creep from seismic swarm
and strain transient



Avalone et al. 2004

1990-2001:
Creep from GPS
1.5 cm/yr

Psathopyrgos fault



Paleoshoreline: 5 rapid uplift episodes
(coseismic?) in 2000 years

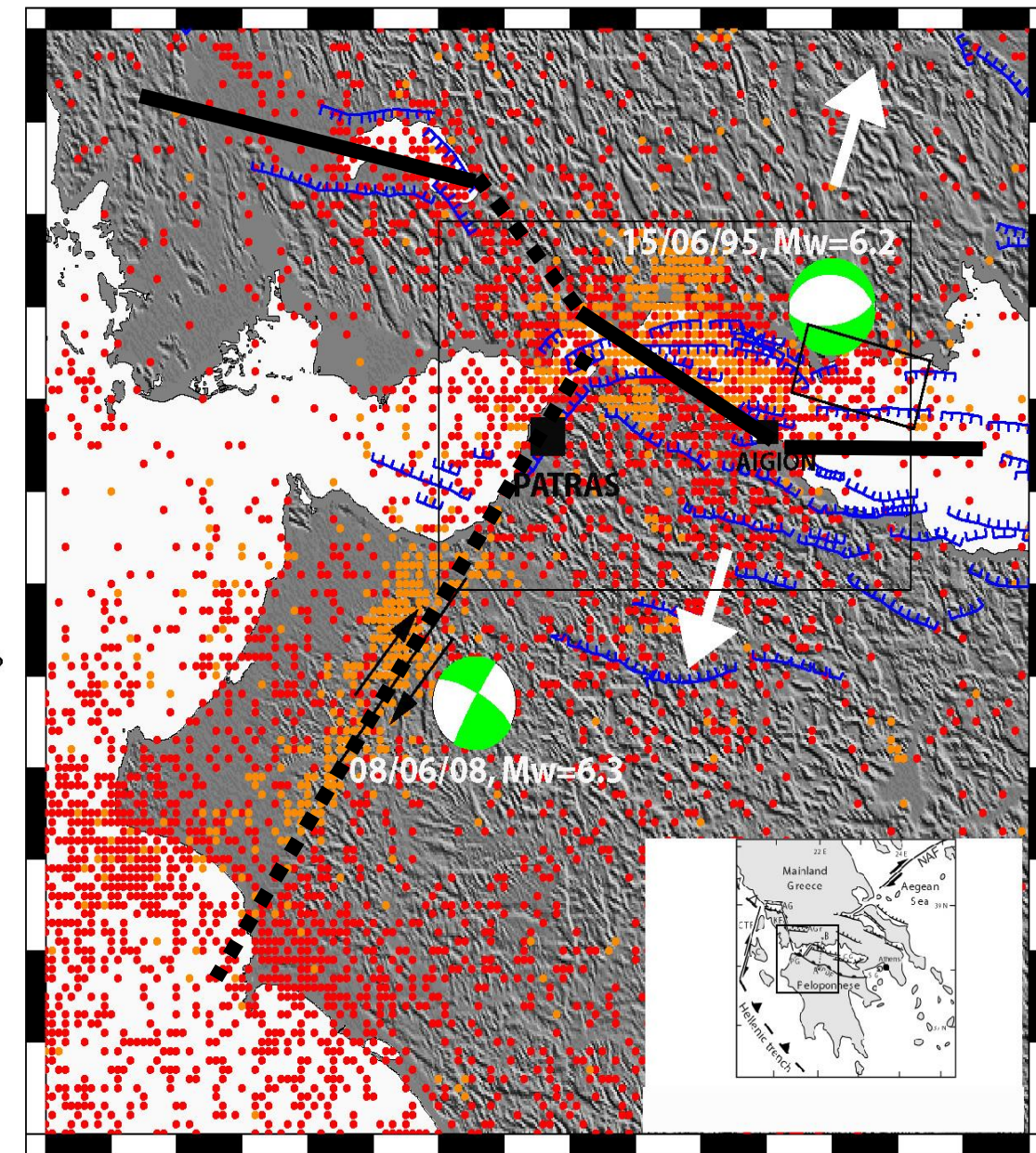
Pantosti et al. 2007

21°

22°

38°

38°



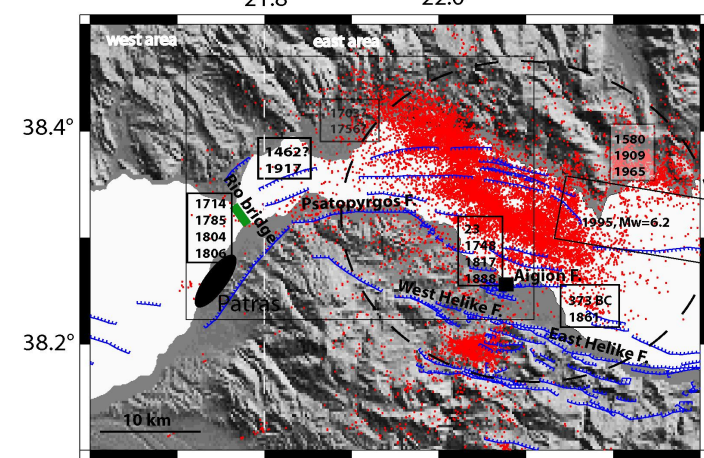
21°

22°

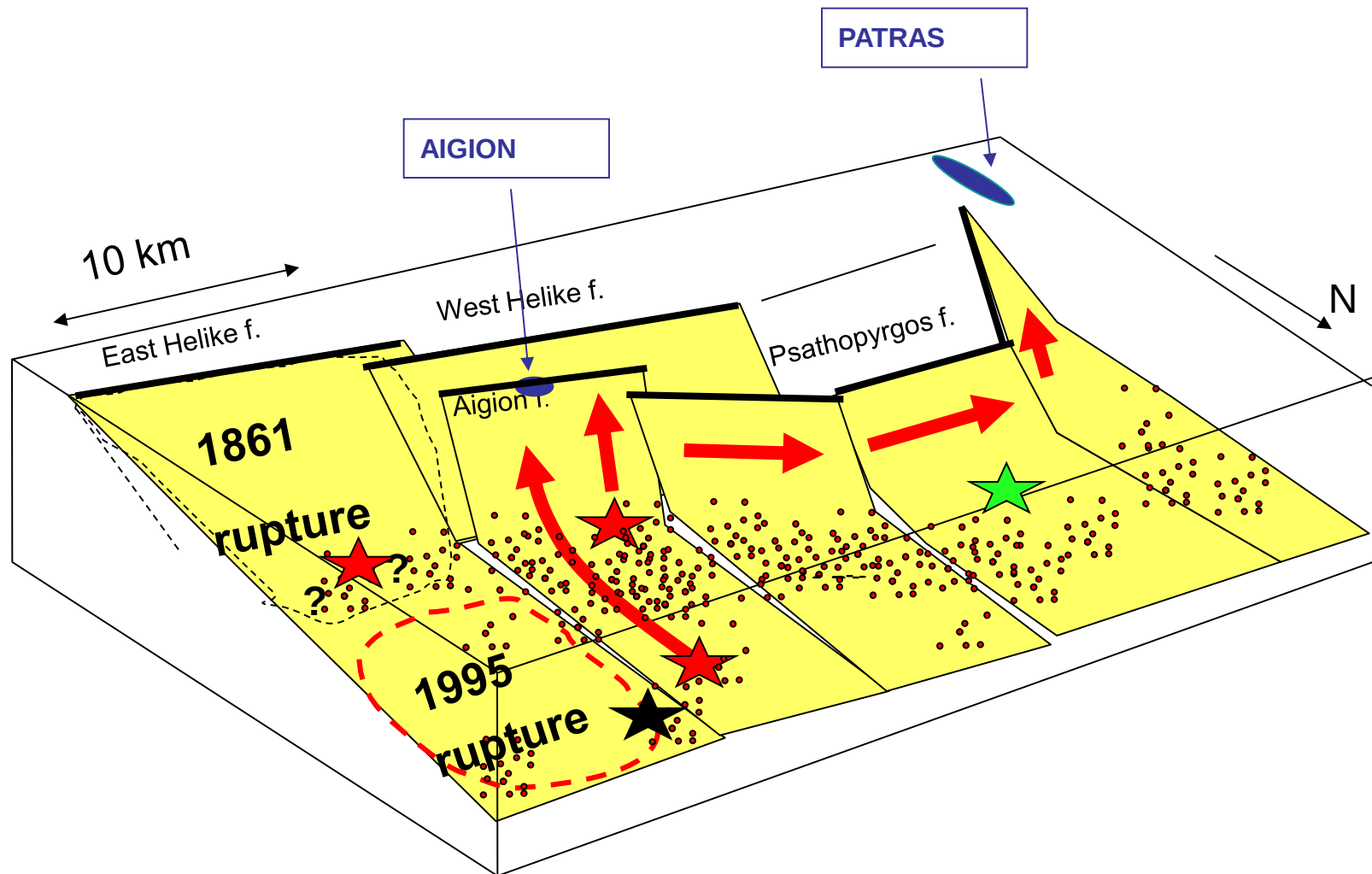
CONCLUSION: normal fault activity

at various space and time scales

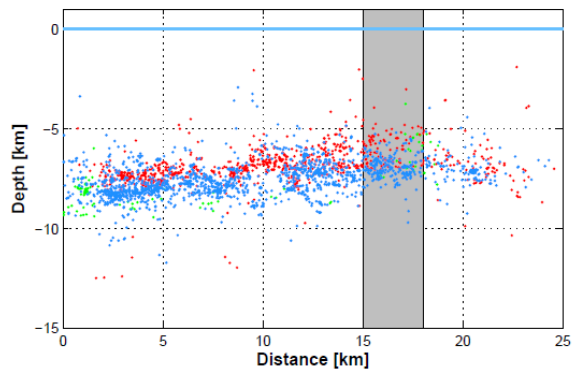
- new fault system, oriented NW-SE, consistent with microseismicity: **what is its cause? when did it start?**
- large earthquakes: cycle 150-300 years; end of seismic cycle for several faults - **what probability for large rupture? Possibility of cascade events?**
- Steady fast creep or shear in 1-2 km thick layer, on small non coplanar faults at depth, loading the locked segments - **but does it relaxes strain on the deep segments?**
- microseismicity: migrating swarms (days, months) related to major creep events on faults, and strong east-west contrast: **is it related to fluid pulses, and why?**
- major transient creep (hour to weeks) on the Psathopyrgos fault: **phase of cyclic relaxation, or start of major failure?**



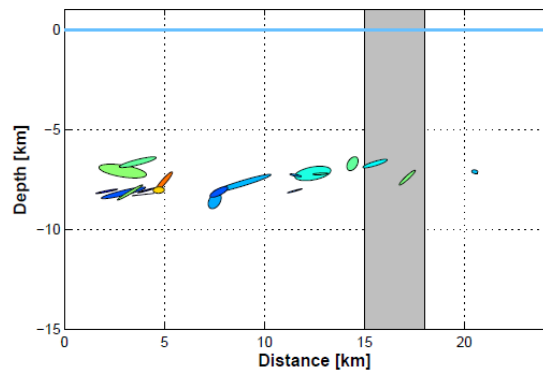
EXPECTED EARTHQUAKES 0 - 30 YEARS ?



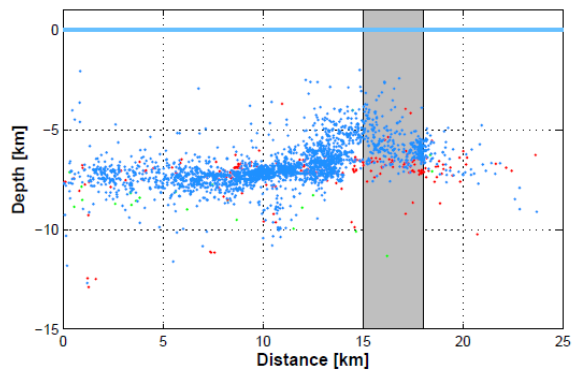
Profil b1-b1'



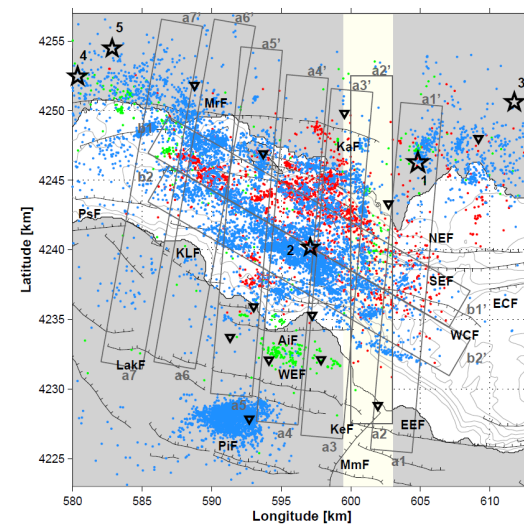
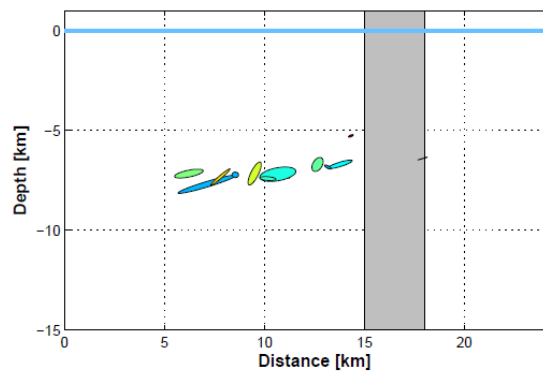
Profil b1-b1'

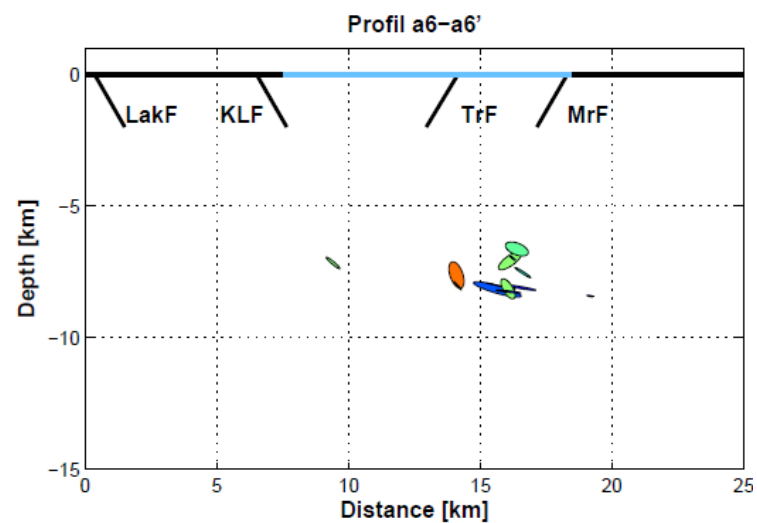
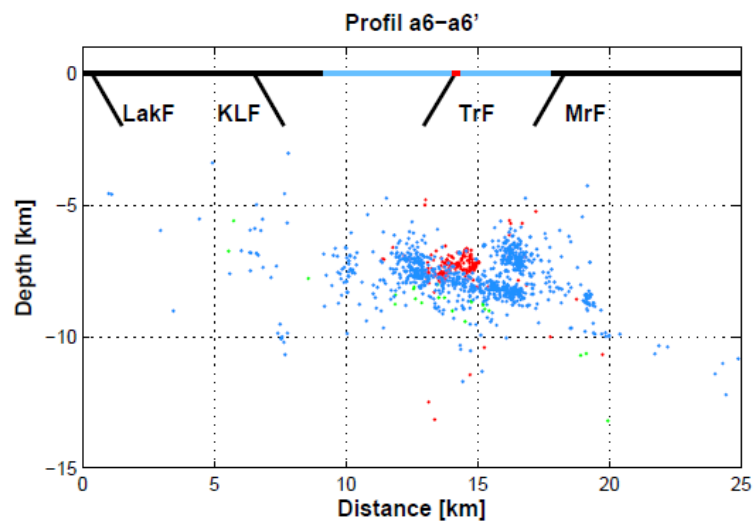
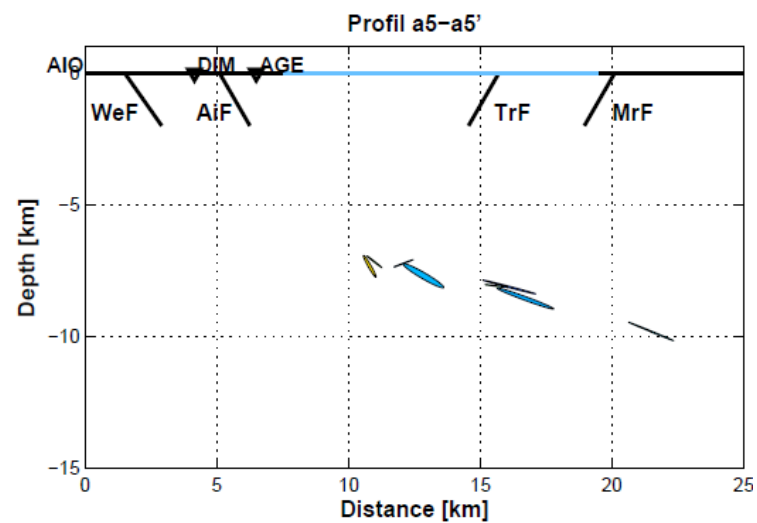
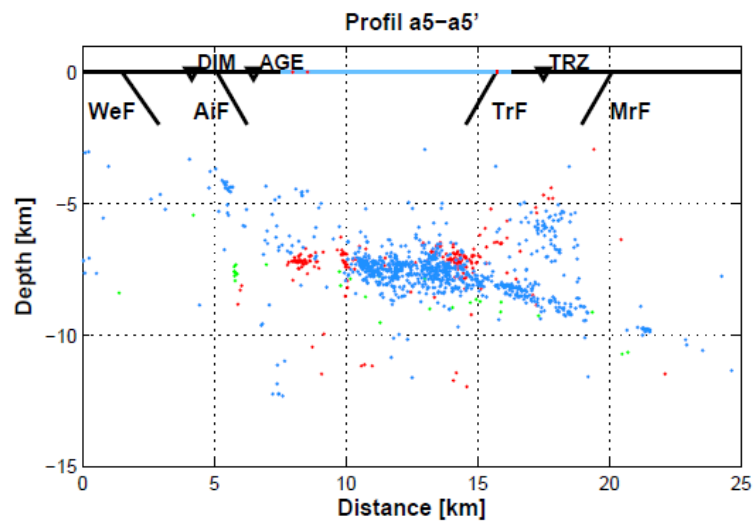


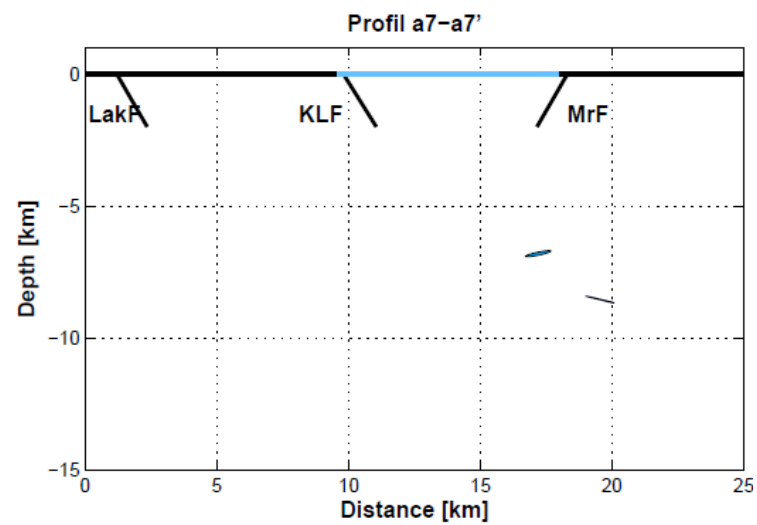
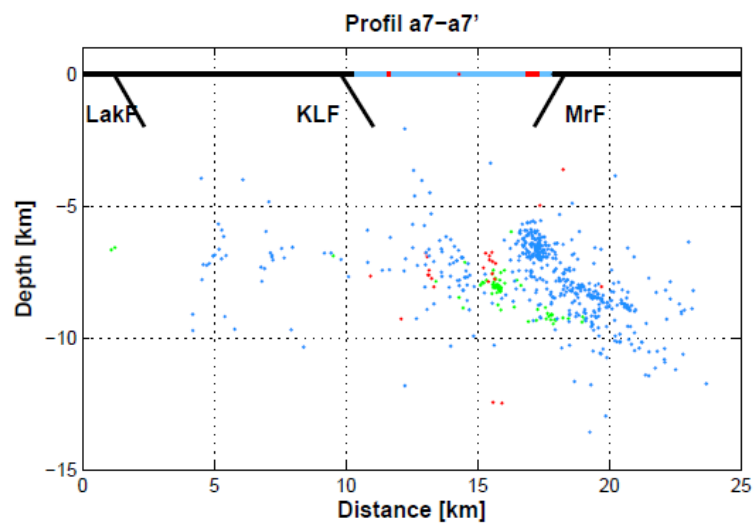
Profil b2-b2'

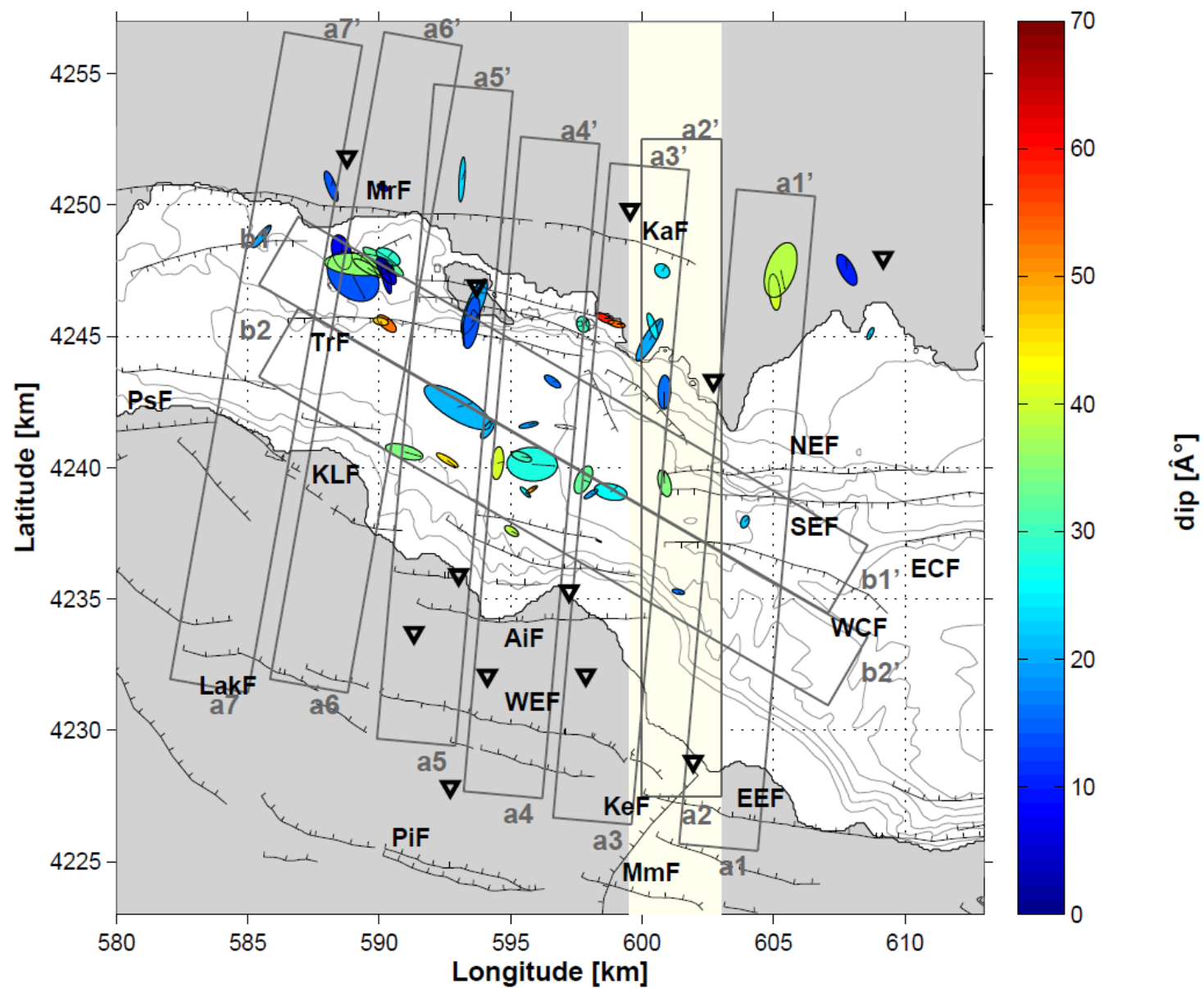


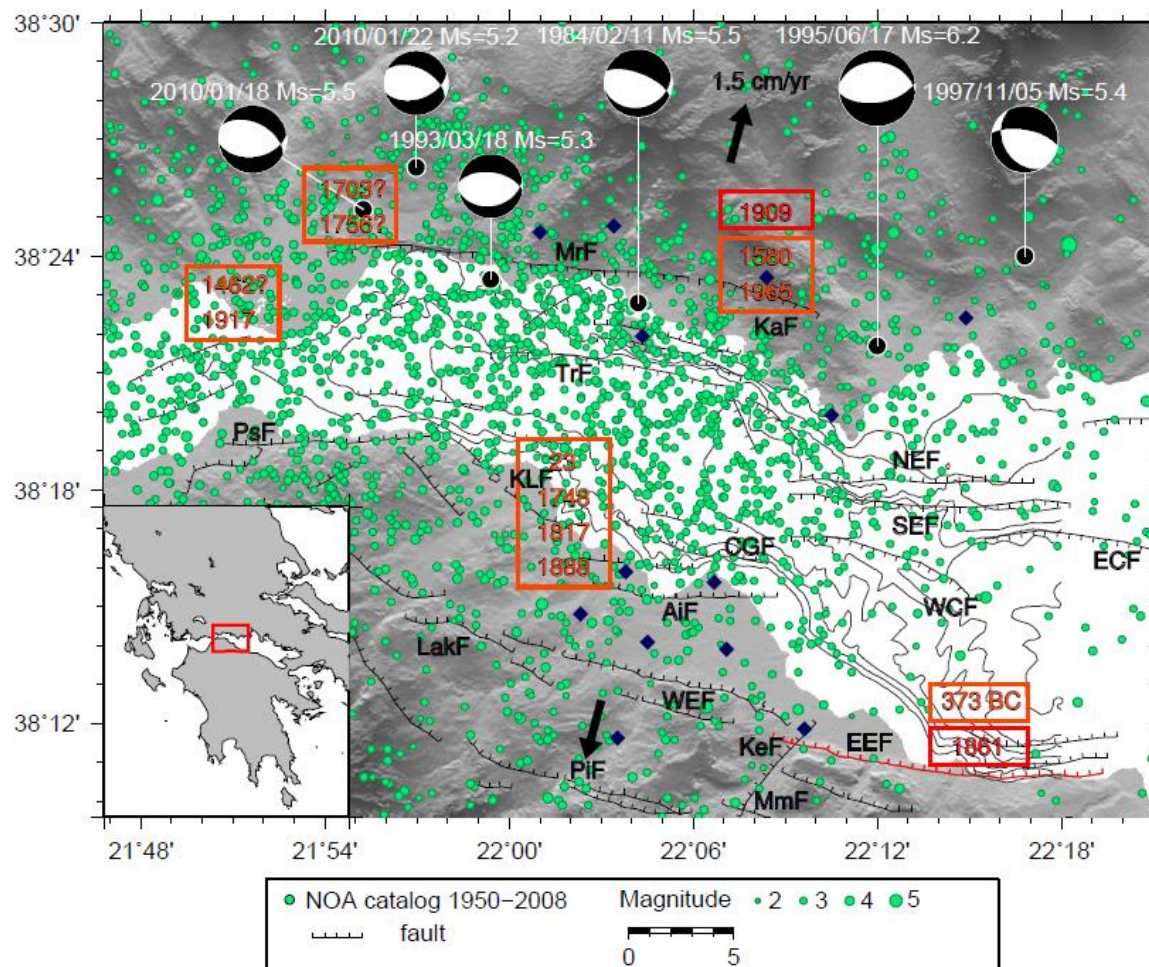
Profil b2-b2'





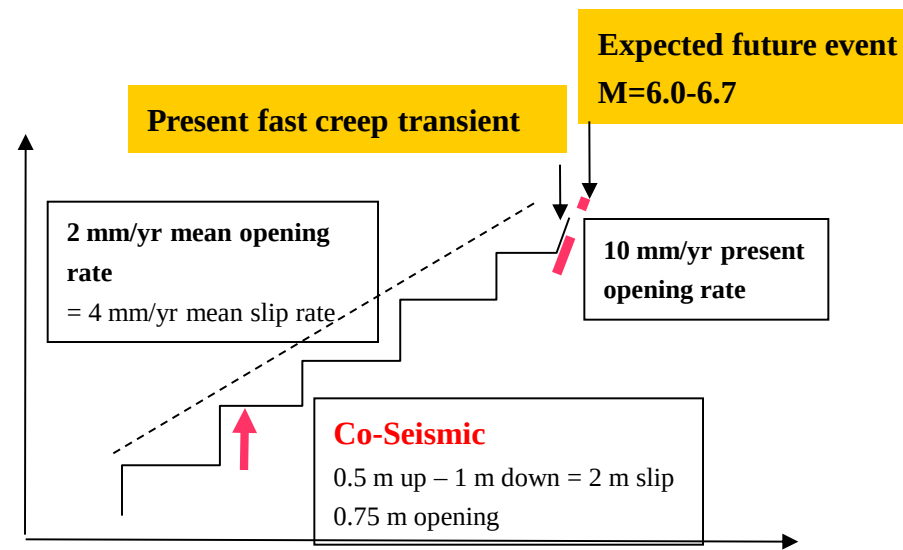






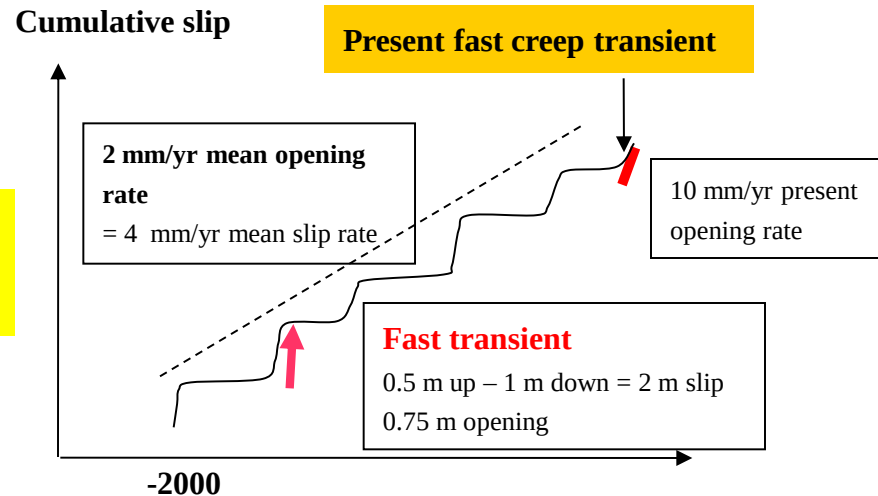
Dual model:

Alternating creep and seismic;
velocity weakening and
strengthening



Pure creep model:

velocity strengthening



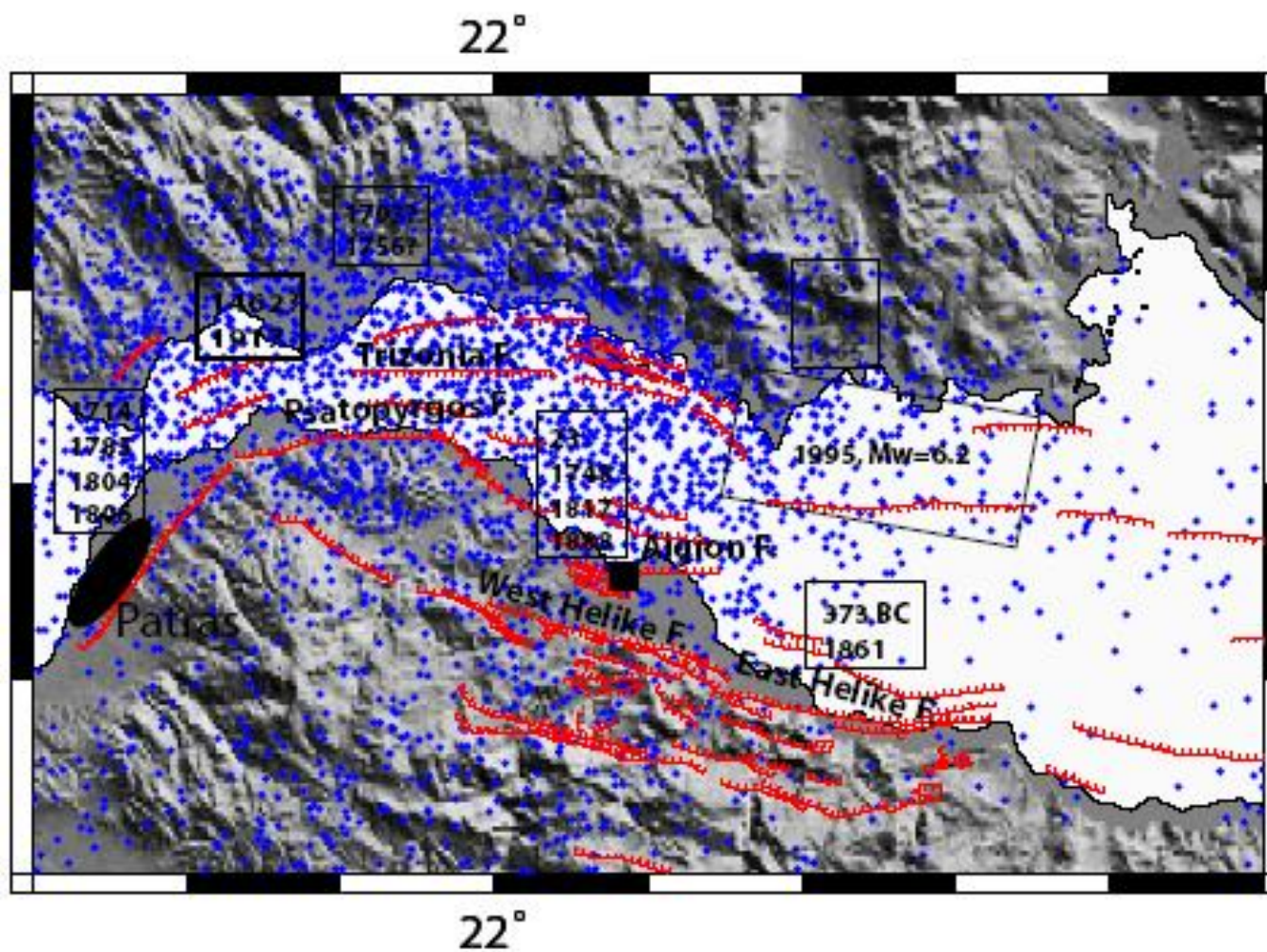
**Creep transients on the Psathopyrgos fault at various time scales:
hours (strain), days-weeks (seismicity), decades (GPS), centuries (paleo-shorelines)**



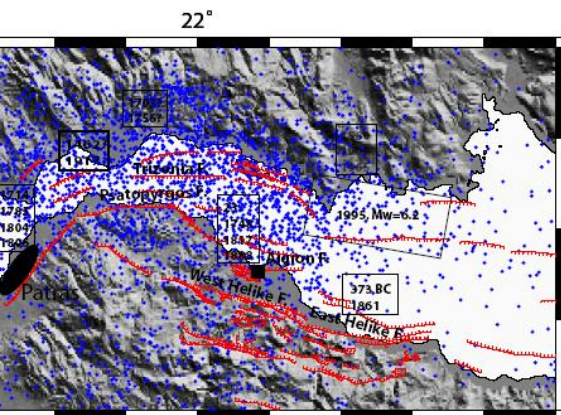
N

HELIKE FAULT





CRL

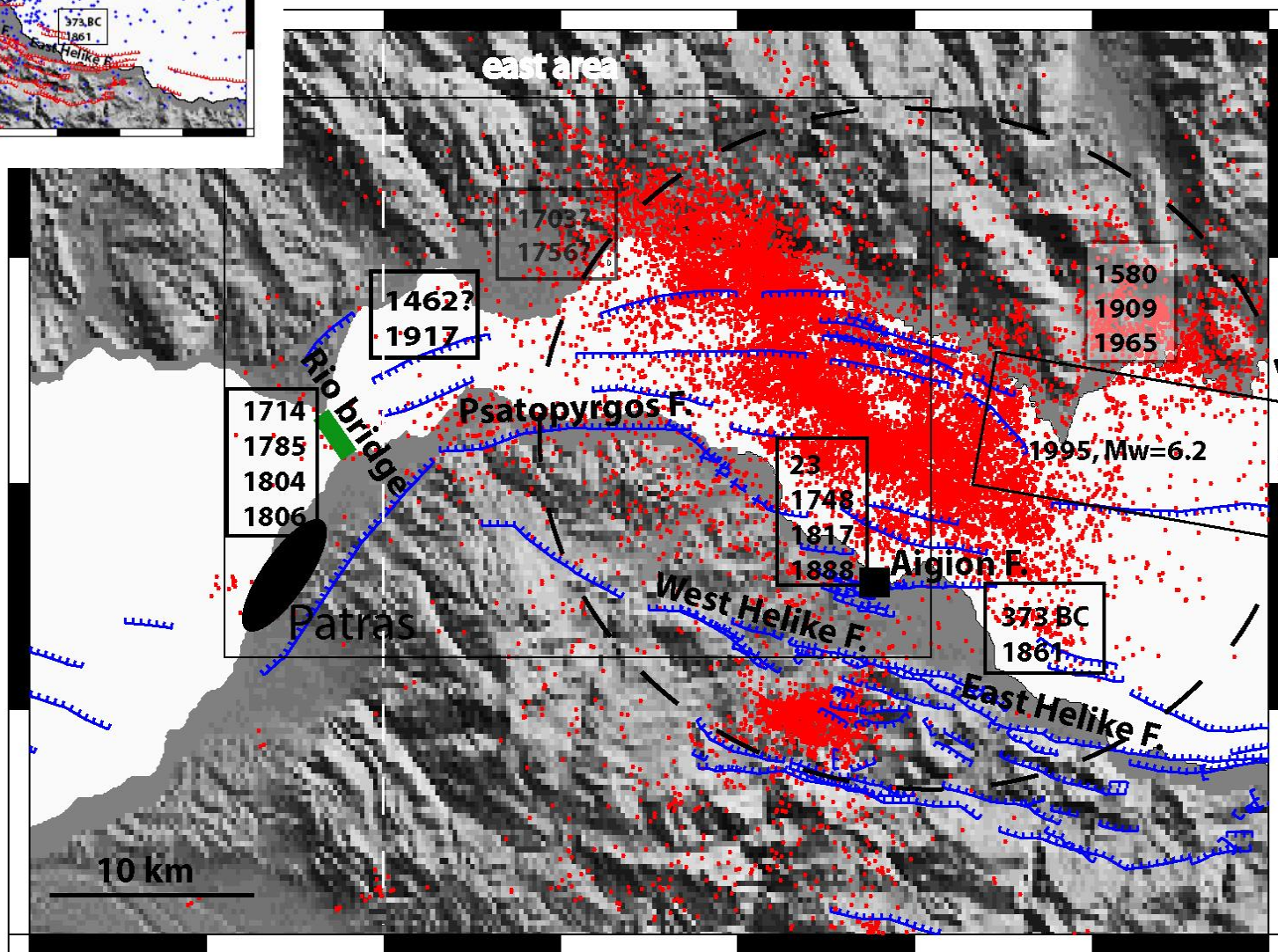


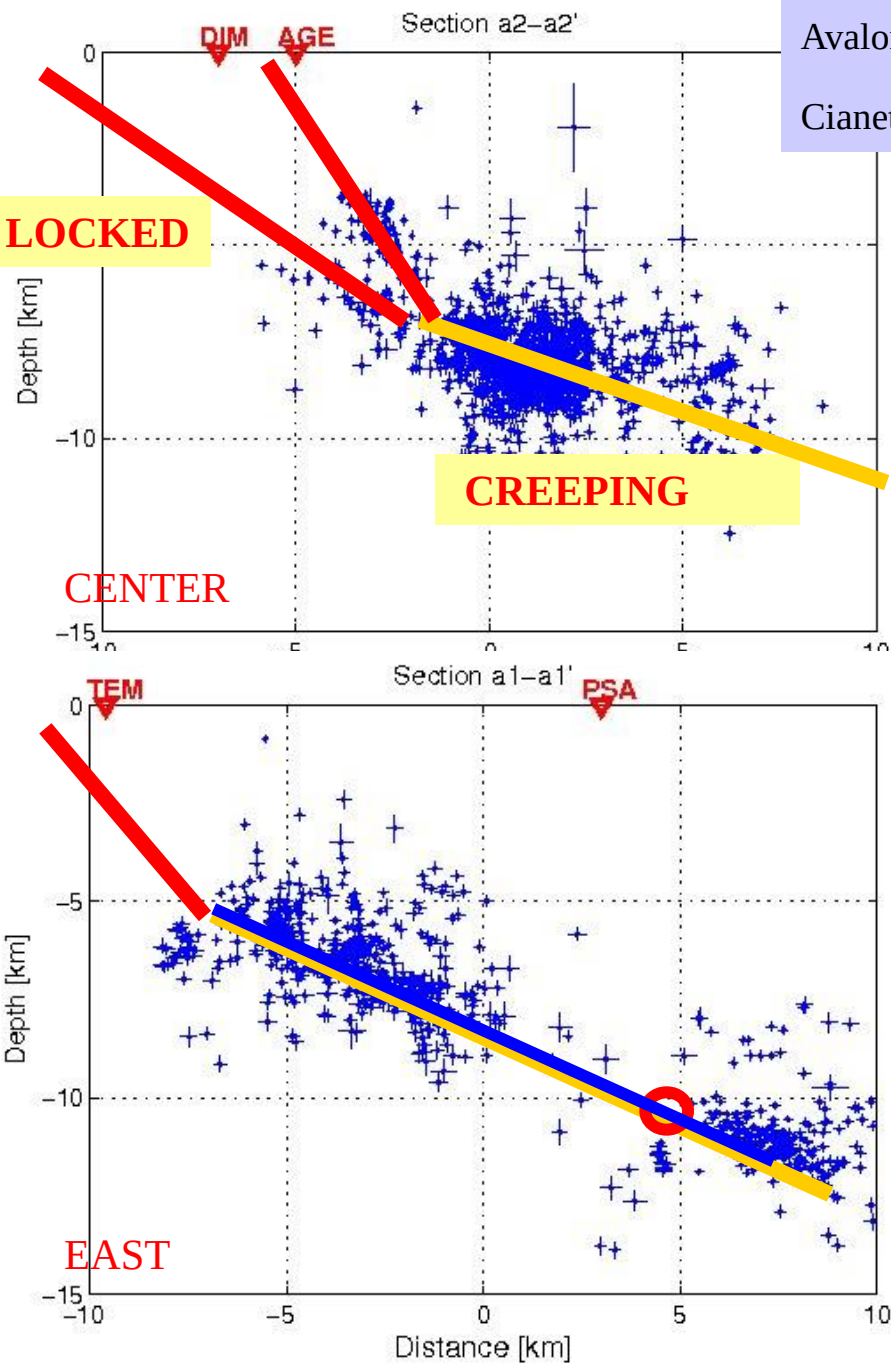
21.8°

22.0°

38.4°

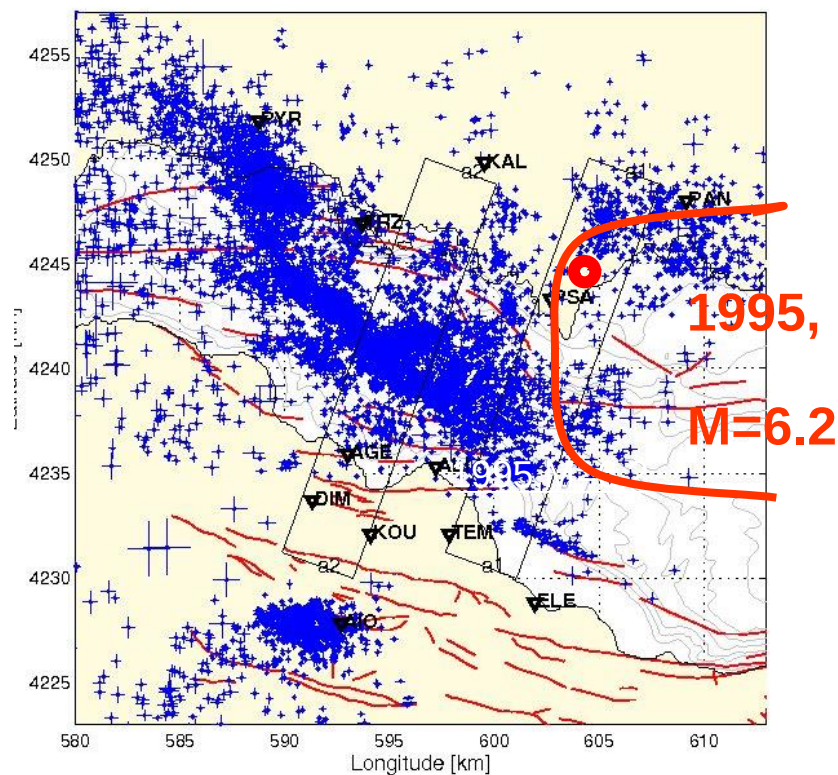
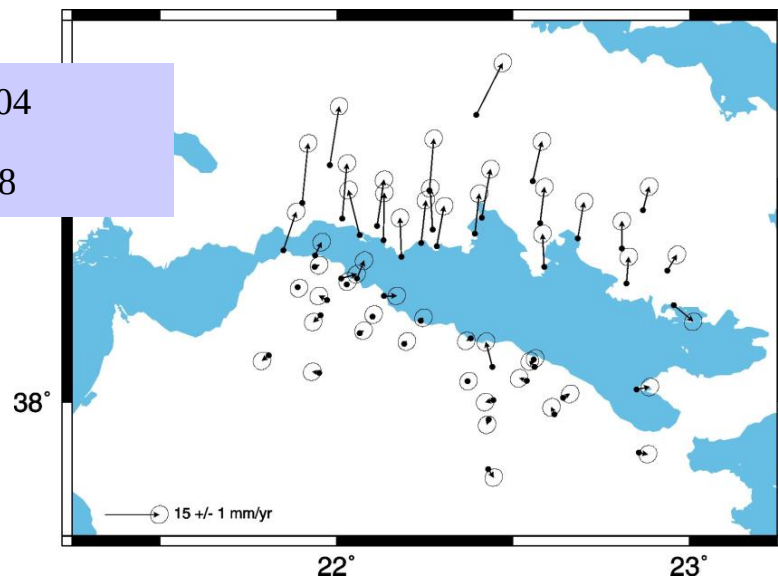
38.2°





Avalone et al., 2004

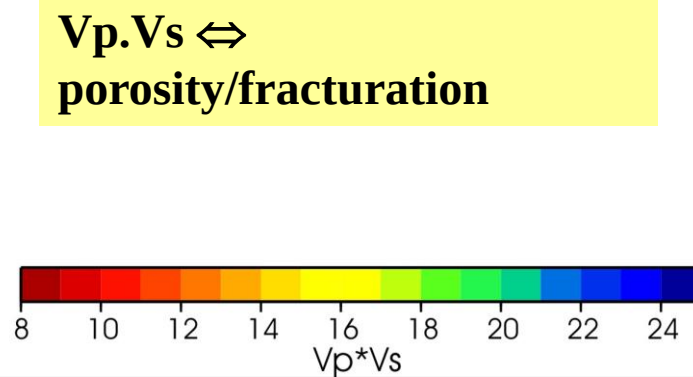
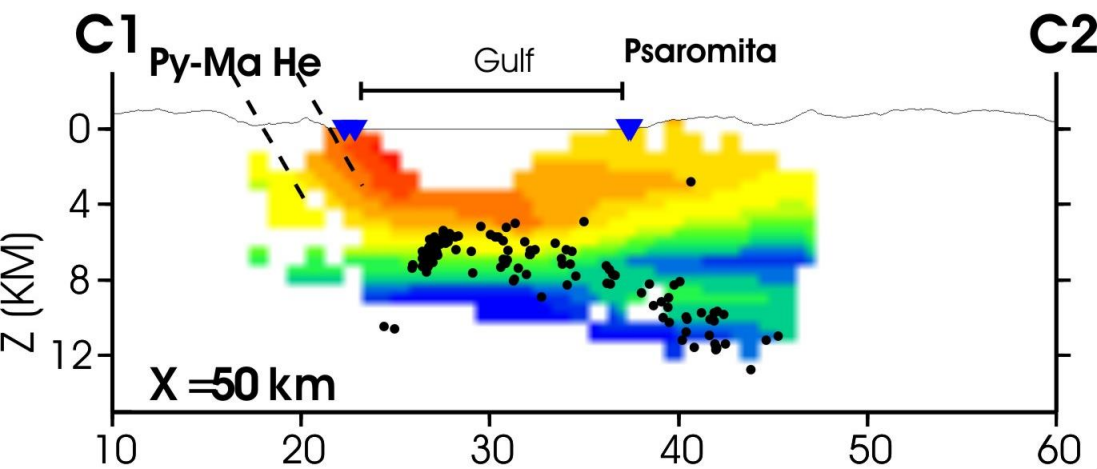
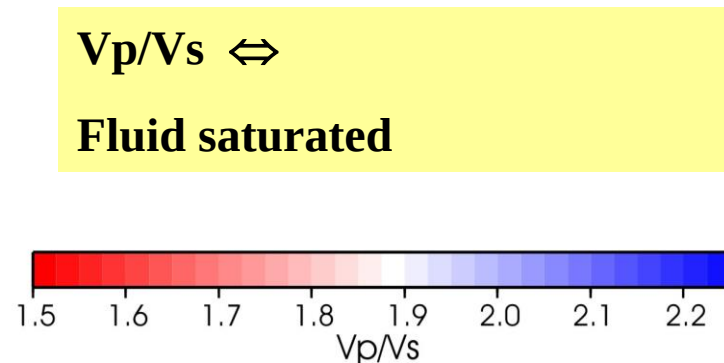
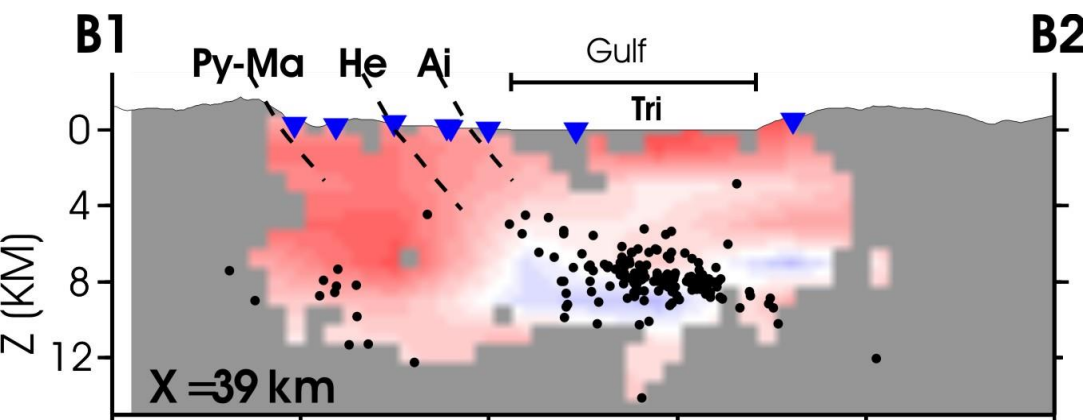
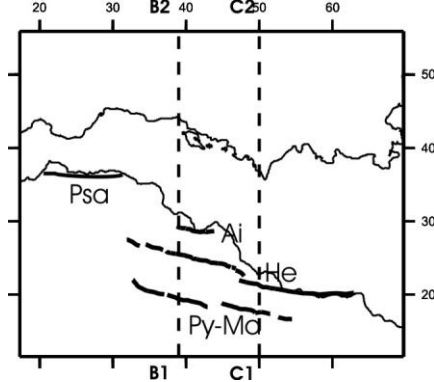
Cianetti et al. 2008



Corinth Tomography: Rifting and fluids

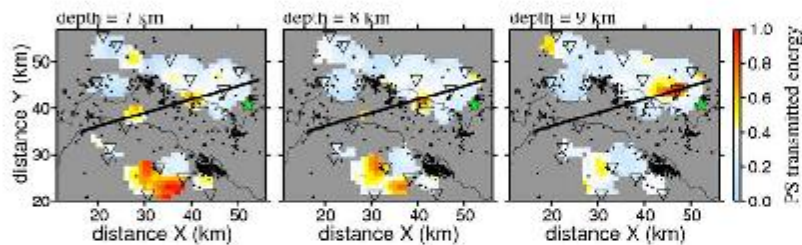
Latorre, 2004

Gautier et al. 2006

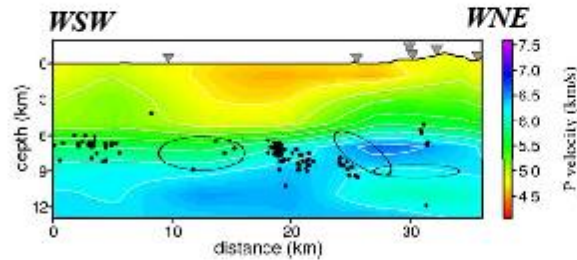
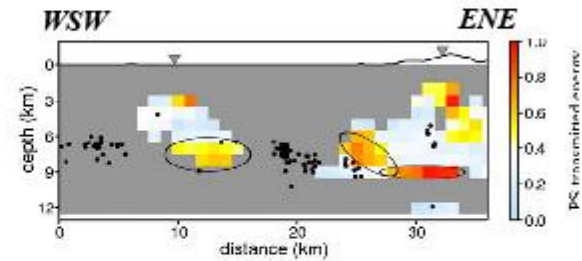


RESULTS

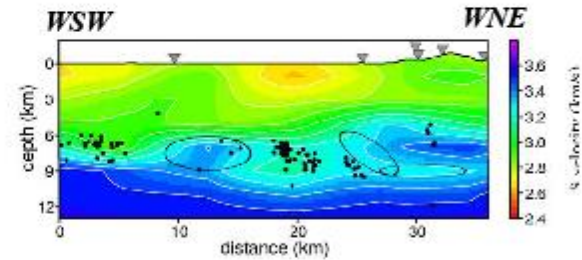
Map view of the migrated model a 7km,
8km and 9 km depth



Vertical cross-section oriented 70° N



P velocity model



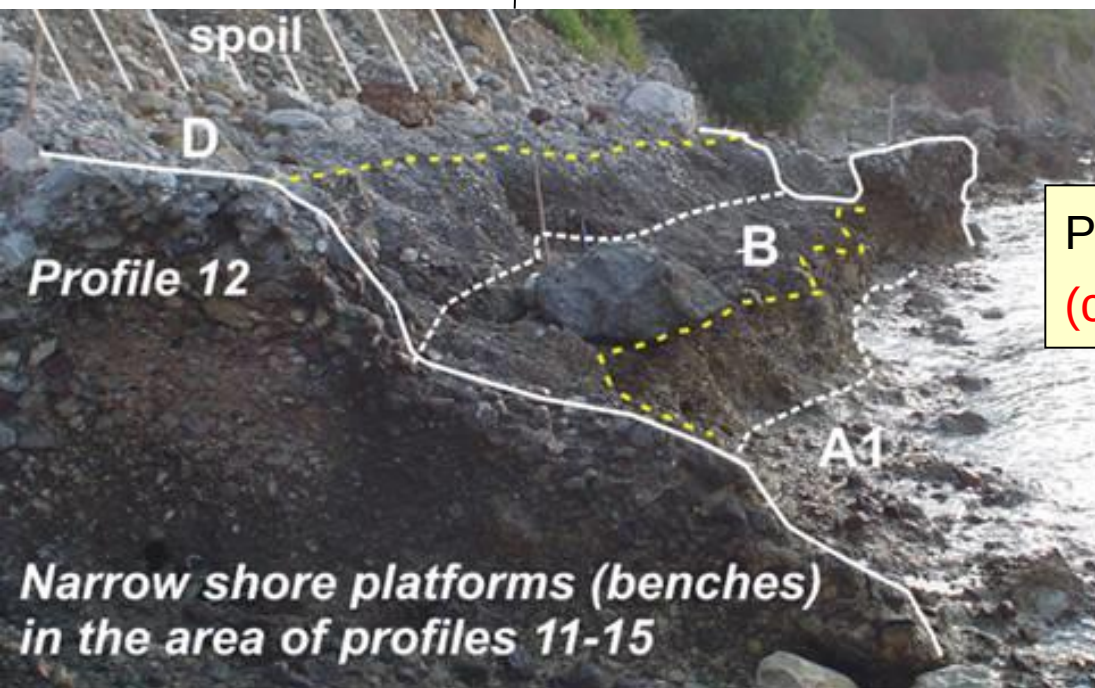
S velocity model

Latorre D., Virieux J., Monfret T., in preparation

Nancy 2-3 Juillet 2007

Le rift de Corinthe

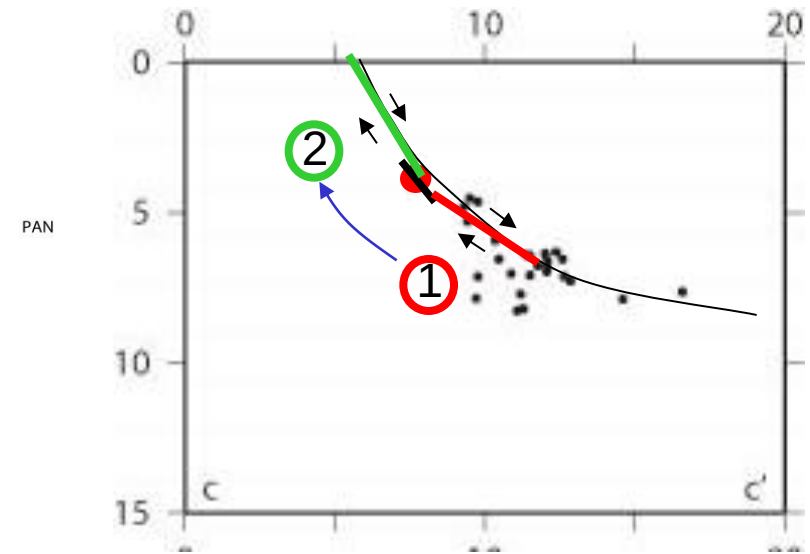
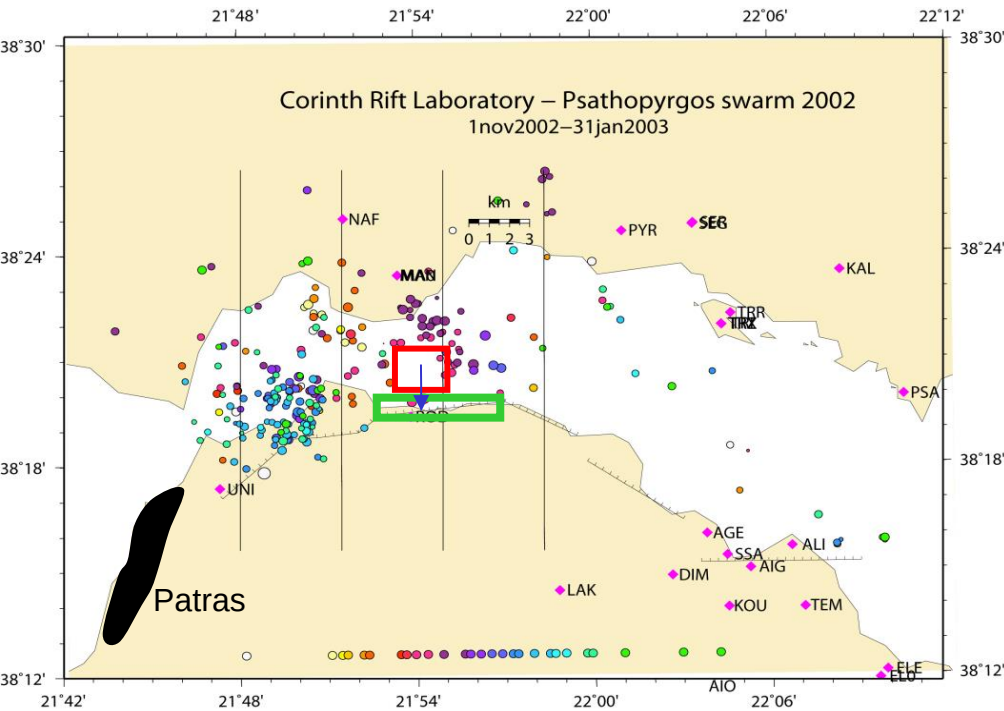
Psathopyrgos fault



Paleoshoreline: 5 rapid uplift episodes (coseismic?) in 2000 years

Pantosti et al. 2007

Transient creep on the Psathopyrgos fault

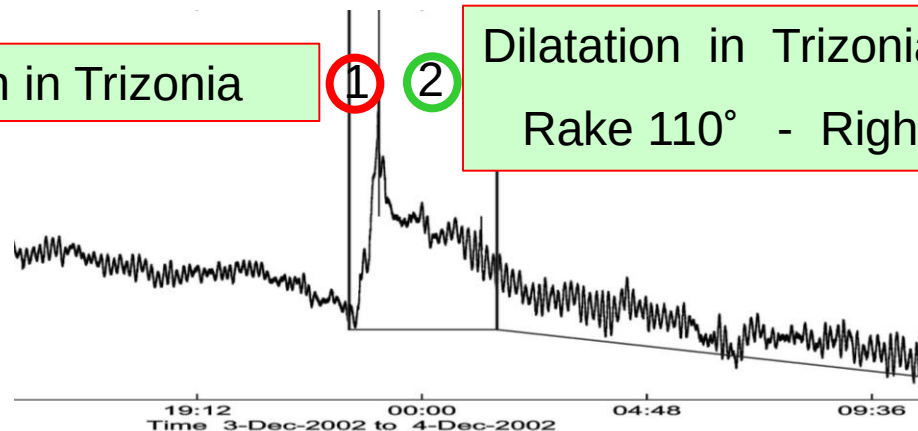


Aseismic slip - $\Delta u=10$ cm - $M_w=5$

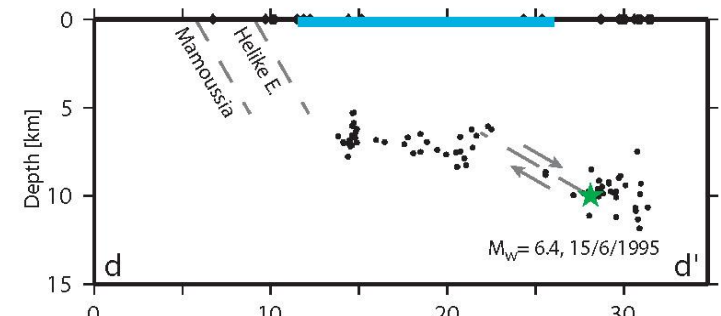
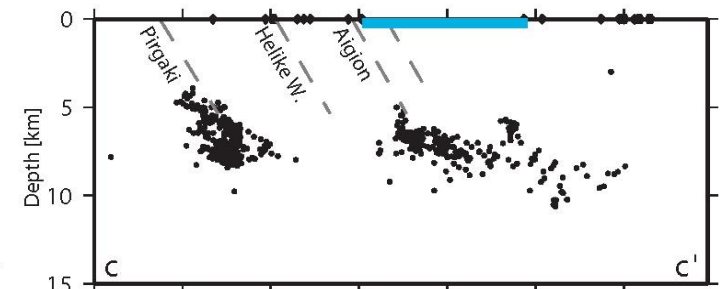
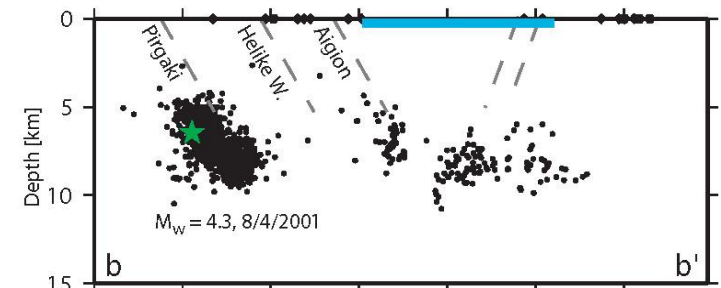
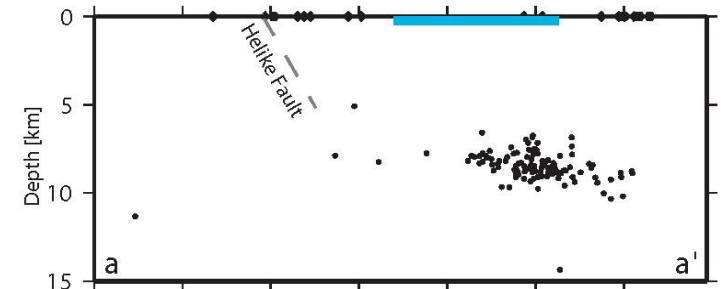
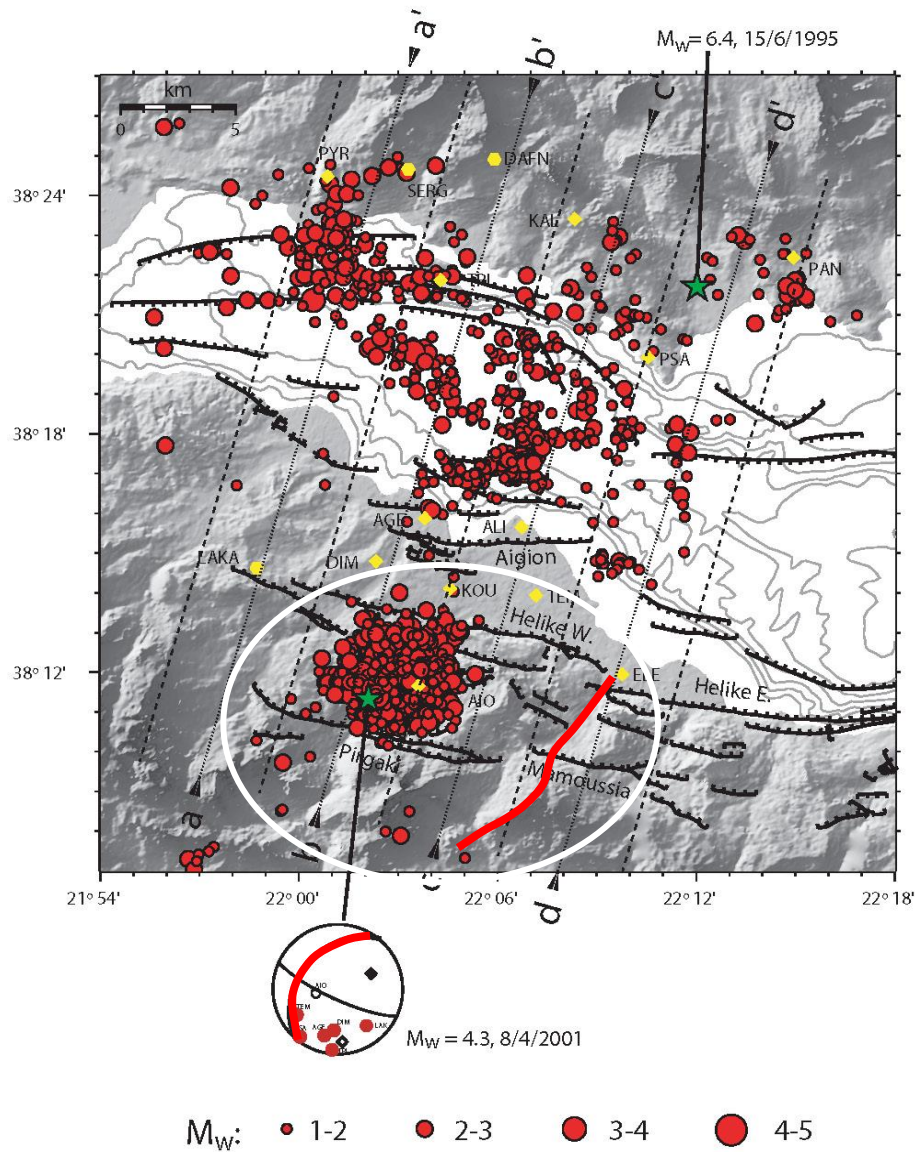
Compression in Trizonia

Dilatation in Trizonia

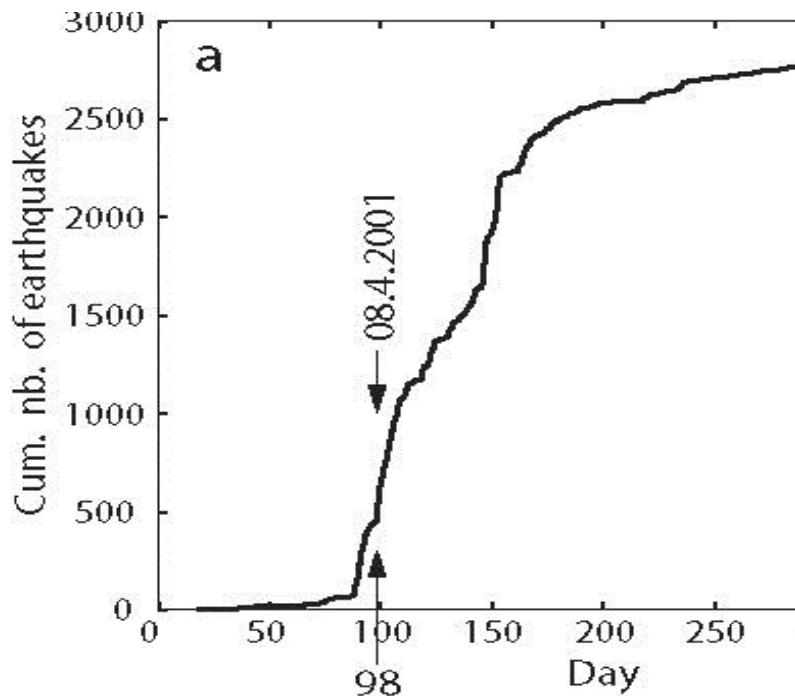
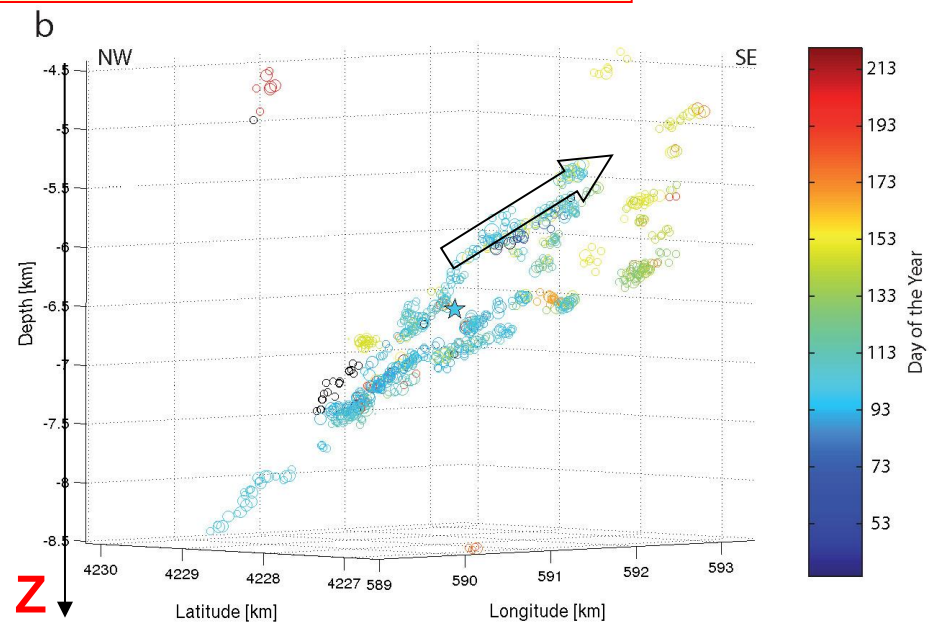
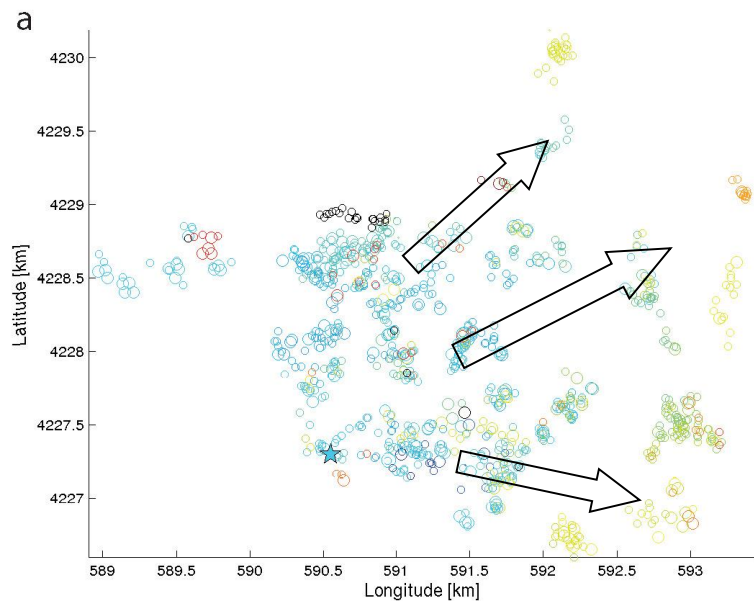
Rake 110° - Right-lateral



2001 seismic swarm - 3 months - $M_{\max}=4.2$
 ancient fault - dip 45° NW - reactivated



2001 seismic swarm: relocated multiplets



2 time scales of transient:

Week-month:

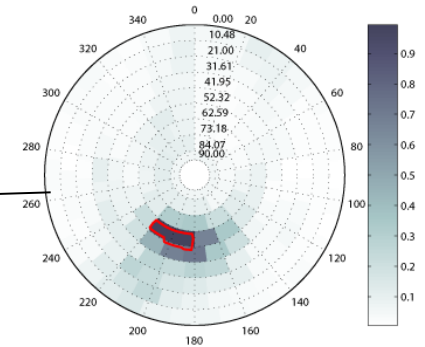
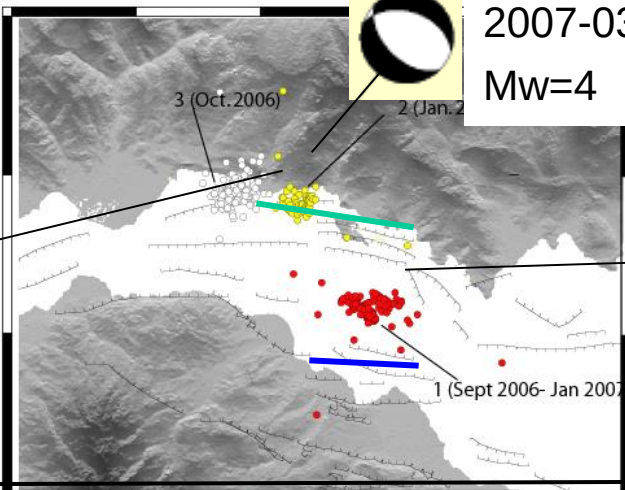
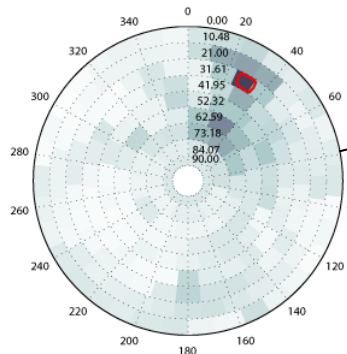
Upward migration :
pore pressure pulse?

Minute-day:

clustering Omori type

2007-03-19

Mw=4



NNE SSW

Trizonia
fault

Aigion
fault

0

5

10

km

janv 07

sept 06-janv 07

-Pendages failles principales vers le nord:

- Helike: inconnu
- Aigion: 60° jusqu'à 6 km
- Kamarai-Lambiri: 60° probable jusqu'à 6 km
- Psathopyrgos (2002 – Latorre – Rigo)

Structure profonde:

- centre et est:

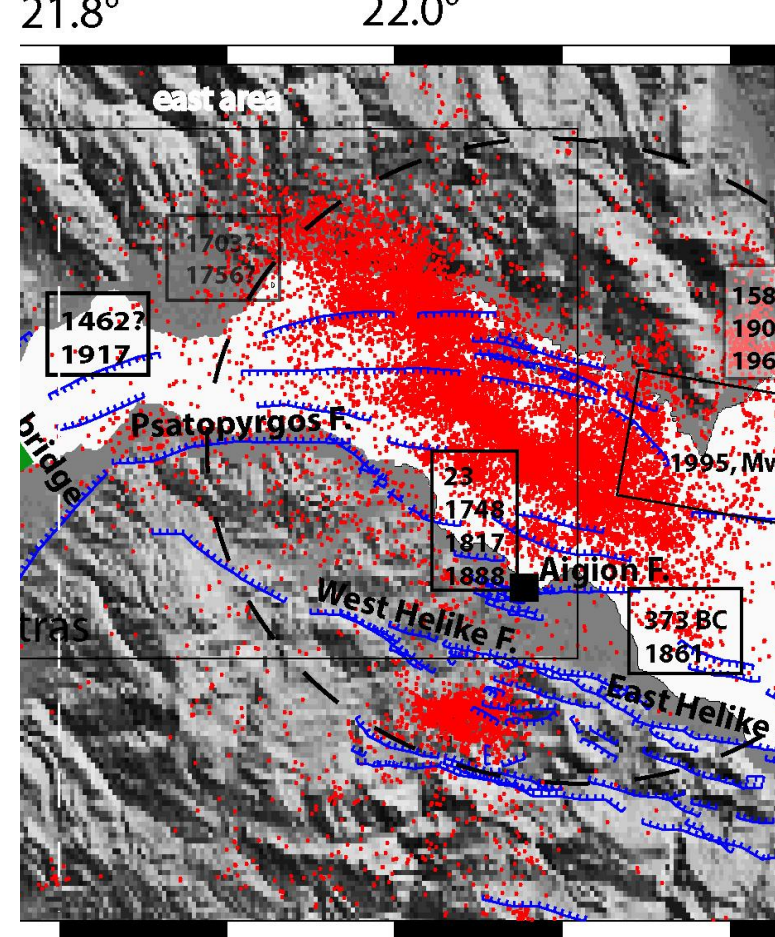
- épaisseur < 2km, liée à une zone de faible vitesse
- Pendage nord, entre 6 et 8 km coté sud, descendant jusqu'à 12-15 km coté nord
- approfondissement vers le NW, haut topo longitude Aigion
- petites failles pendage nord, 10°-30°, quelques petites structures décrochantes
- Petite faille oblique pendage NE pres de l'hypocentre du seisme de 1995

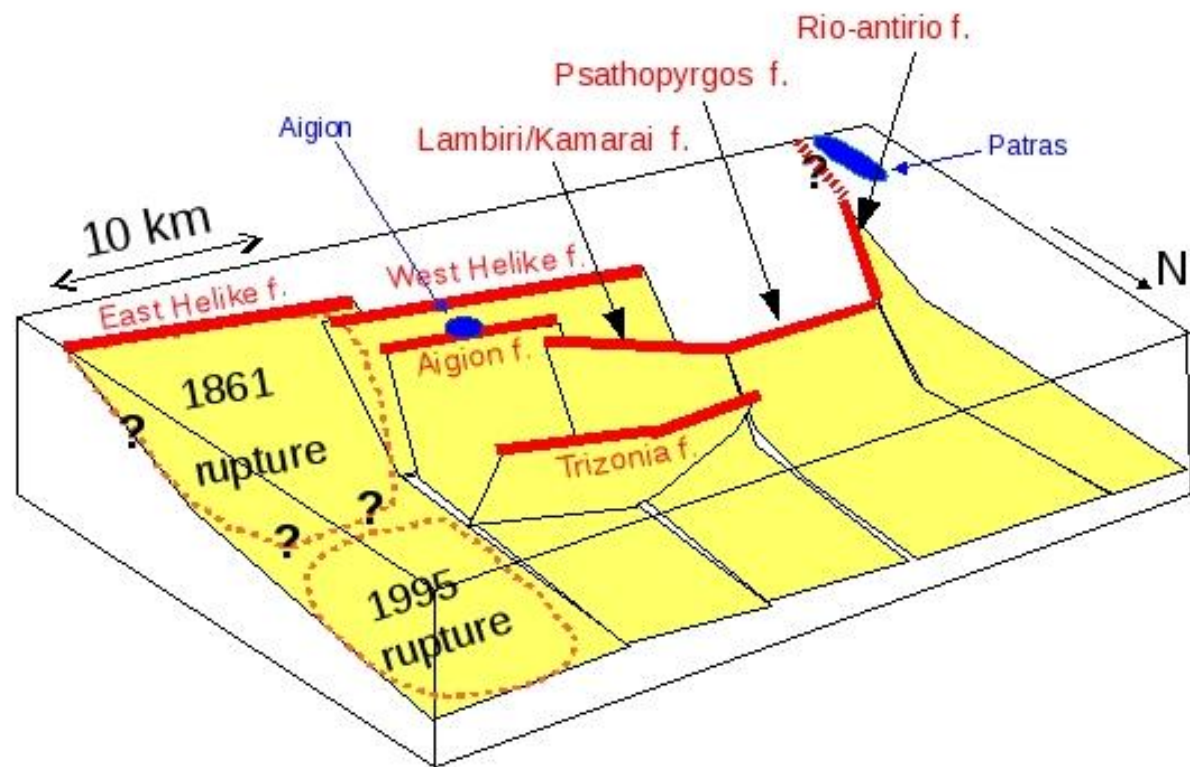
-Failles obliques

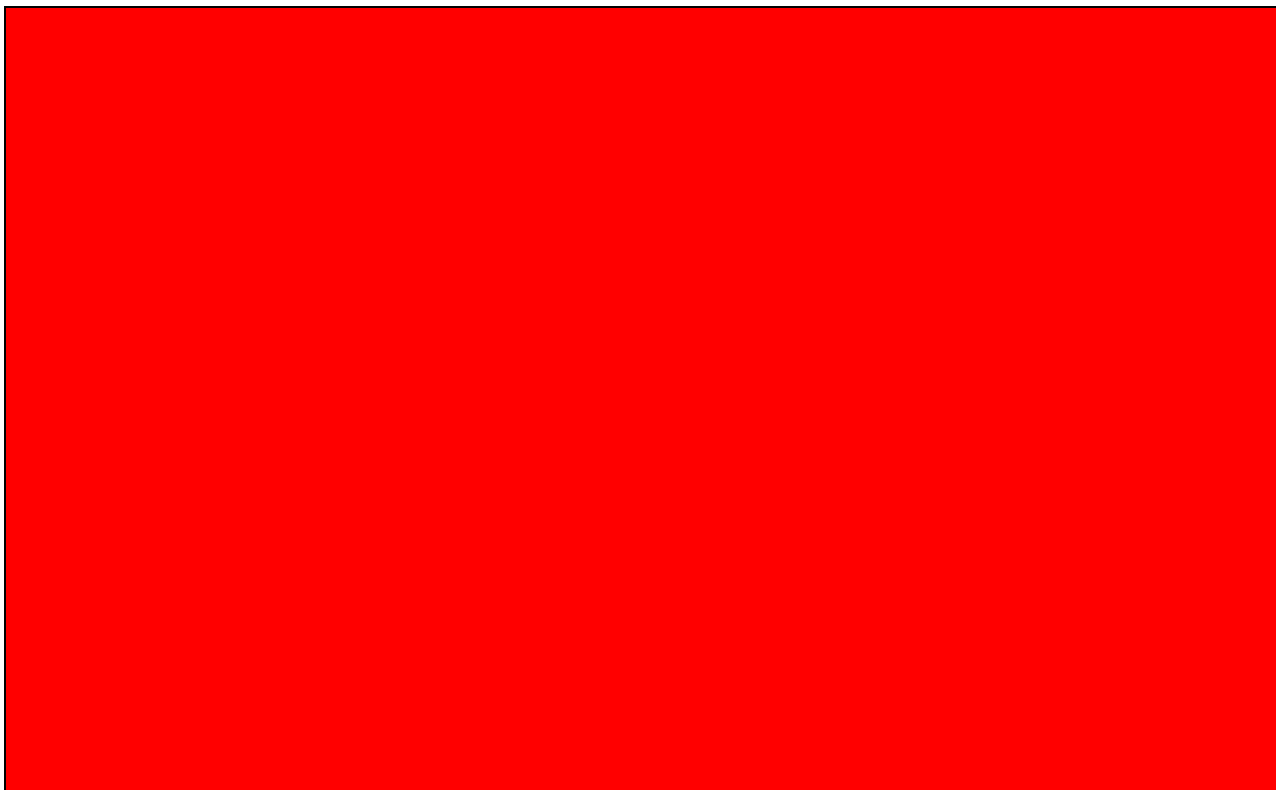
- faille de 2001: décrochante, 5-8 km, pendage NW, peut être liée à une structure majeure

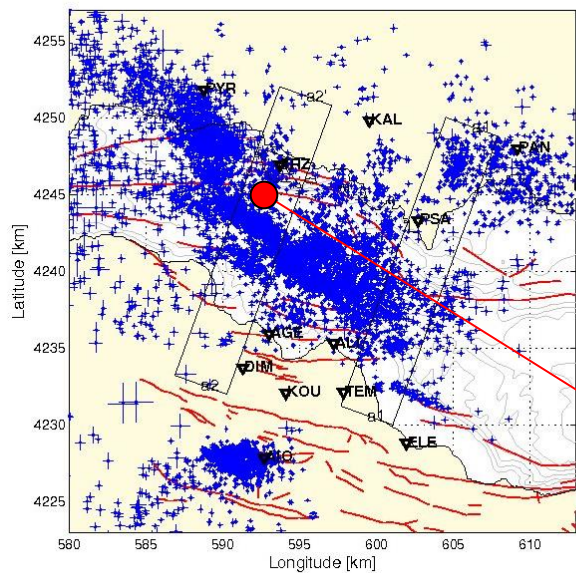
-Failles antithétiques:

- faille de Trizonia: activité diffuse vers 5 km, pas d'activité de multiplet
- séisme de 2007: faille normale sous cote nord, plus au nord que Trizonia



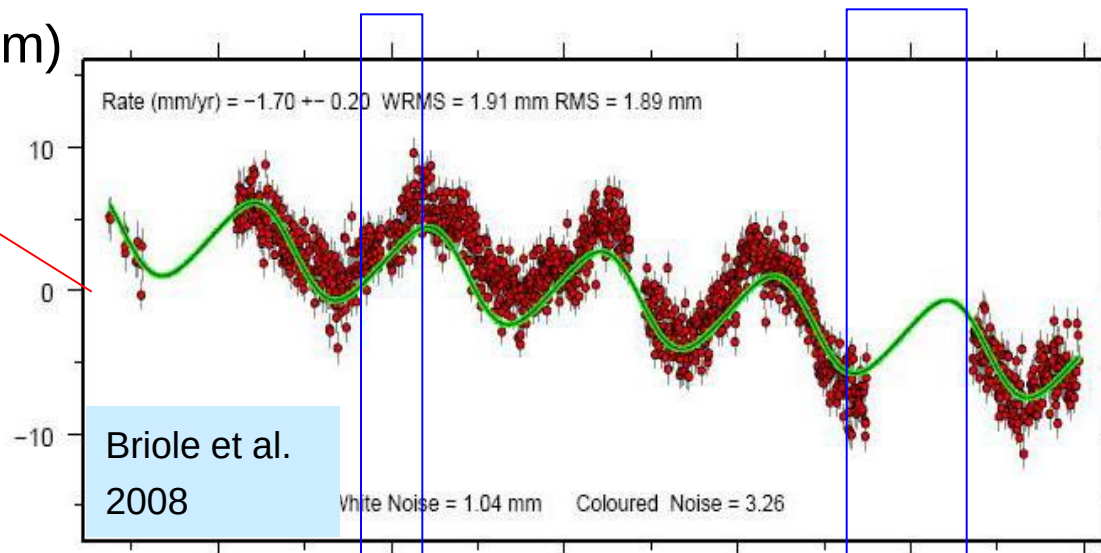






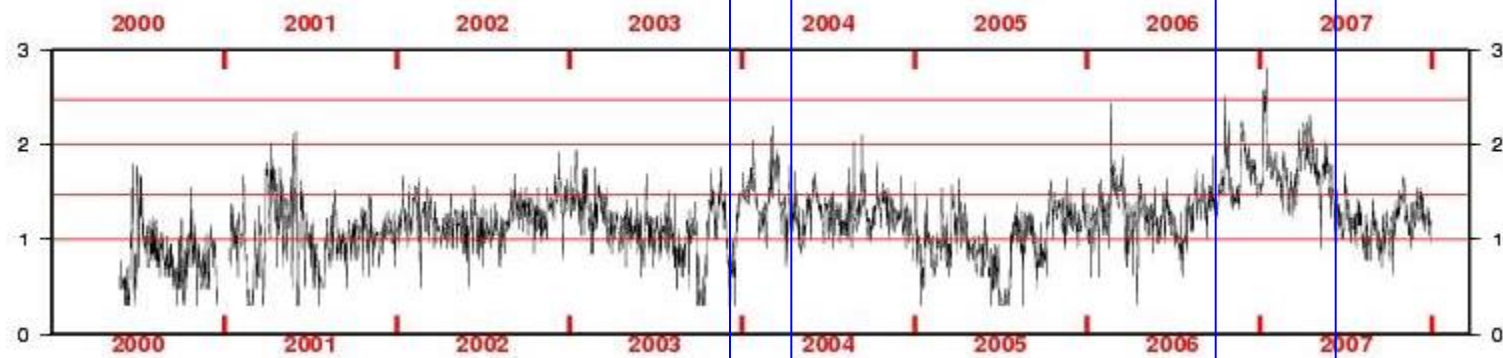
Displacement (N)
(mm)

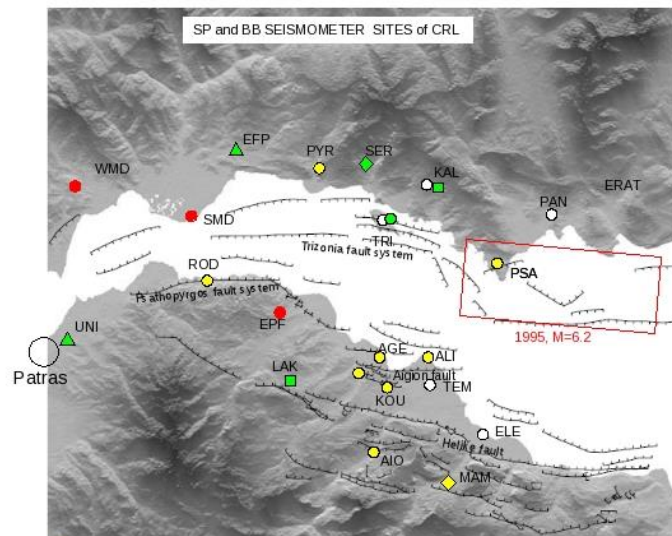
cGPS



Log(seismicity rate)

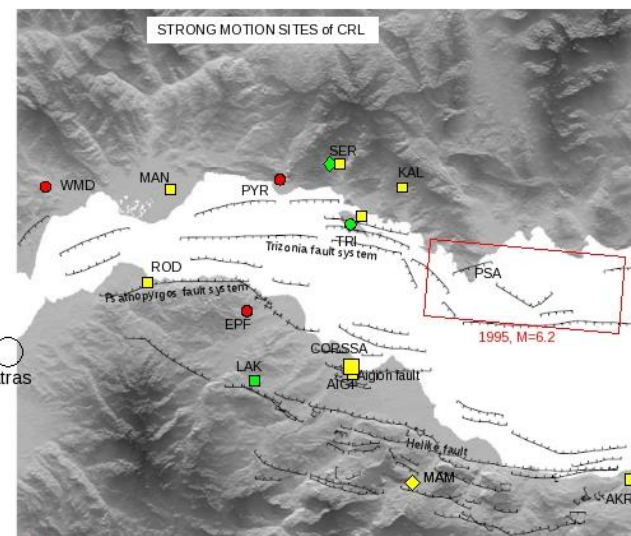
/day





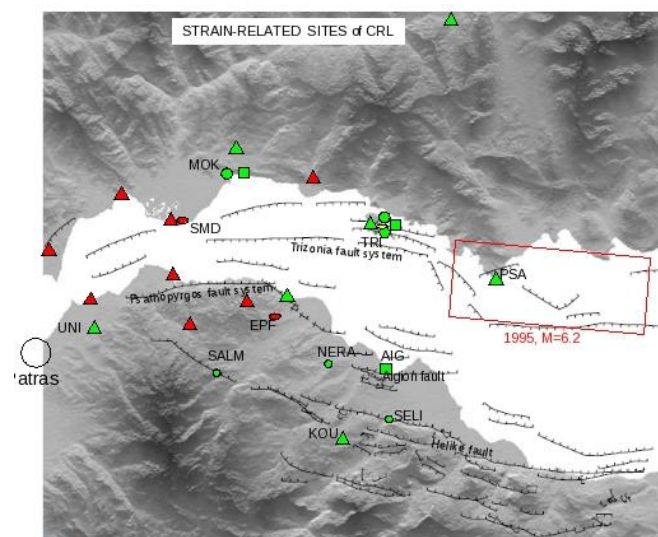
- NKUA
- ⬢ NOA
- ▲ PATRAS
- ◆ PRAGUE
- ⊙ FRANCE CNRS

- ▲ in operation, to be maintained
- ▲ in operation, to be upgraded
- △ to be suppressed
- seismometer planned in SISCOR



- NKUA
- ⬢ NOA
- ▲ PATRAS
- ◆ PRAGUE
- ⊙ FRANCE

- ▲ in operation, to be maintained
- ▲ in operation, to be upgraded
- accelerometer planned in SISCOR

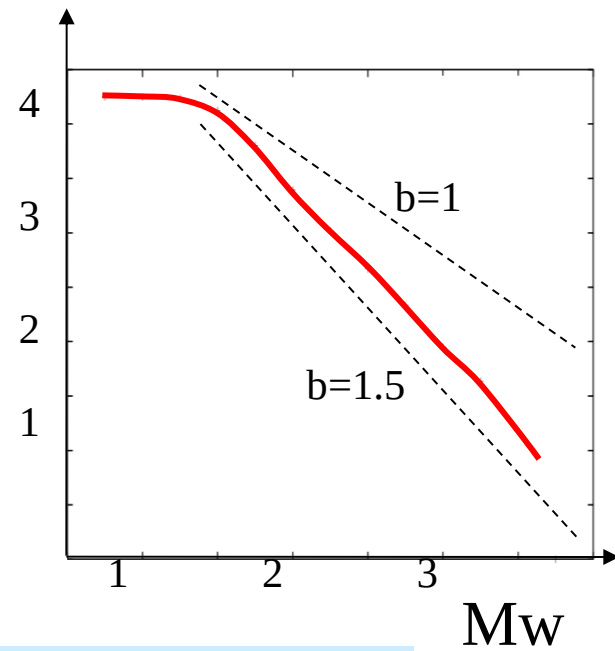


- ▲ GPS (ENS)
- ⊙ Borehole Strainmeter (IPGP)
- ⊙ Borehole tiltmeter (IPGP)
- ⊙ Borehole pore pressure/water level (IPGP/UM)
- ⊙ Long base tiltmeter (IPGP)
- Tide-gage (IPGP)
- ⊙ Meteo station (IPGP)

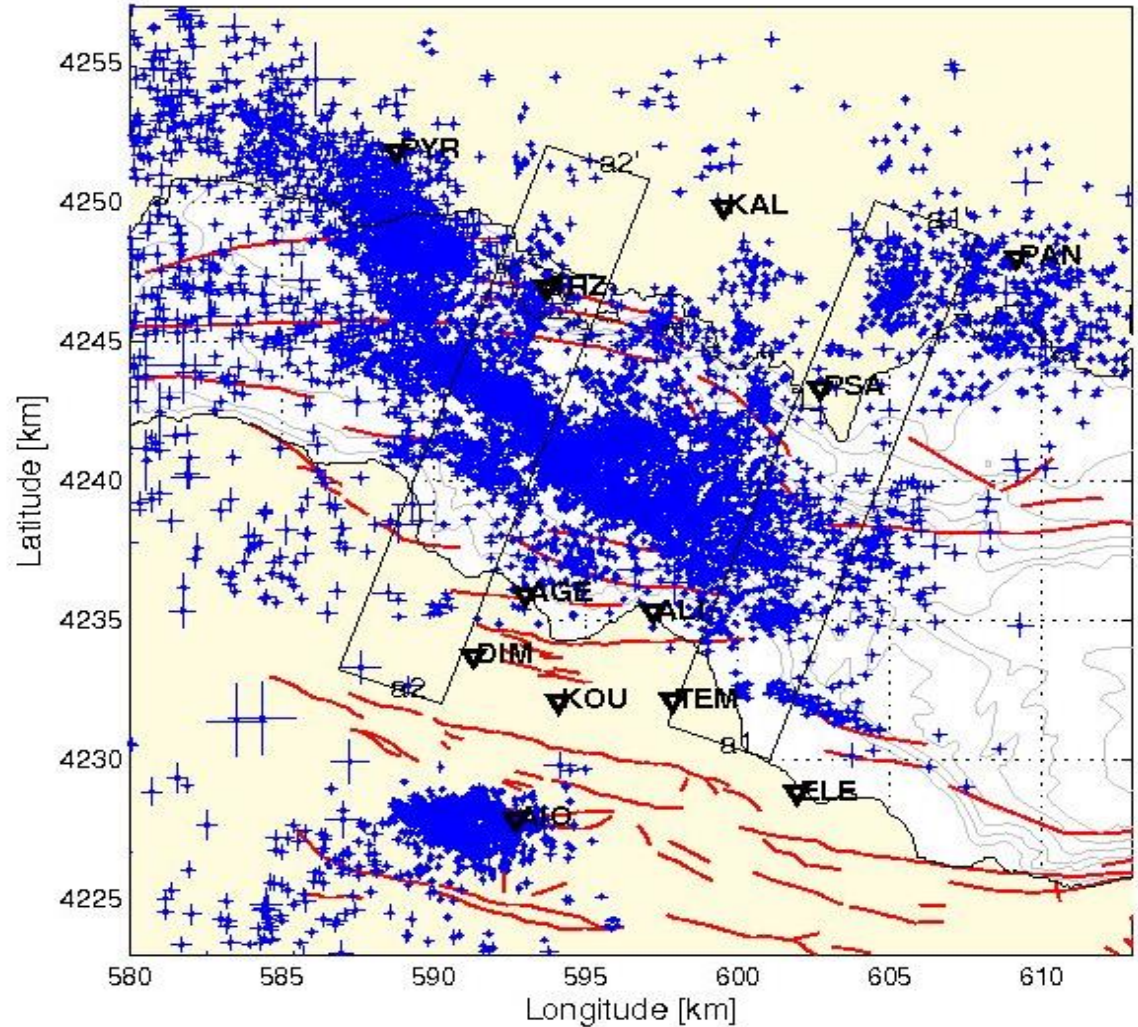
- ▲ in operation, to be maintained
- ▲ in operation, to be upgraded
- borehole tiltmeter planned in SISCOR
- ▲ continuous GPS planned in SISCOR

Seismicity 2000-2007

$\log(N)$

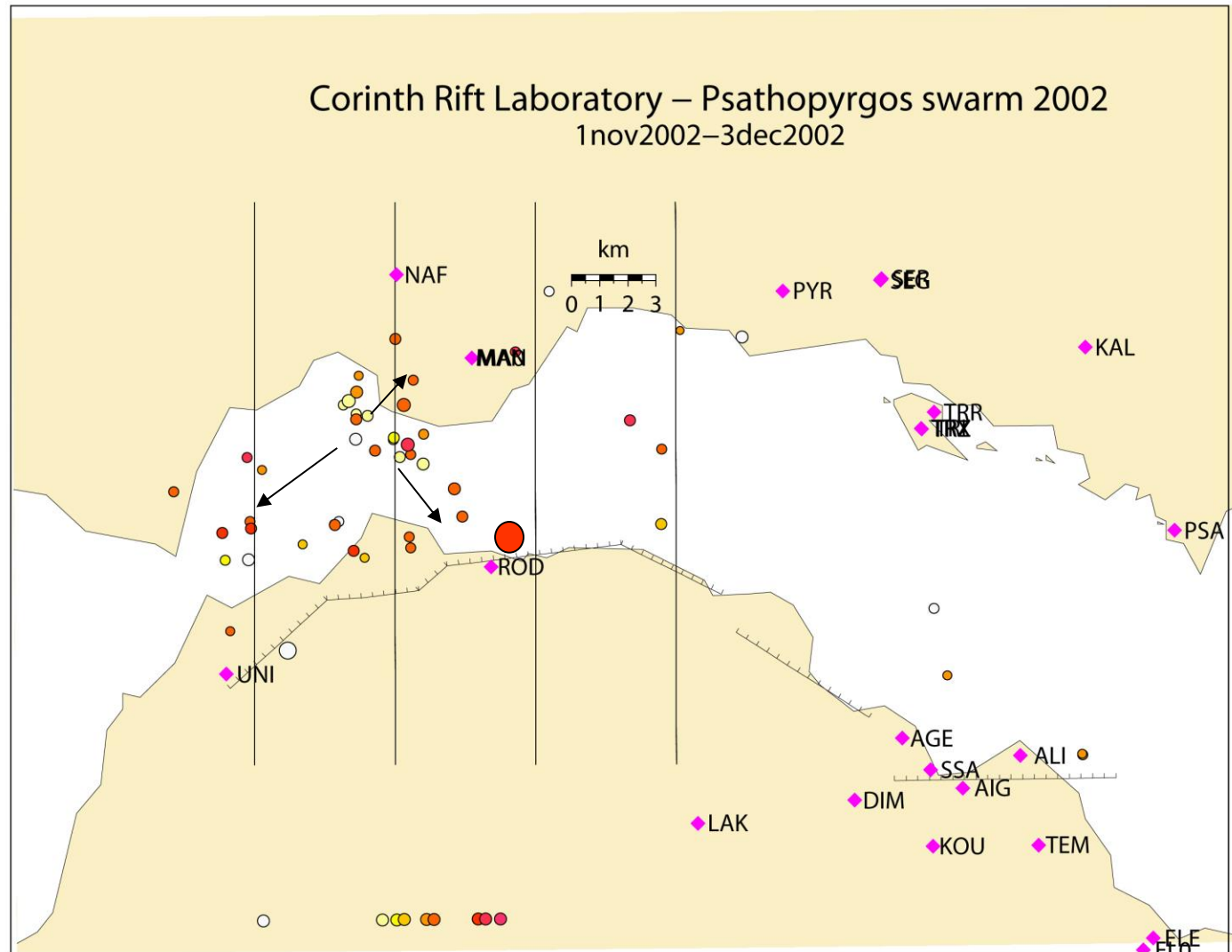


Pacchiani , 2006

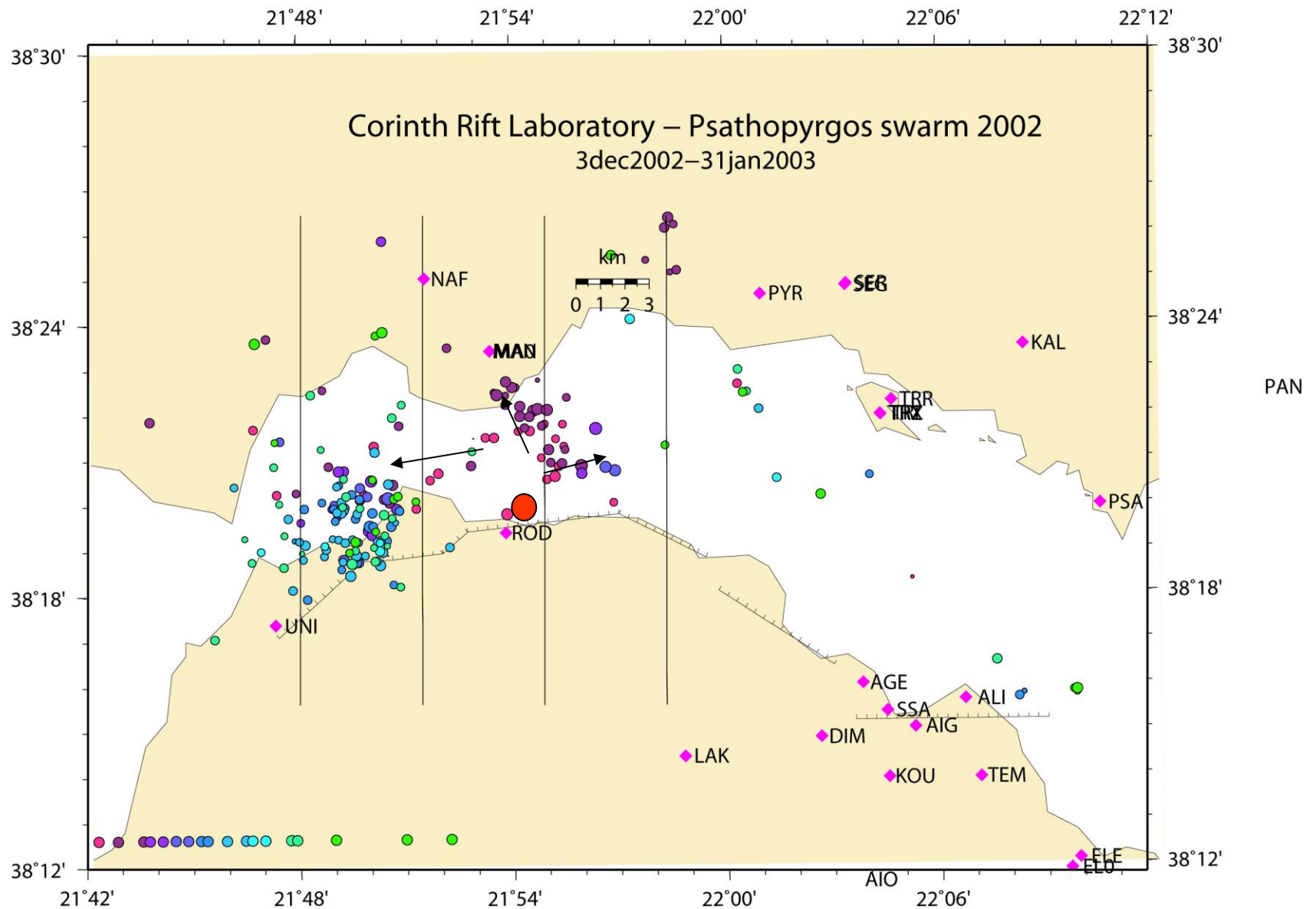


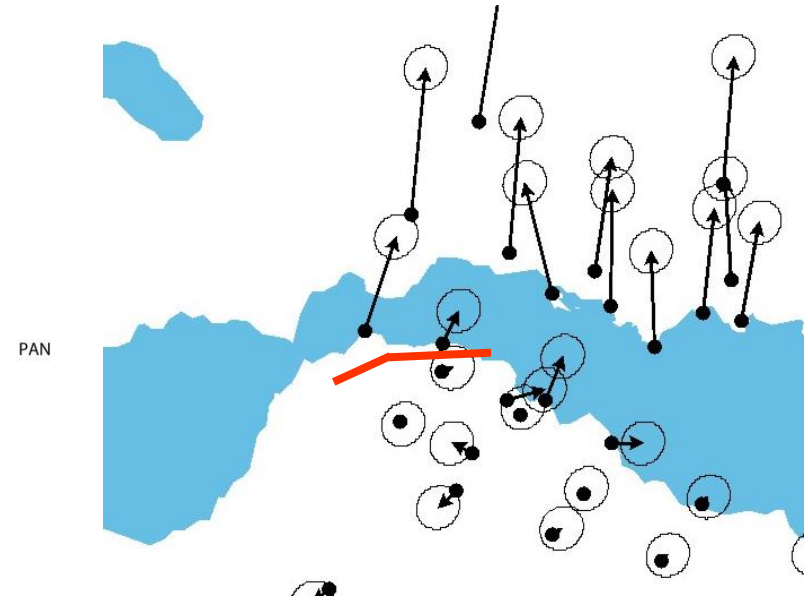
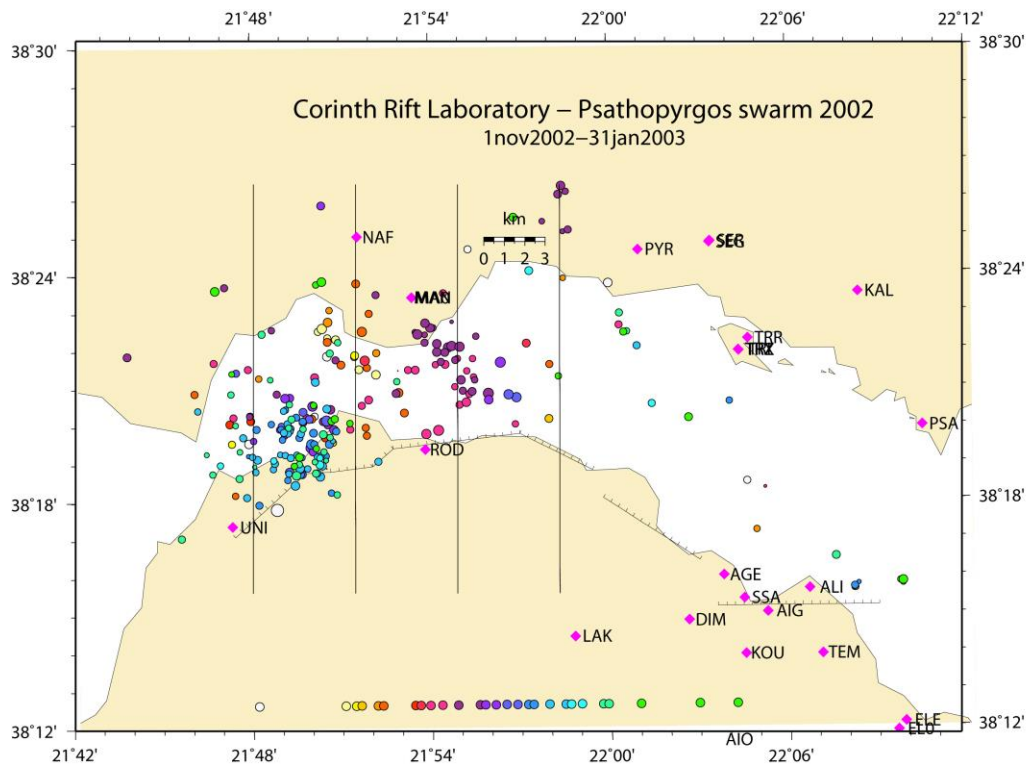
Lambotte, 2008

Before 3 december earthquake

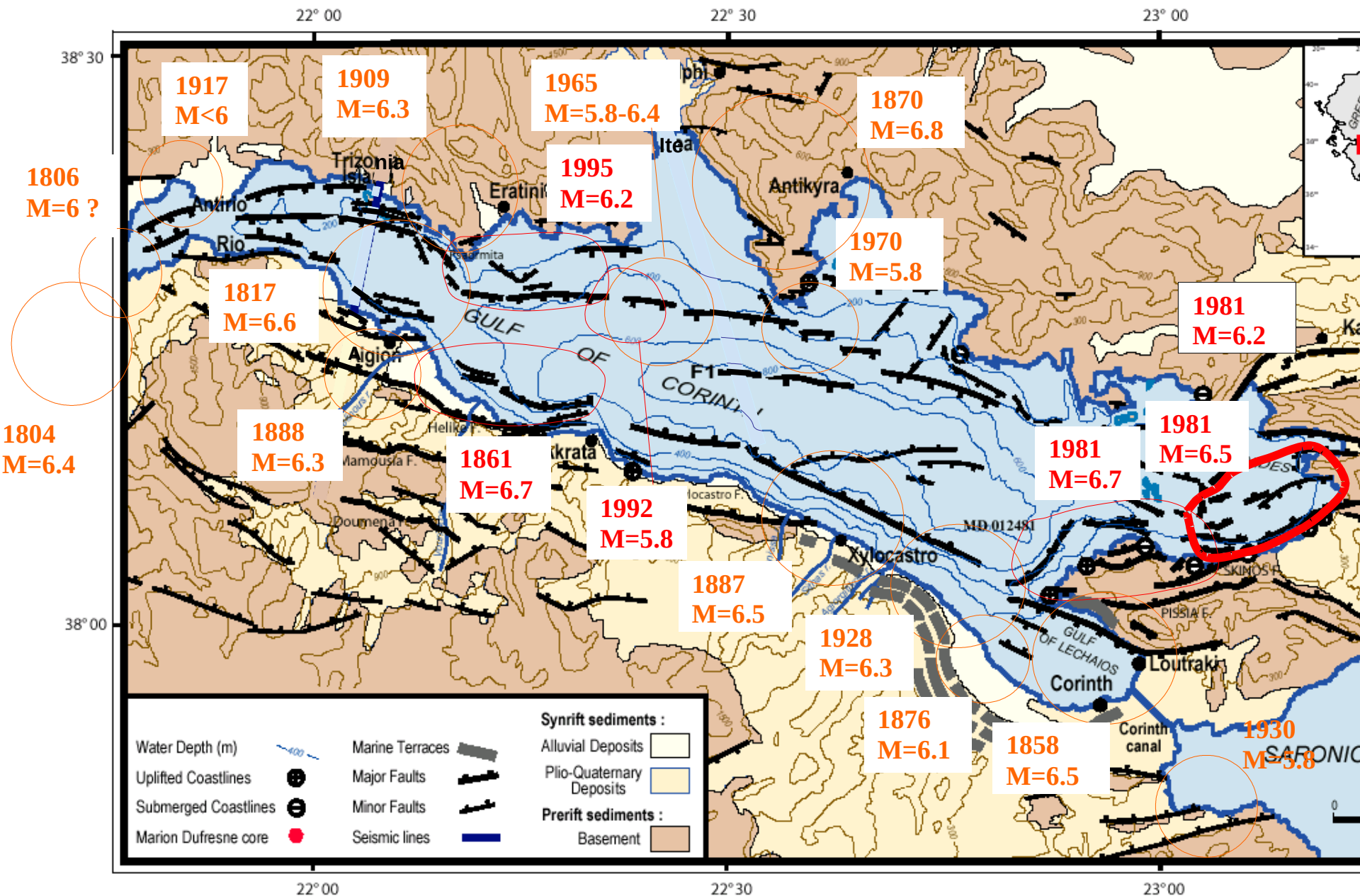


After 3 december earthquake





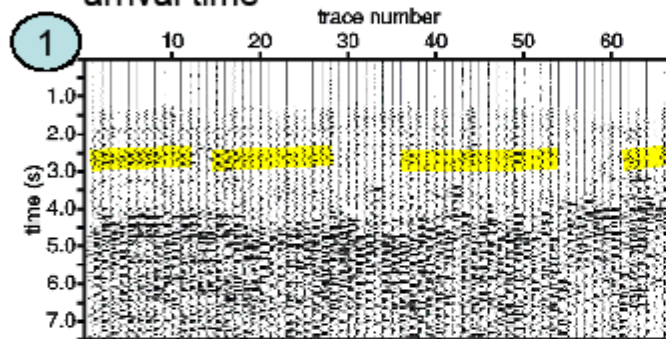
- No historical earthquakes (300 yrs)
- GPS >1.5 cm/yr
- creeping and seismic



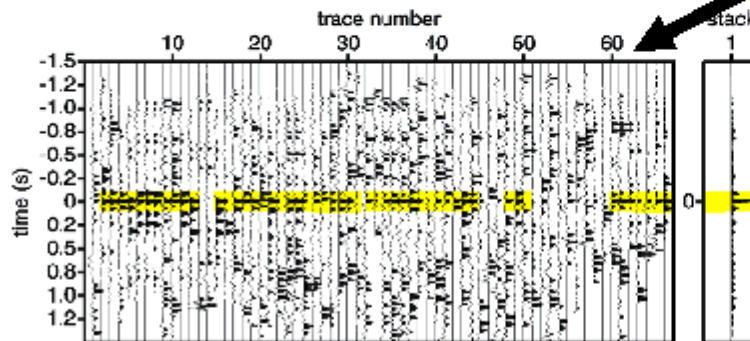
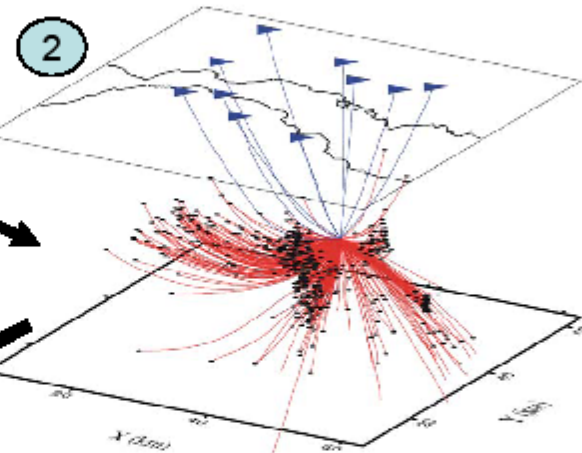
1800-2008

Example on real data

Example of starting data: radial components aligned on the P-first arrival time



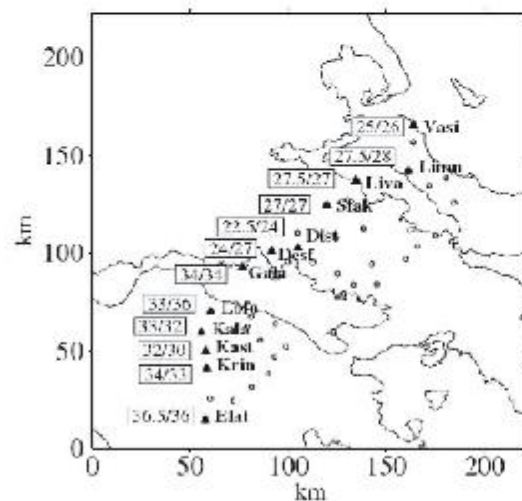
Ray tracing in the 3D velocity model for a PS converted wave at a given grid point



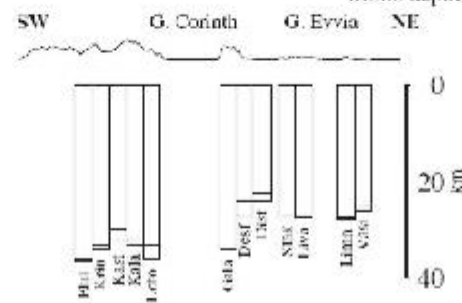
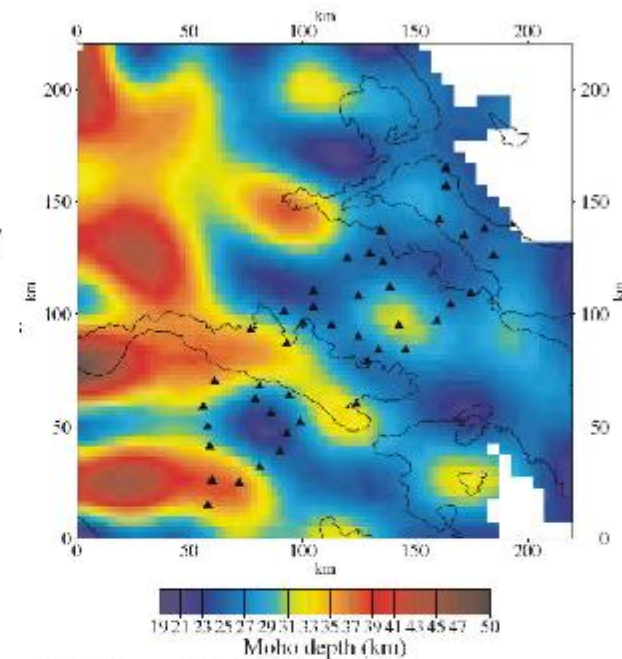
3

Stacking of shifted records: the migrated image at the grid point is computed by summing the weighted amplitudes at $t=0$

Inversion de données gravimétriques Comparaison à la tomographie aux fonctions récepteur

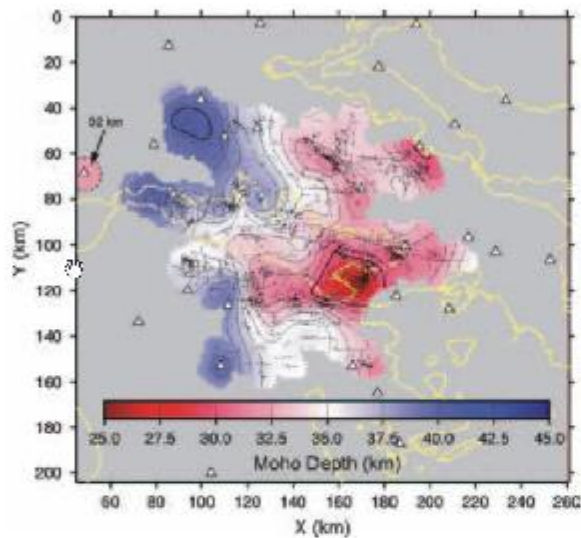


May 2001



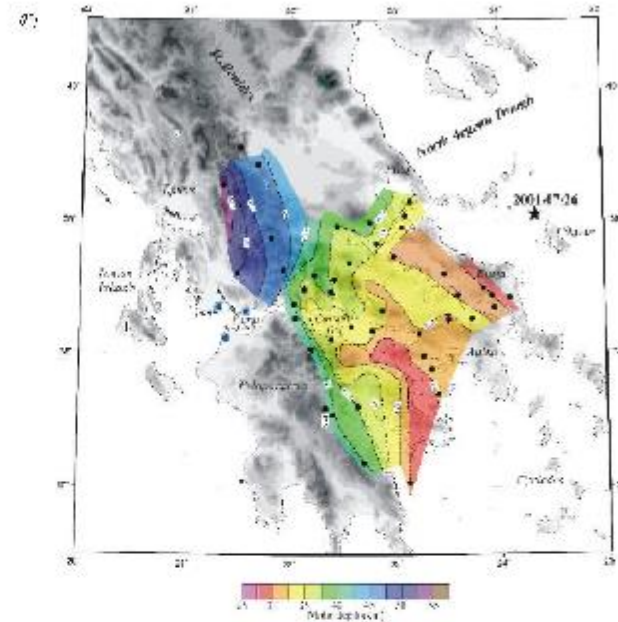
ECHEC DE CORRECTION

Tiberi et al.,
Geophys. J. Int.,
2001



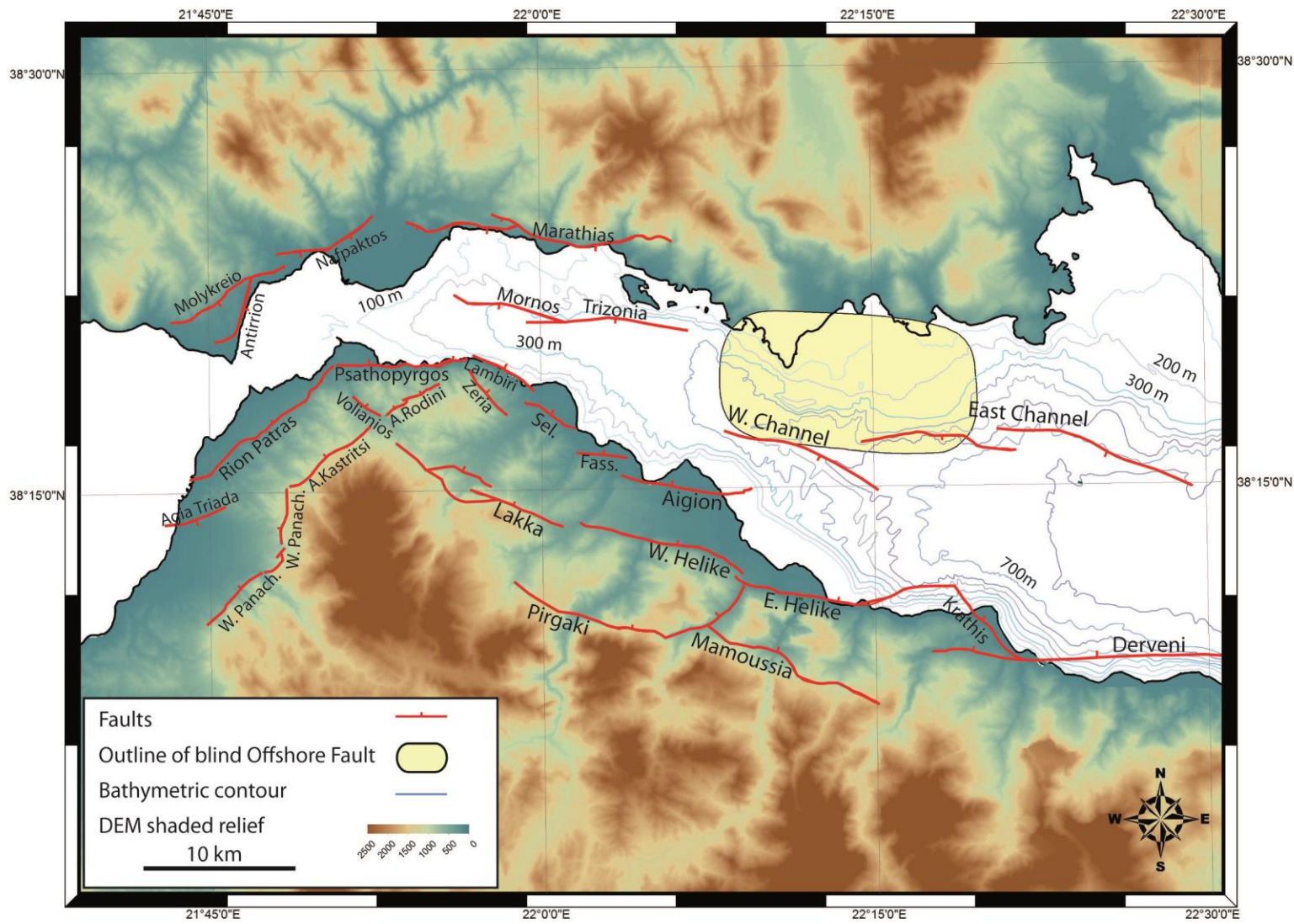
**Moho obtenu par tomographie
2D des temps de réflexion PmP**

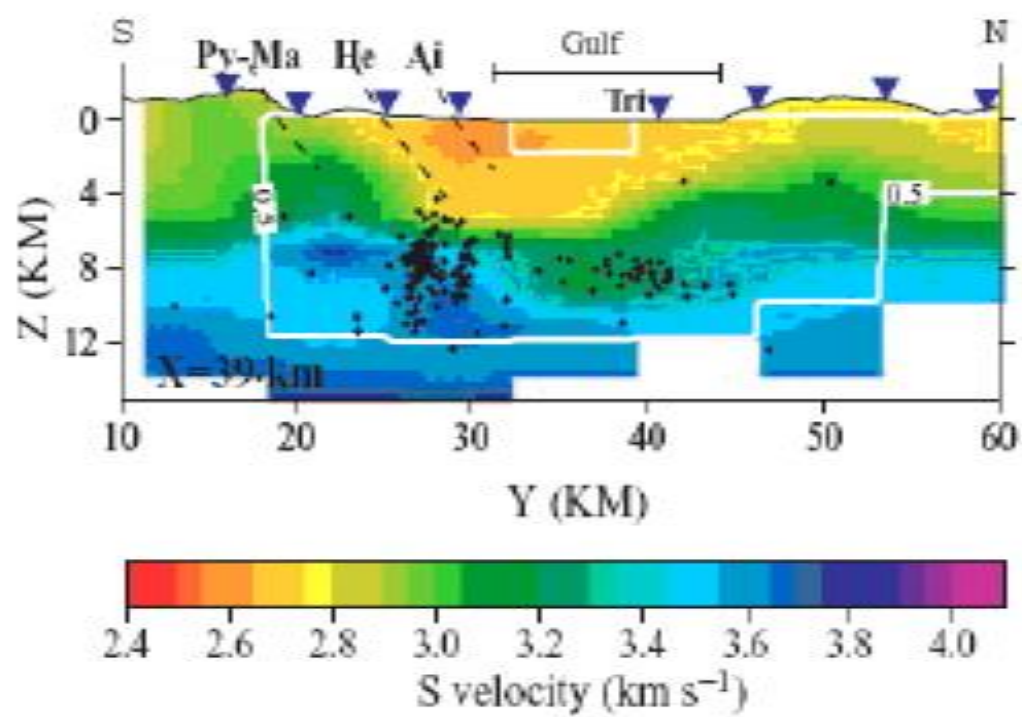
Zelt et al., Geophys.J. Int., 2005

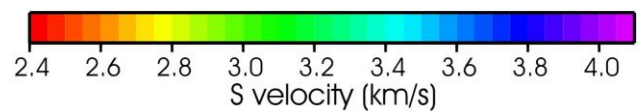
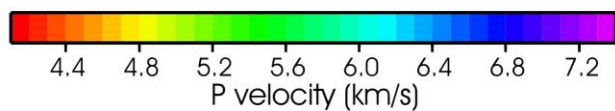
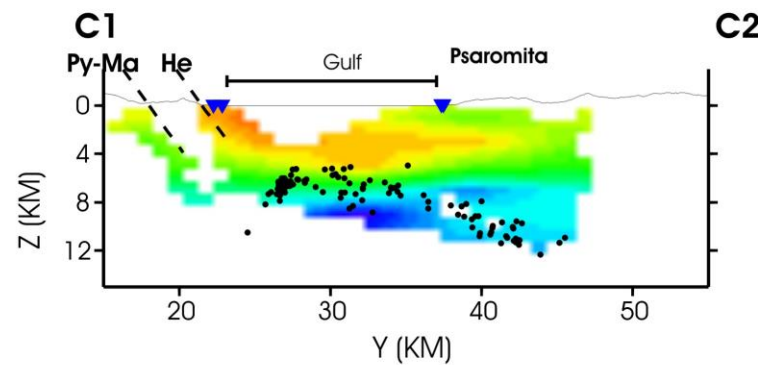
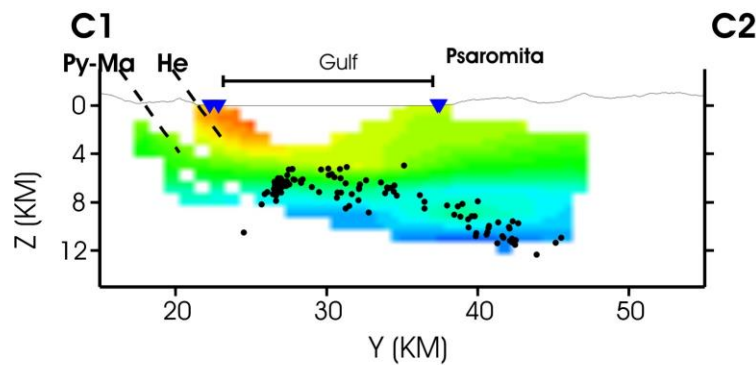
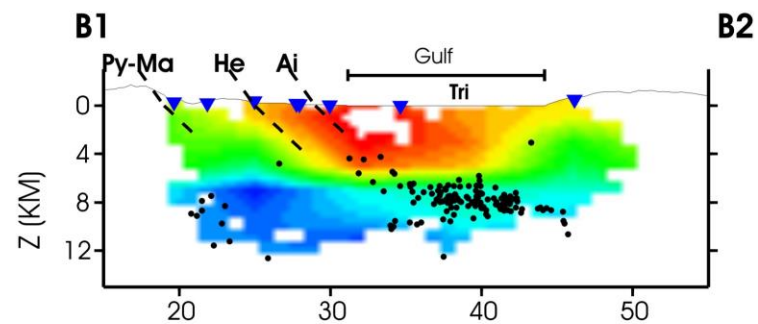
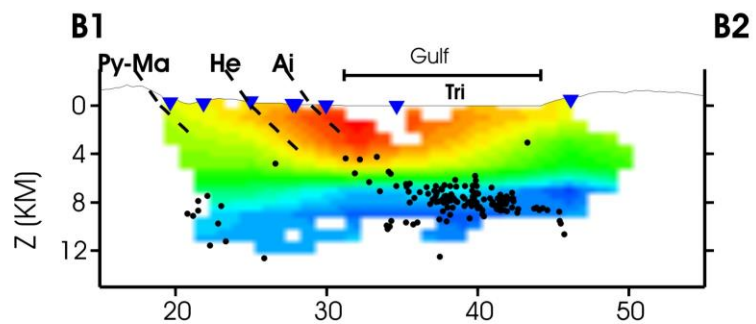
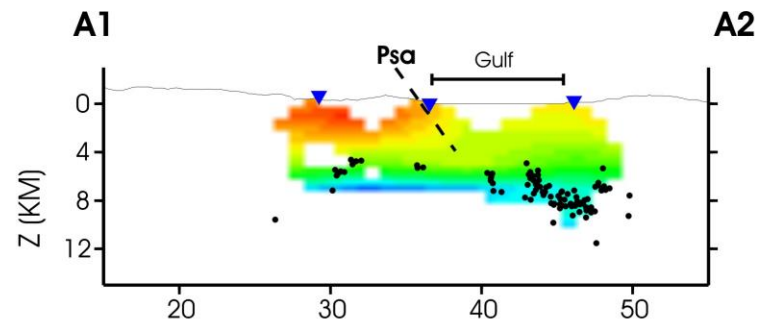
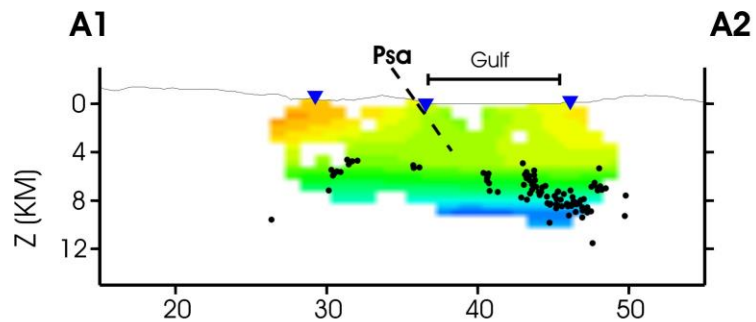


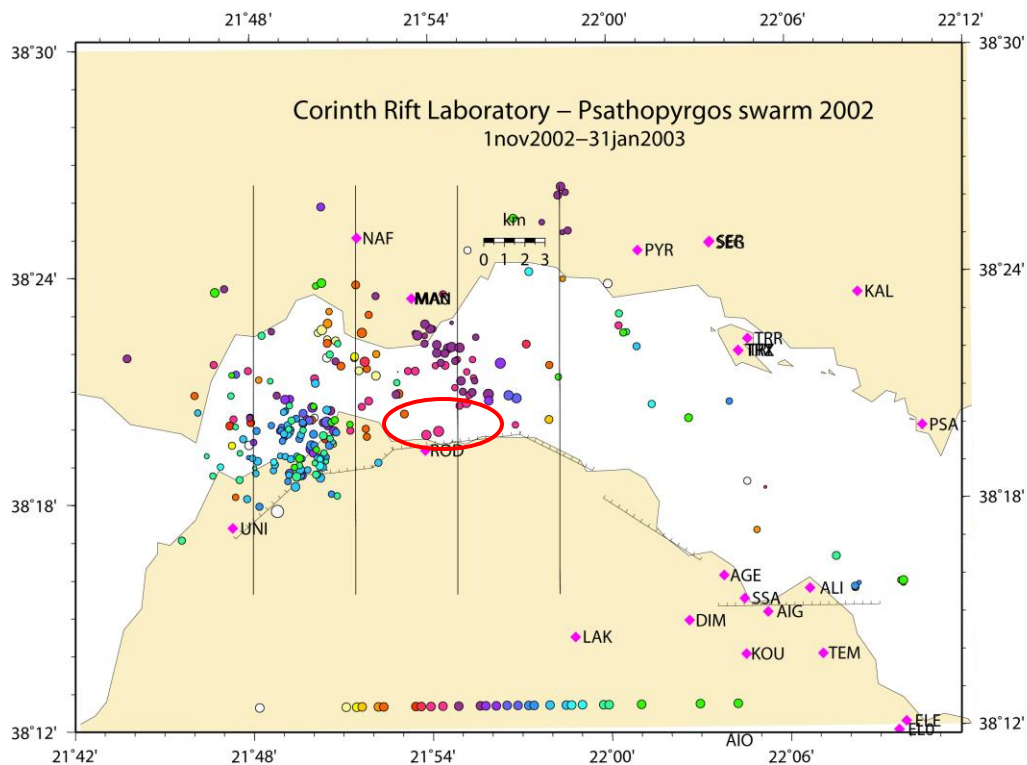
Extension du modèle avec des Pn

Sachpazi et al., Tectonophys. 2007

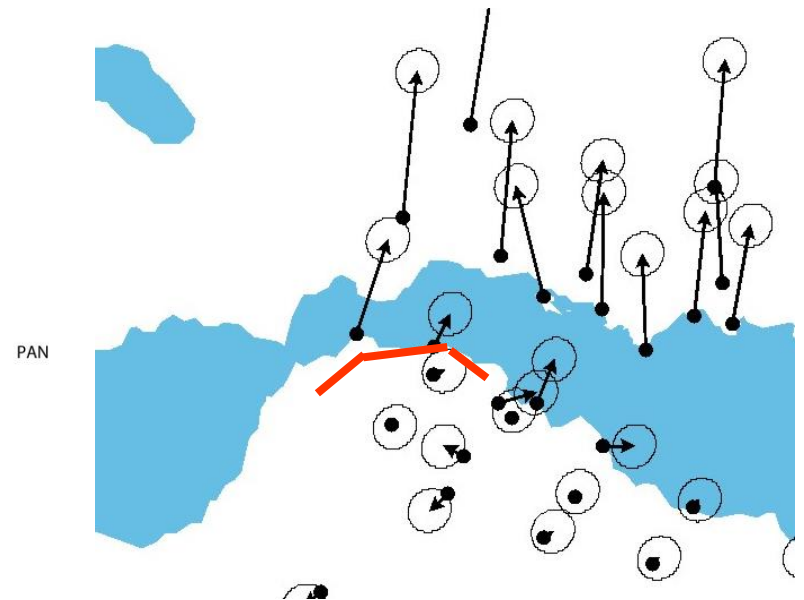








Nov 02 – jan 03:
**Creep from seismic swarm
and strain transient**



Avalone et al. 2004

1990-2001:
**Creep from GPS
1.5 cm/yr**