Observatoire de Corinthe
Corinth Rift Laboratory (CRL)

P. Bernard, H. Lyon-Caen, A. Deschamps, S. Lambotte, P. Briole , A. Nercessian, M. Aissaoui, M. Grunberg, M. Ford, Ch. Beck, A. Hubert-Ferrari, F.Cornet, P. Elias, M. Vidal, N. Meyer, A. Canitano, M. Godano, O. Scotti, A. Boiselet, S. El Arem, C. Duverger, P. Dublanchet, A.Serpetsidaki, E. Sokos, P. Papadimitriou, V. Kapetanidis, N. Voulgaris , P. Albini, D. Katsonopoulou, J .Zahradnick, K. Makropoulos, A. Tselentis,
et al …

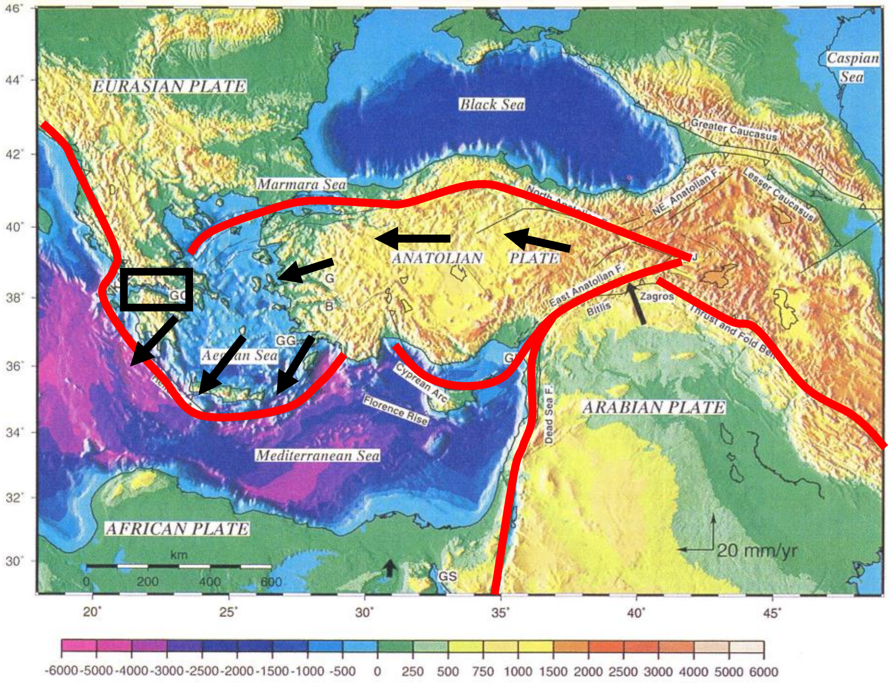
France : IPGP, ENS, GEOAZUR, EOST, CRPG, IRSN, Ecole Mines, Univ. Montpellier , ISTerre ….
Greece: NKUA, Univ. Patras, NOA
Belgium : Univ. Liège
Italy : INGV (Rome, Milano, Napoli)
Czech Rep., : Charles Univ. Prague

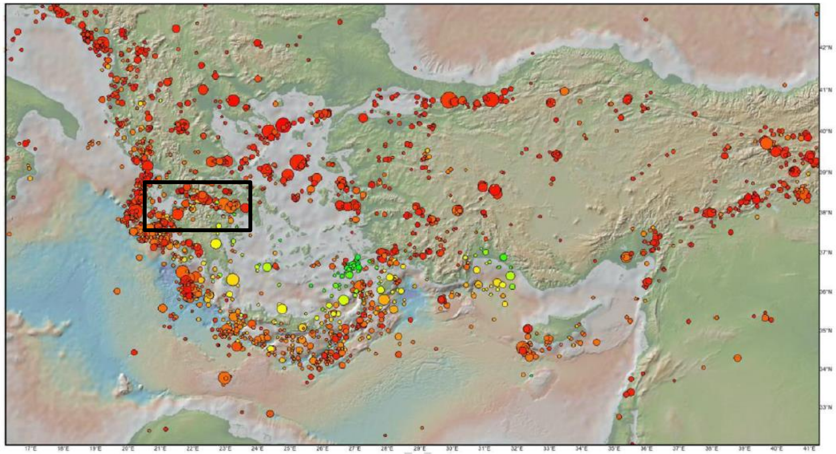
http:/www.crlab.eu

EC projects:

… CORSEIS, 3HAZ, REAKT, SERA

French ANR SISCOR

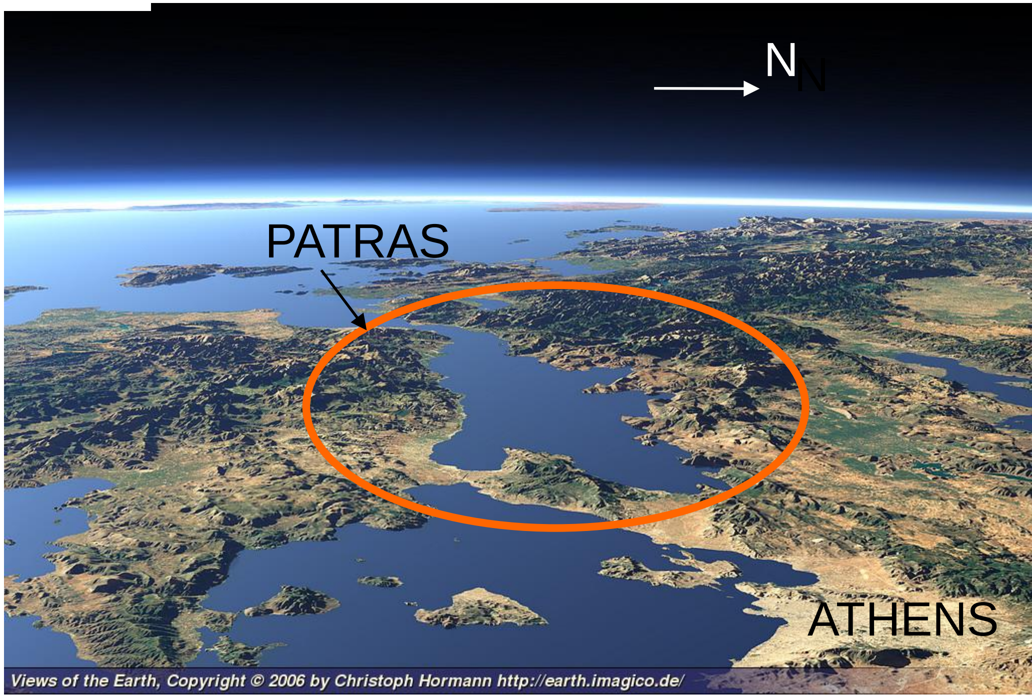


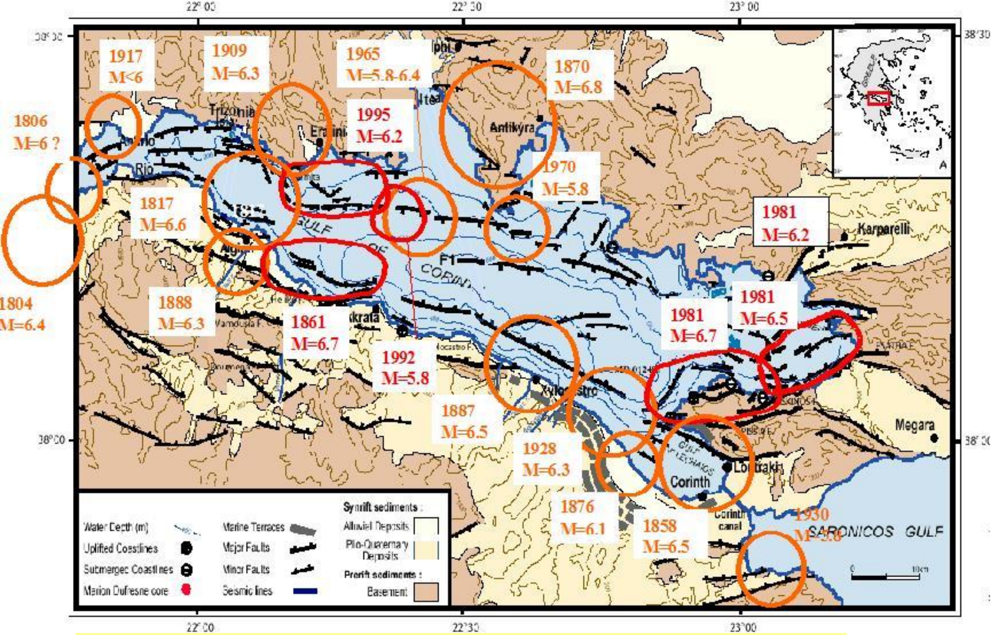


USGS-NEIC
1970+ M>4.5

The rift of Corinth:

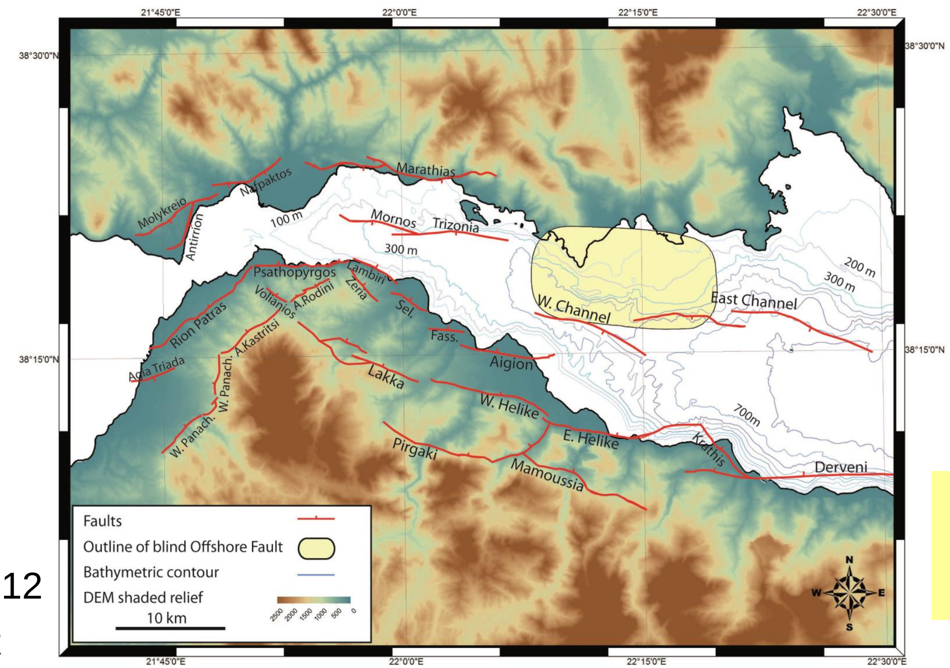
- Extension of the Aegean plate due to the roll-back of the subducting African plate
- connection with northern branch of the North Anatolian Fault
- Associated to a large instrumental and historical earthquakes – M ~ 6.5-7





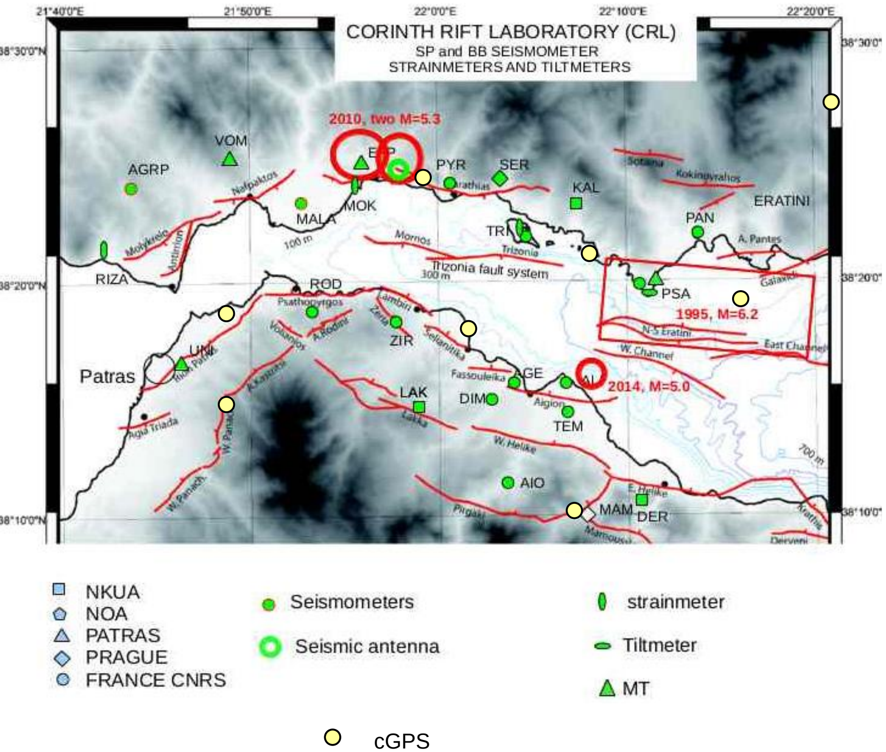
Major Earthquakes since 1800

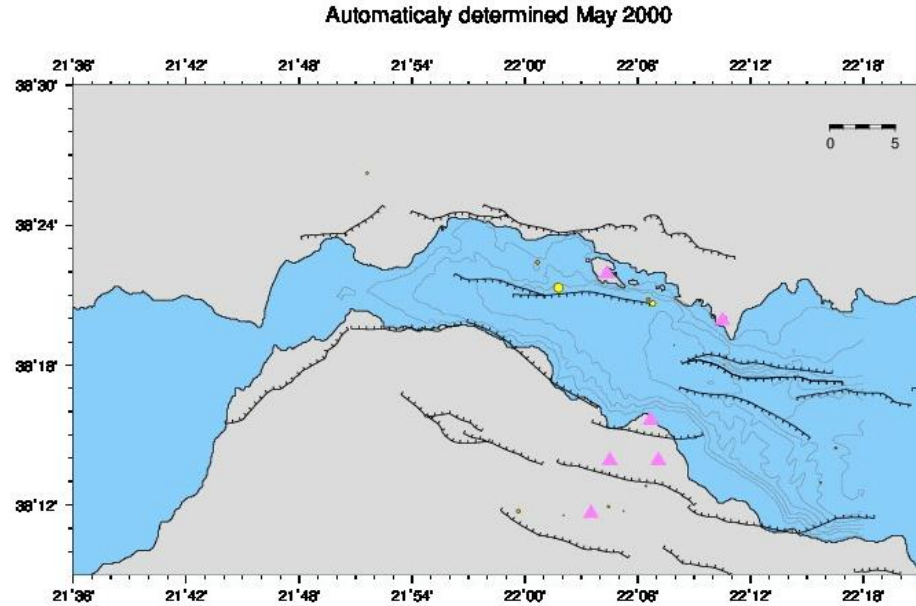
Helike fault scarp



Ford, Meyer, 2012 – ANR SISCOR

Main faults in the western rift of Corinth





Seismicity 2001-2013

- 1995 Aigion earthquake, M=6.2, low-dip, blind normal fault

CRL starts in 2000, seismology

+ multiparameter monitoring (GPS, strain, MT, …)

Seismicity 2000-2014 : ~ 10 000 EQ/year – large swarms, days to months

M compl. ~ 1.5

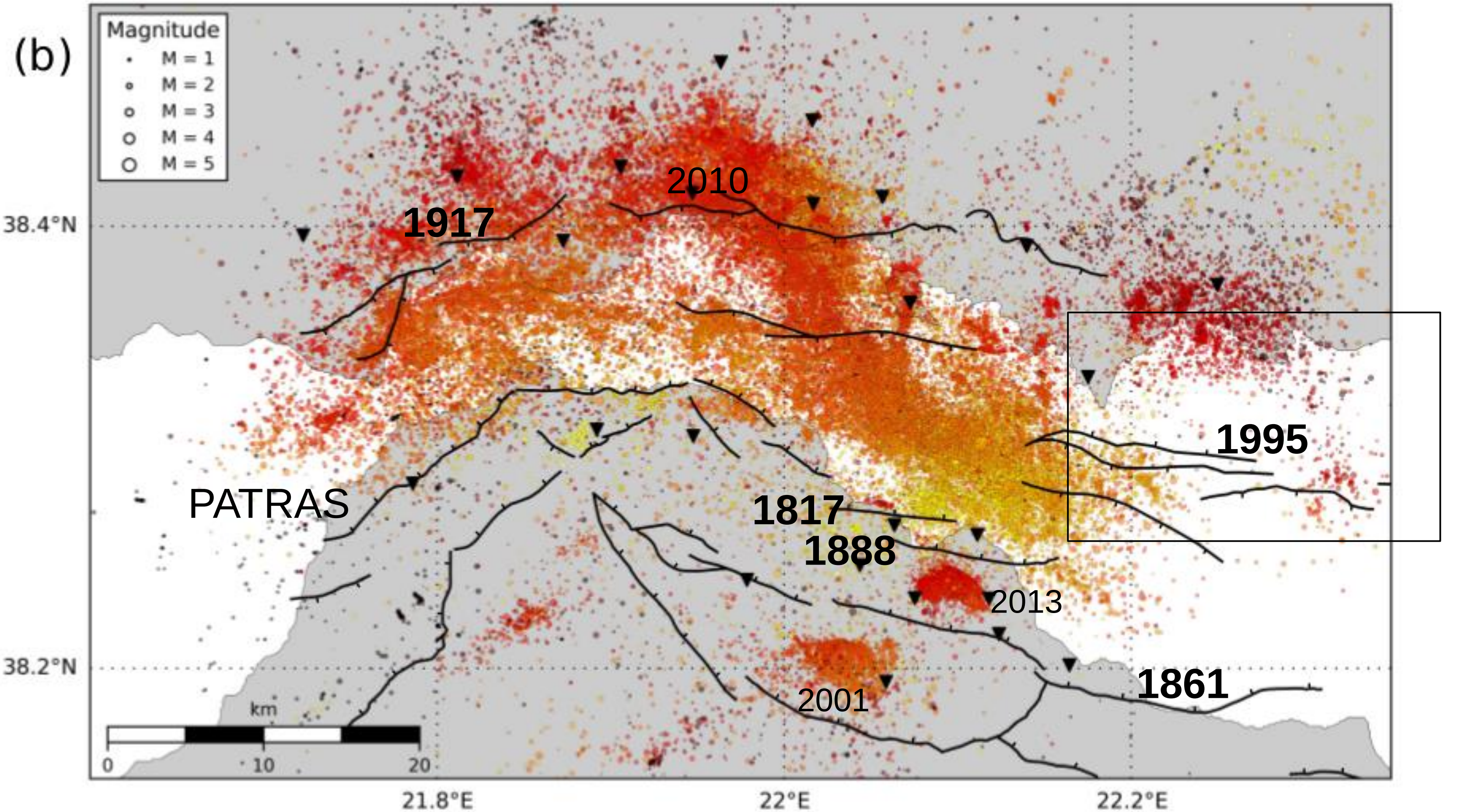
two M=5.3, 2010

M=5.0 , 2014

Relocated seismicity 2000-2015

HypoDD –

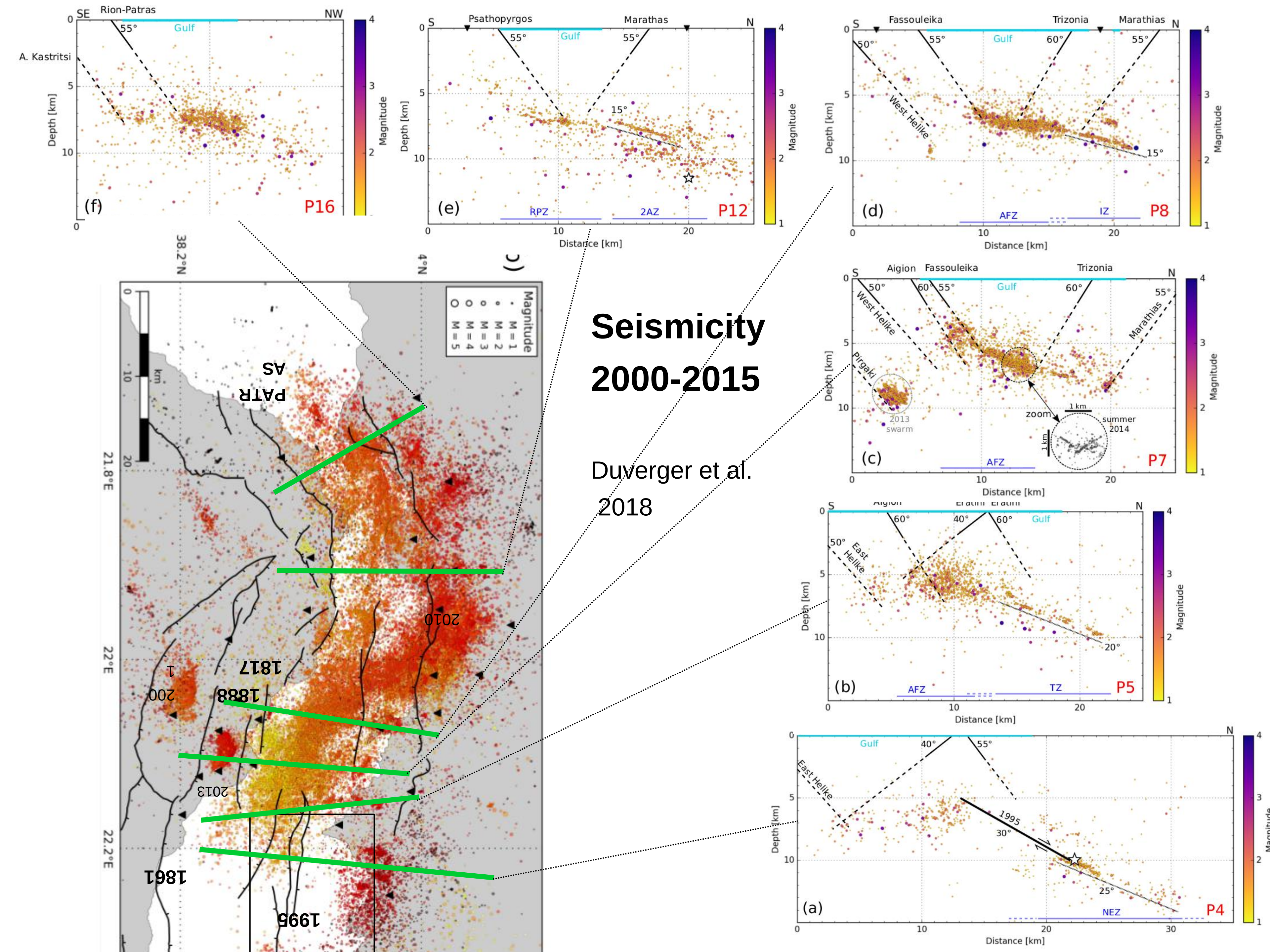
200,000 evts



Duverger et al., 2018

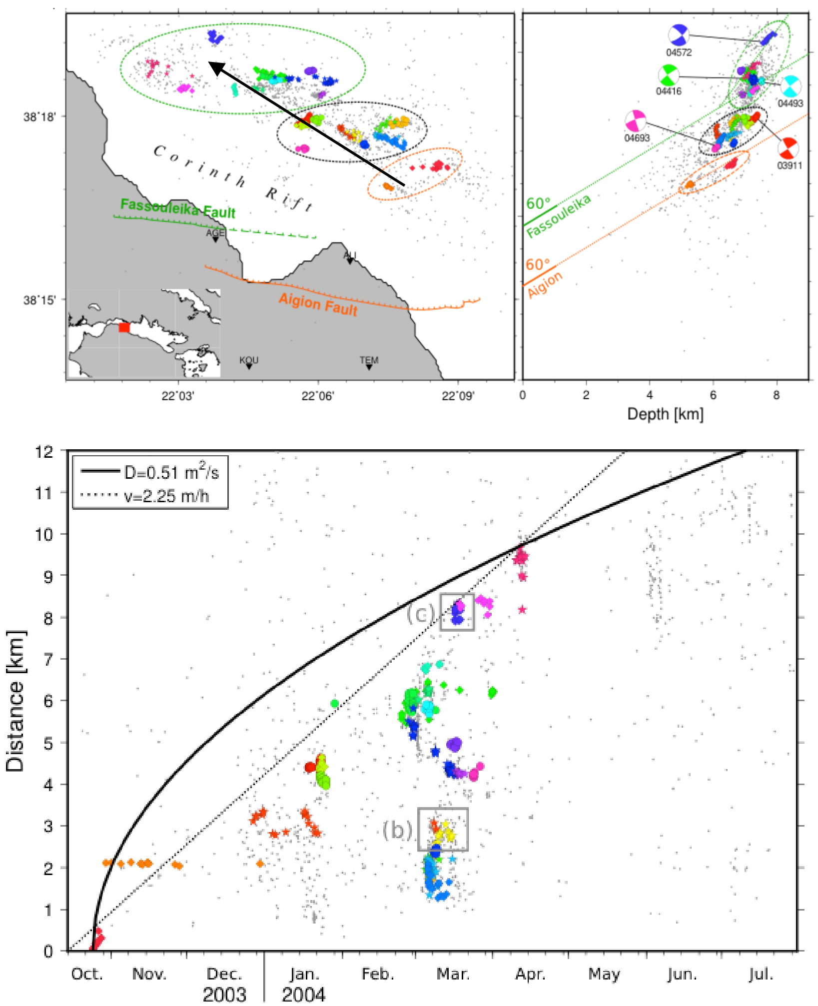
Seismicity 2000-2015

Duverger et al. 2018



Space-Time characteristics of microseismicity: Swarms and migration

Swarm 2004



Duverger et al. 2015

Swarm 2014

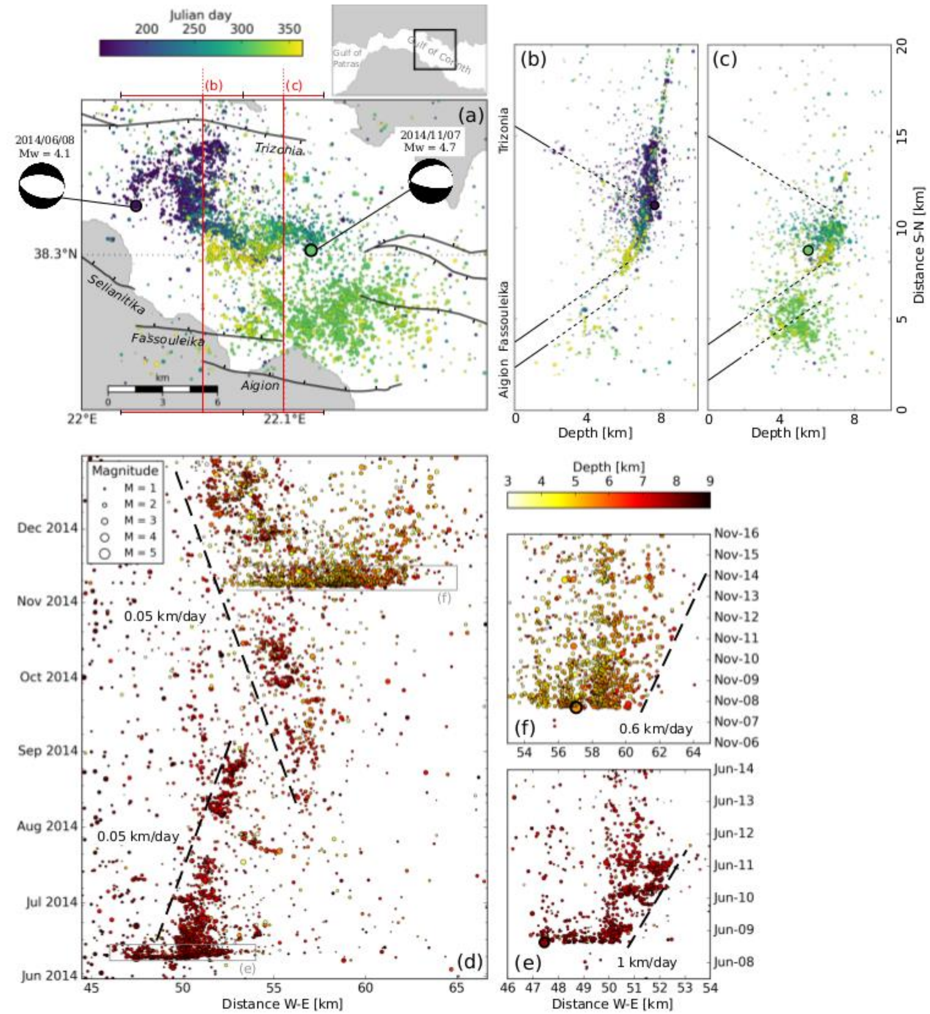
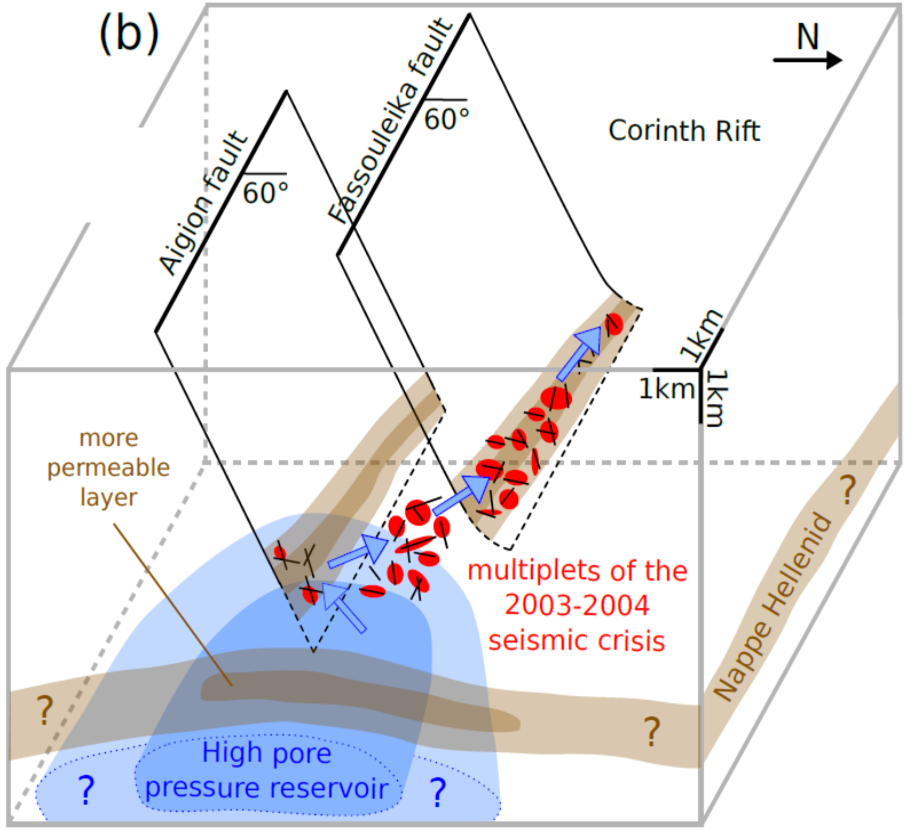


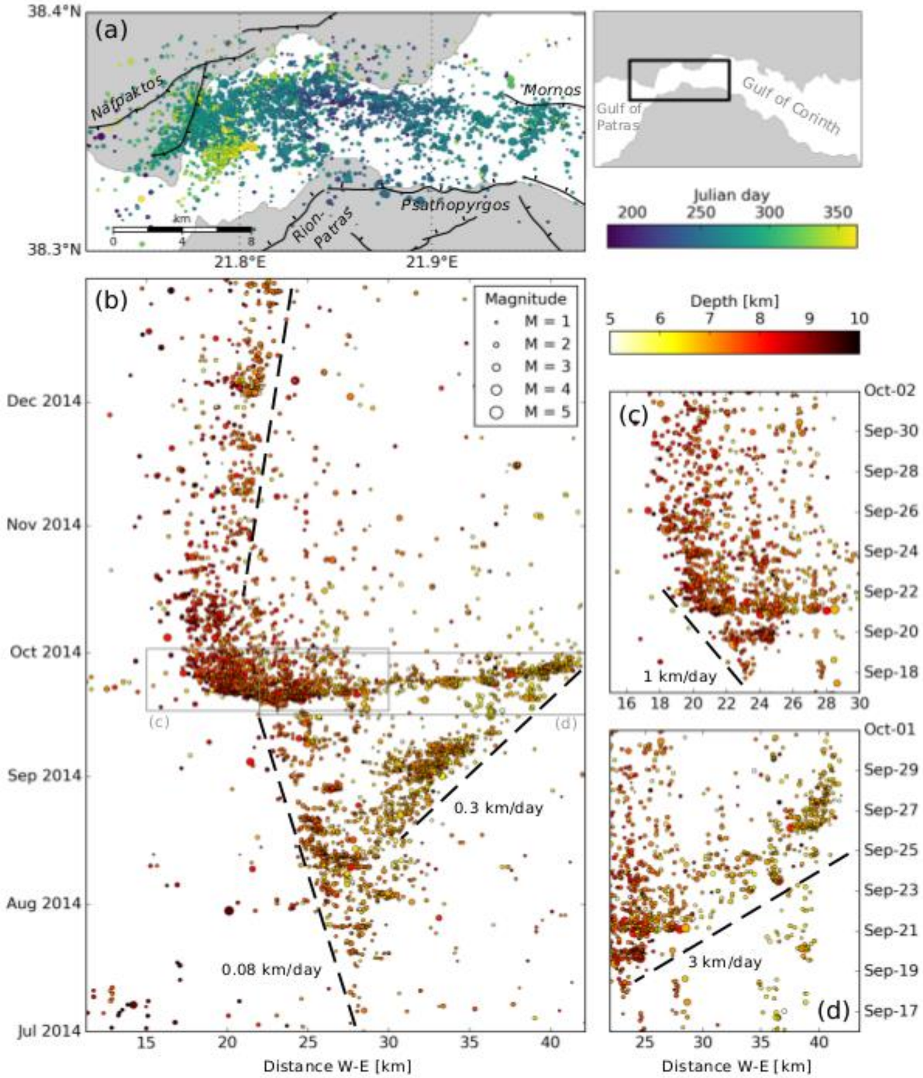
Figure 7. Seismic migration velocities during the western (ZW) swarm in 2014. (a) Map of the seismicity

Duverger et al. 2018



Permeable corridor at the intersection of the active normal faults and a geological structure (Phyllade nappe?)

Space-Time characteristics of microseismicity: Swarms and migration



Migration velocity < 0.5-1 km/day
Pore pressure diffusion control

Migration velocity> 1 km/day
Creep diffusion control

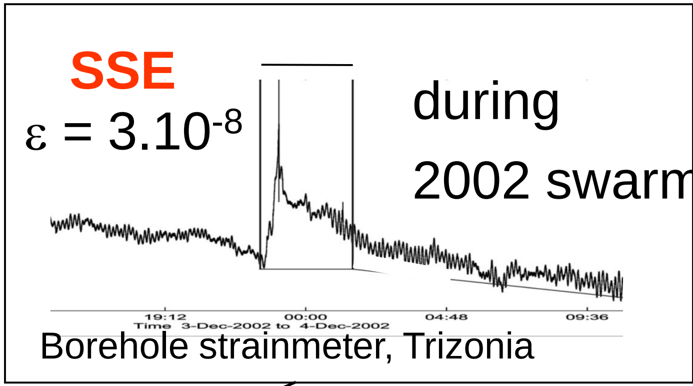
Swarm summer 2014

Duverger et al. 2018

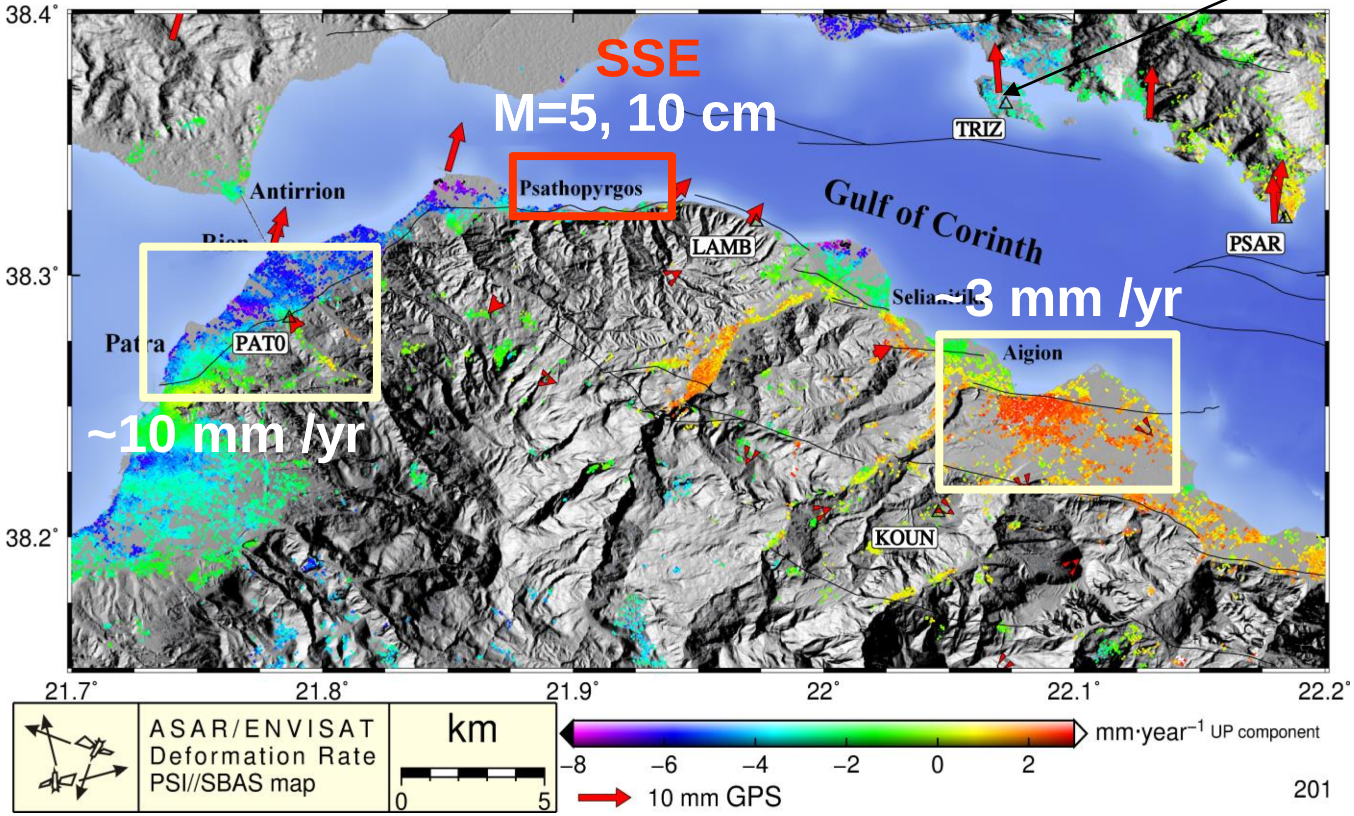
Aseismic creep on major faults

from GPS, InSAR, and borehole strainmeters

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



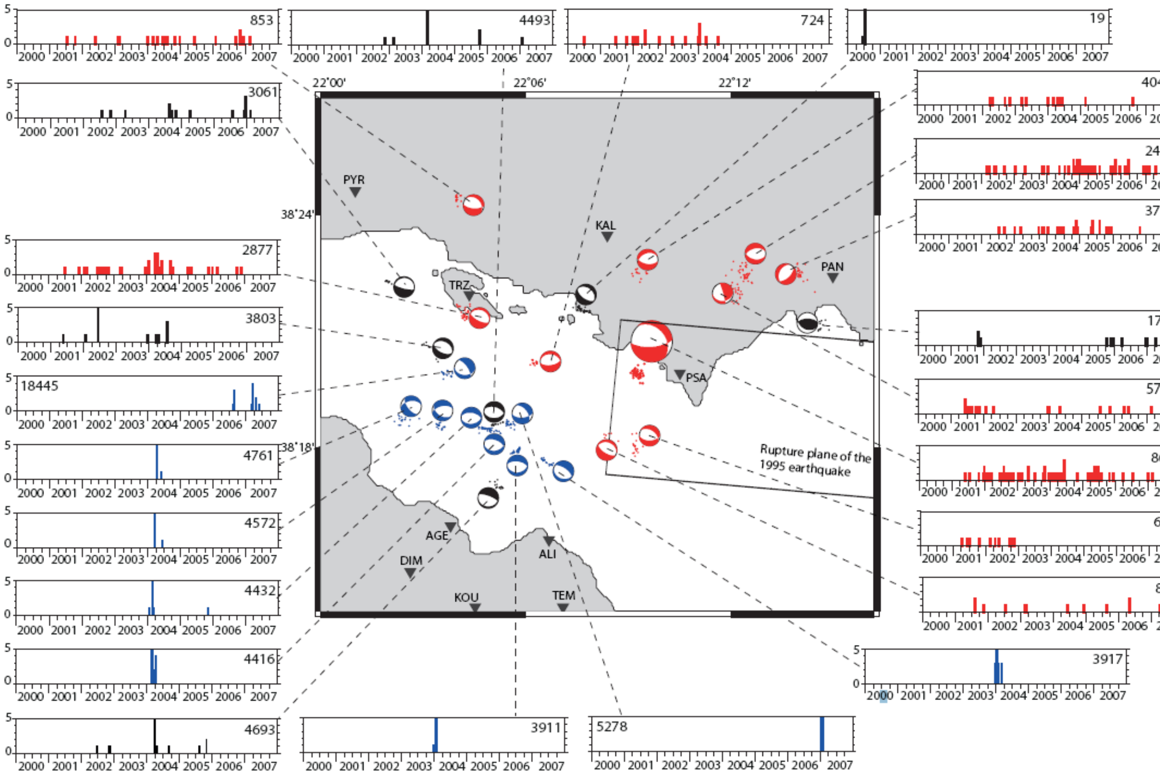
Bernard et al., 2008

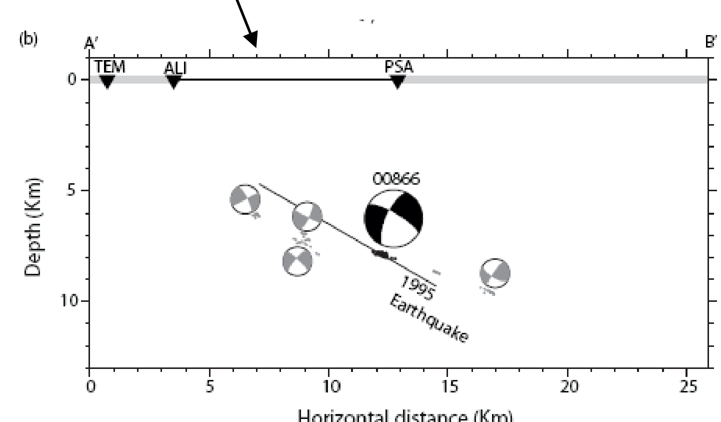


Elias and Briole, 2013

Continuous creep on deep faults:

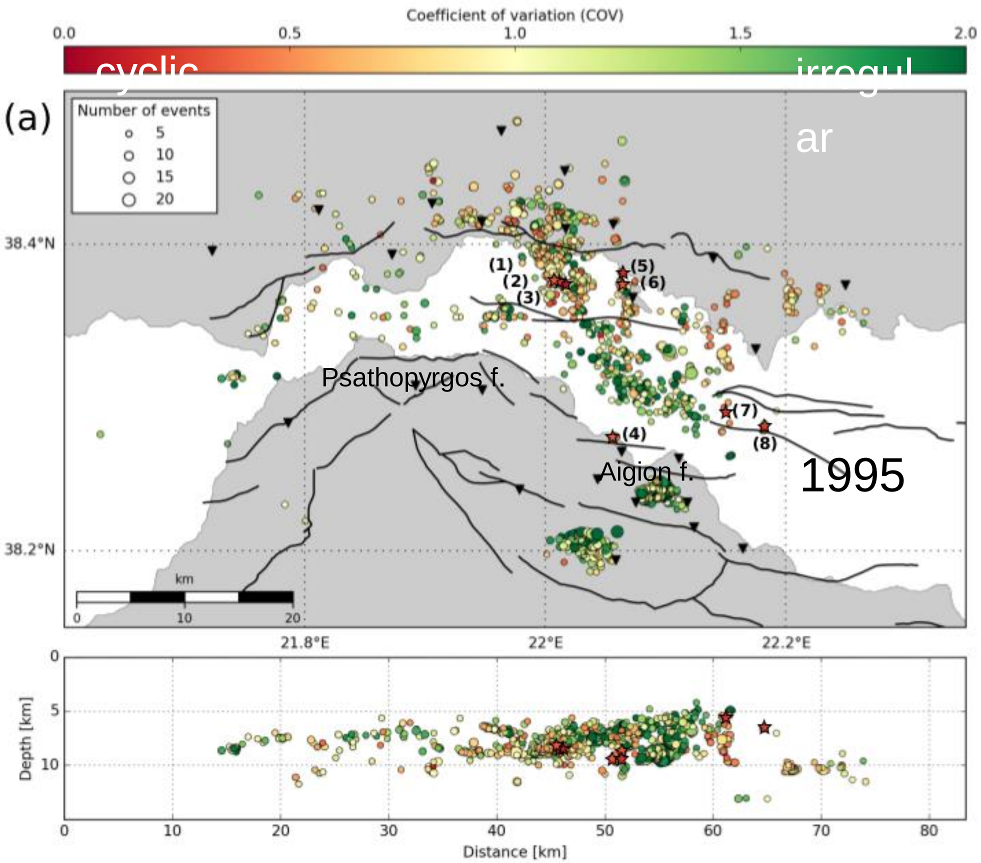
Evidence from persistent multiplets?

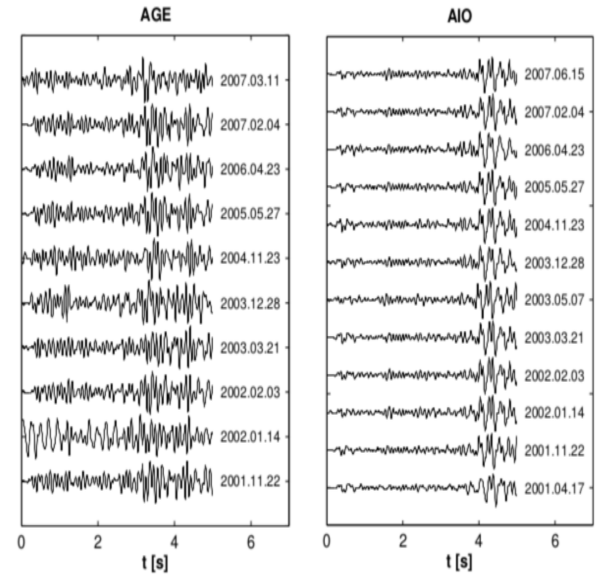


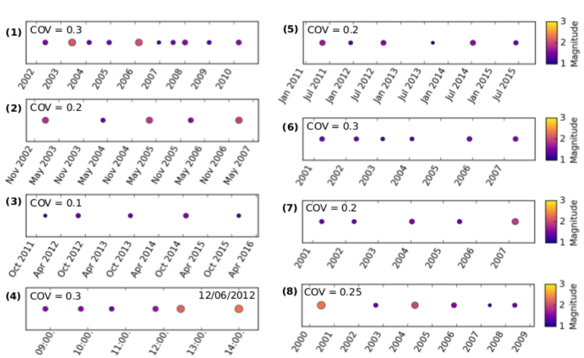


Godano et al. , 2015

Interevent times of earthquakes within multiplets







cyclic multiplets / repeaters
surrounding:

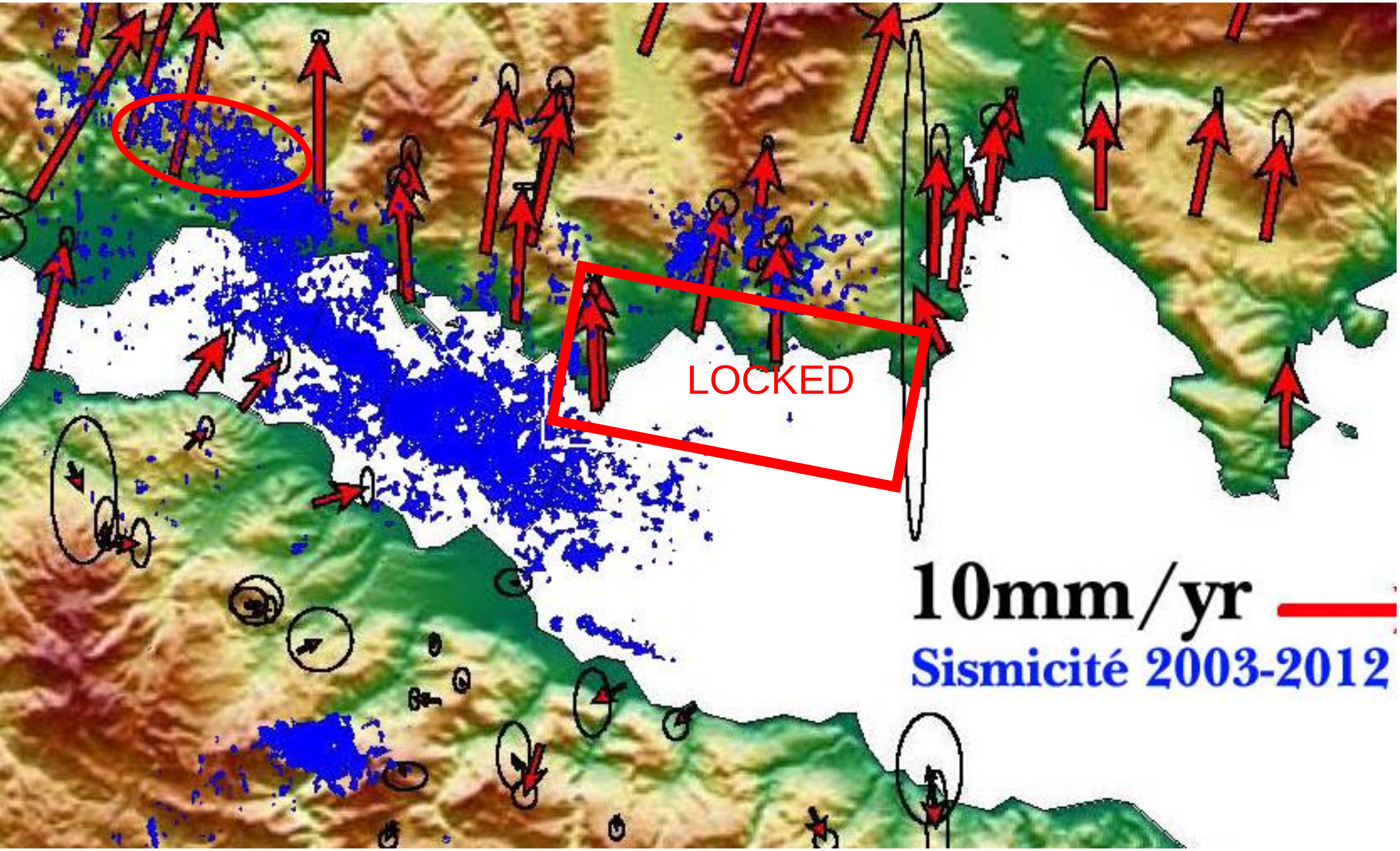
- 1995 fault zone
- deep Agion fault zone
- deep Lambiri/Psathopyrgos fault zone

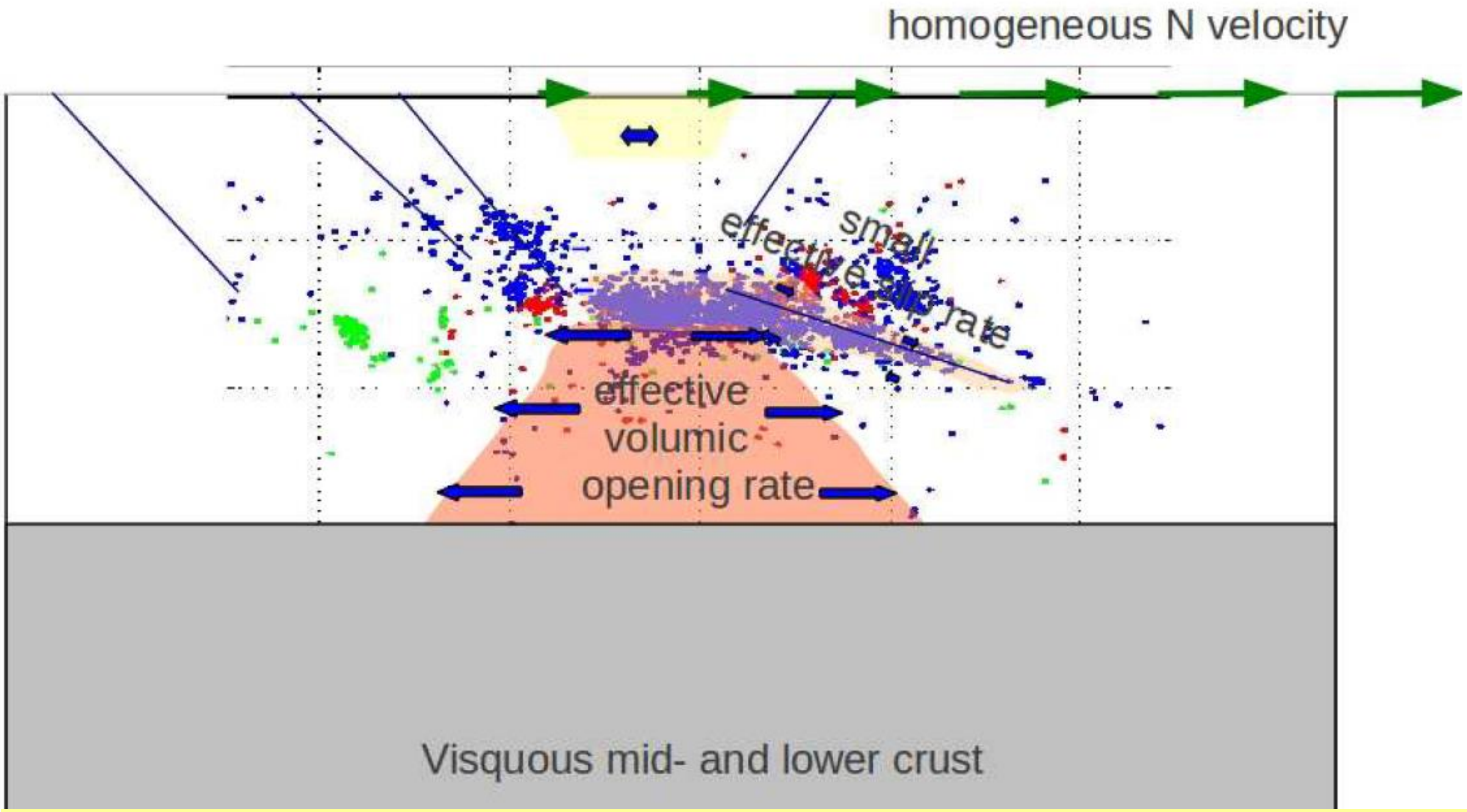
Duverger et al. 2018

Locked fault surfaces on 1995 and 2010 rupture zones :

Does not seem to affect GPS rates –

Suggests deeper or shalower interseismic sources



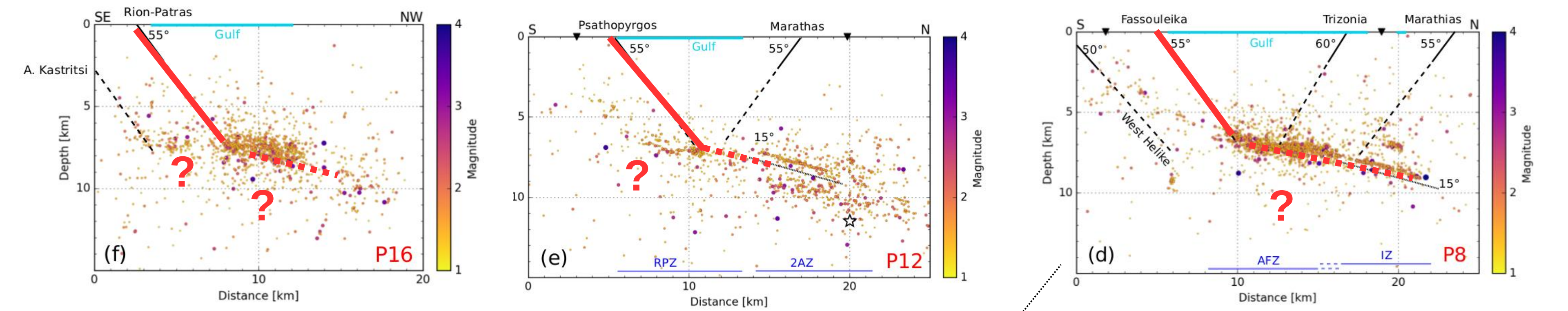


The « detachment » is probably unmature, growing downwards,

- not yet efficiently connected to the visquous mid-crust

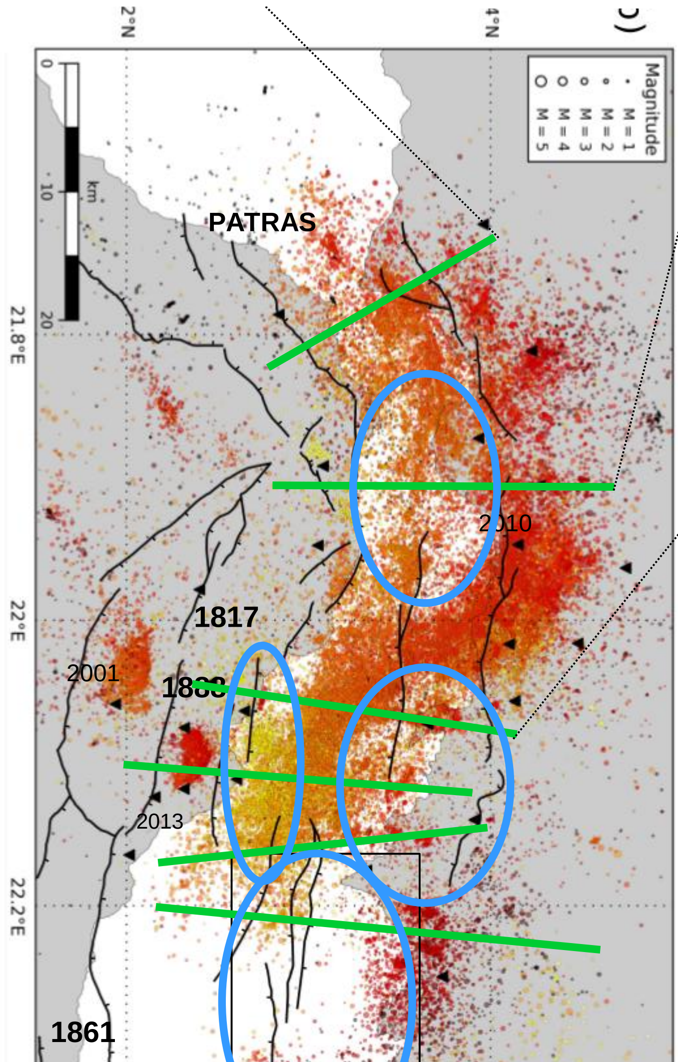
- not the main guide for the western rift opening…

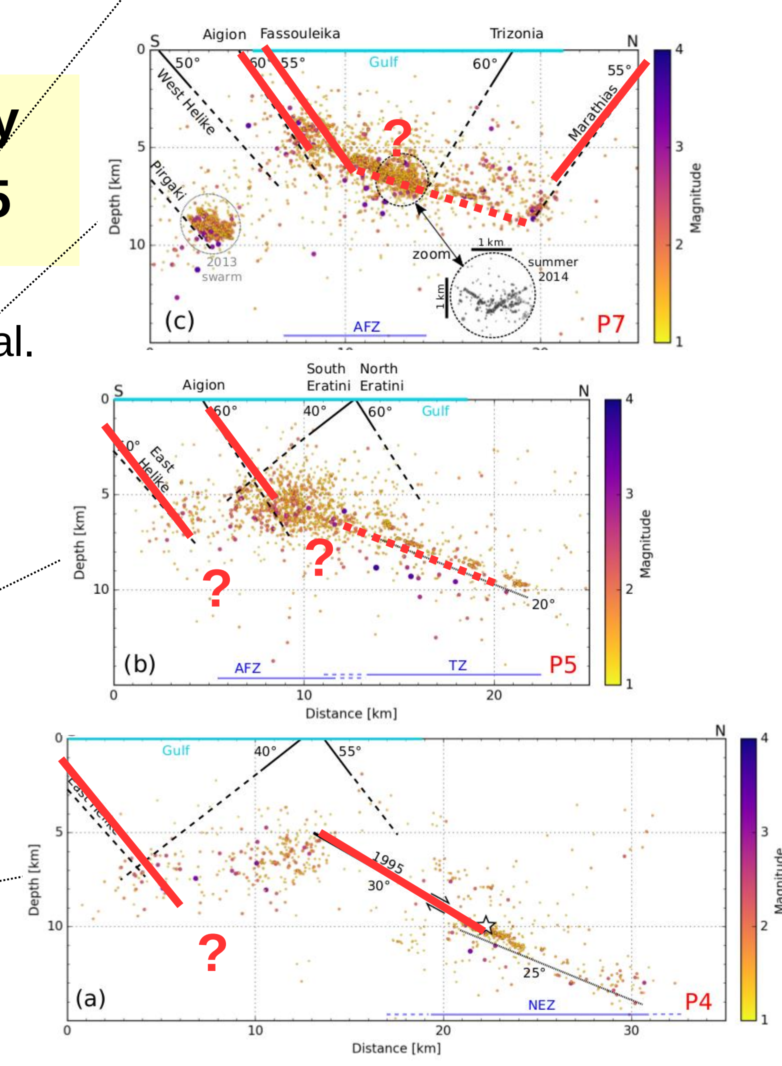
Lambotte et al. 2013



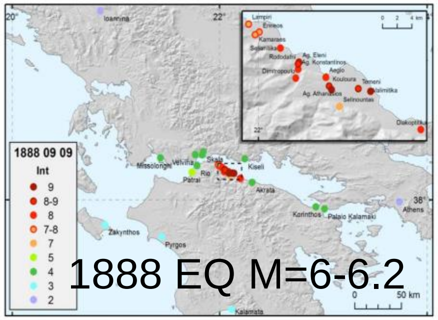
Seismicity 2000-2015

Duverger et al. 2018





Earthquake rupture forecast for M>6



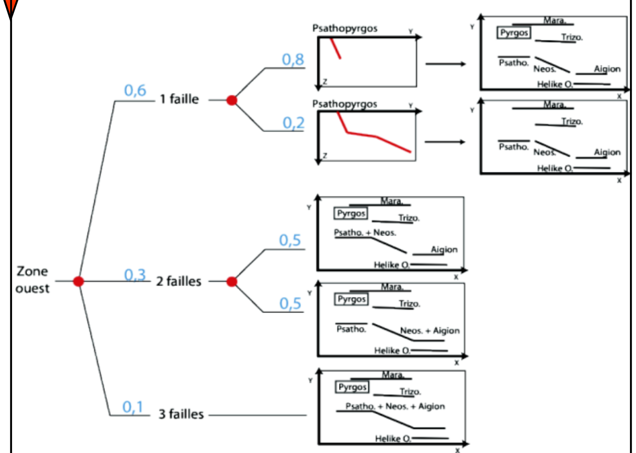
Albini, 2013;

- Fault slip rates
- Strain from geodesy
- Paleoseismicity
- Historical seismicity
- Instrumental seismicity

+ uncertainties

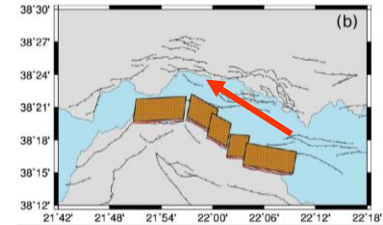
Logic tree:

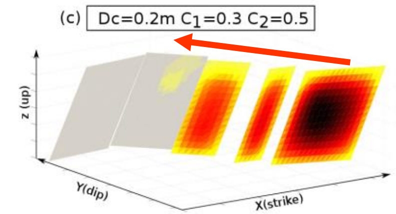
- Seismicity models
- fault geometries



Boiselet et al. , 2014

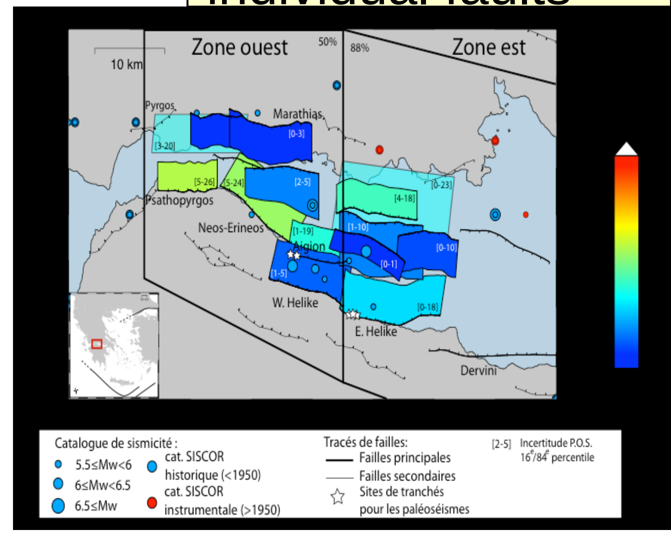
Dynamic ruptures across fault segments



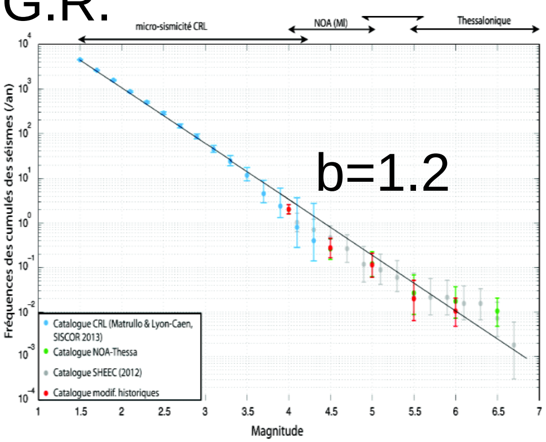


Durand et al. 2014

ERF forecast for individual faults



G.R.



Next 30 years:

P=1 % to 20 % of rupture on individual faults

P>50% on the fault system

études en cours sur CRL

- **Imagerie de la Structure :**
  ondes de surface par corrélation de bruit (UPatras)
  temps d'arrivées de la microsismicité (Ecole des Mines, ENS,...)
  Fonction récepteur : interfaces crustales (Montpellier, Ecole des Mines)
  Anisotropie des ondes S (NKUA)

- **Imagerie des Sources :** ENS, IPGP, Géoazur, Isterre, ...
  analyse des multiplets long et court terme
  dynamique spatio-temporelle de la sismicité

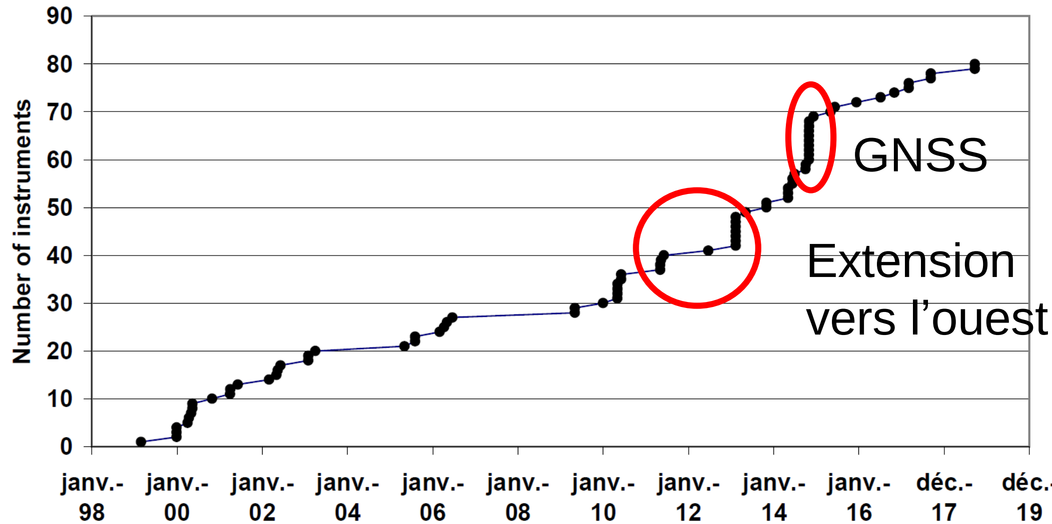
- **aléa sismique**
  lois d'atténuation pour évaluation rapide de dégats : Aigion et Patras (NKUA)
  utilisation des flux temps réel pour alerte précoce au séisme (Upatras)

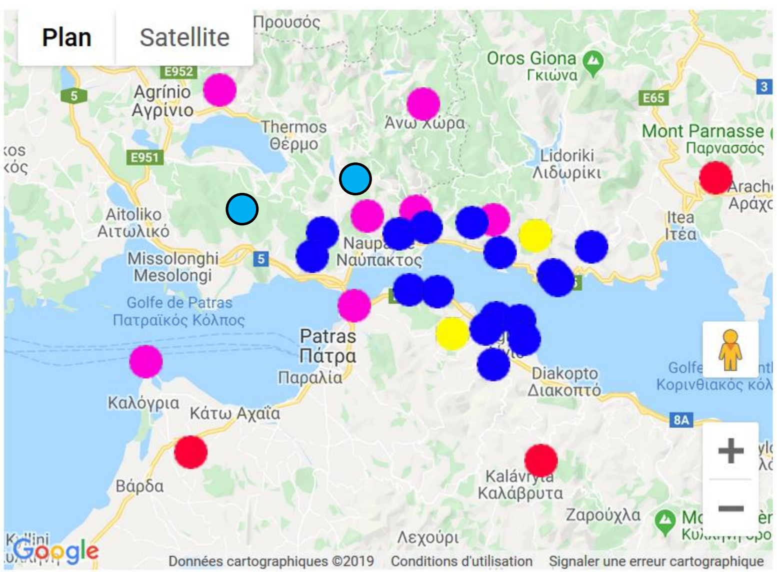
CRL : Near Fault Observatory (NFO) , EPOS

crlab.eu

70 articles depuis 2005
>20 thèses

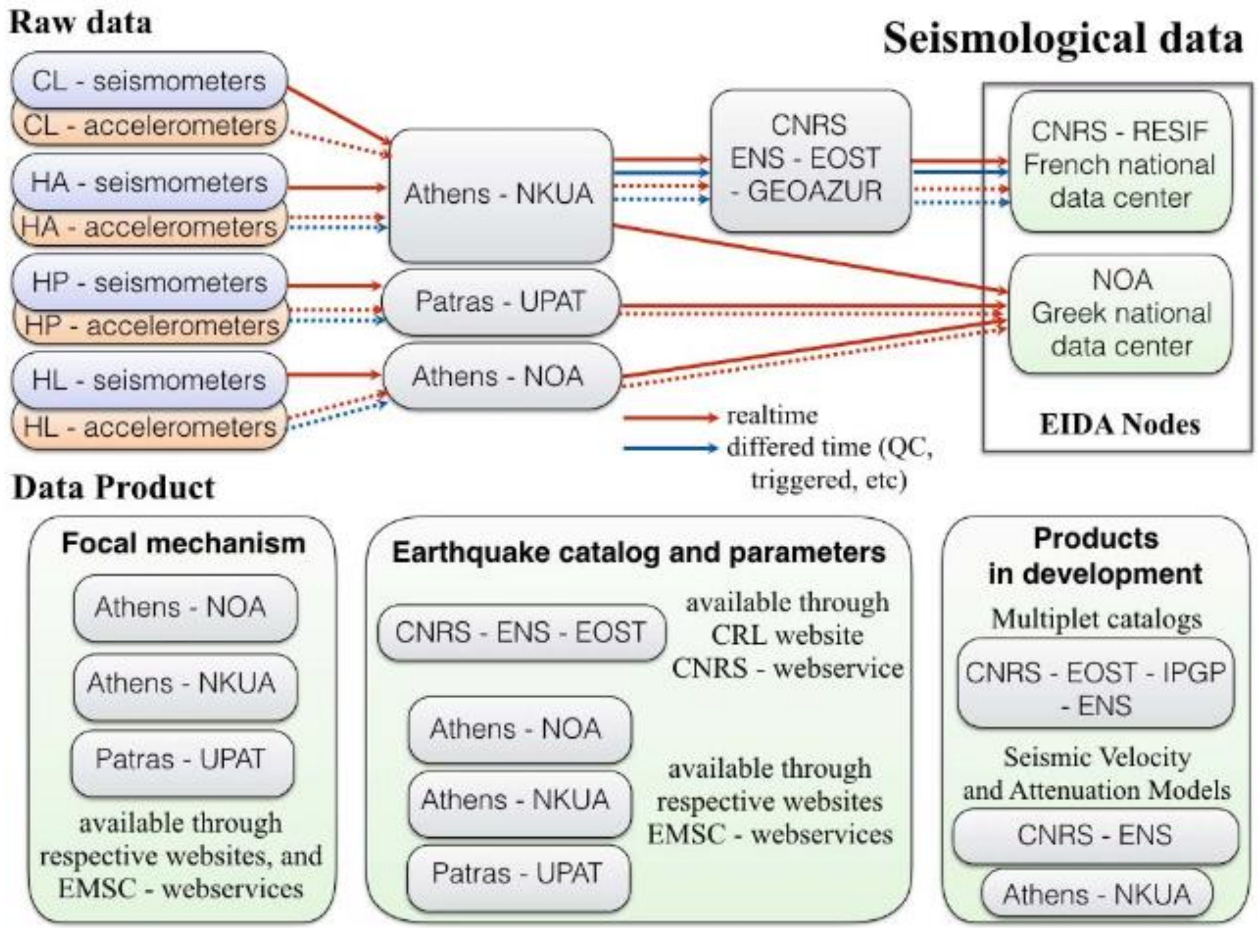
2019: 83 instruments on
70 différent sites operated by:
51 CNRS
10 UPAT
12 NOA
7 NKUA
3 CUP





Velocimétrie et déformation
en bleu les instruments du CNRS

Toutes les données (velocimétrie et GNSS) sont collectées en temps réel


Raw data
Seismological data
CL - seismometers
CL - accelerometers
HA - seismometers
HA - accelerometers
HP - seismometers
HP - accelerometers
HL - seismometers
HL - accelerometers
Athens - NKUA
Patras - UPAT
Athens - NOA
CNRS
ENS - EOST
- GEOAZUR
CNRS - RESIF
French national
data center
NOA
Greek national
data center
EIDA Nodes
realtime
differed time (QC,
triggered, etc)
Data Product
Focal mechanism
Athens - NOA
Athens - NKUA
Patras - UPAT
available through
respective websites, and
EMSC - webservices
Earthquake catalog and parameters
CNRS - ENS - EOST
available through
CRL website
CNRS - webservice
Athens - NOA
Athens - NKUA
Patras - UPAT
available through
respective websites
EMSC - webservices
Products
in development
Multiplet catalogs
CNRS - EOST - IPGP
- ENS
Seismic Velocity
and Attenuation Models
CNRS - ENS
Athens - NKUA

CRL :

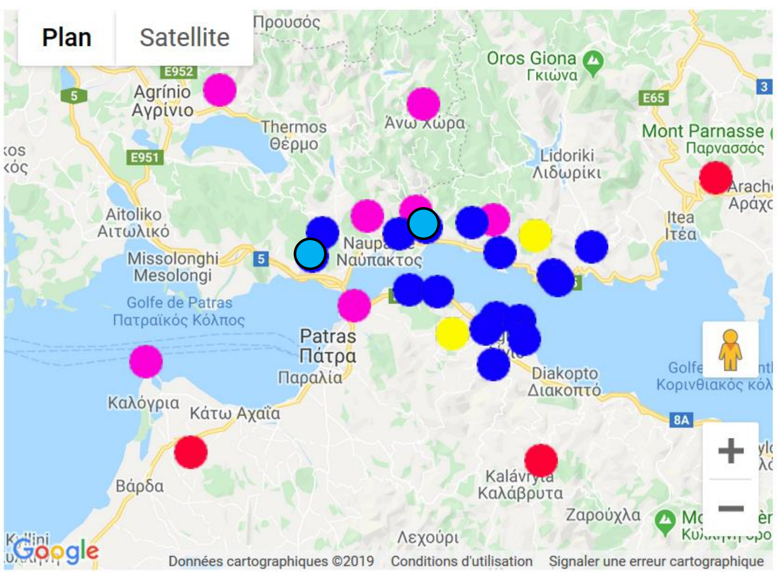
- Near Fault Observatory (NFO) dans EPOS depuis 2017

- données CRL sismo et GNSS disponibles en temps réel par RESIF
- comité de coordination CRL, bureau de direction des 5 NFOs
- financement grec indépendant (HELPOS)
-

- “Site instrumenté” de l'INSU depuis 2017

mais pas de soutien récurrent du CNRS : 0 ke en 2017-2018, 5 ke en 2019

→ financement sur projet ANR et EC jusqu'en 2015
\+ soutiens ponctuels des labos



→ **Infrastructure de terrain CRL en situation critique pour maintenance**

→ **besoin de 75 ke/an pour les 50 instruments du CNRS**

- **maintenance terrain**
- **base de données**
- **management**

(112 ke/an pour CRL)

CRL : observatoire international depuis 2001

- Near Fault Observatory (NFO) , EPOS, depuis 2017
- Site instrumenté de l'INSU depuis 2017

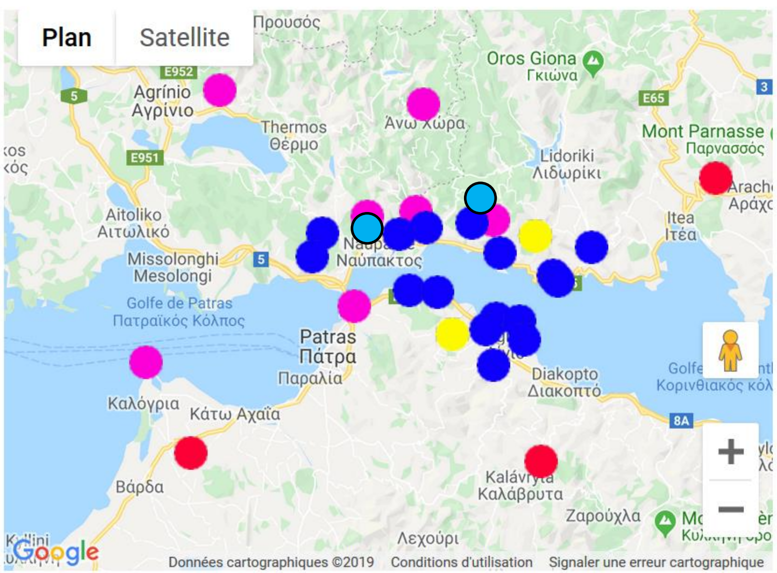
Observatoire = infrastructure de terrain + base de données

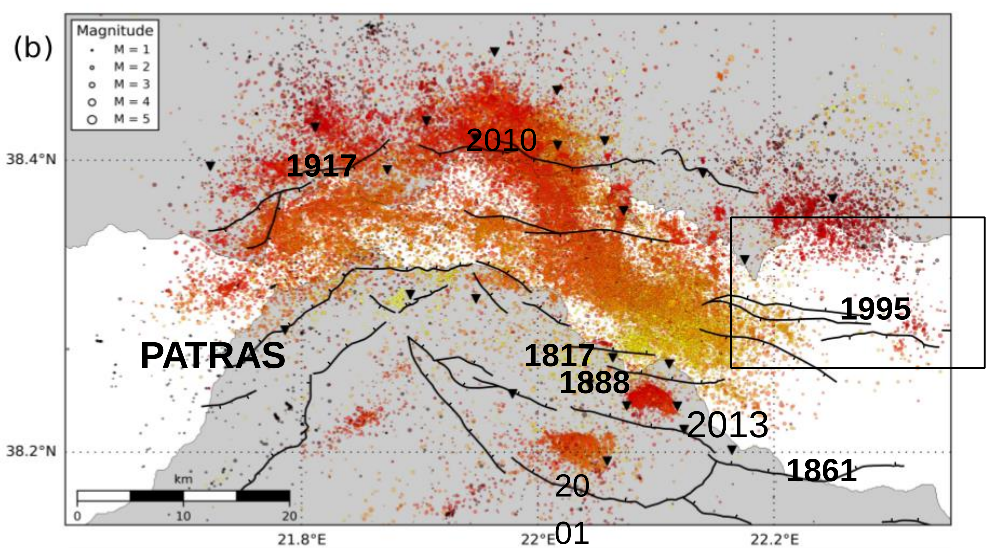
Quel statut/financement pour maintenir l'infrastructure de terrain?

France:

ENS, EOST, GEOAZUR, IPGP, GM, ISTerre, IRSN, Ecole Mines, ...

+ partenariat international: Grèce, Italie, Rep. Tchèque





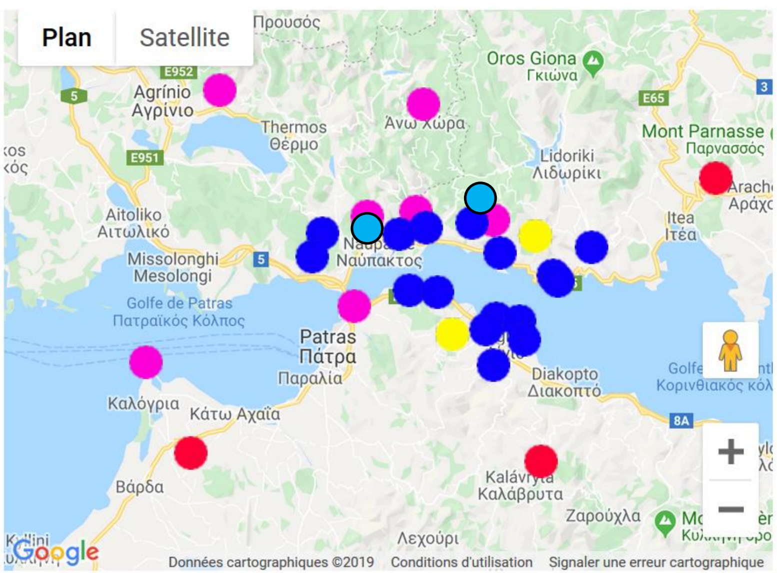
Observatoire international de Corinthe - CRL

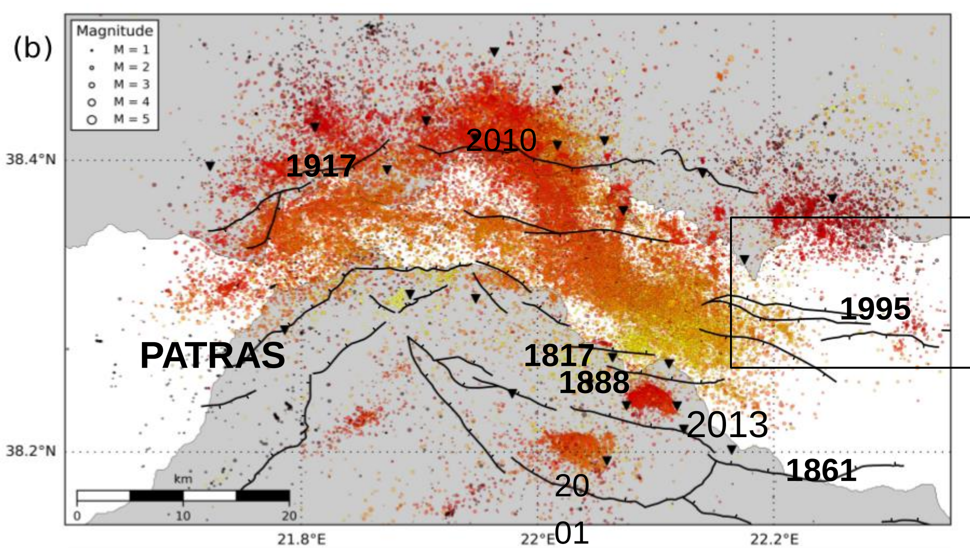
Thématiques de recherche sur le long terme

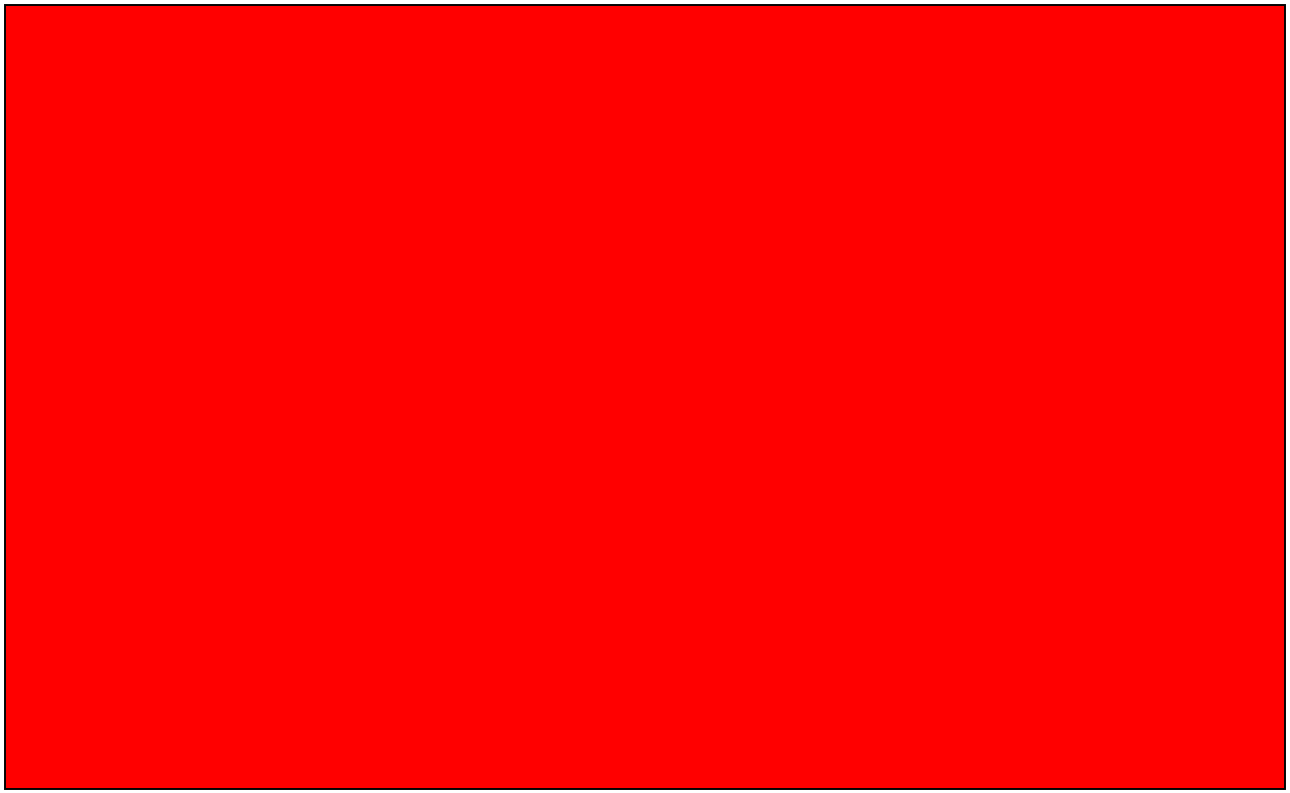
- Mécanique multi-echelle d'un système de failles
- Dynamique spatio-temporelle de la sismicité: essaims, migration, repeaters
- Couplages sismique/asismiques
- Rôle des fluides
- Lien entre structure crustale, sismicité, et déforation/glissements asismiques
- Mécanique du rifting
- Aléa et risque sismique

...

Continuité d'observation -> Maintien de l'infrastructure de terrain







Observatoire de Corinthe – NFO

Mécanique sismogène des failles:

Multidisciplinaire: Sismologie, géodésie, tectonique

Structure + Dynamique

Couplage sismique-asismique - rôle des fluides

- sismicité espace-temps
- multiplets - repeaters
- variation temporelle du milieu (corrélation de bruit, repeaters)
- tomographie 3D (réseaux actuels ou temporaires)
- recherche de transitoires asismiques (GPS, extensomètres)
- deformation GPS et INSAR : modeles elastiques
- lien sismicité / taux déformation
- modélisations hydromécaniques
- modélisation mécanique du rifting (cycles simiques) – 2D- 3D
- cinématique/mécanique des différentes zones sismogènes
- aléa sismique dépendant du temps
- mouvements forts (analyses et prédictions)
- risques: Aigion, Patras

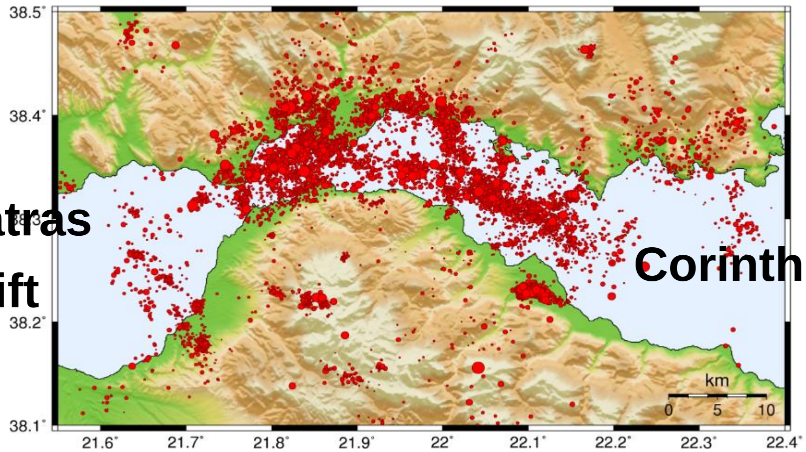
……

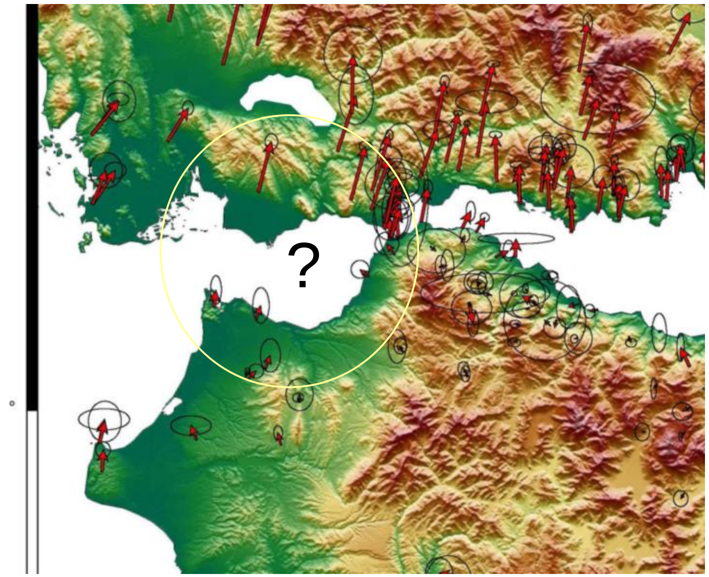
Instrumentation nouvelle

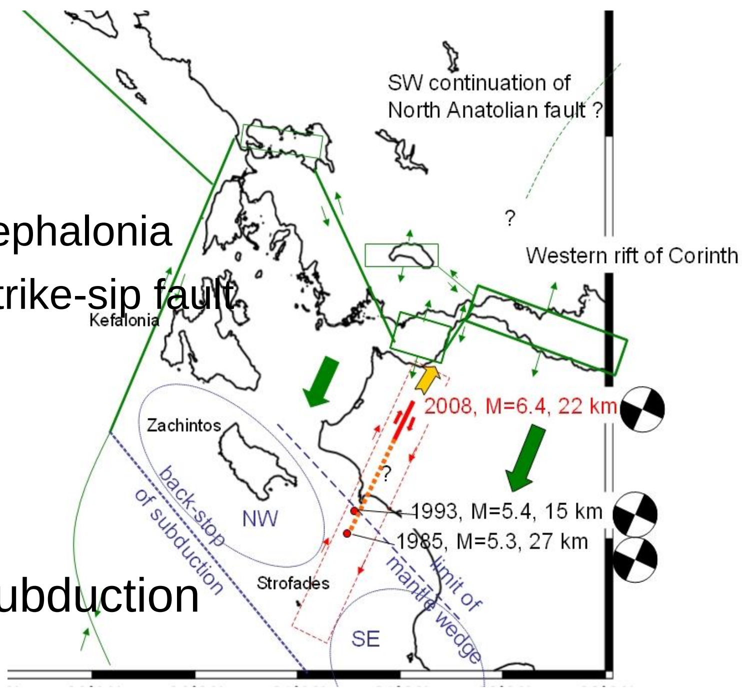
- Faille Rio-Patras / Psathopyrgos
- Réseaux temporaires tomo sismique
- instrumentation sous-marine
- MT – tomographie resistivité

Pascal Bernard
Pierre Briole
Lucile Bruhat
Louis de Barros
Fabian Bonilla
Anne Deschamps
Pierre Dublanchet
Blandine Gardonio
Stéphanie Gautier
Alexandrine Gesret
Maxime Godano
Agnès Helmstetter
Emilie Klein
Hélène Lyon-Caen
David Marsan
Jean-Arthur Olive
Alexis Rigo
Clara Duverger
Cécile Doubre
Françoise Courboulex
Claudio Satriano
Christel Tiberi
Sophie Lambotte
Olivier Lengliné
Sébastien Hock
Oona Scotti
Marc Noble
…….
+NKUA,NOA,UPatras,CUP,...

How does the rift change towards west?







Western Corinth **Near Fault Observatory (NFO-EPOS** **:**

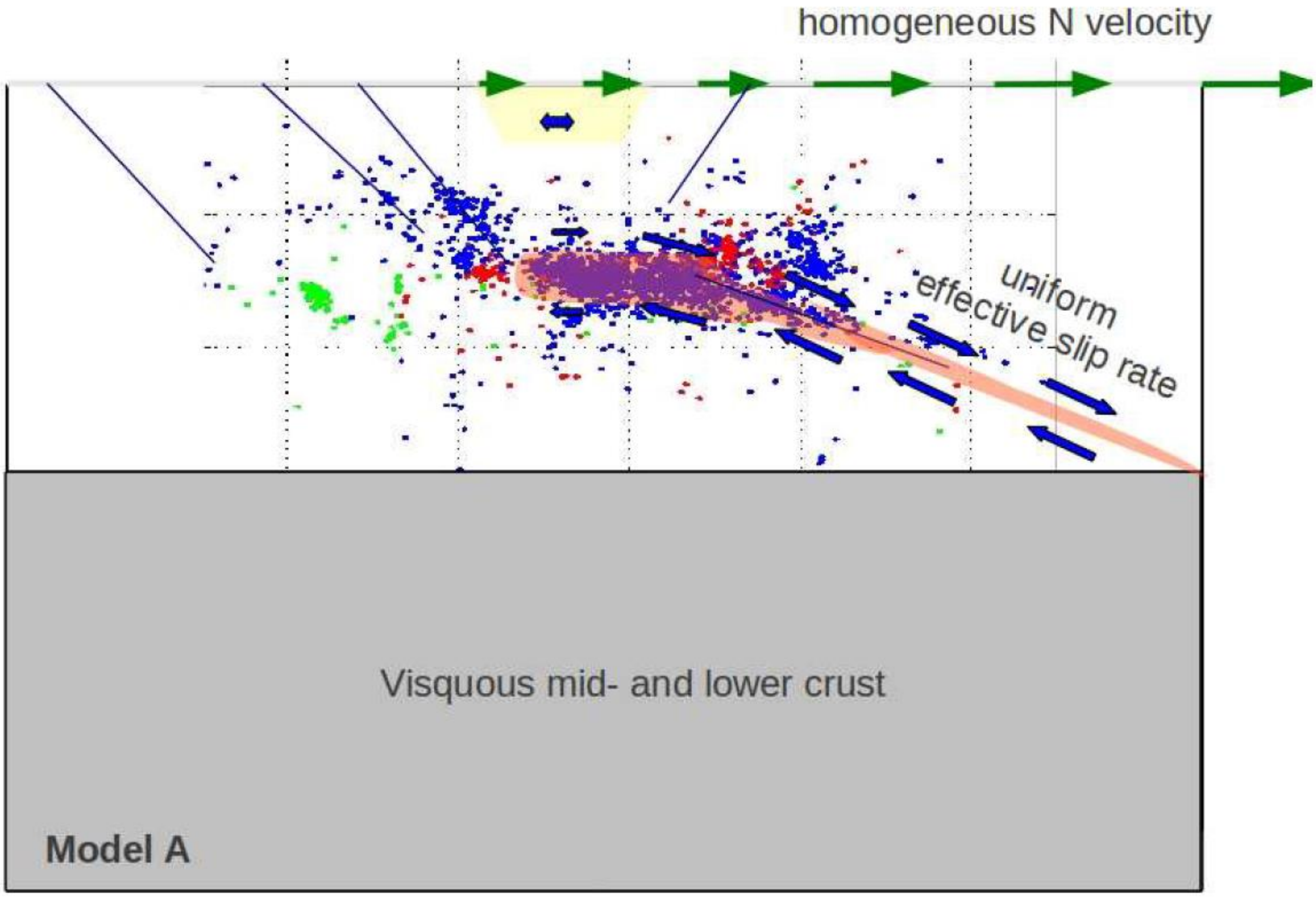
Multidisciplinary research infrastructure

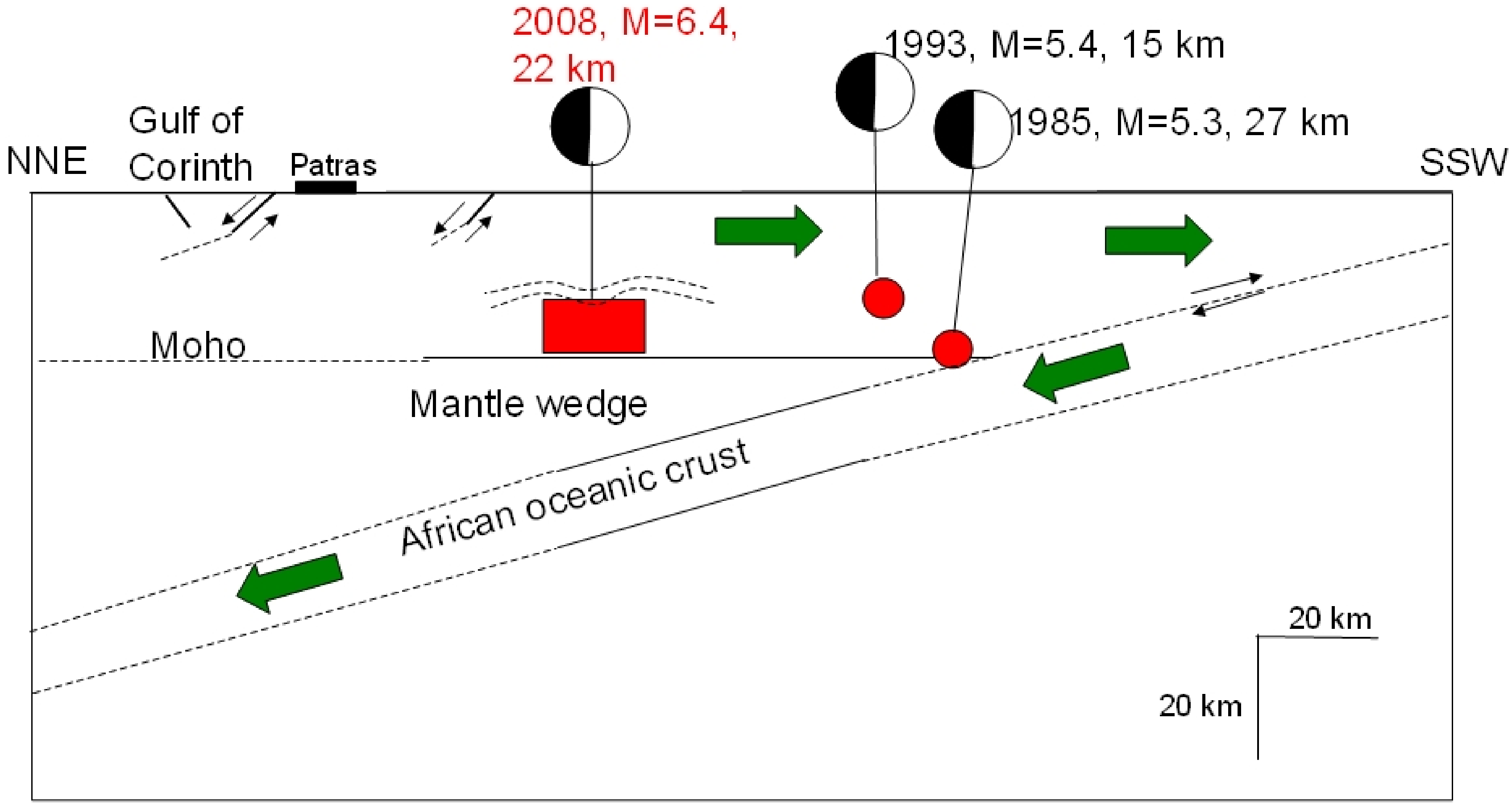
Analysis and modeling of multiscale , coupled seismic/aseismic processes on fault systems

- Enlarge to Patras Rift , to the West

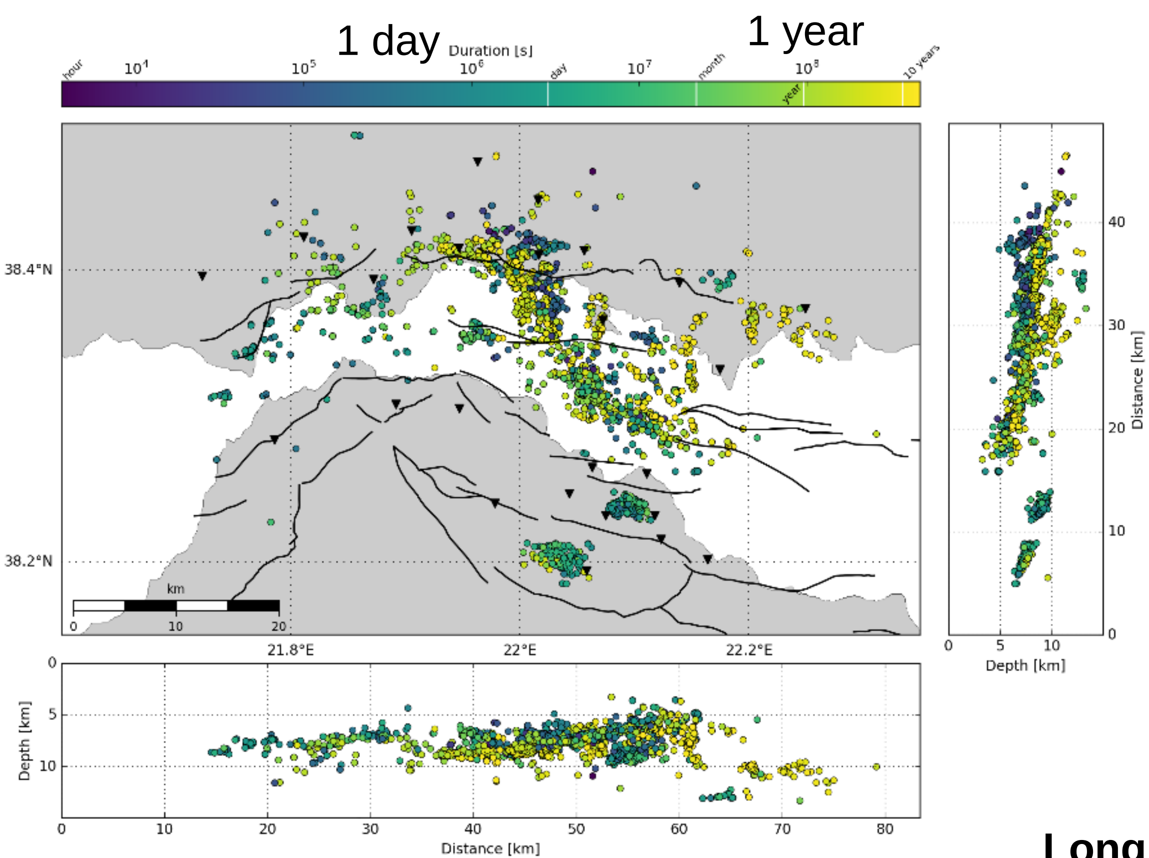
- Connection to subduction and Kephalonia fault system?

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




2008, M=6.4,
22 km
1993, M=5.4, 15 km
1985, M=5.3, 27 km
NNE
Gulf of
Corinth
Patras
SSW
Moho
Mantle wedge
African oceanic crust
20 km
20 km

Long-lasting multiplets



Short duration:

Swarms,

pore pressure diffusion

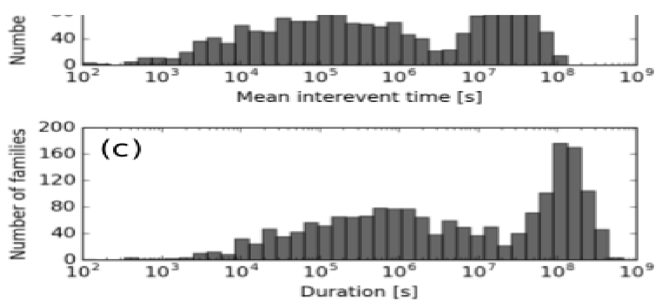
Long Duration:

Creep,

Edge of major asperities

(Godano et al., 2015)

Multiplets with N>10 events

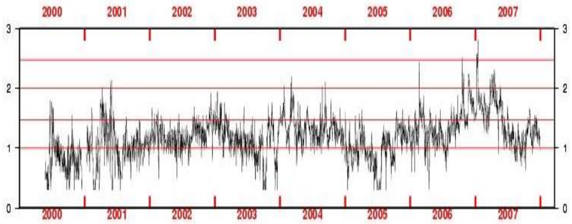


Long duration multiplets:

- 1995 fault zone
- deep Agion fault zone
- deep Lambiri/Psathopyrgos fault zone

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

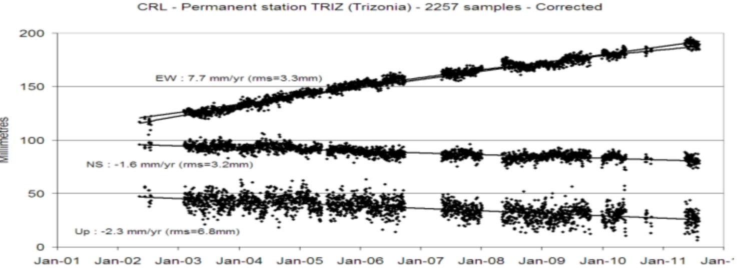
Log(seismicity rate) /day



Seismicity:
Fluctuating
stressing rate

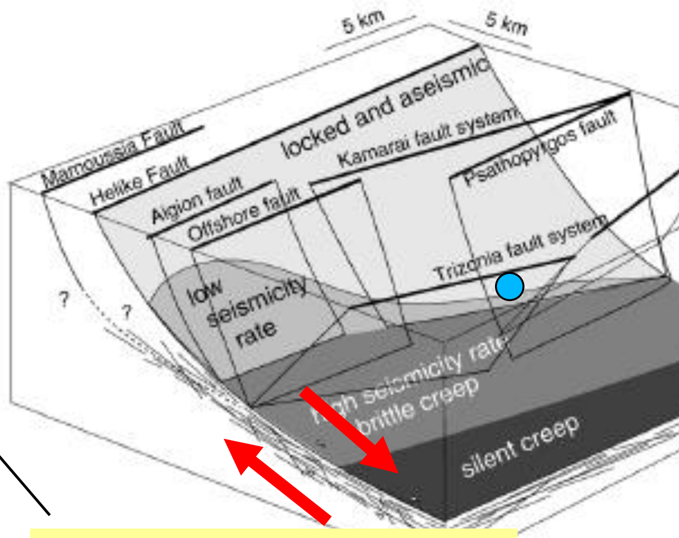
contradiction

Displacement (N) (mm)



cGPS (TRI) Briole et al. 2013

GPS:
constant
stressing rate



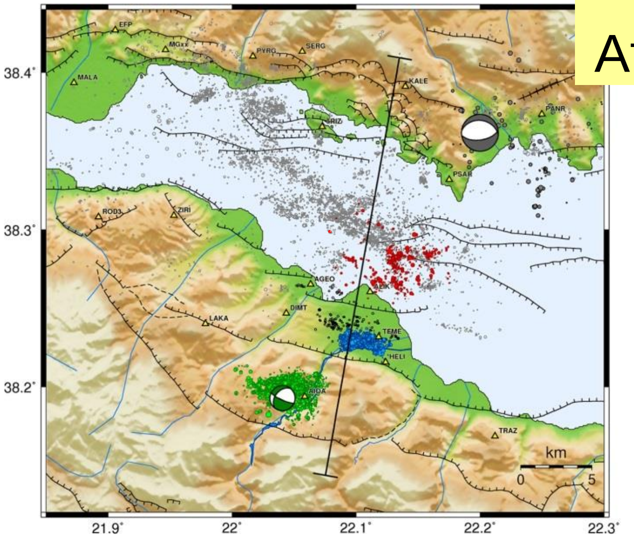
Shearing of the « detachment »

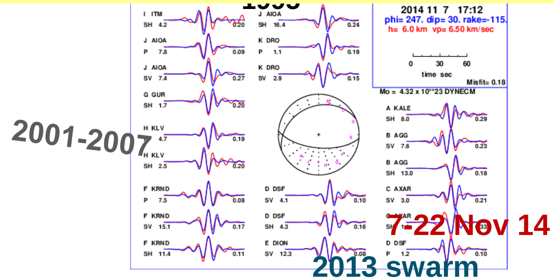
The fluctuating micro-seismicity and the stationary GPS rate are unlikely to have the same source:

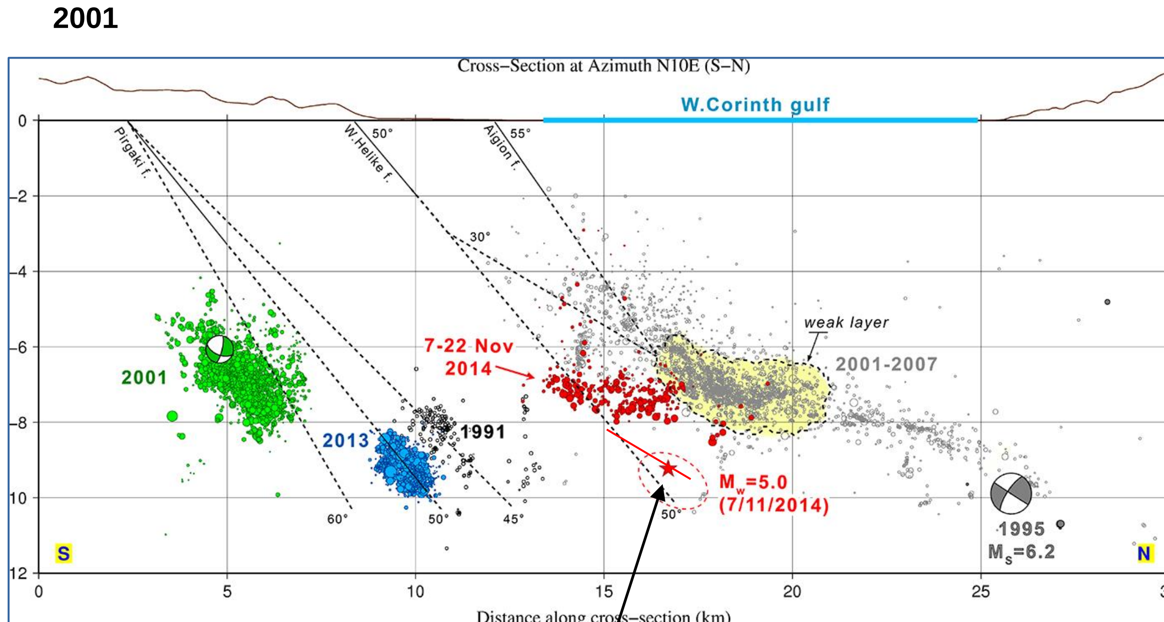
The main source of GPS rate may not be the shearing of the seismic layer

The 7 nov 2014 earthquake, M=5

At the root of the Helike fault?





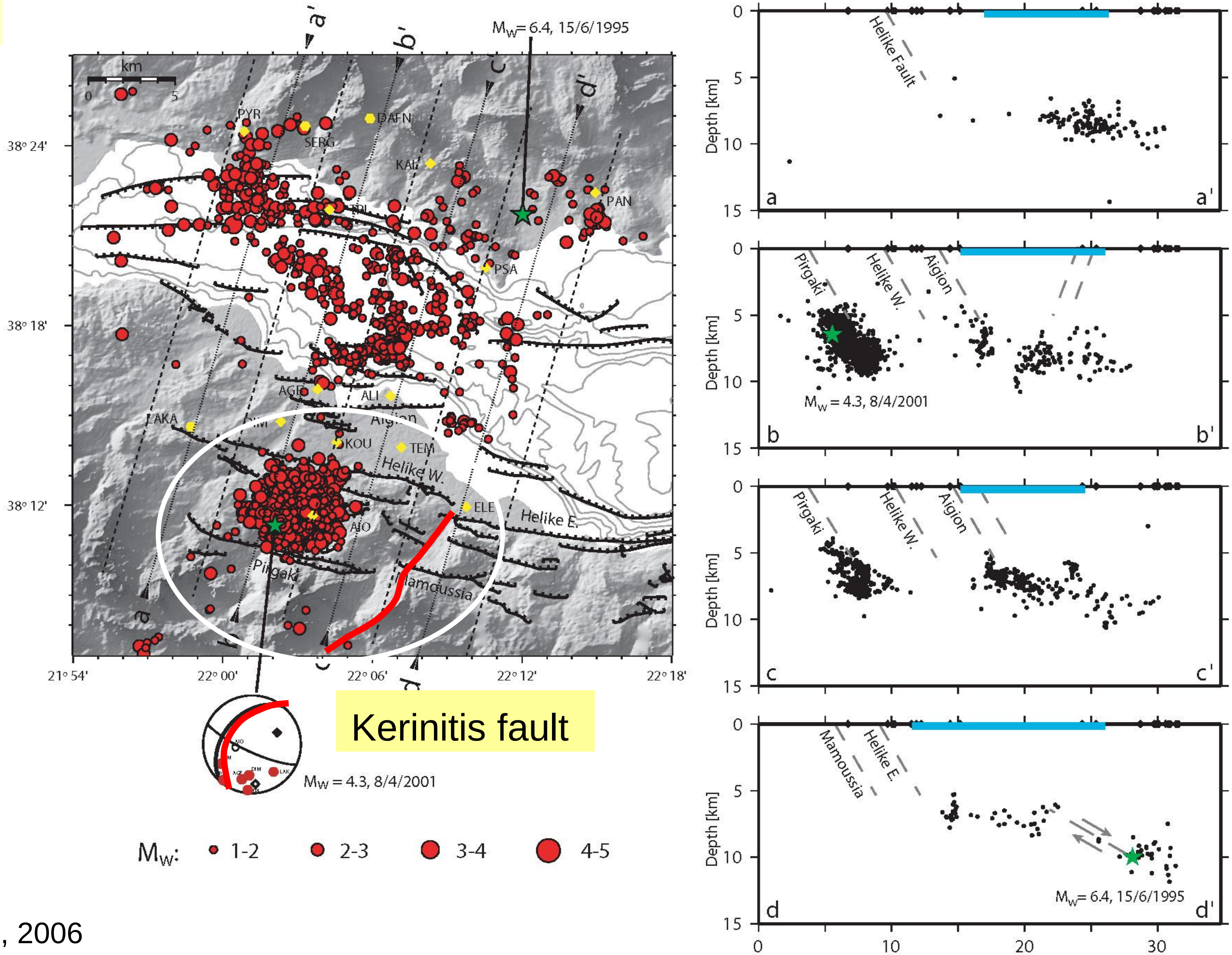


The crust is brittle and seismically active **beneath** the main seismic layer

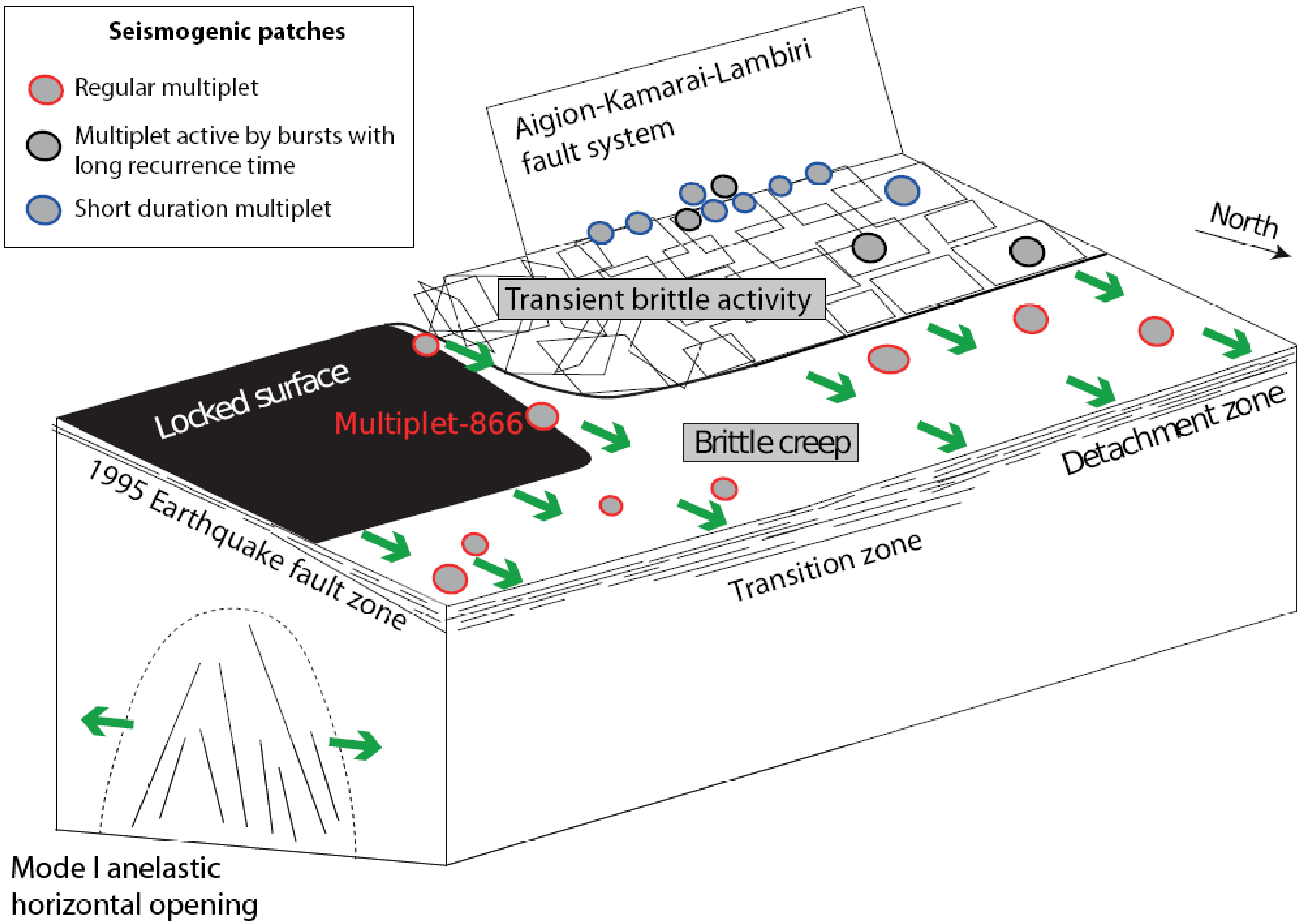
2001 seismic swarm

Re-activation of an ancient fault, dip 45 NW

3 months - Mmax=4.2

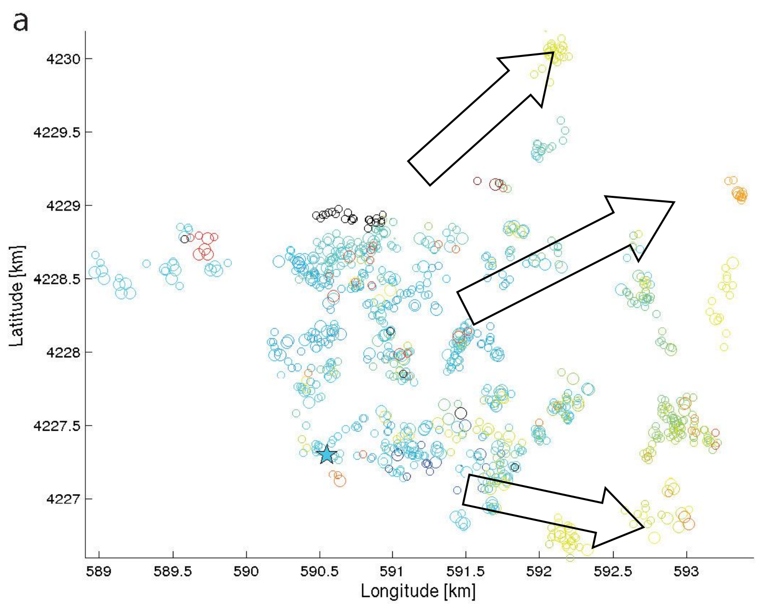


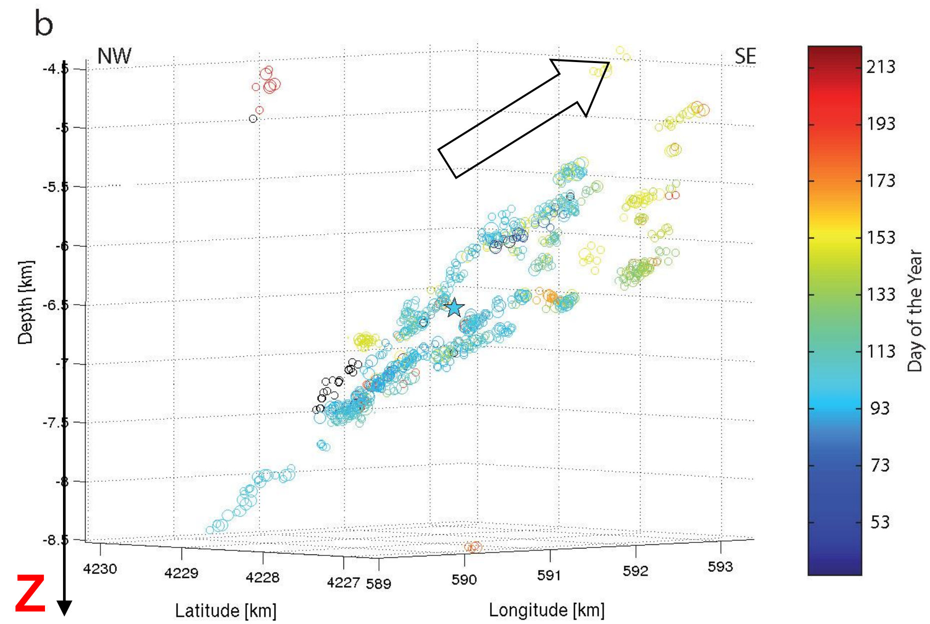
Pacchiani , 2006

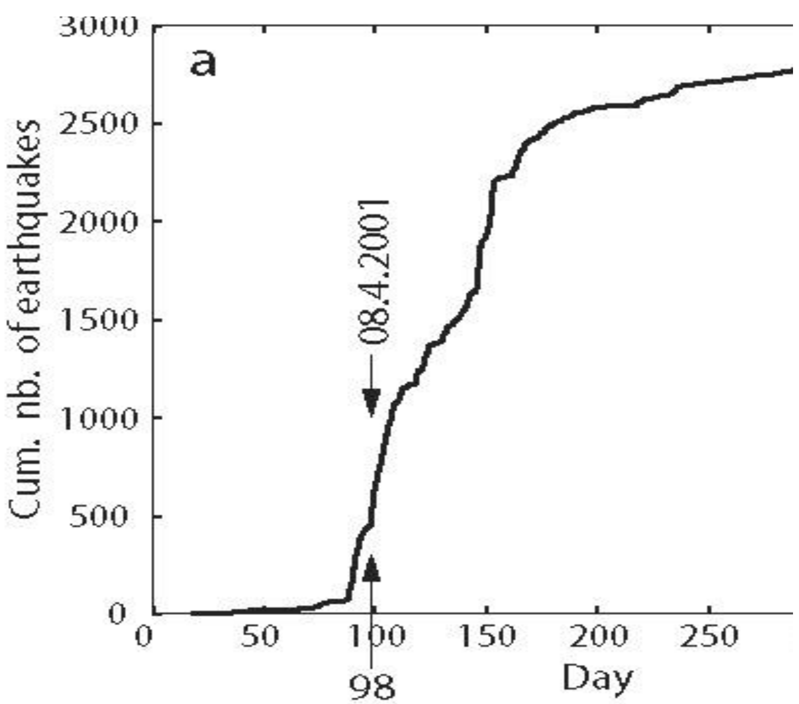

Seismogenic patches
Regular multiplet
Multiplet active by bursts with long recurrence time
Short duration multiplet
Aigion-Kamarai-Lambiri fault system
North
Transient brittle activity
Locked surface
Multiplet-866
Brittle creep
Detachment zone
1995 Earthquake fault zone
Transition zone
Mode I anelastic horizontal opening

Pacchiani, 2006

2001 seismic swarm: relocated multiplets







3 – 4 months:

Upward migration on the Kerinitis fault, 20-30 m/day

pore pressure pulse?

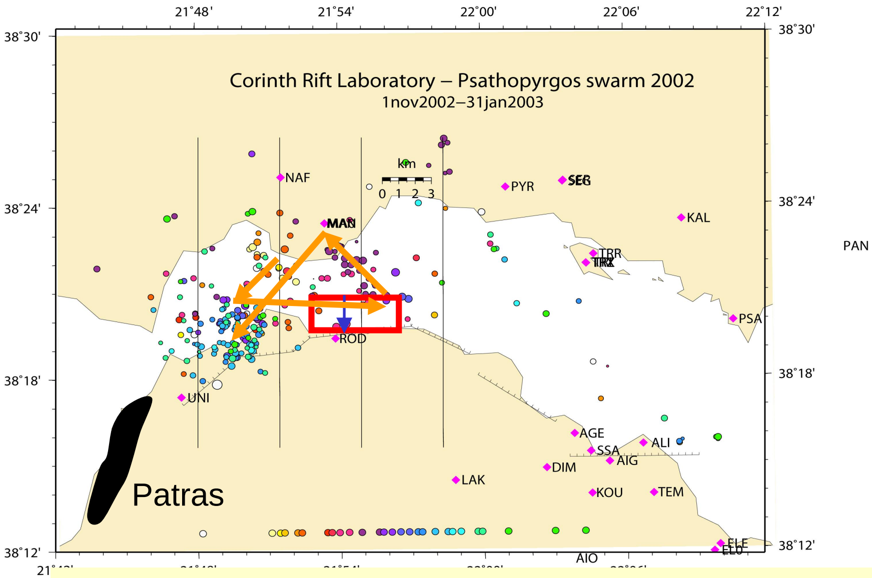
- Diffusivity 0.1 m^2/s

- Hydraulic conductivity 10^{-5}m/s

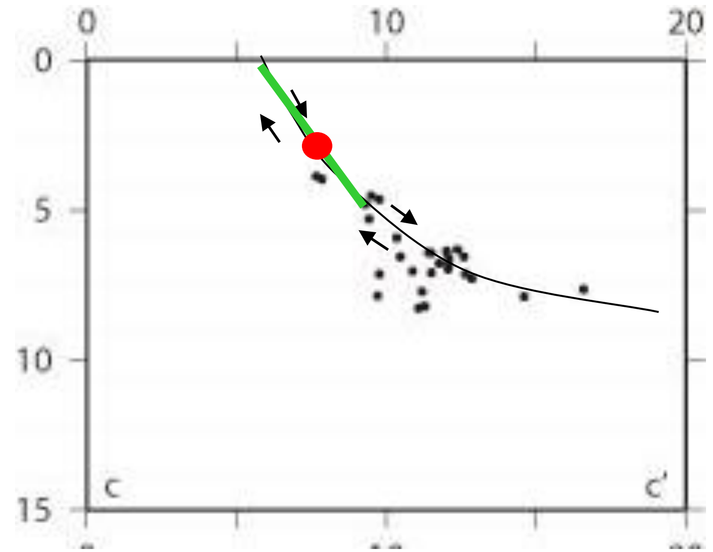
-Permeability 7.10^{-13} m^2

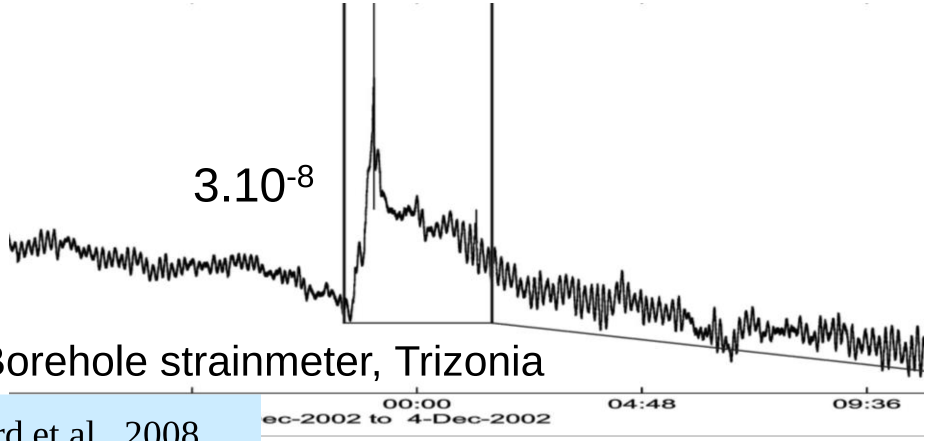
+ coupled slow slip ?

2002 : seismic swarm and transient creep on the Psathopyrgos fault



Migration velocity 100 m/day to 1 km/day





3.10^{-8}

Aseismic slip, 30 minutes on

Psathopyrgos fault :

SLIP =10 cm - Mw equiv =5

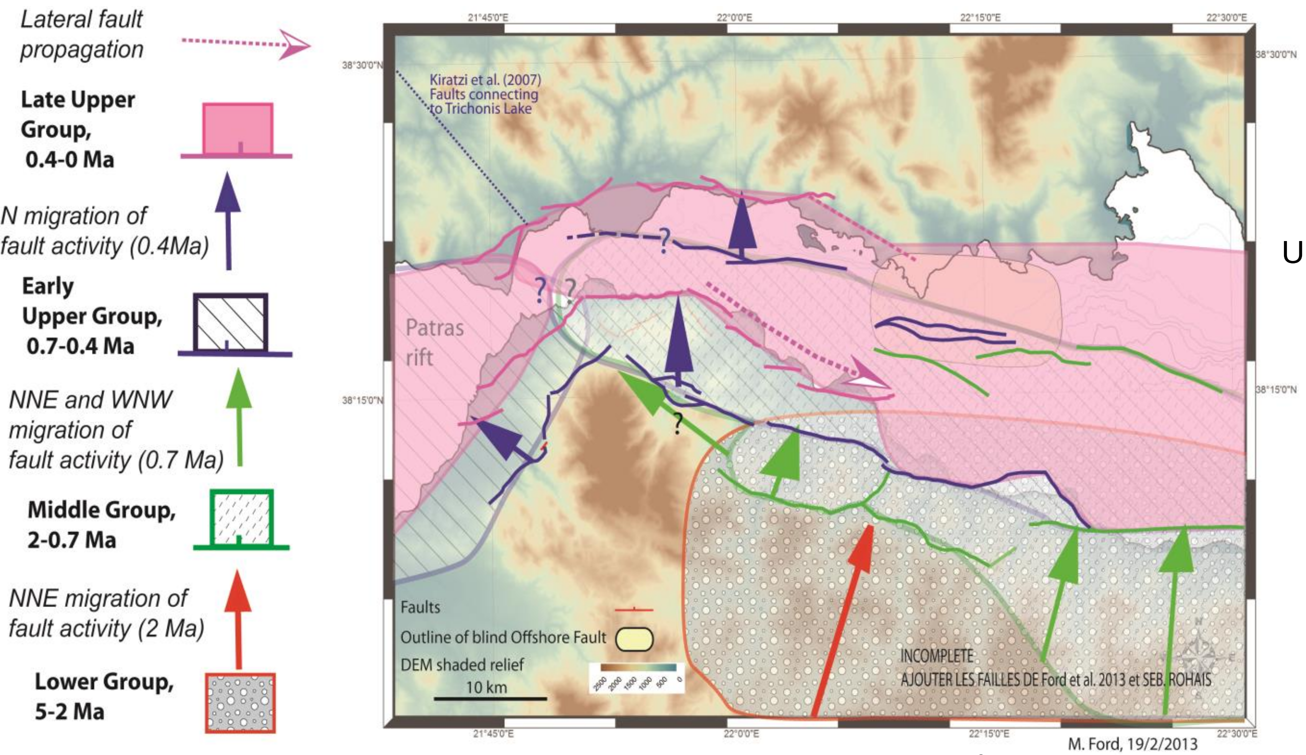
Strain peak:

M=3.5 eathquake,

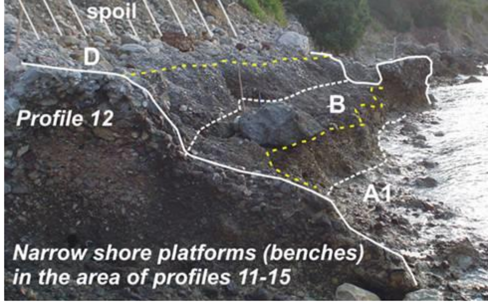
very shallow depth 2.5 km

Bernard et al., 2008

Geological studies



Ford, 2013

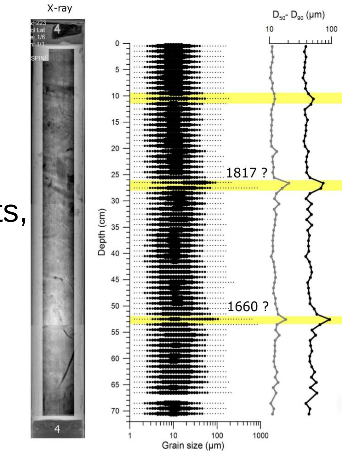


Uplifted paleo-shorelines, Palyvos et al.,2008

Cores of

offshore sediments,

Beckers et al., 2013



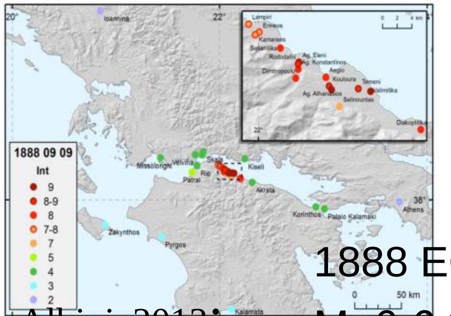
Evolution and present activity of fault system:
migration of depocenter, uplifted fan deltas,
dating of fault activity and marine terraces,
offshore sedimentology (cores, seismics), ...

complex inherited 3D faulted structure,
results in a complex mechanical and seismic interplay
of old and new faults

Helike fault and fan deltas

Earthquake rupture forecast for M>6

Boiselet et al. , 2014



Albini, 2013;

1888 EQ
M=6-6.2

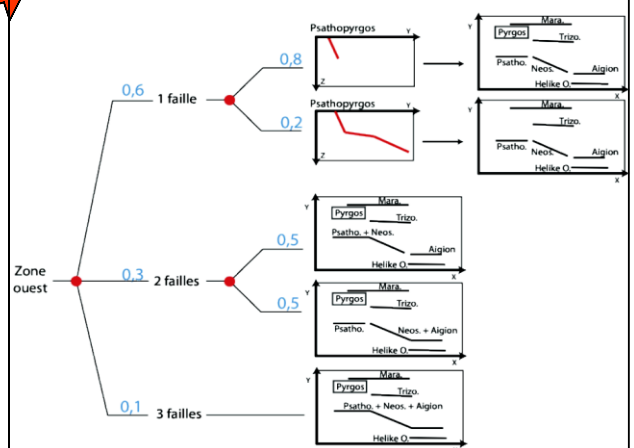
- Fault slip rates
- Strain from geodesy
- Paleoseismicity
- Historical seismicity
- Instrumental seismicity

+ uncertainties

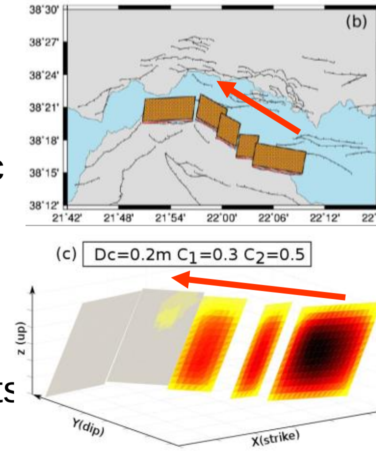
Logic tree:

-Seismicity models

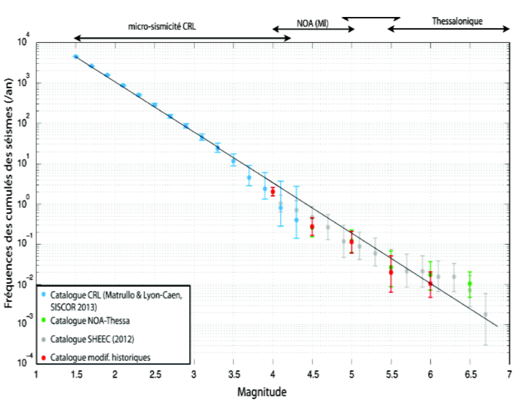
-fault geometries



Dynamic ruptures across fault segments



Durand et al. 2014

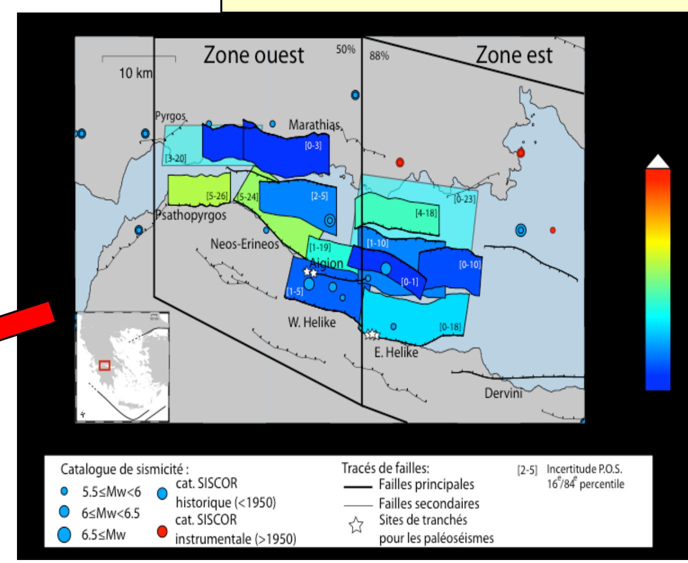


P = 45 - 75 %

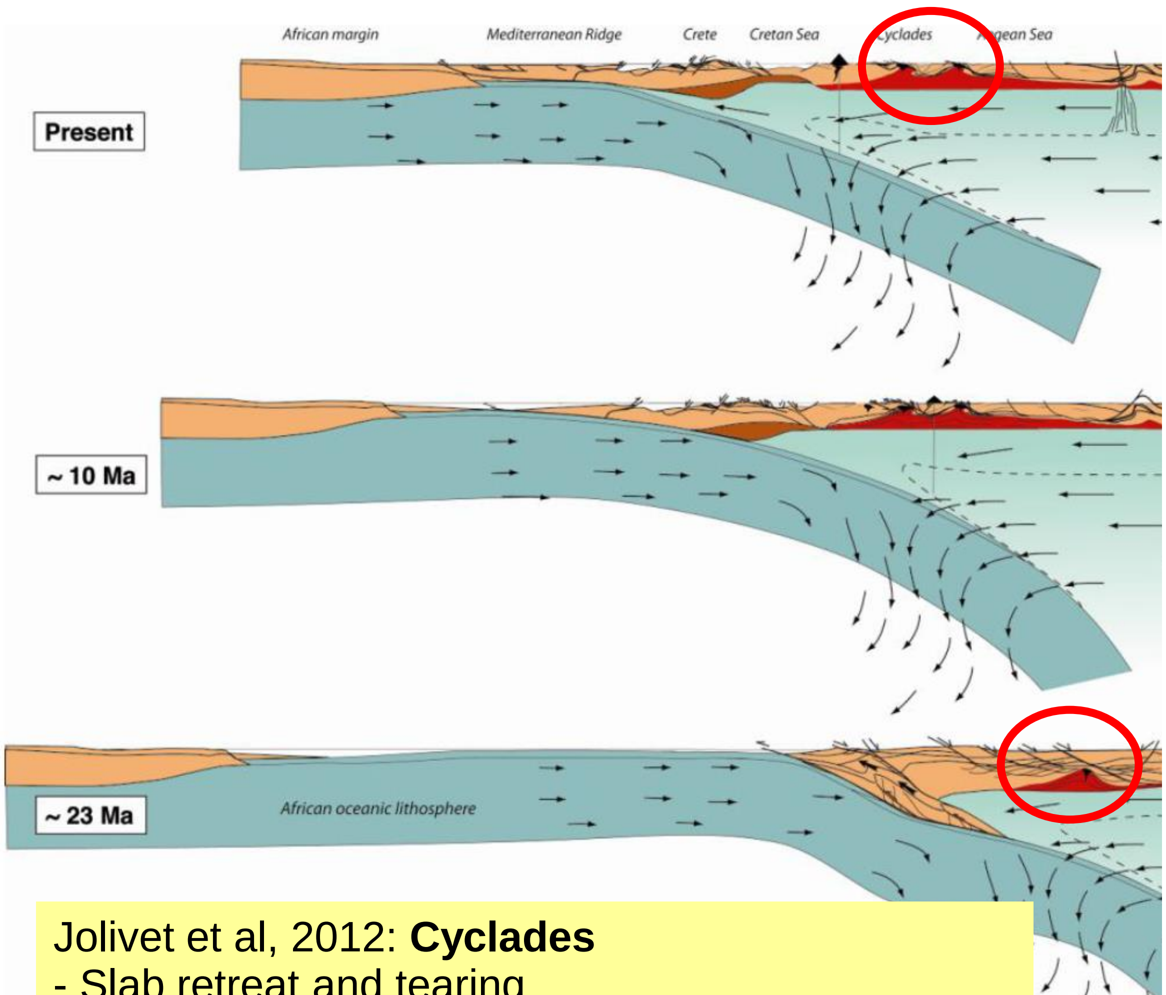
pour M>6

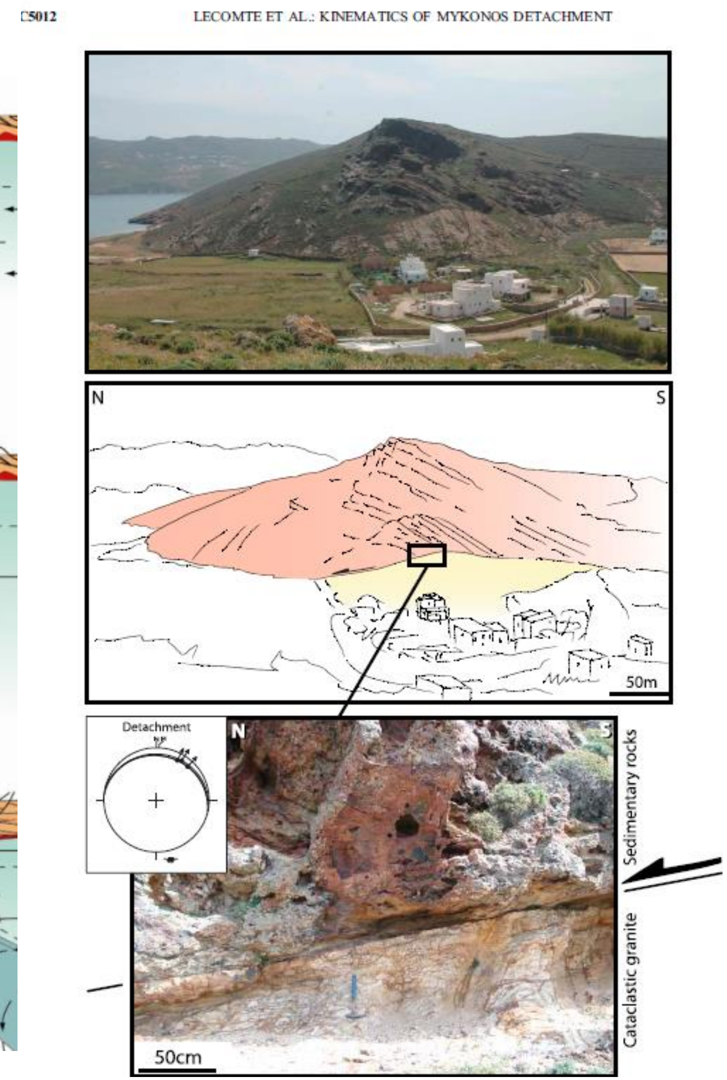
0 – 30 ans

ERF forecast for individual faults



Aegean tectonics – large scale extension





Jolivet et al, 2012: **Cyclades**
- Slab retreat and tearing
- Crustal scale detachment
- Exhumation of core complex, from 8-15 km depth

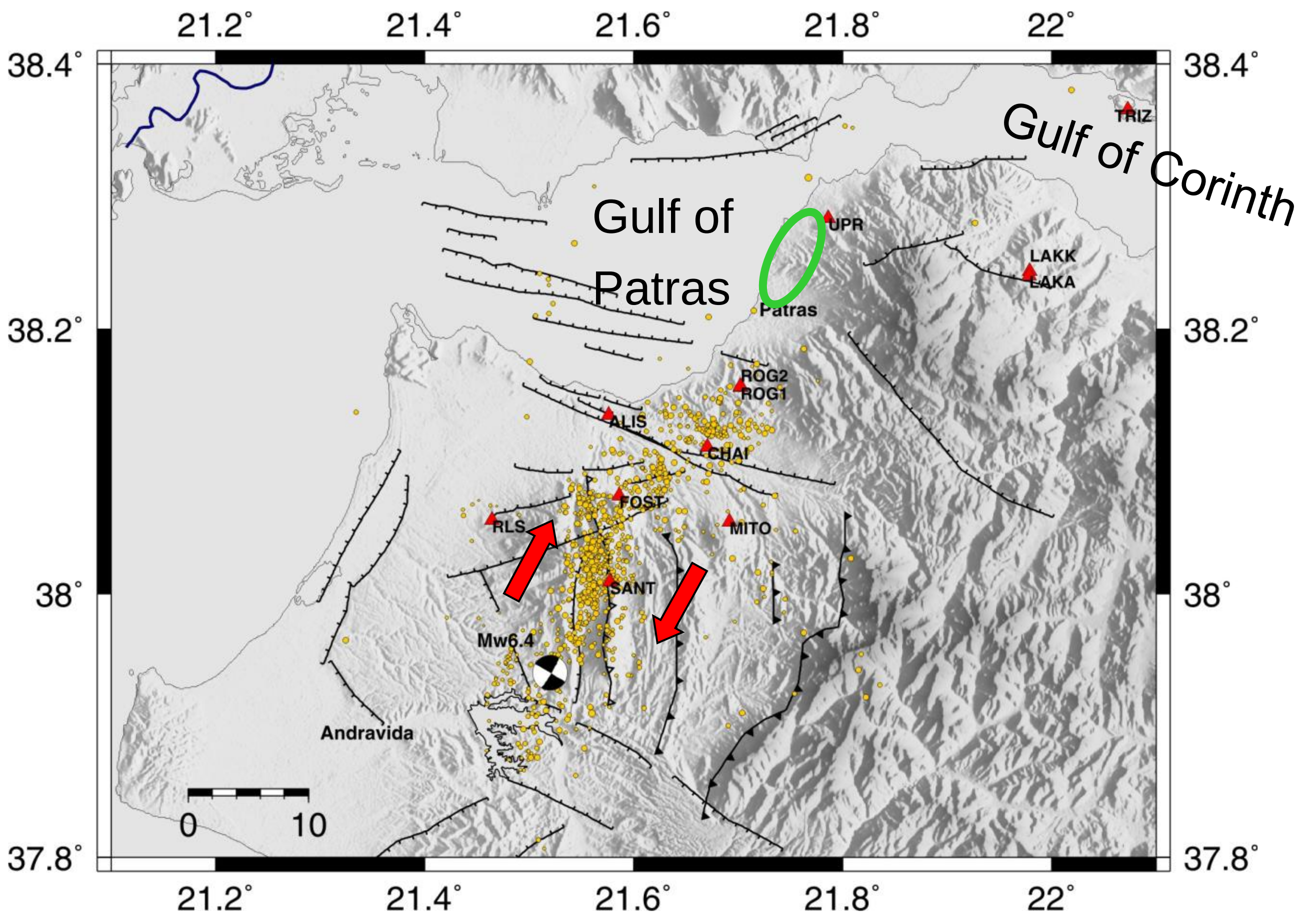
Western Corinth rift:
similar to early stage of Cyclade detachment?

LeComte et al. 2010
Cyclades:
Mykonos detachment

The western end of the Corinth rift:

the SW connection to the subduction

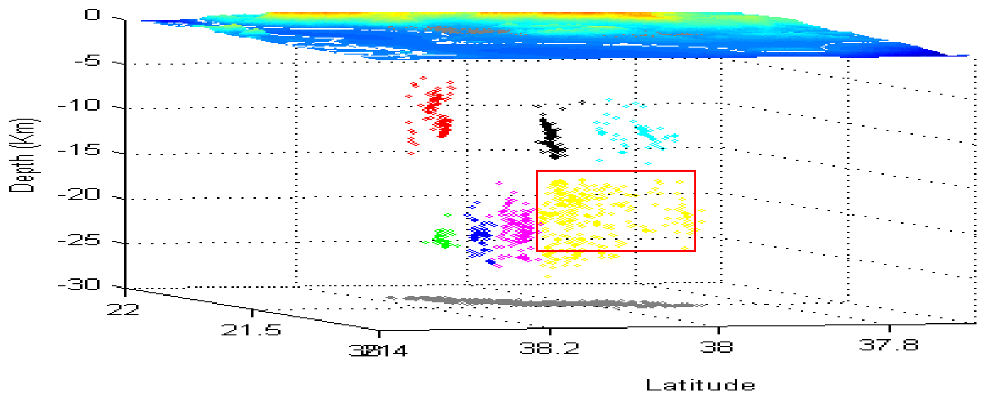
Insights from the M=6.2, Achaia-Ilia, 2008 earthquake

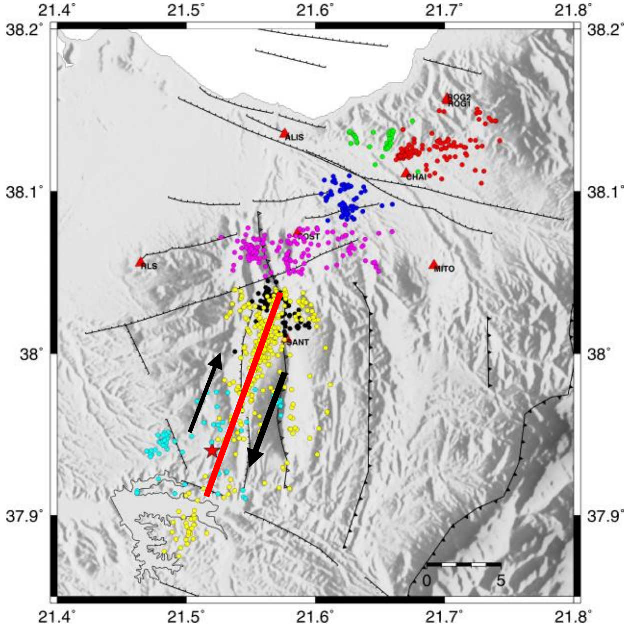


Serpetsidaki et al. 2013

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

A deep strike slip event on
a unmature fault

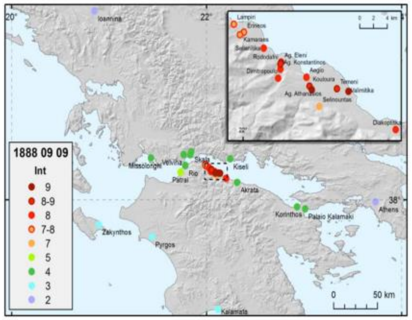




Serpetsidaki et al. 2013

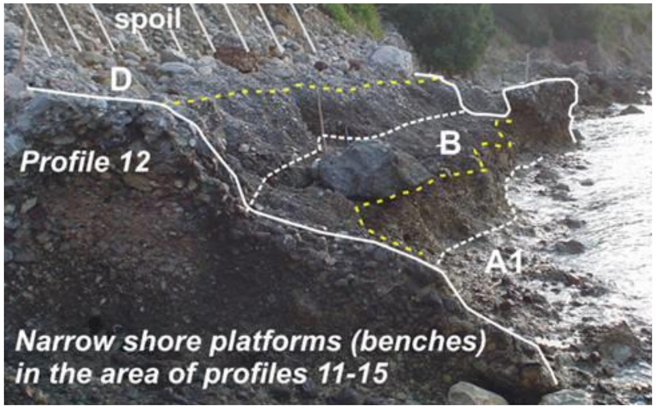
Past large earthquakes for fault activity and seismic hazard assesment:

Work in progress



Intensity maps of historical earthquakes

Albini, 2013

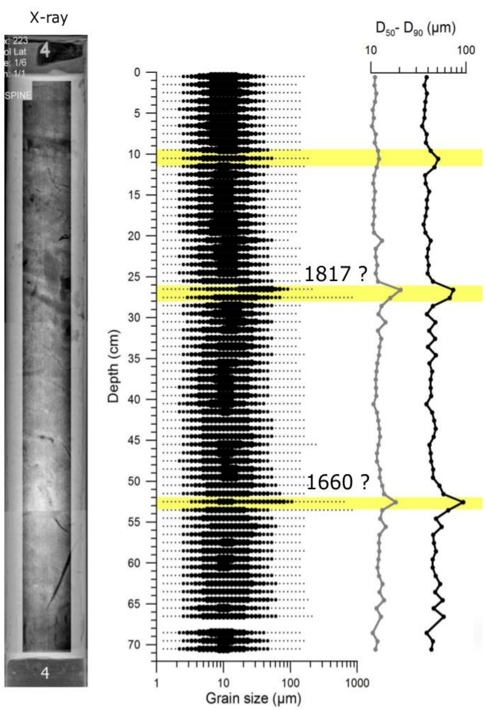


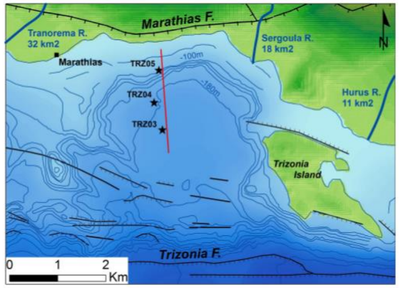
Uplifted paleo-shorelines:

5 event, 0.5 m each

in 2000 years

Palyvos et al. 2008



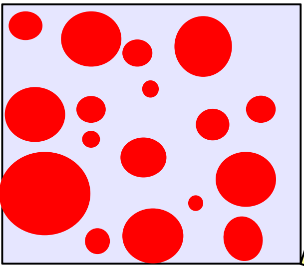


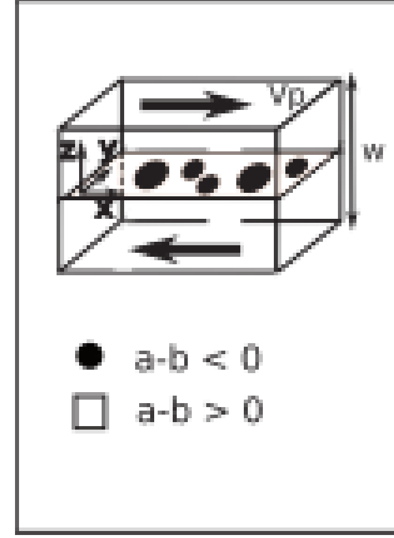
Short gravity core – grain size variations

Beckers et al., 2013

Models of Interacting Mechanical asperities with R&S friction:

threshold for system stability

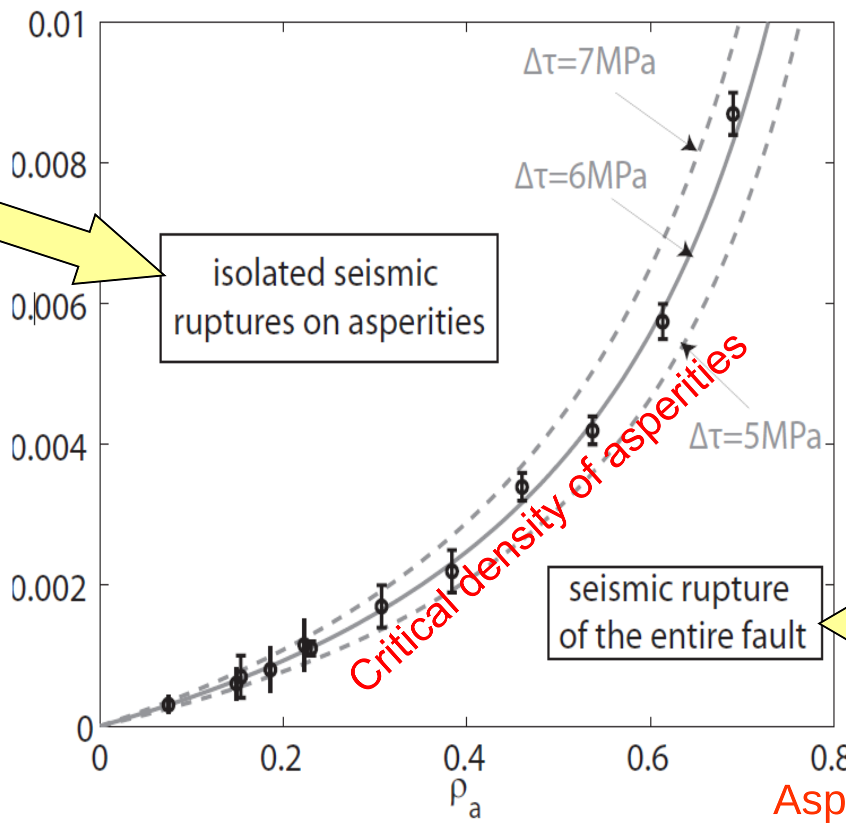




Dublanchet, 2013

Delayed interaction

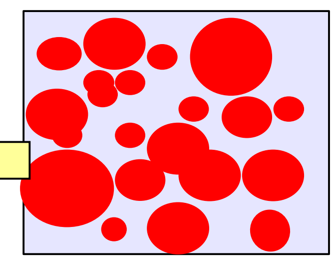
(a-b) (velocity strenghtening)



Effective

Friction parameters

Dynamic rupture



Asperity density

(velocity weakening)

Dublanchet et al., 2013

Stability threshold depends on:

asperity density and friction characteristics of inter-asperity « barriers »

Aseismic creep on major faults

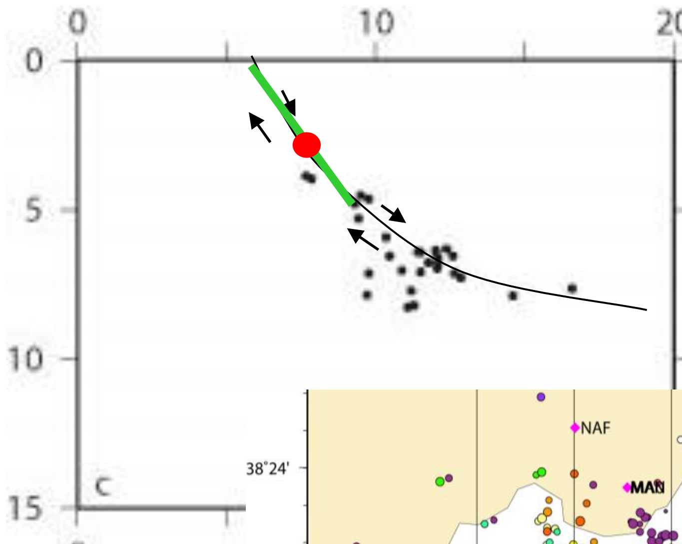
from GPS, InSAR, and borehole strainmeters

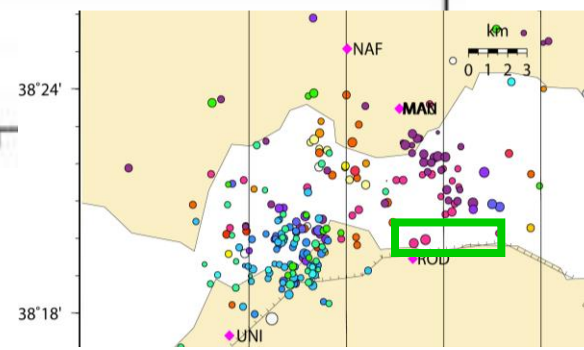
Psathopyrgos (transient creep), Rio-Patras, and Aigion faults

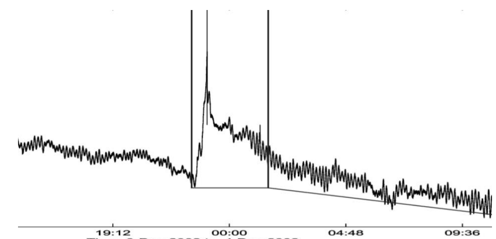
Bernard et al. 2007

2002 swarm

and slow slip

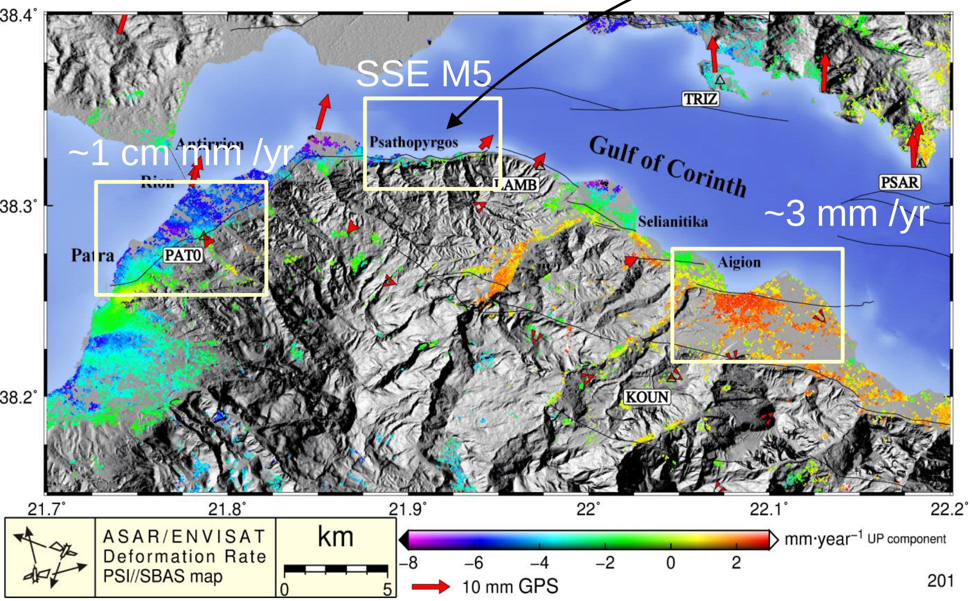






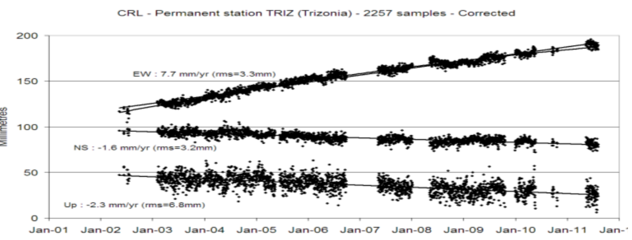
30 minutes strain transient

on dilatometer, 3 10^{-8}



Elias and Briole, 2013

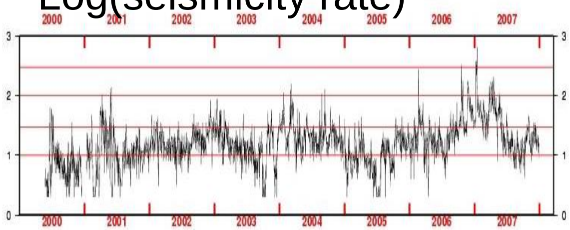
Rifting process

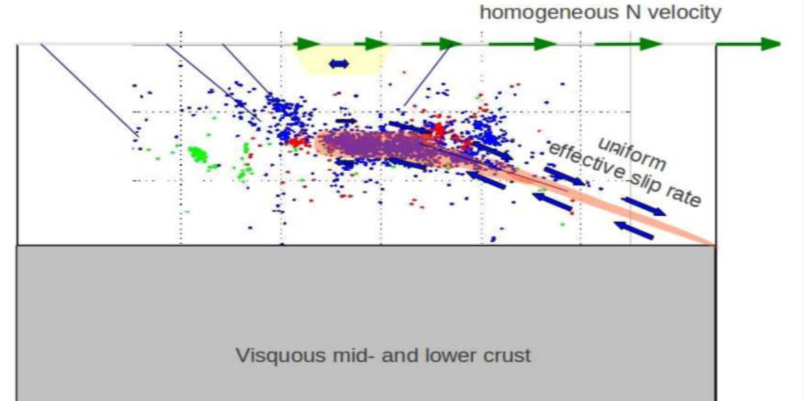


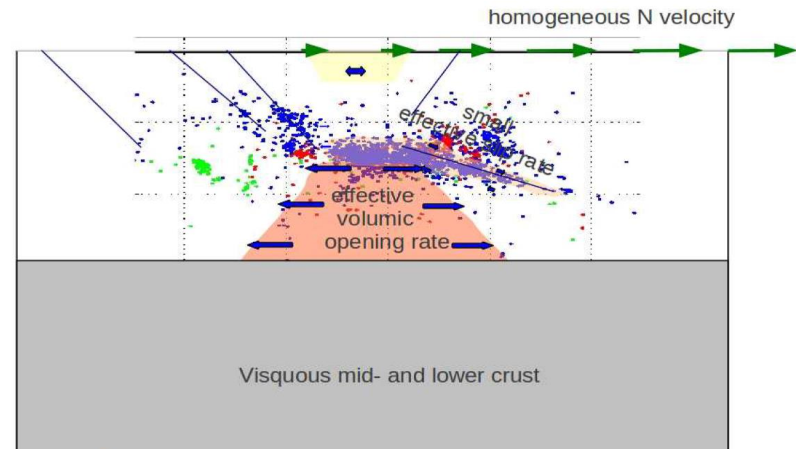
cGPS: constant stressing rate

Seismicity: Fluctuating stressing rate

Log(seismicity rate)







Lambotte et al. 2013

The « detachment » is unmature, growing downwards,

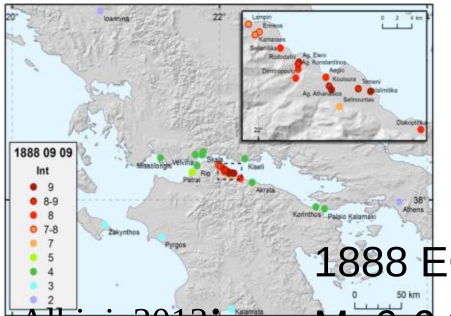
- not yet efficiently connected to the visquous mid-crust

-Another source of anelastic strain, below the seismic layer … mode I ?

-Requires 3D mechanical modeling

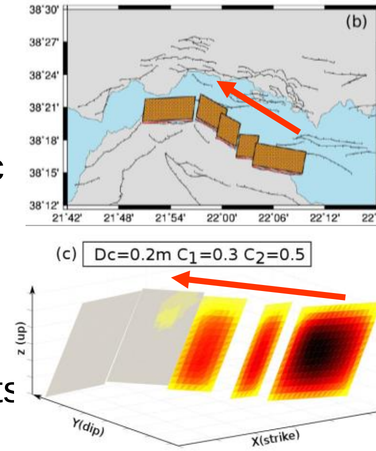
Earthquake rupture forecast for M>6

Boiselet et al. , 2014



Albini, 2013;

1888 EQ
M=6-6.2



Dynamic ruptures across fault segments

Durand et al. 2014

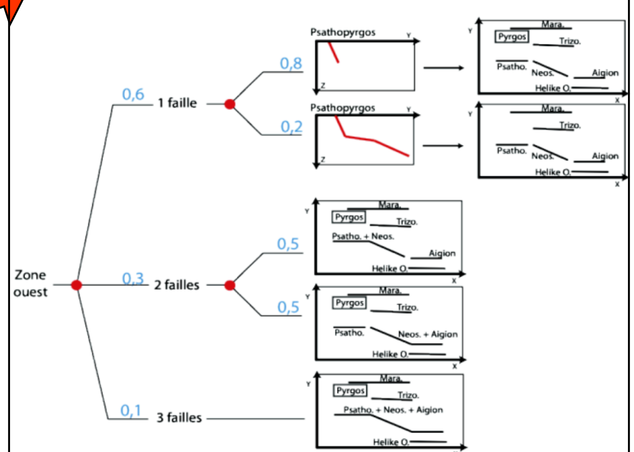
- Fault slip rates
- Strain from geodesy
- Paleoseismicity
- Historical seismicity
- Instrumental seismicity

+ uncertainties

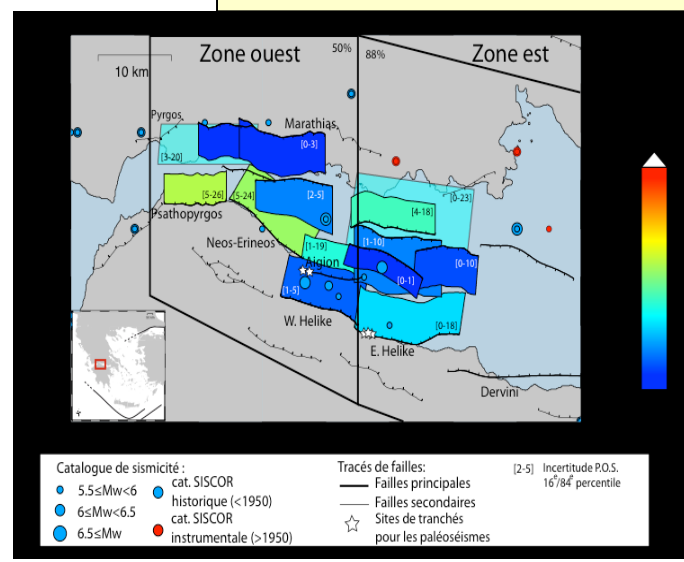
Logic tree:

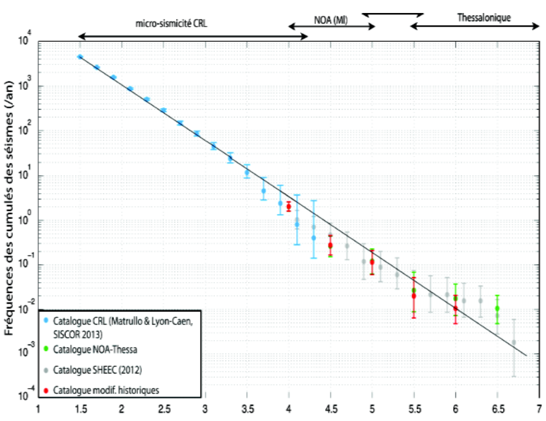
-Seismicity models

-fault geometries



ERF forecast for individual faults



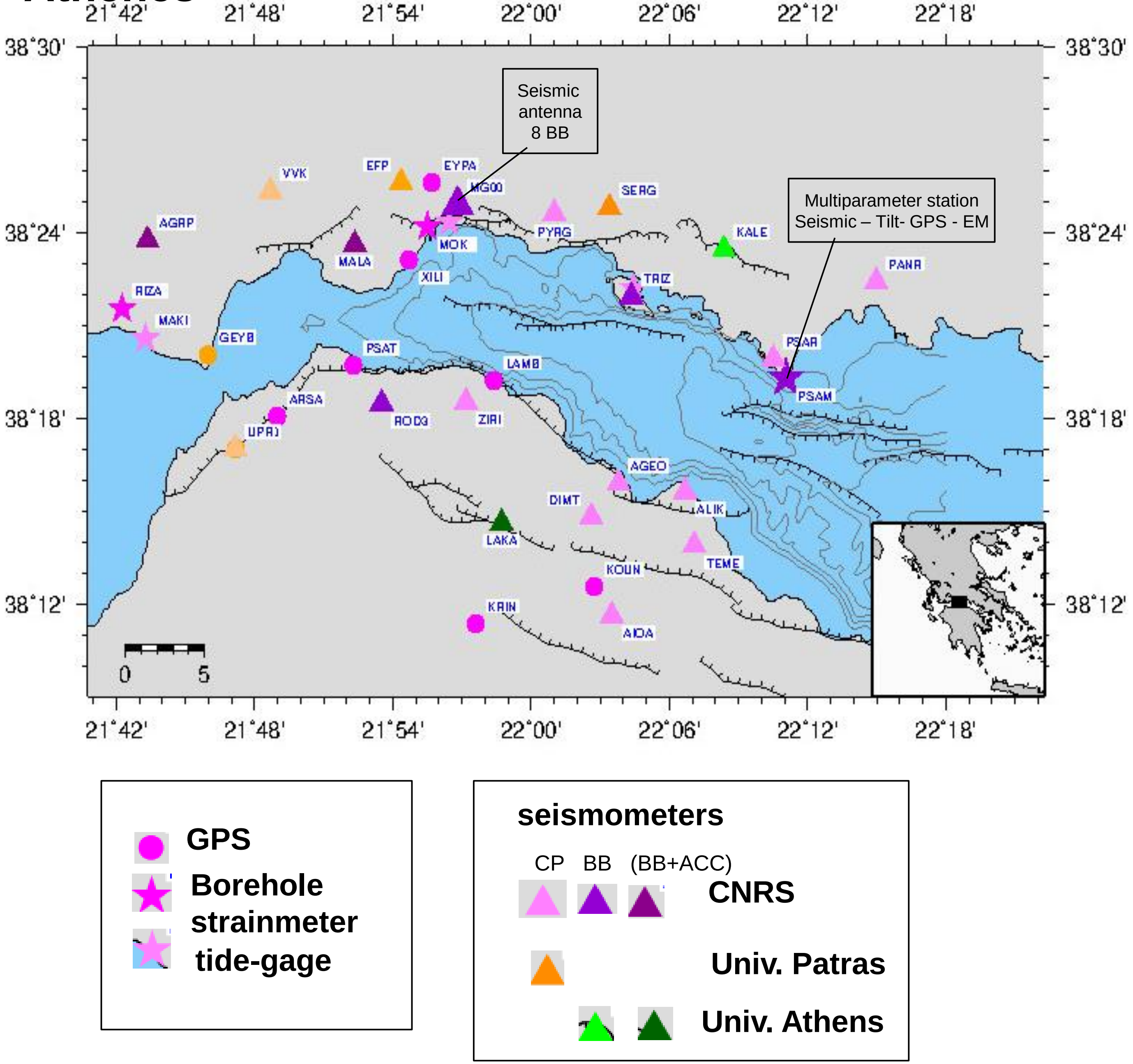


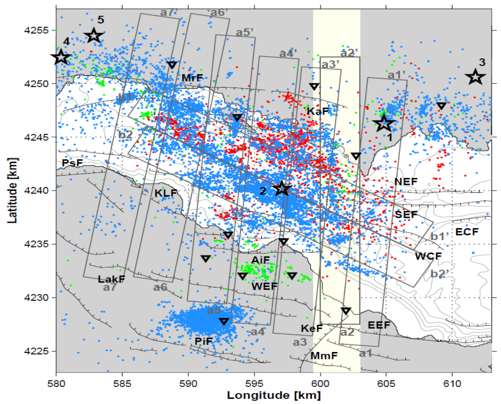
P= 45 - 75 %

pour M>6

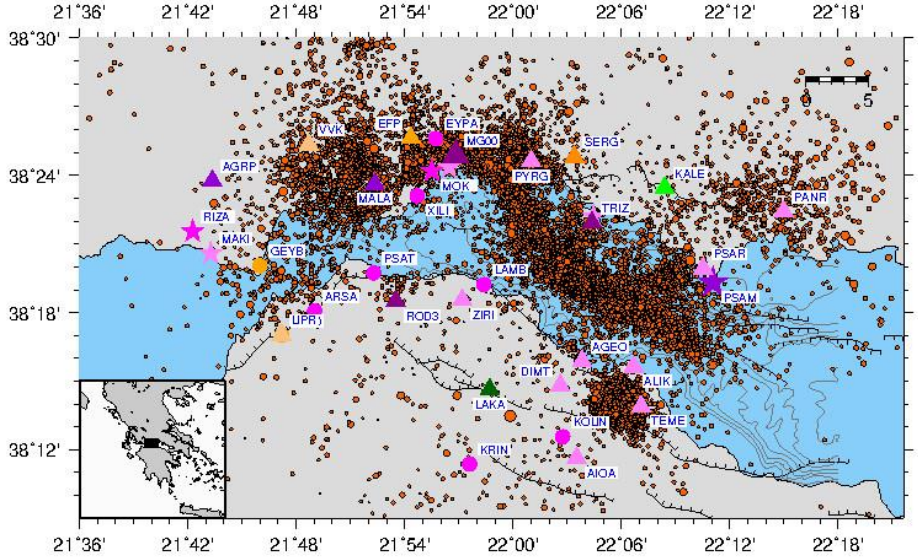
0 – 30 ans

RESEAU PERMANENT CRL – Télémétrie Univ. Athènes





2000-2006



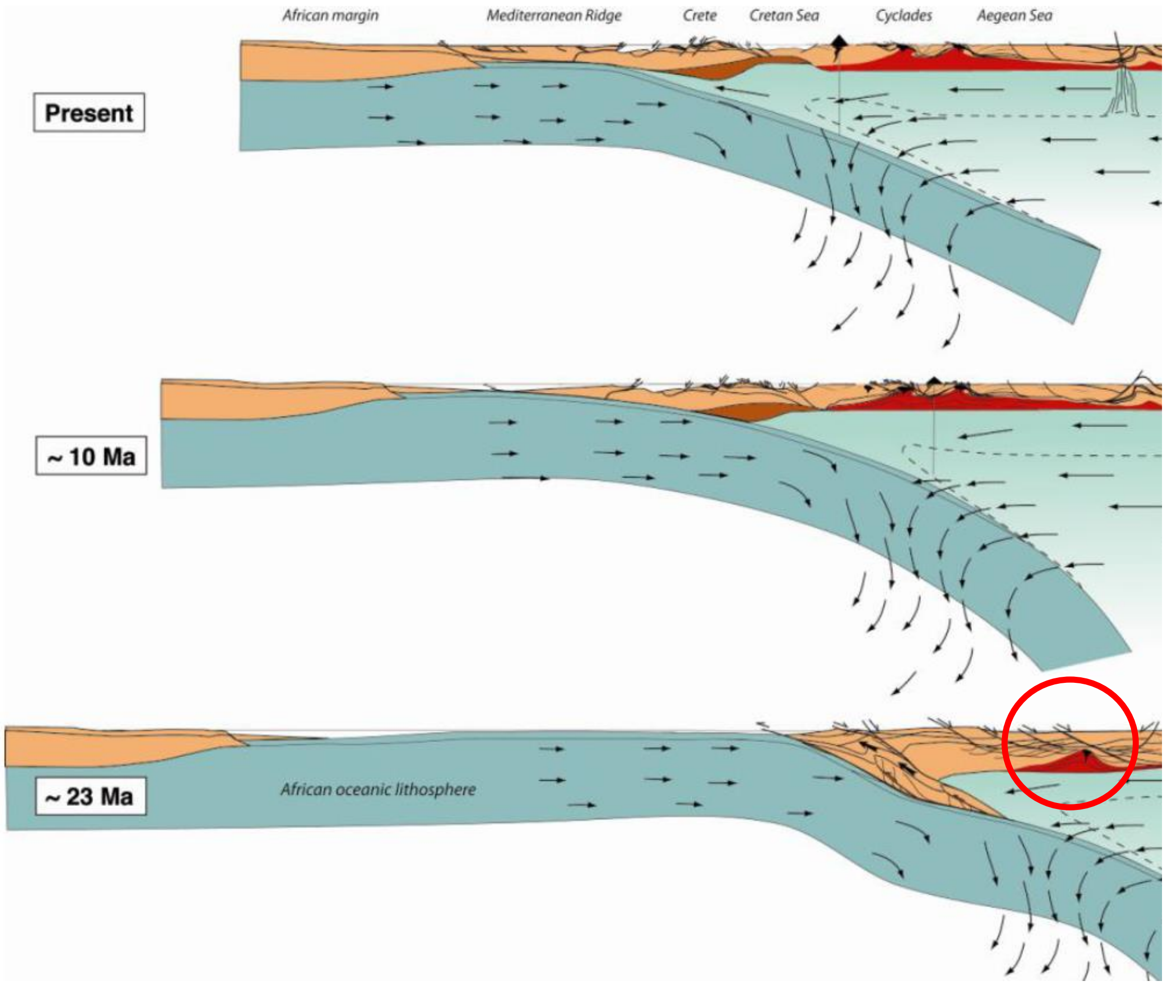
2010-2013

Réseau CRL étendu

ftp://geoazur.unice.fr/pub/outgoing/deschamp/crl/film_sismib_2000_2013.lent.gif

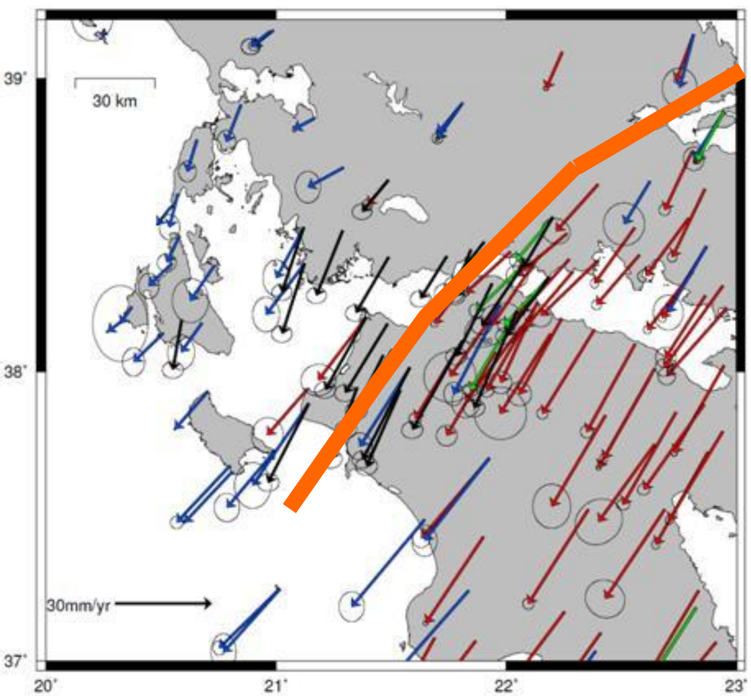
The western end of the Corinth rift:

The link to the subduction



The western end of the Corinth rift:

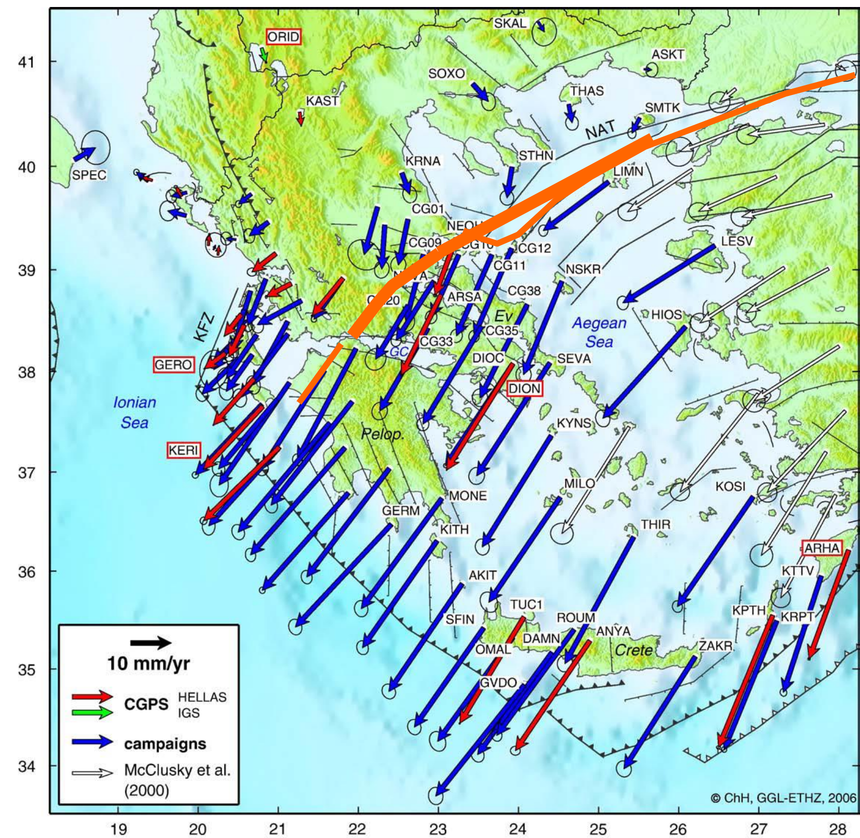
The link to the North Anatolian fault system



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

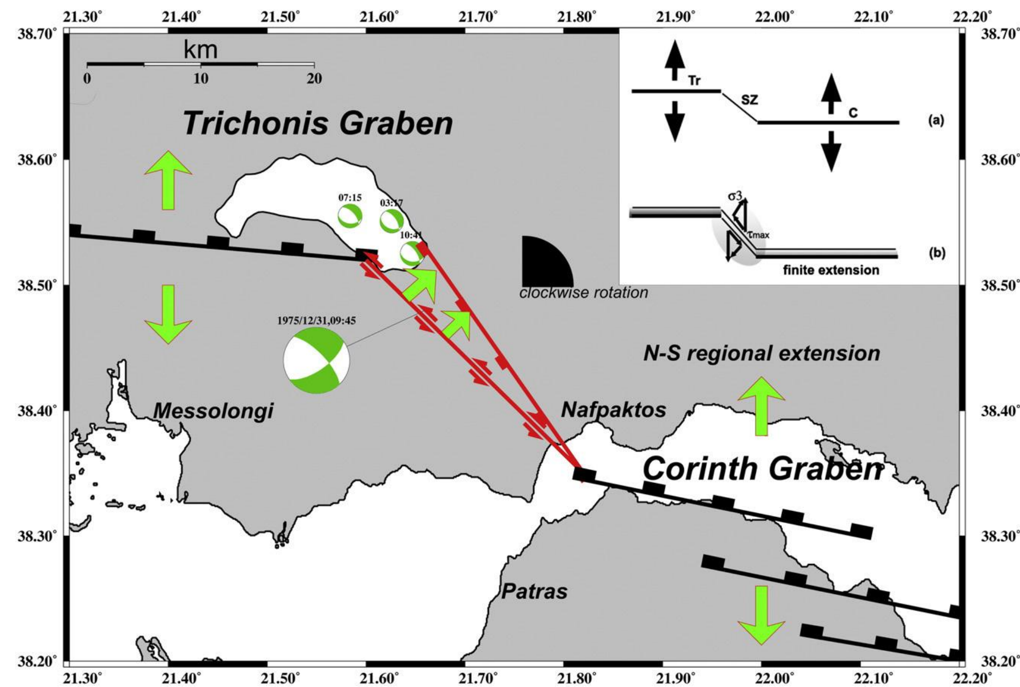
Insights from the M=5, 2006 sequence

Seismicity:

1975: M=6.0

2007: swarm, M=5.0-5.2

Left-Lateral Shear between right-stepping rifts

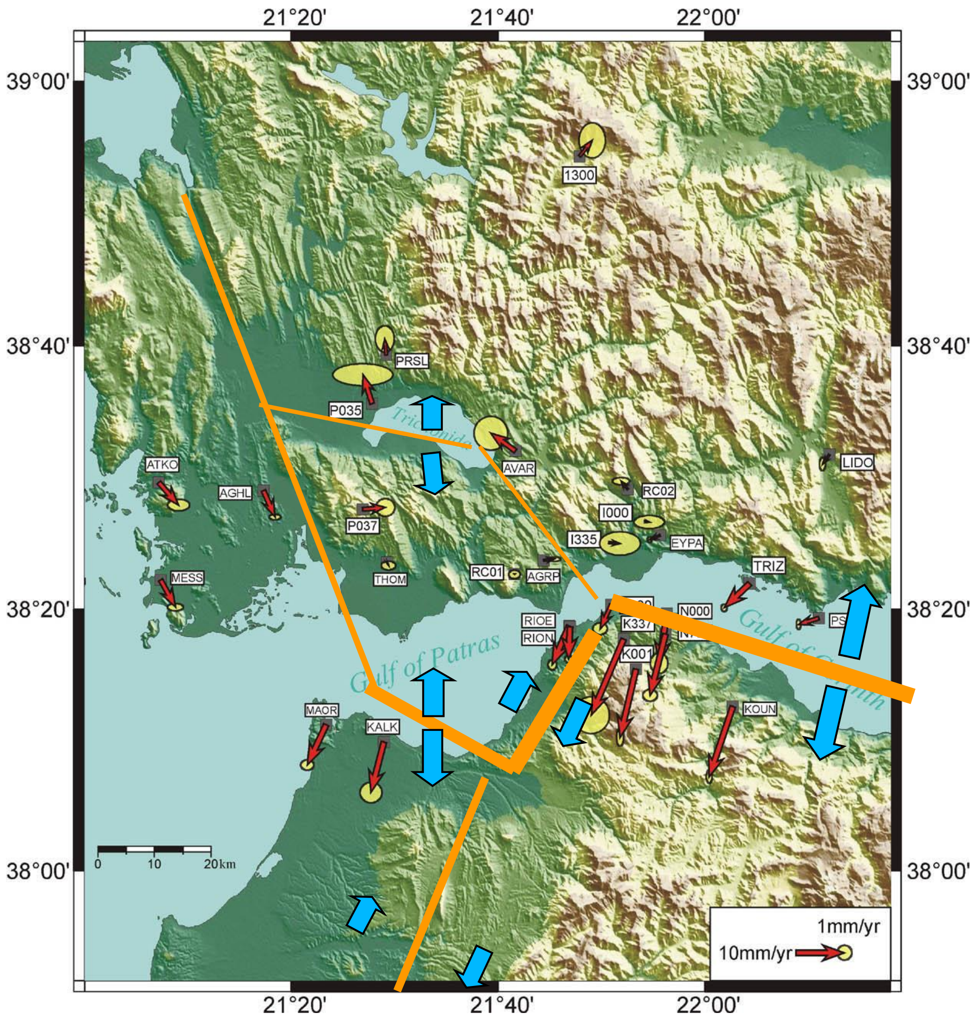


Seismicity:
Kiratzi et al., 2008

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

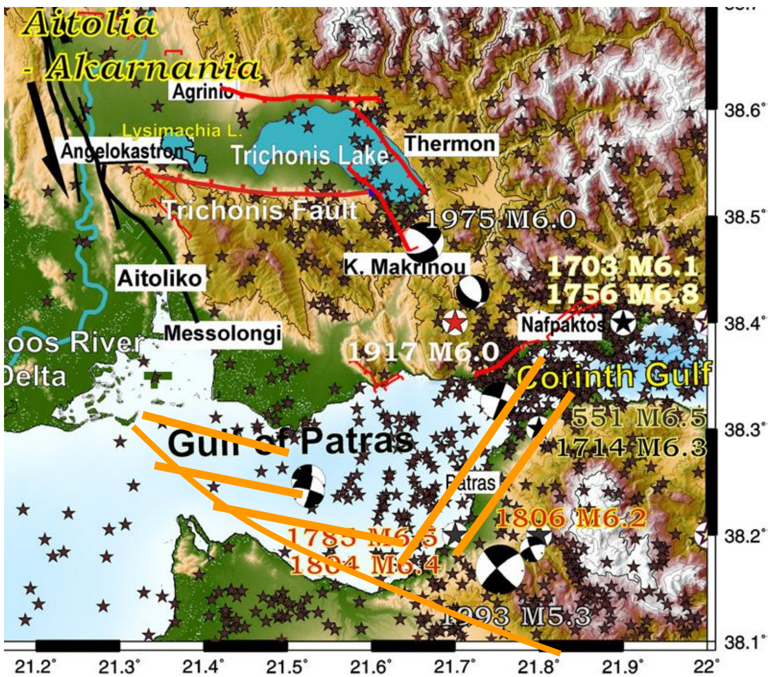
The western end of the Corinth rift:

clues from GPS….



The western end of the Corinth rift:

the western connection through the rift of Patras…



Kiratzi et al. 2008

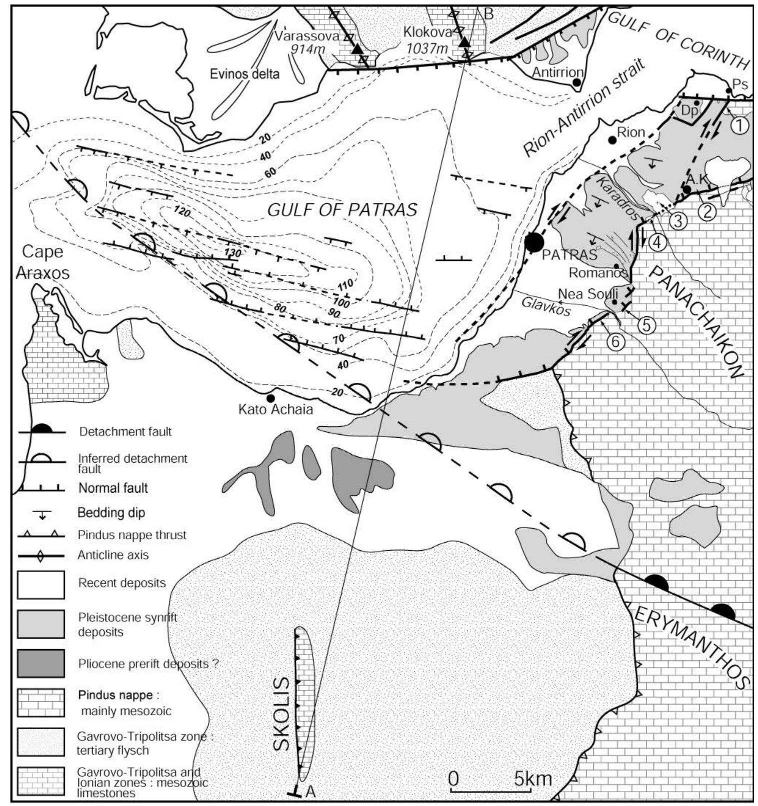
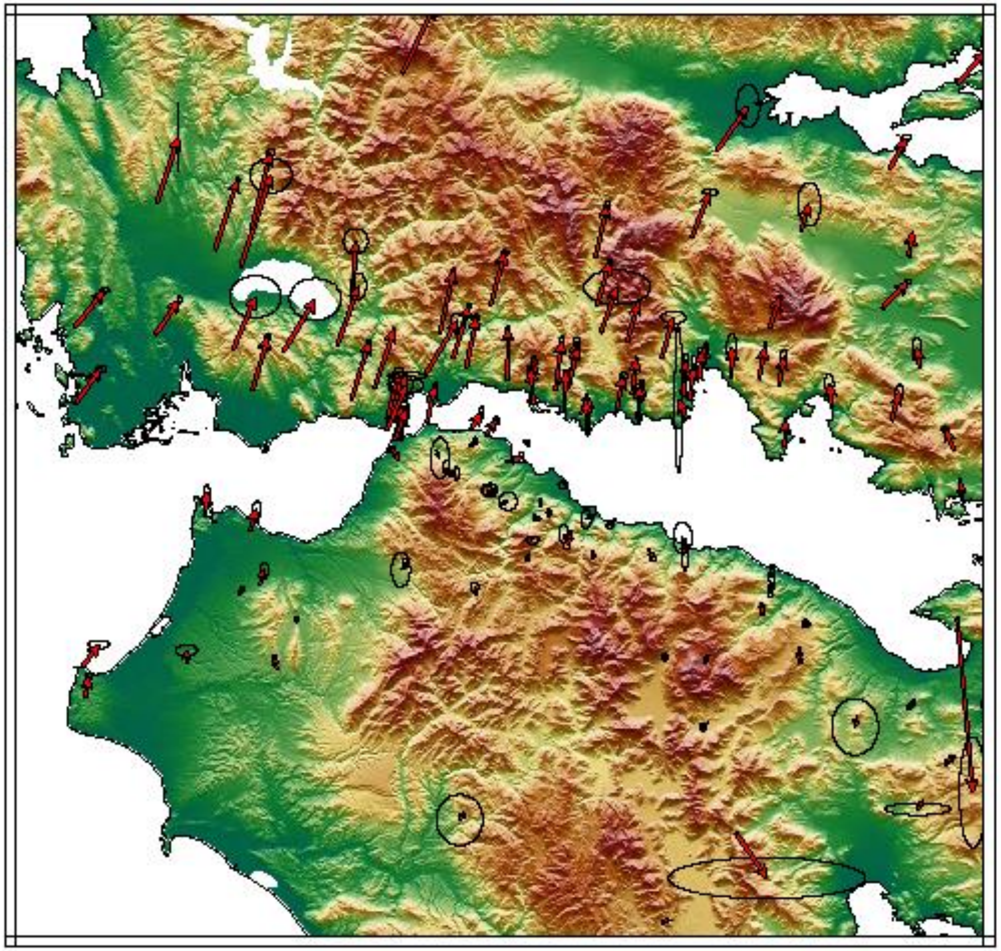
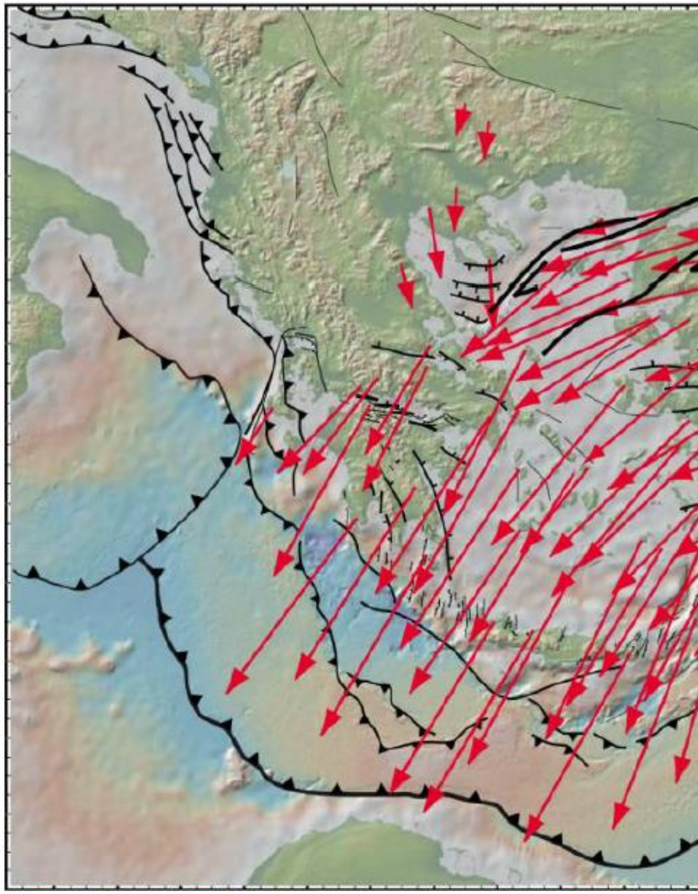


Fig.IV-10. Simplified geological map of the surroundings of the Gulf of Patras. Geology after British Petroleum (1971), Dufaure (1975), and personal data. Bathymetry after Ferentinos et al. (1985). Numbers 1 to 6 locate the areas described in the text. A-B: location of the section of Fig.III-69.

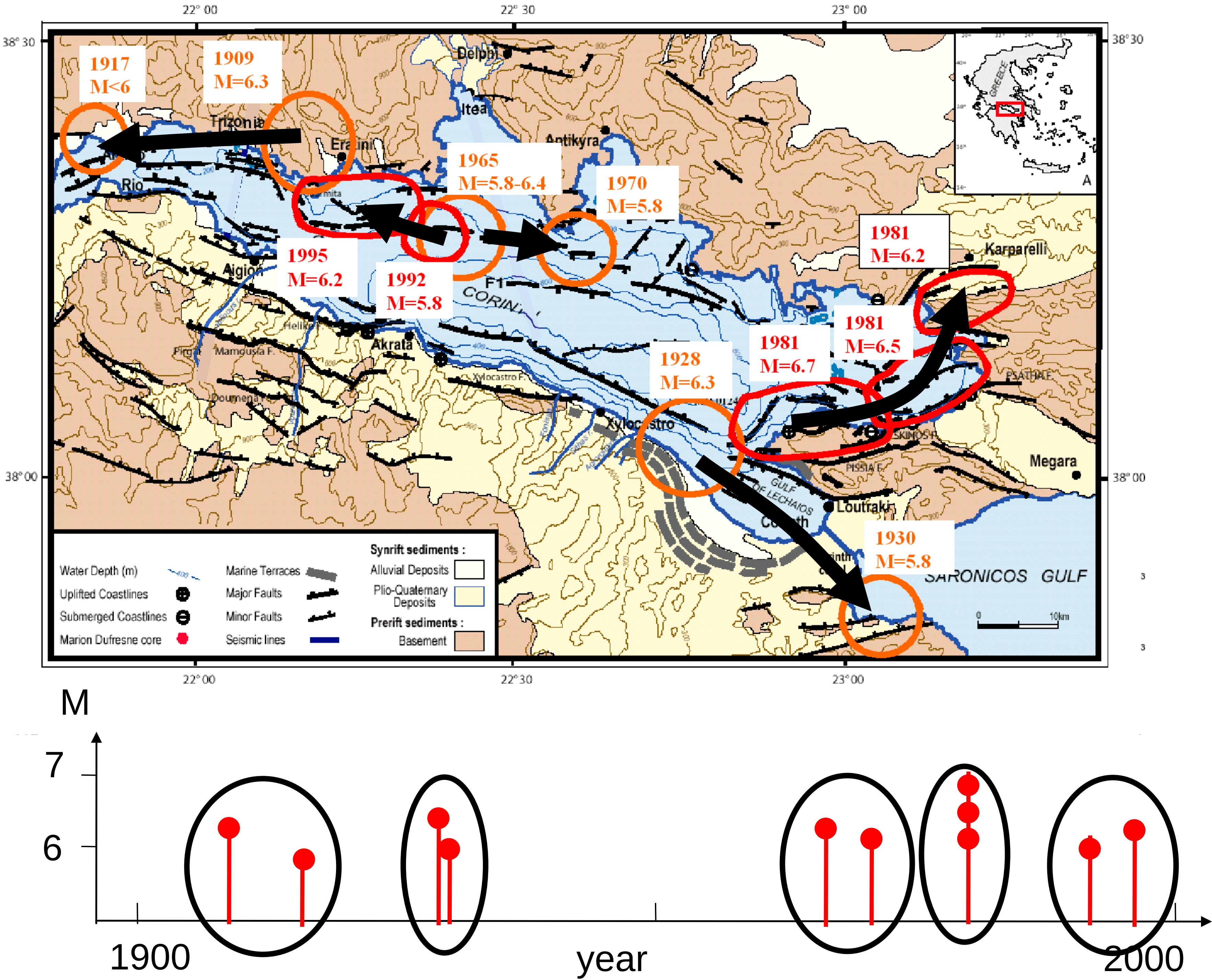
Flotté, 2005



GPS, Briole et al 2013



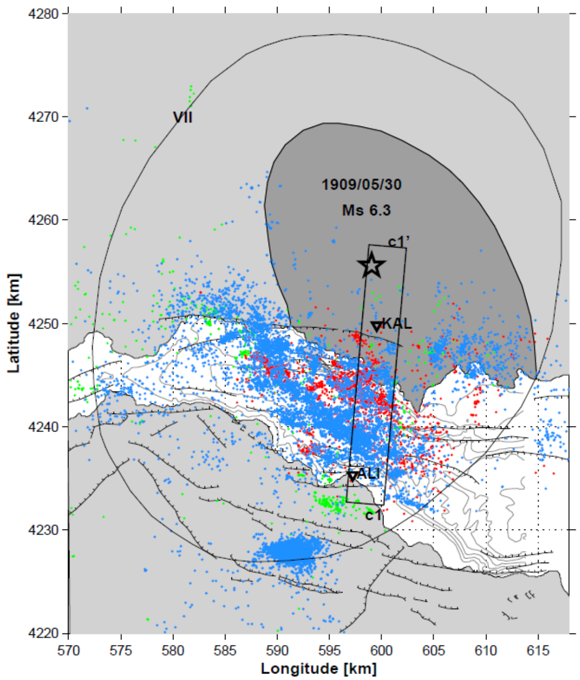
GPS d'après Reilinger et al. (2010).

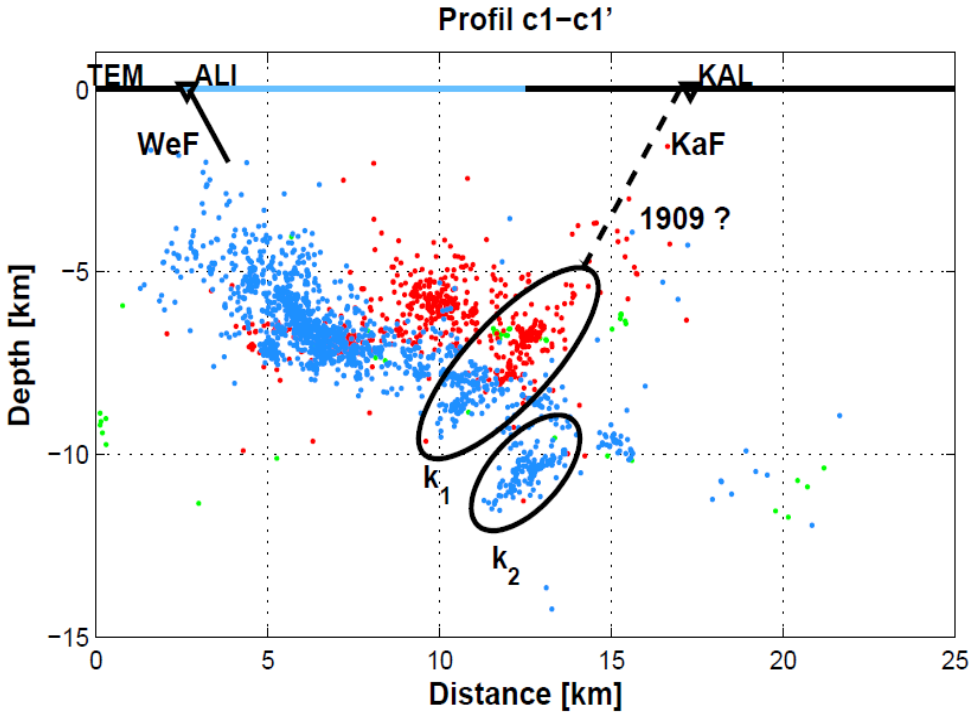


1917
M<6
1909
M=6.3
1965
M=5.8-6.4
1970
M=5.8
1995
M=6.2
1992
M=5.8
1981
M=6.2
1981
M=6.5
1981
M=6.7
1928
M=6.3
1930
M=5.8
Delphi
Itea
Trizonia
Antikyra
Rio
Aigion
Akrata
Xylocastro
Karparelli
Megara
Loutraki
SARONICOS GULF
Water Depth (m)
Uplifted Coastlines
Submerged Coastlines
Marion Dufresne core
Marine Terraces
Major Faults
Minor Faults
Seismic lines
Synrift sediments :
Alluvial Deposits
Plio-Quaternary Deposits
Prerift sediments :
Basement
M
7
6
1900
year
2000

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

- on the Kalithea fault?





Quelles sont les zones bloquées:

Analyse temporelle

-GPS - sismicité: fluctuations différentes

- strainmeter:

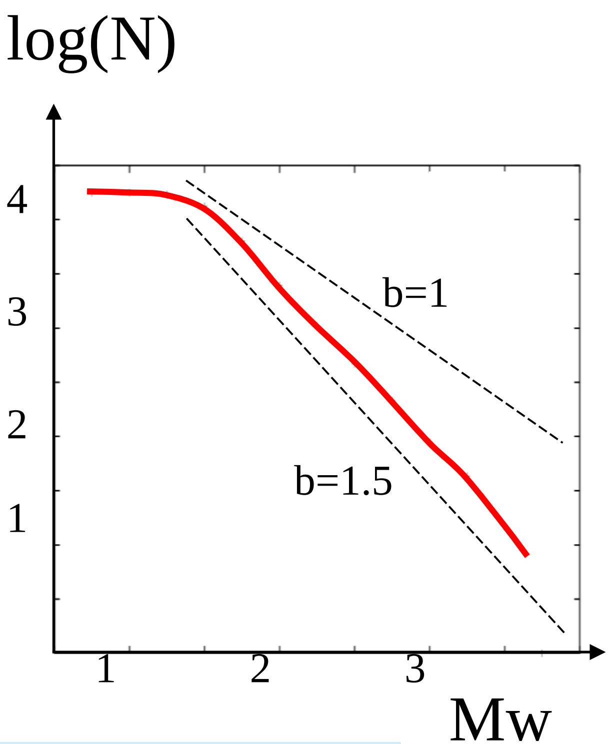
les courtes crises n'ont pas deformation marquée

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

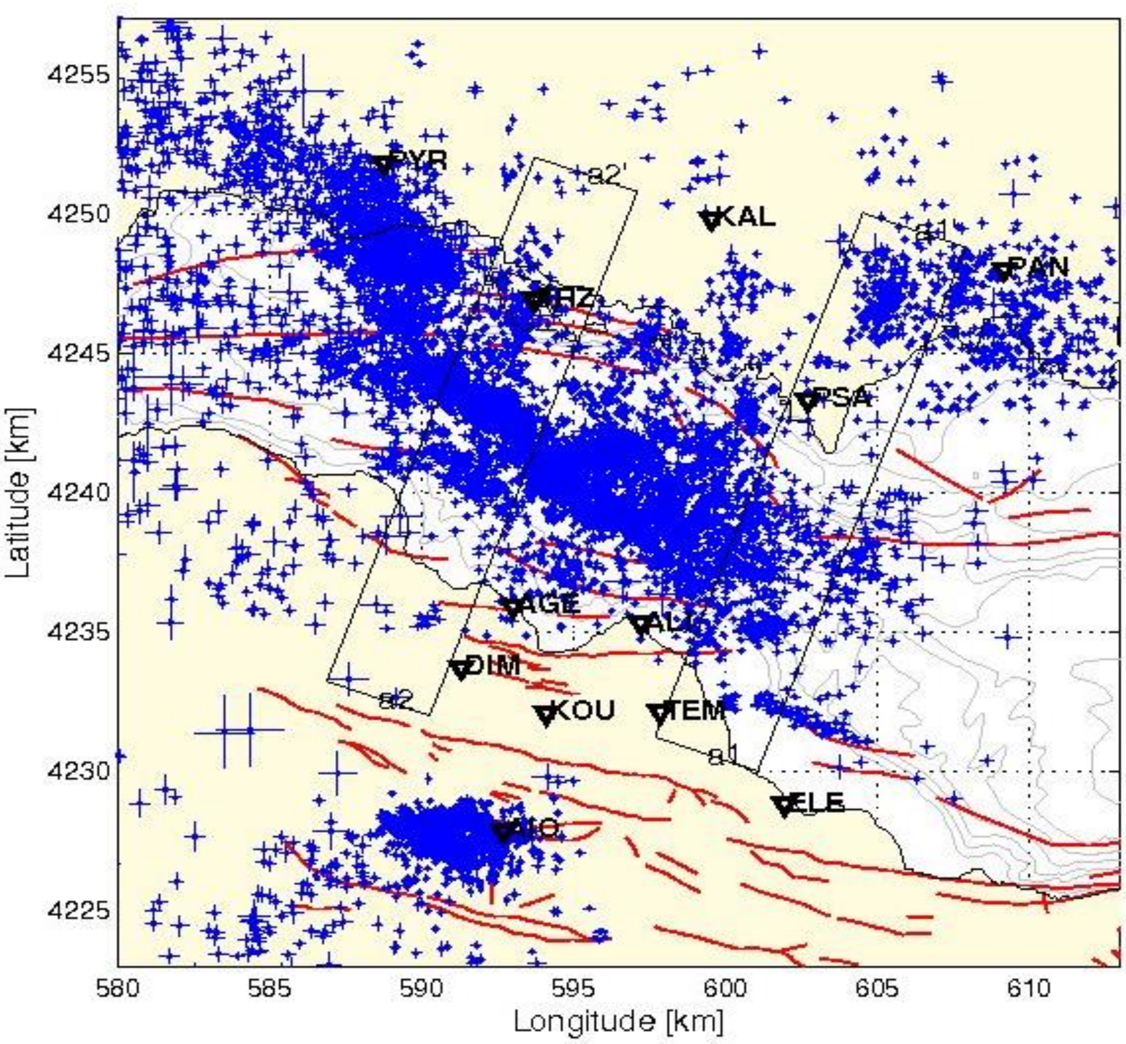
Analyse spatiale:

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

Seismicity 2000-2007



Pacchiani , 2006

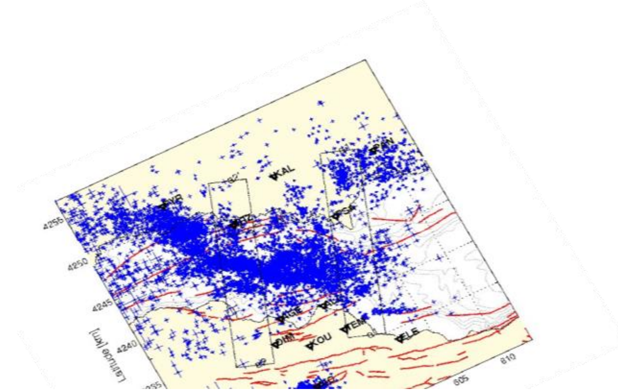


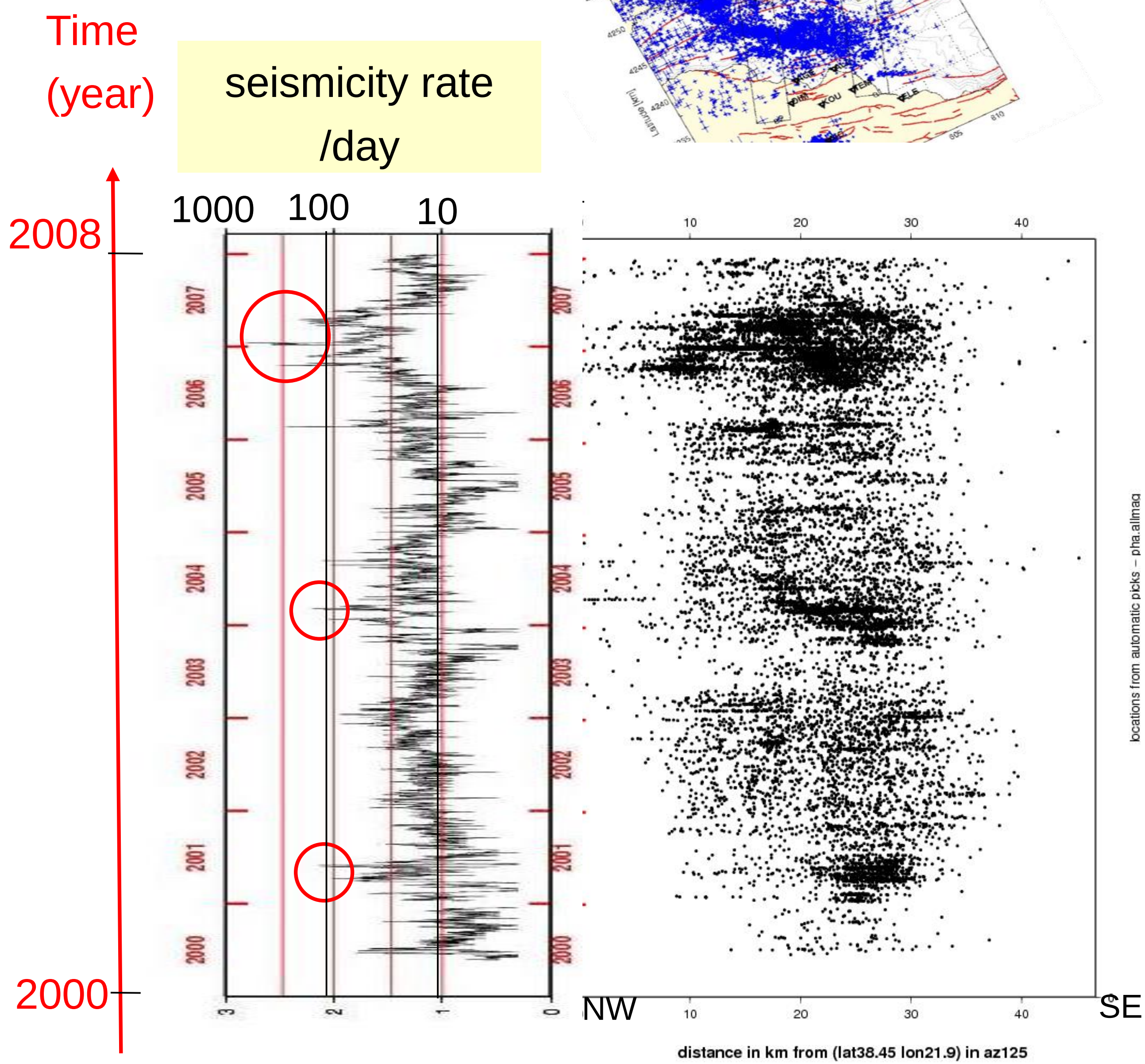
Lambotte, 2008

Space clustering

Fault segments

1 km – 10 km





Time Clustering :

Pulsations

year-month-day

3 large crisis:

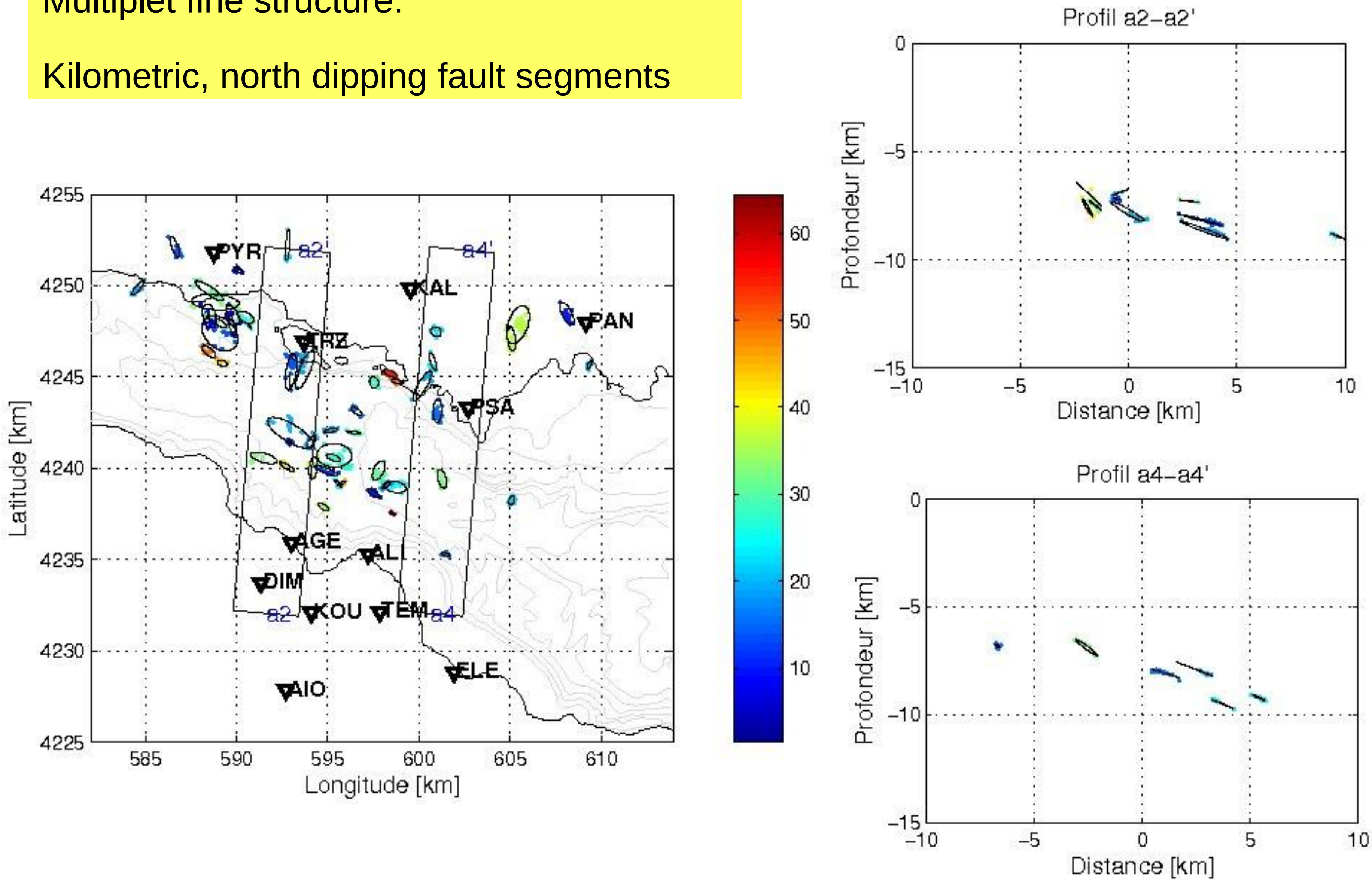
2001

2004

2007

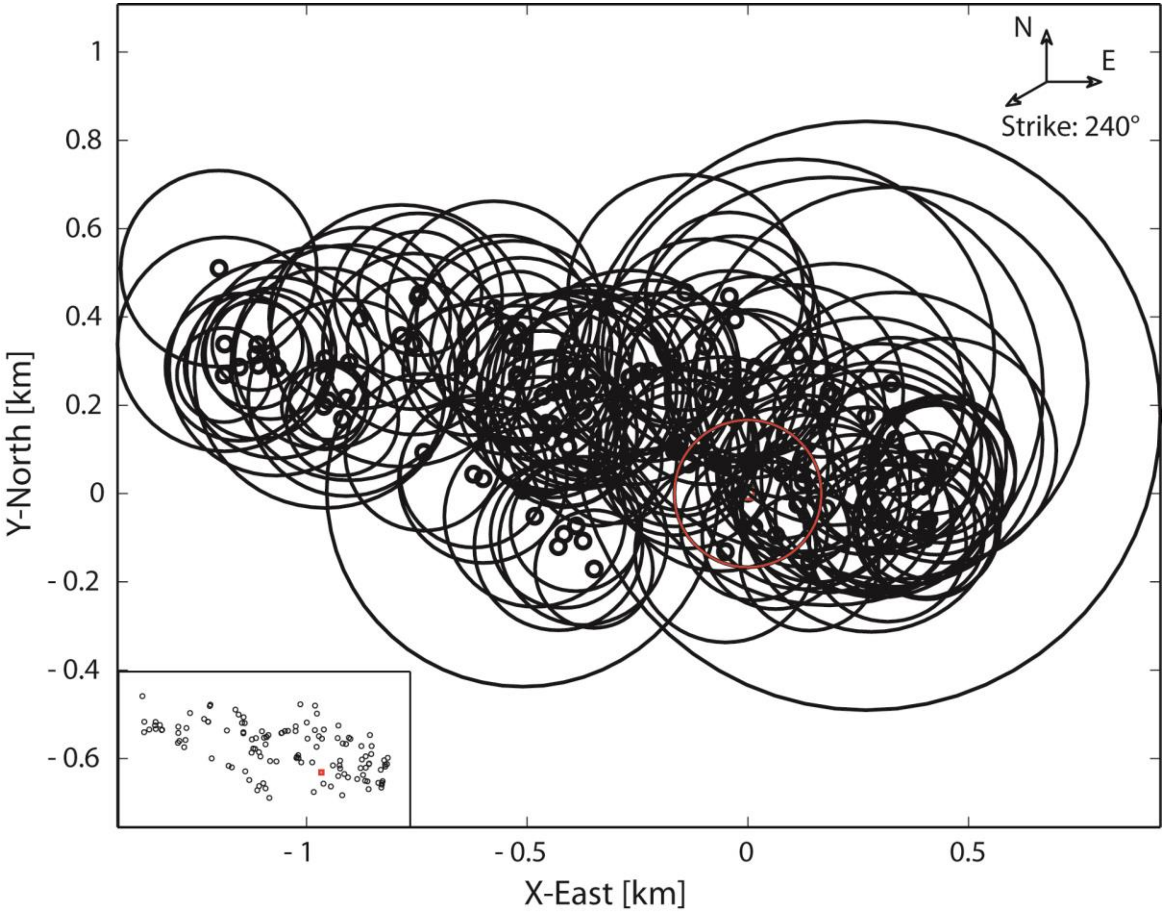
Multiplet fine structure:

Kilometric, north dipping fault segments



Lambotte et al 2009

spatial distribution of events in one multiplet



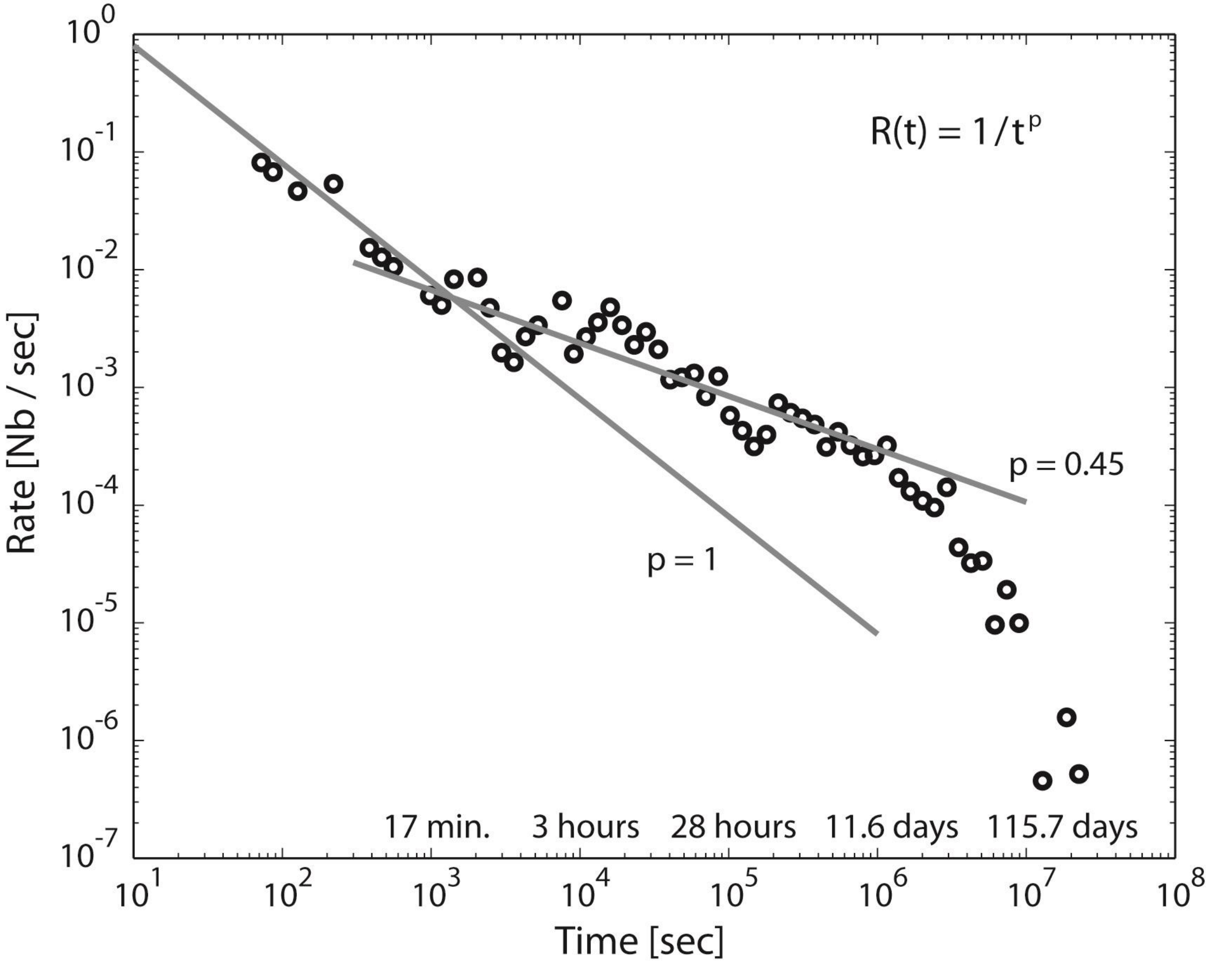
Multiple rupture of the same asperities

- Multiplet seismicity is forced/controlled by creep

- Creeping area must be larger than the seismic area

- Creep may be triggerred/assisted by pore pressure

Decay rate stacked for all multiplets



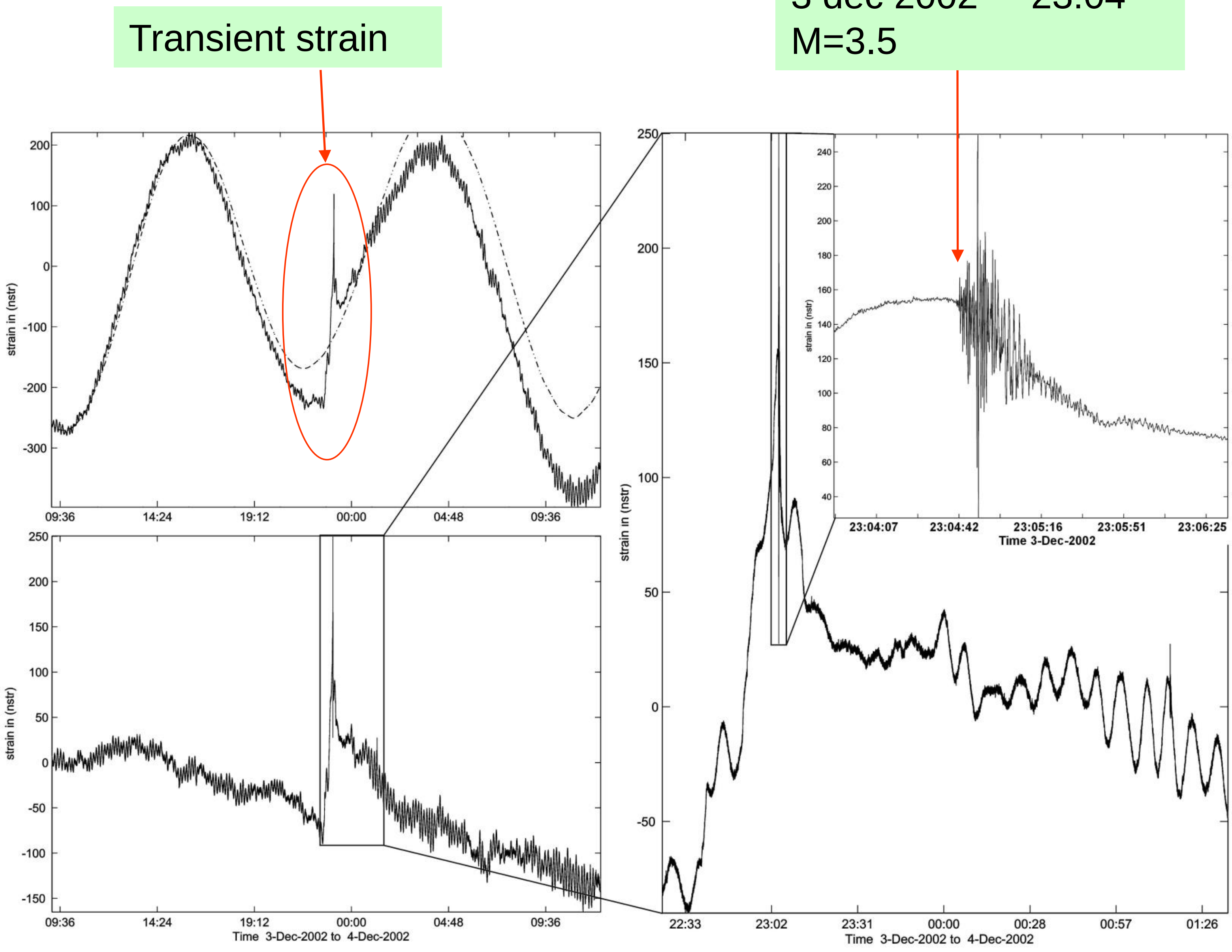
No standard Omori law:

persistent process after 100 – 1000 s

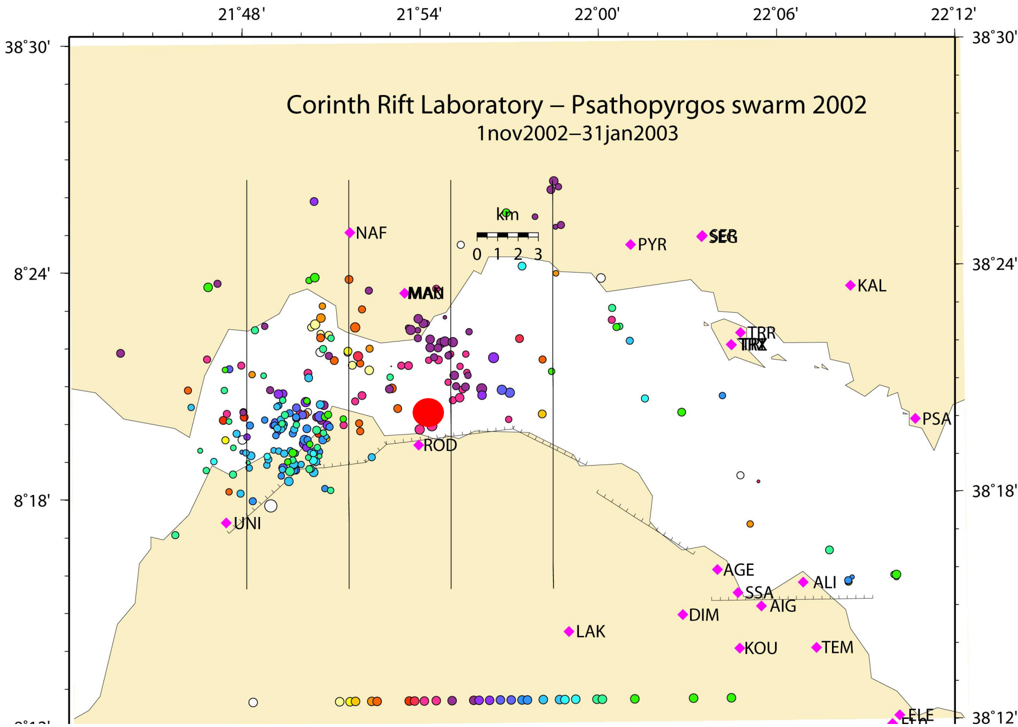
- Multiplet seismicity forced by creep
- Creep triggered by fluid flow

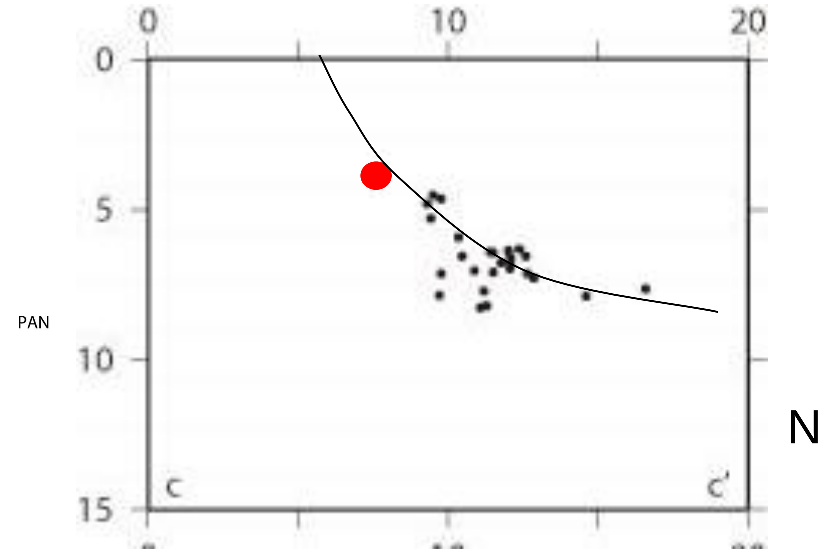
Trizonia borehole Sacks-Evertson strainmeter

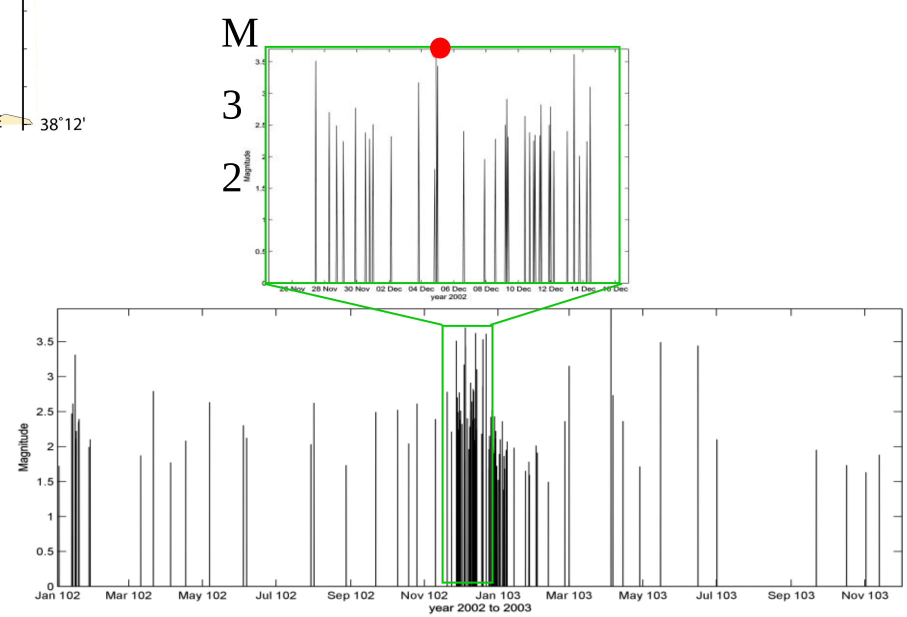
Bernard et al., 2006



Psathopyrgos fault seismic swarm - Nov-dec 2002

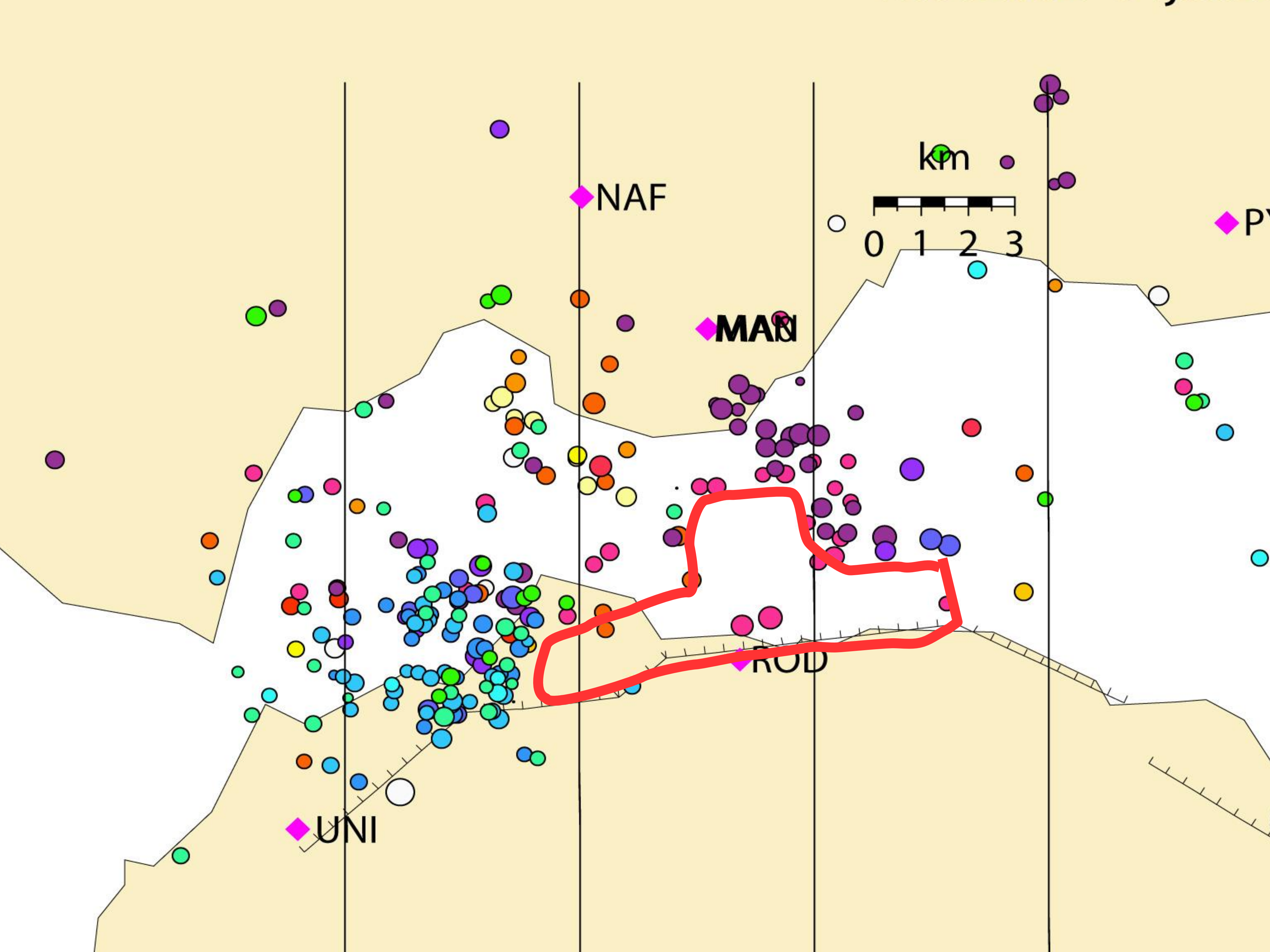




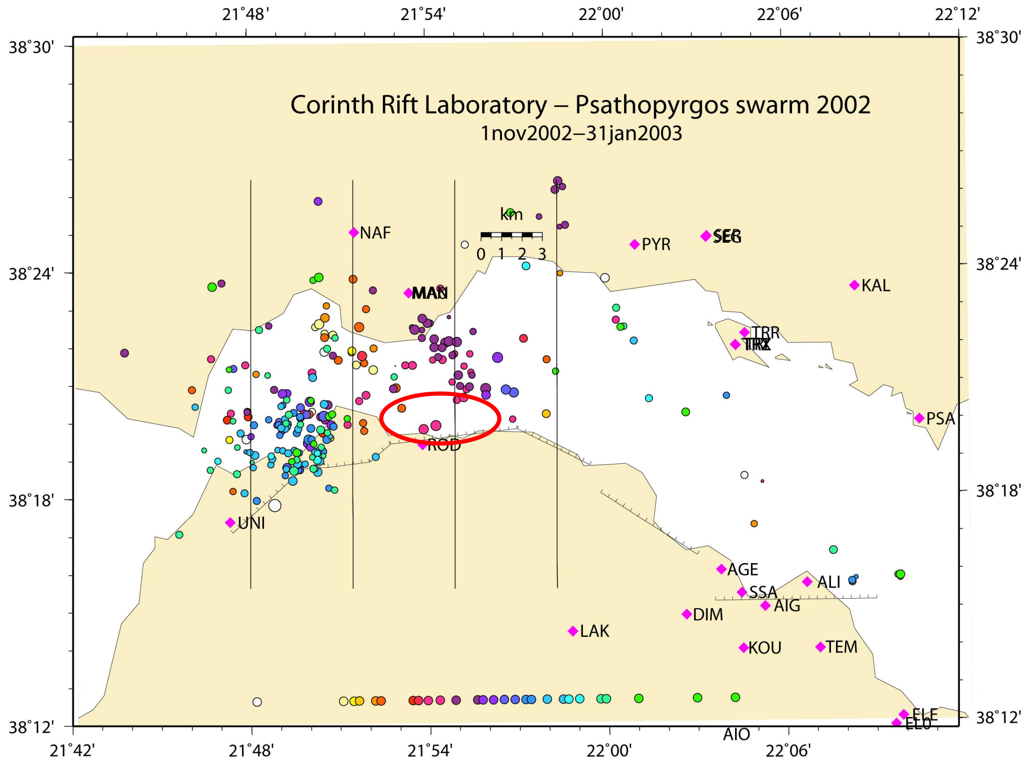


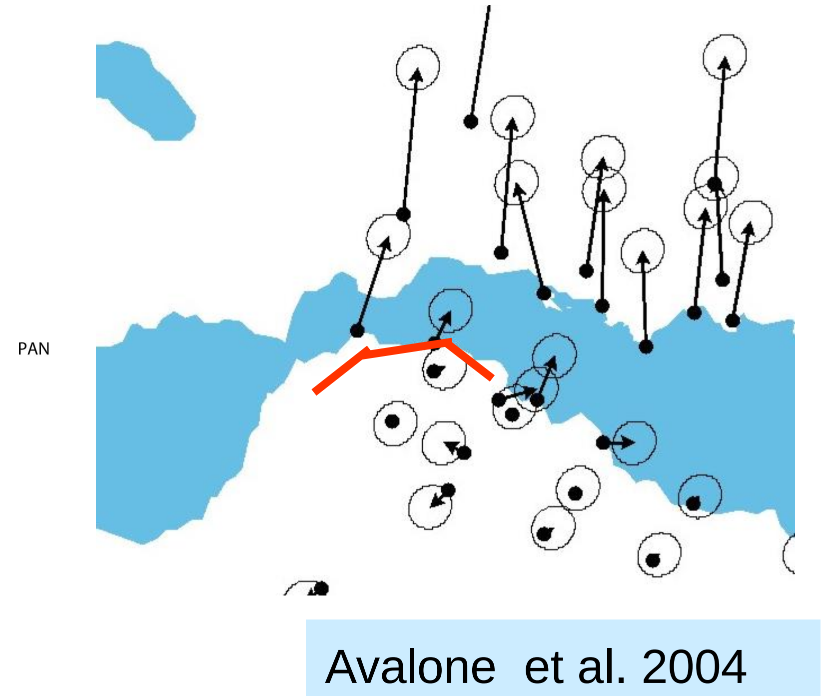
2002-2003

Bernard et al., 2007



NAF
MAN
PY
ROD
UNI
km
0 1 2 3





Nov 02 – jan 03:

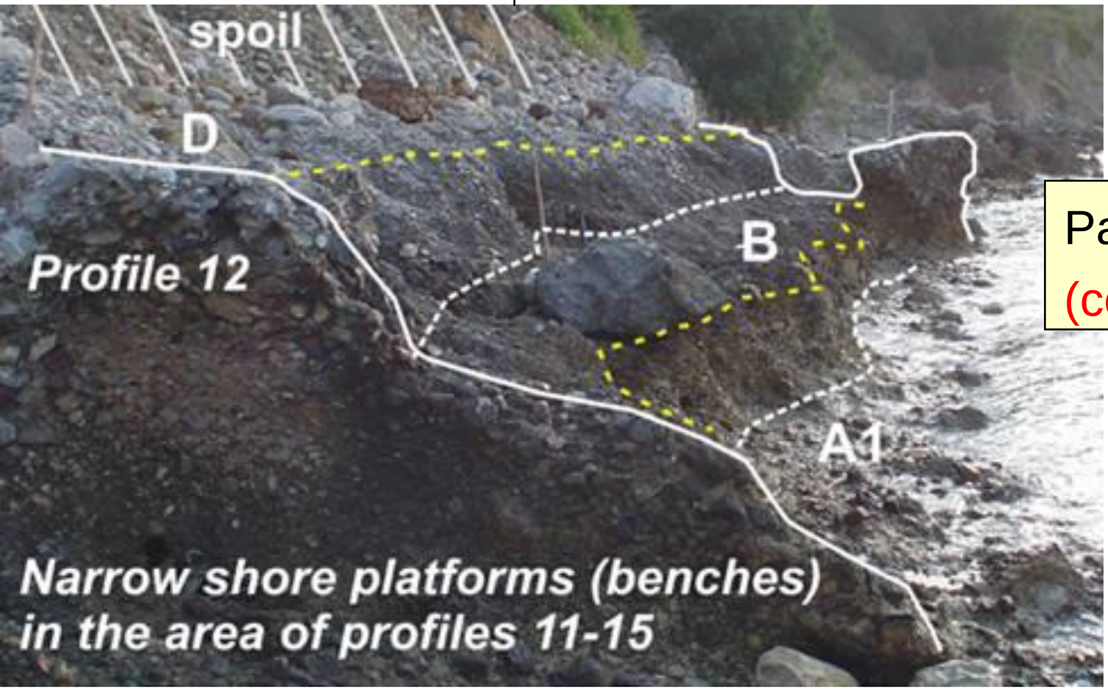
Creep from seismic swarm and strain transient

1990-2001:

Creep from GPS

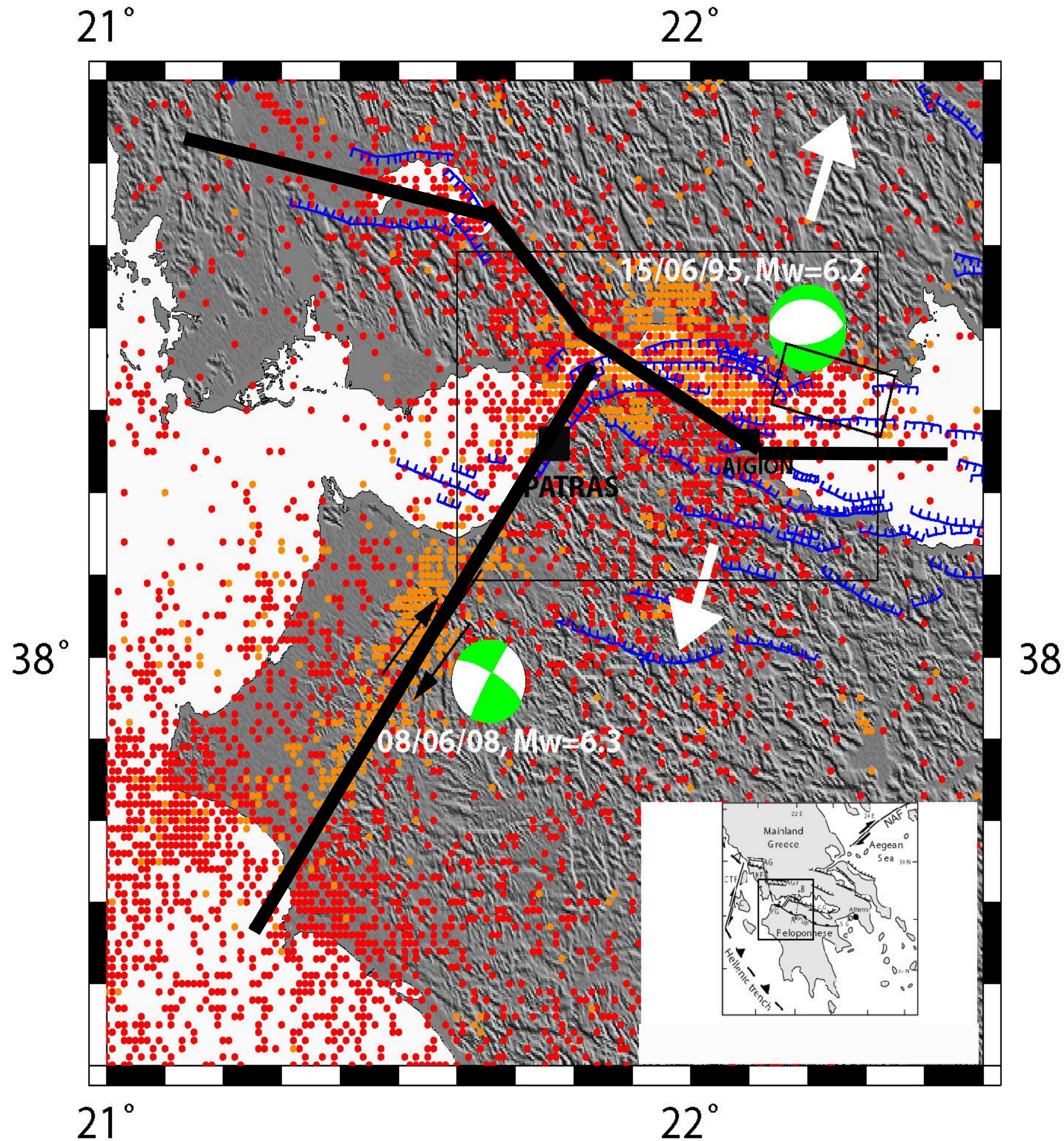
1.5 cm/yr

Psathopyrgos fault



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

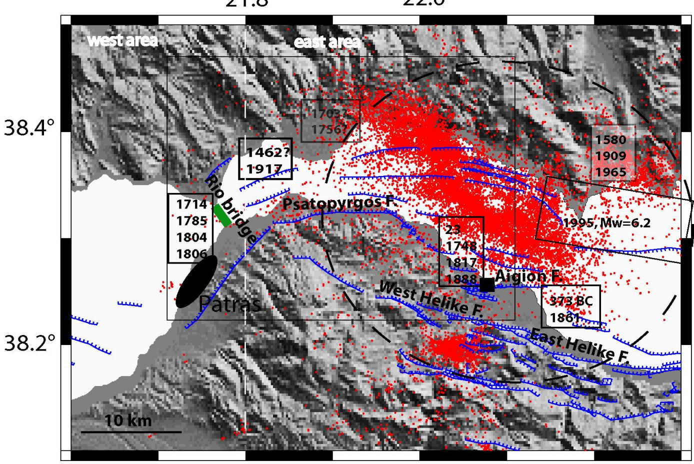
Pantosti et al. 2007



21°
22°
38°
38°
15/06/95, Mw=6.2
PATRAS
AIGION
08/06/08, Mw=6.3
Mainland Greece
Aegean Sea
NAF
Peloponnese
Hellenic trench
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?**

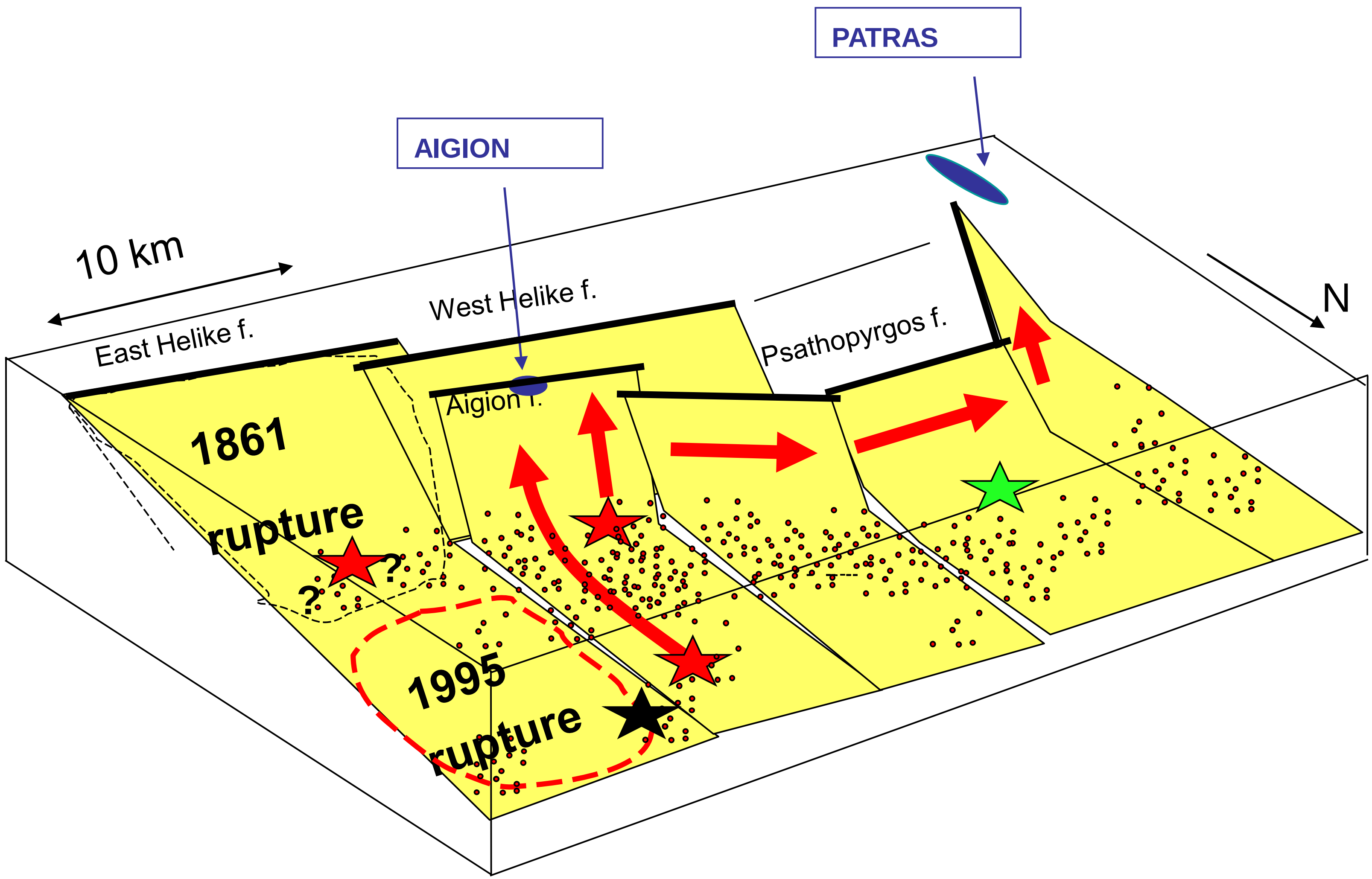
- Steady fast creep or shear in 1-2 km thick layer, on small non coplanar faults at depth, loading the locked segments - **but does it relaxes strain on the deep segments?**

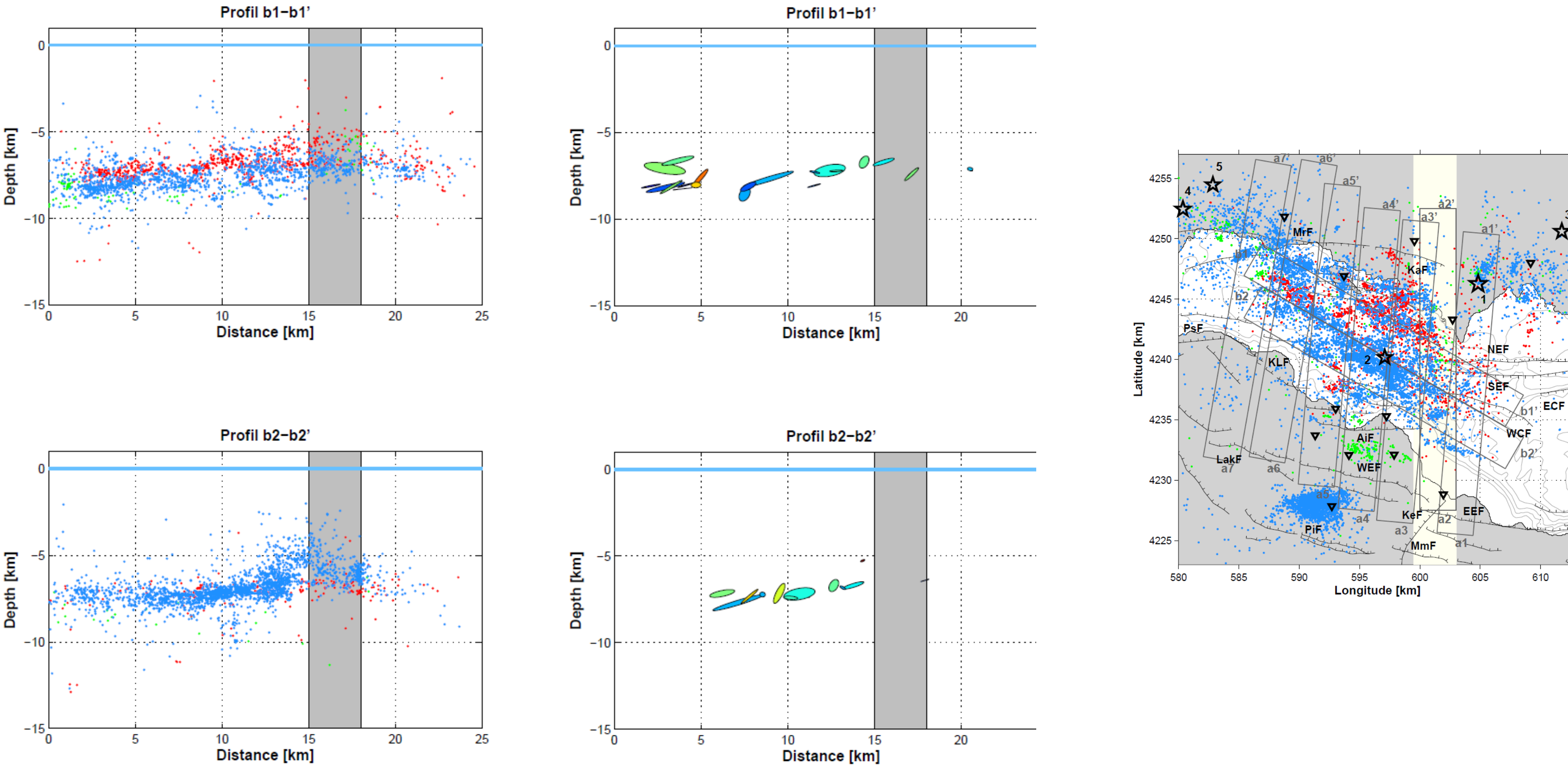
- microseismicity: migrating swarms (days, months) related to major creep events on faults, and strong east-west contrast: **is it related to fluid pulses, and why?**

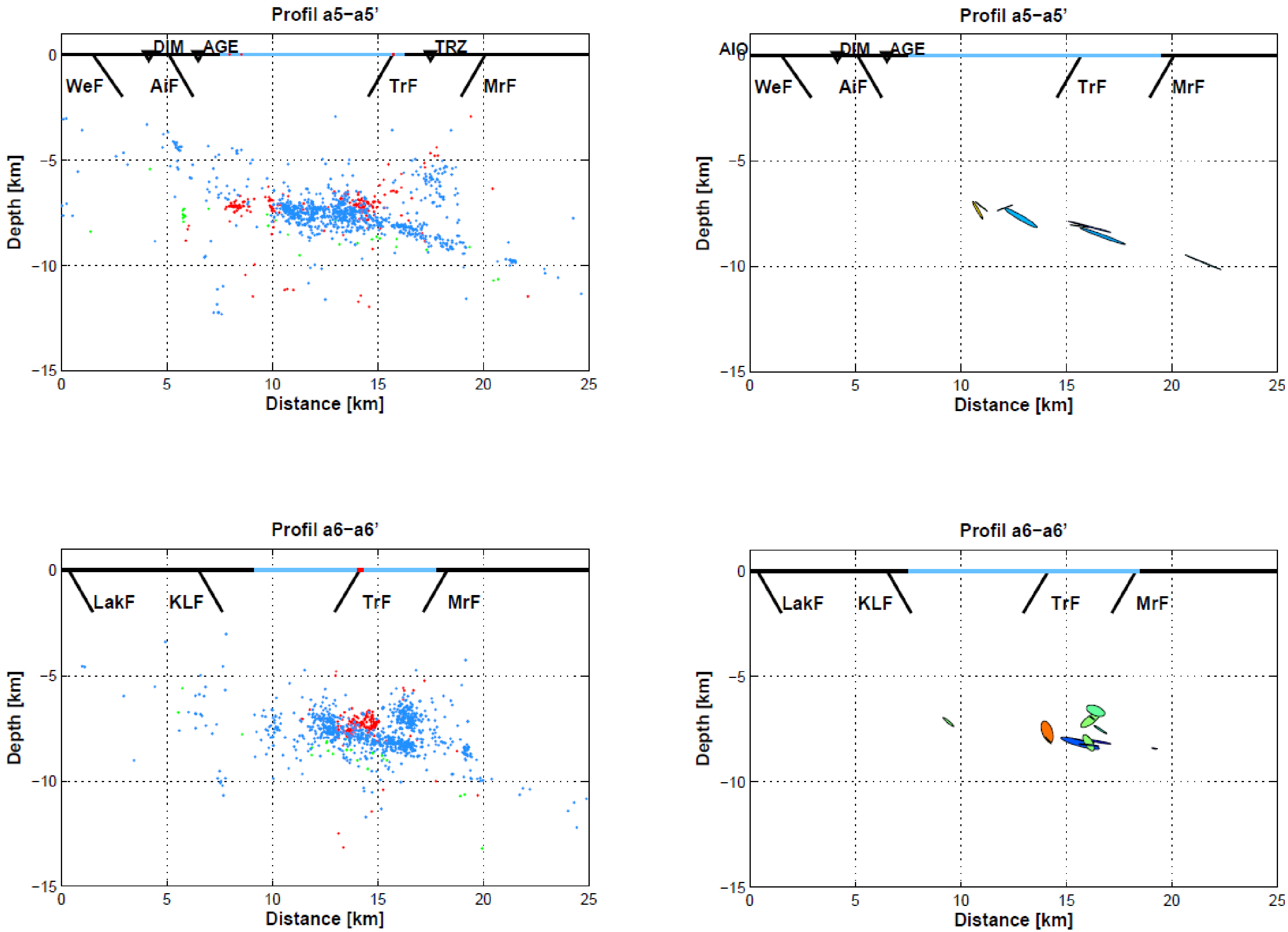
- major transient creep (hour to weeks) on the Psathopyrgos fault: **phase of cyclic relaxation, or start of major failure?**

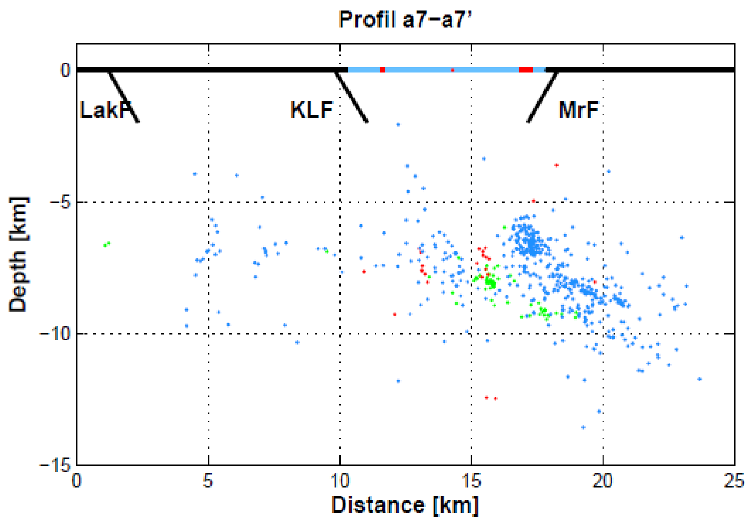
EXPECTED EARTHQUAKES

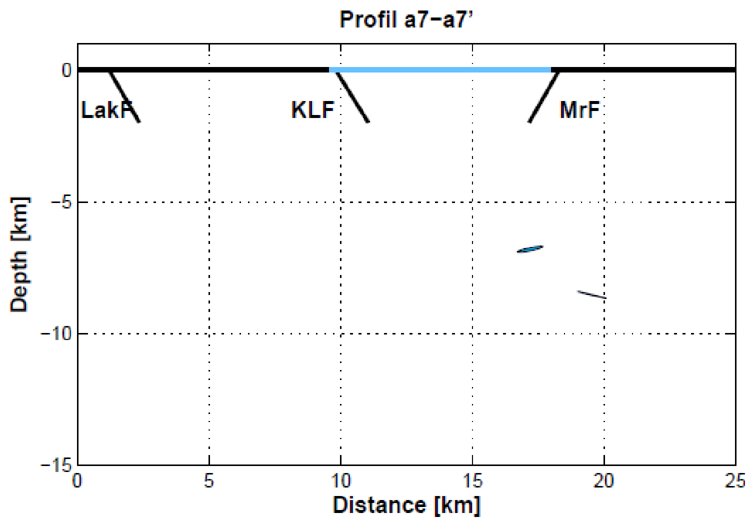
0 - 30 YEARS ?

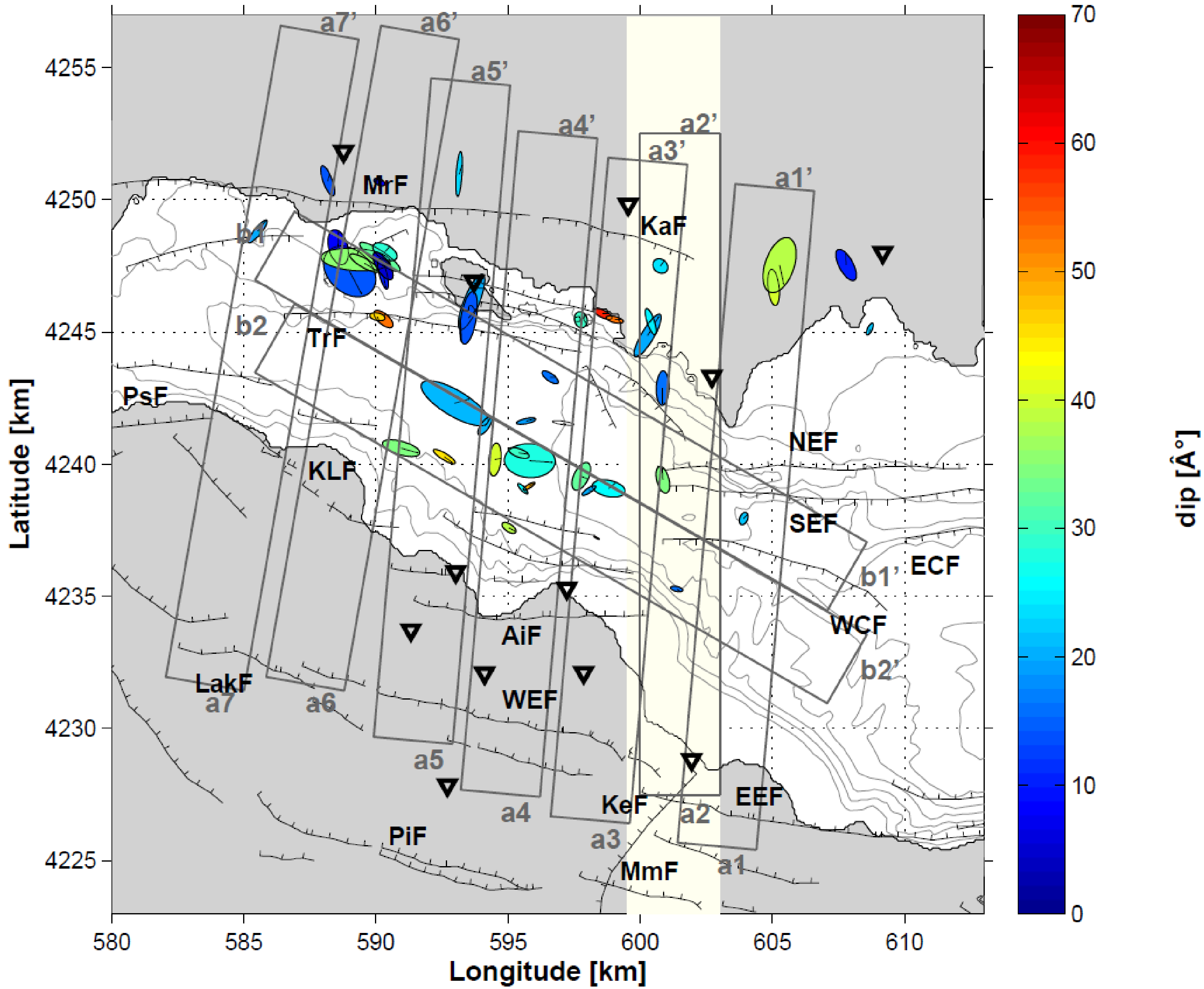



Profil b1−b1’
Depth [km]
Distance [km]
Profil b1−b1’
Depth [km]
Distance [km]
Profil b2−b2’
Depth [km]
Distance [km]
Profil b2−b2’
Depth [km]
Distance [km]
Latitude [km]
Longitude [km]
MrF
KaF
PsF
KLF
NEF
SEF
ECF
WCF
AiF
WEF
LakF
PiF
KeF
MmF
EEF

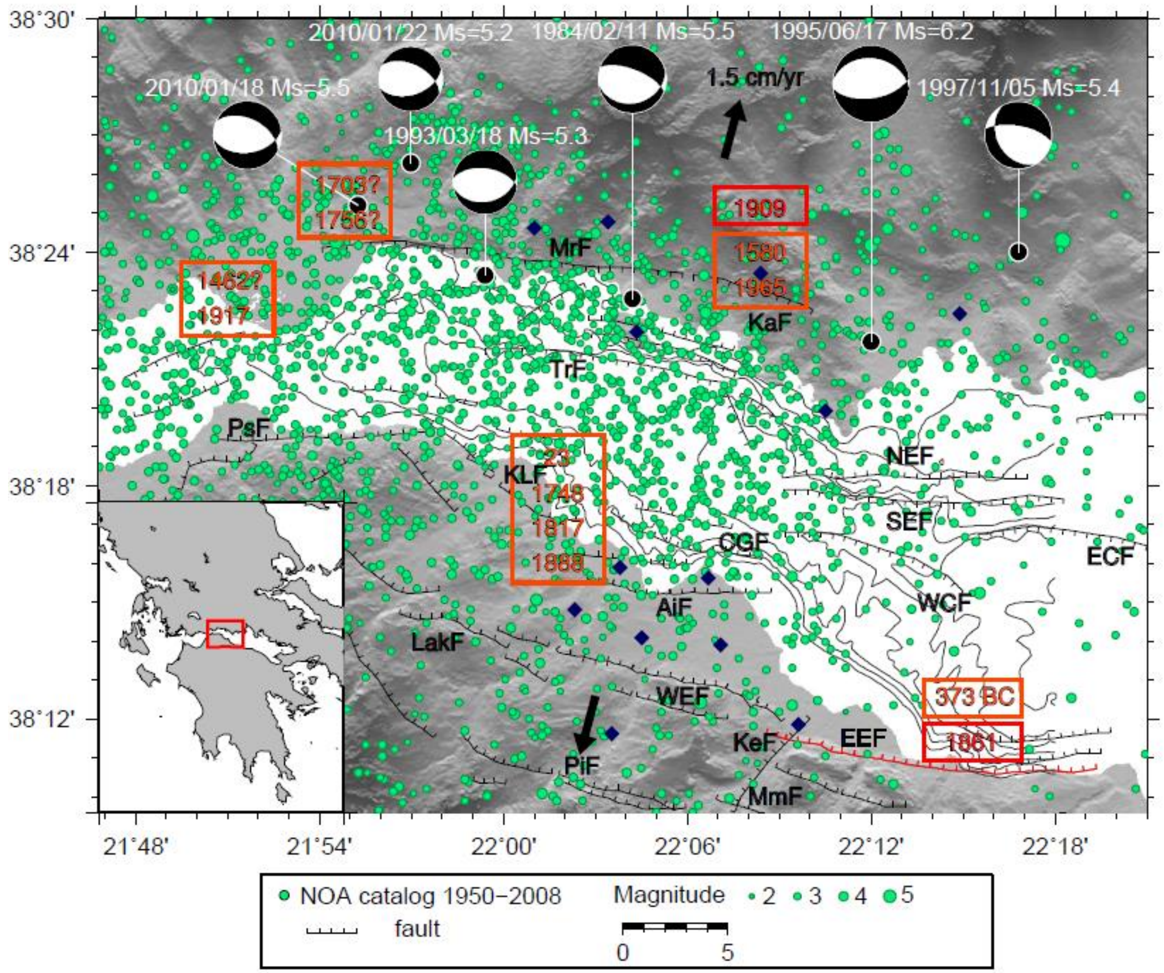

Profil a5–a5'
DIM
AGE
TRZ
WeF
AiF
TrF
MrF
Depth [km]
Distance [km]
Profil a5–a5'
AIO
DIM
AGE
WeF
AiF
TrF
MrF
Depth [km]
Distance [km]
Profil a6–a6'
LakF
KLF
TrF
MrF
Depth [km]
Distance [km]
Profil a6–a6'
LakF
KLF
TrF
MrF
Depth [km]
Distance [km]


Profil a7−a7'
0
−5
−10
−15
Depth [km]
LakF
KLF
MrF
0
5
10
15
20
25
Distance [km]

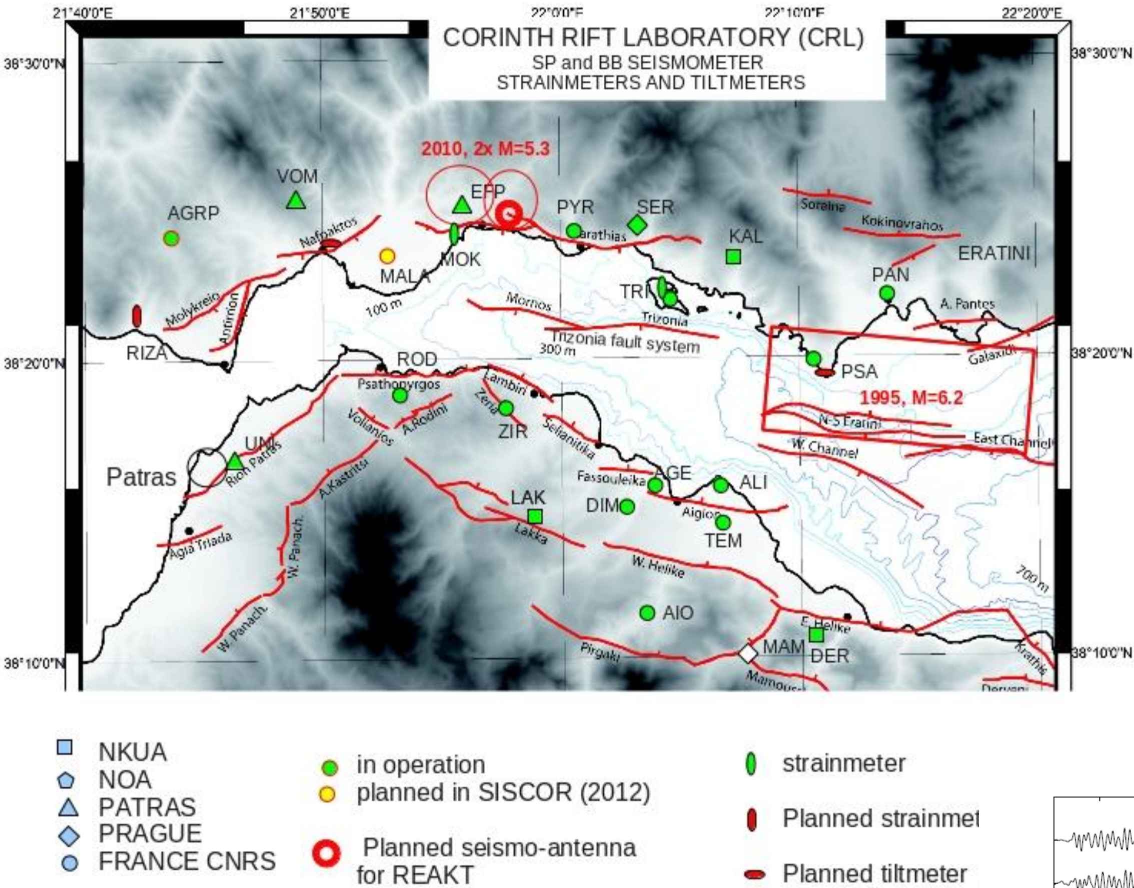

Profil a7−a7'
0
−5
−10
−15
Depth [km]
LakF
KLF
MrF
0
5
10
15
20
25
Distance [km]



a7'
a6'
a5'
a4'
a2'
a3'
a1'
MrF
KaF
b1
b2
TrF
PsF
KLF
NEF
SEF
ECF
b1'
WCF
b2'
AiF
WEF
LakF
a7
a6
a5
a4
KeF
a3
a2
EEF
a1
PiF
MmF
4255
4250
4245
4240
4235
4230
4225
580
585
590
595
600
605
610
Latitude [km]
Longitude [km]
70
60
50
40
30
20
10
0
dip [Â°]



2010/01/22 Ms=5.2
1984/02/11 Ms=5.5
1995/06/17 Ms=6.2
2010/01/18 Ms=5.5
1.5 cm/yr
1997/11/05 Ms=5.4
1993/03/18 Ms=5.3
1703?
1756?
1909
1580
1965
1462?
1917
MrF
KaF
TrF
PsF
23
1748
1817
1888
KLF
NEF
SEF
CGF
ECF
AiF
WCF
LakF
WEF
373 BC
1861
KeF
EEF
PiF
MmF
38°30'
38°24'
38°18'
38°12'
21°48'
21°54'
22°00'
22°06'
22°12'
22°18'
NOA catalog 1950-2008
fault
Magnitude 2 3 4 5
0 5

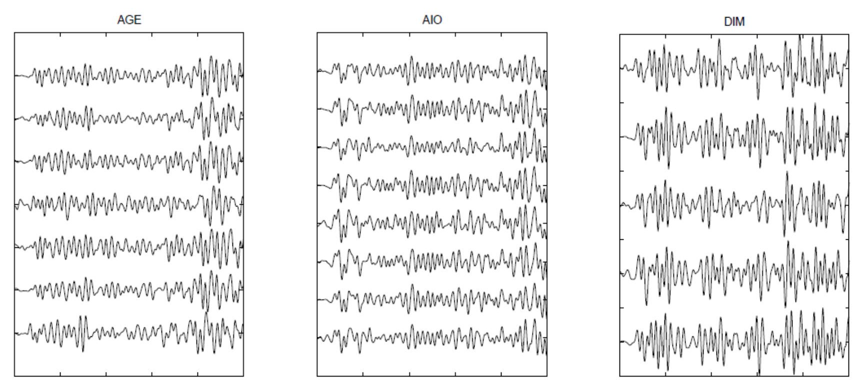


Permanent seismic array since 2000

-Double difference location

-Multiplets: improved locations through cross-correlations

Lambotte et al. 2013

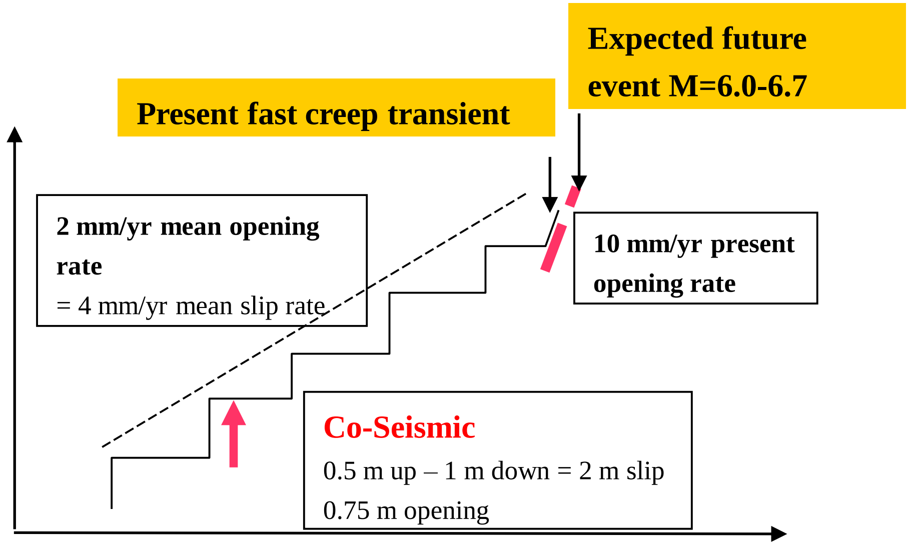


Structure and dynamics of the detachment?

Connection of the normal faults to the detachement?

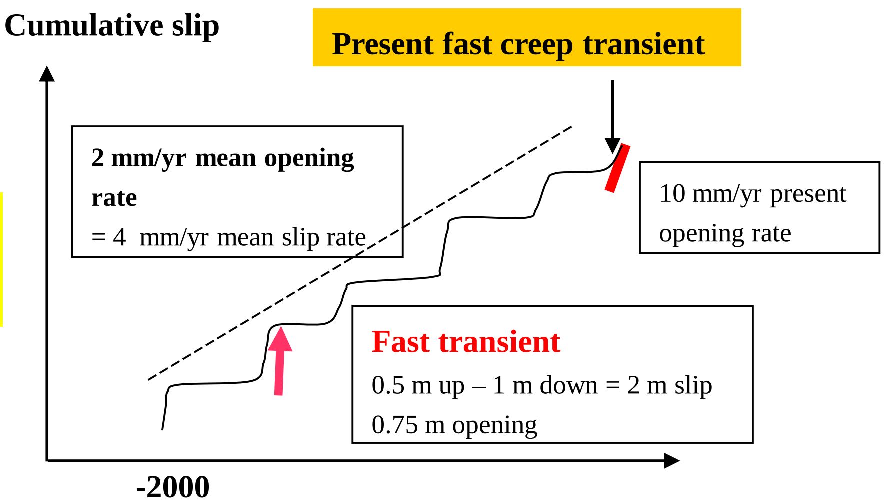
Dual model:

Alternating creep and seismic; velocity weakening and strengthening



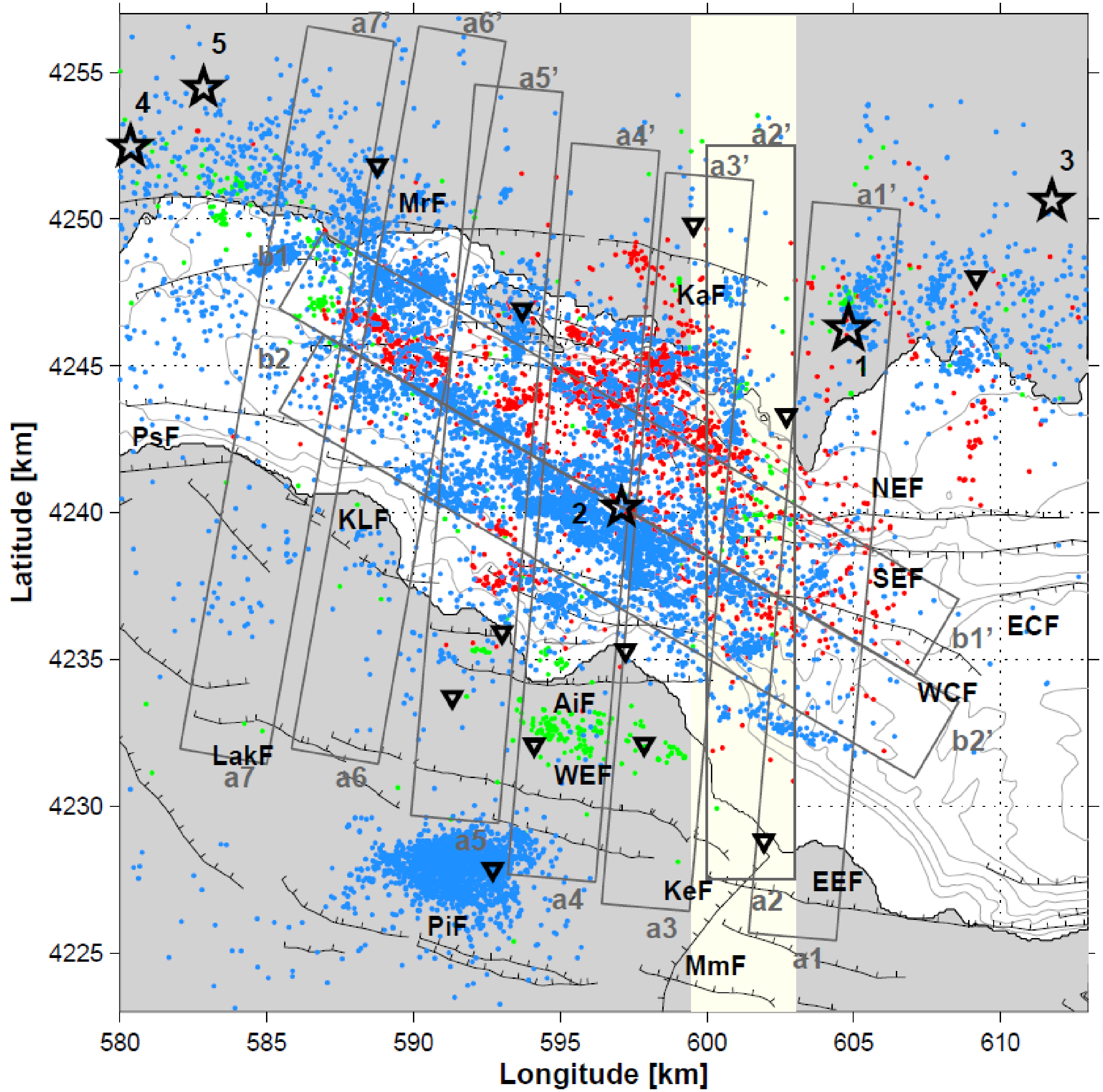
Pure creep model:

velocity strengthening



Creep transients on the Psathopyrgos fault at various time scales:

hours (strain), days-weeks (seismicity), decades (GPS), centuries (paleo-shorelines)



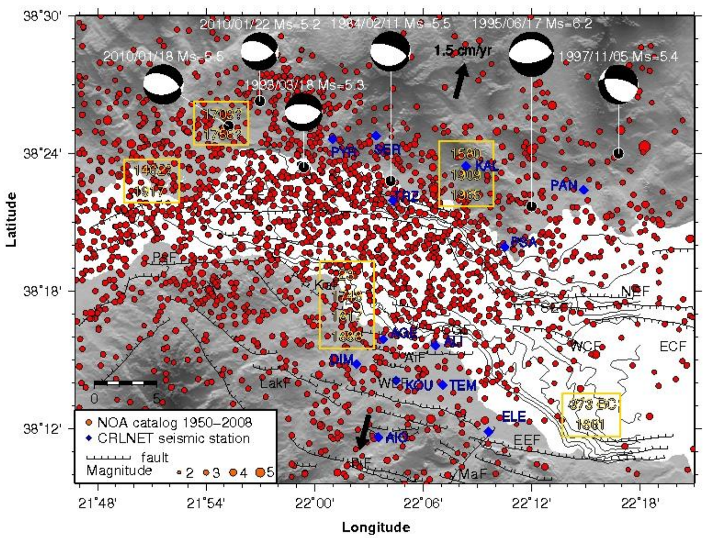
Double-difference relocation, Lambotte et al.(2013)

-NW trend of micro-seismicity: at the root of the recent fault system

-strong segmentation

- isolated clusters

NOA locations since 1975



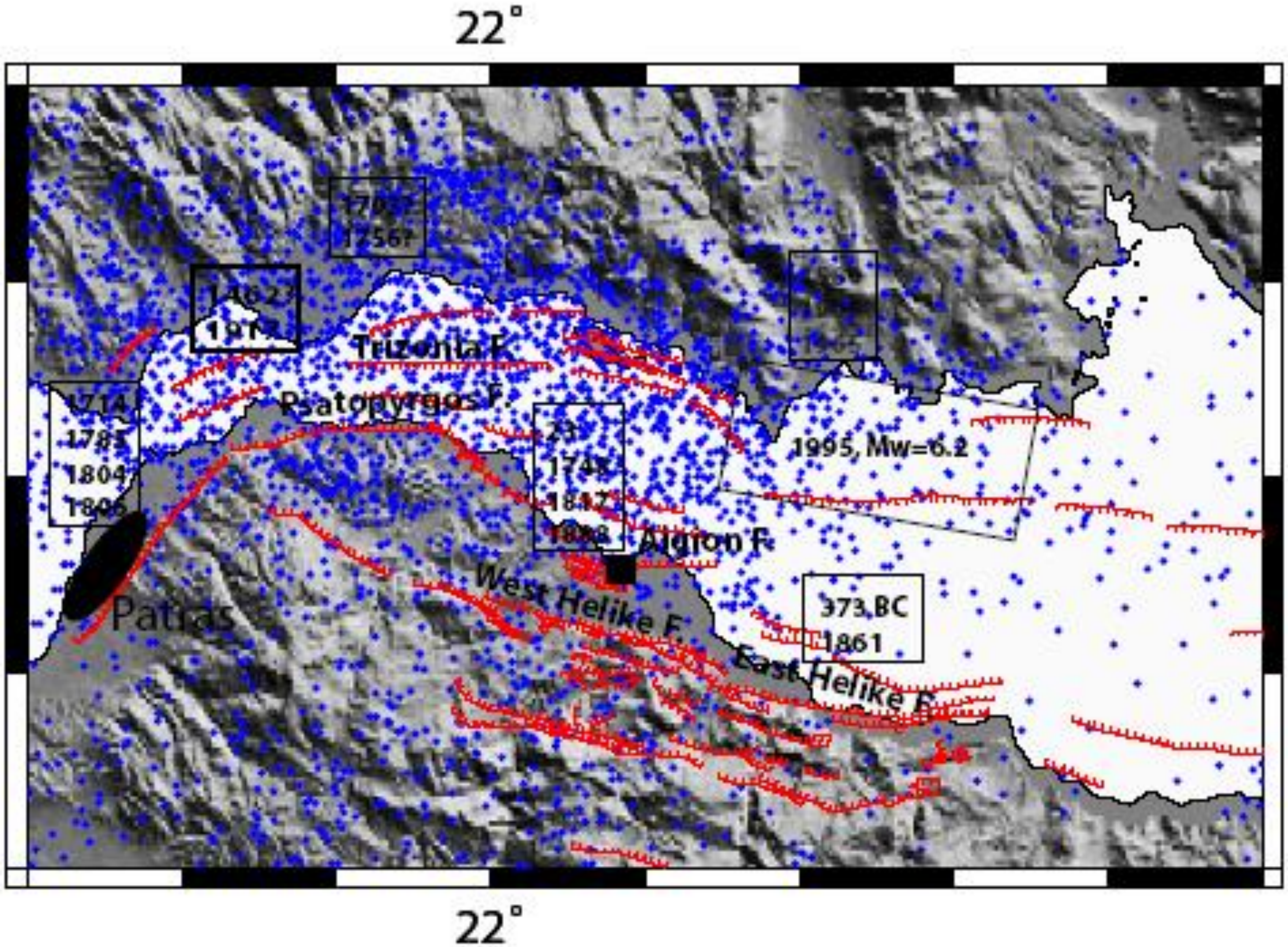
Blue: 2001-2007

Red: Aftershocks 1995

Green: july 1991

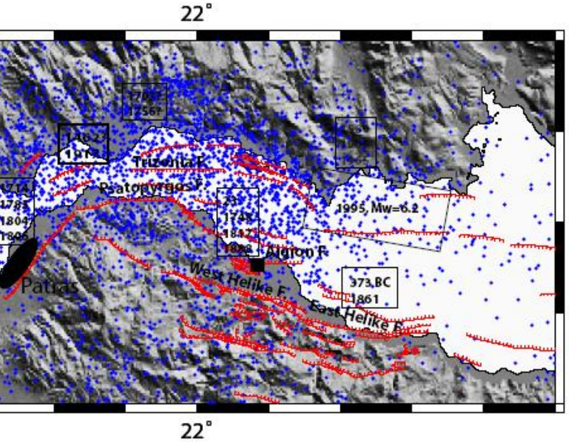

N
HELIKE FAULT

NOA

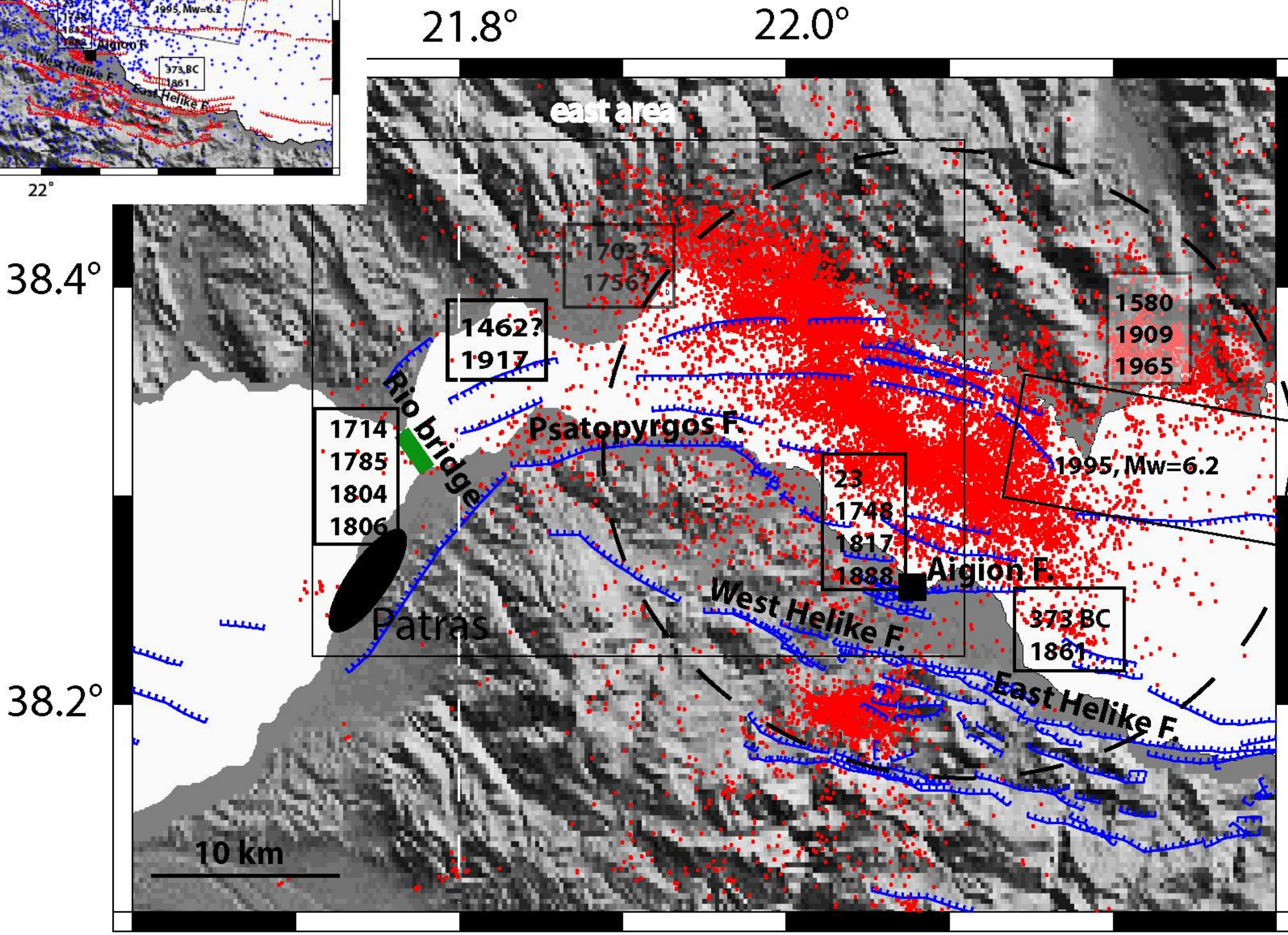


22°
Trizonia F.
Psatopyrgos F.
1714
1785
1804
1806
1995, Mw=6.2
Aigion F.
West Helike F.
East Helike F.
Patras
373 BC
1861
22°

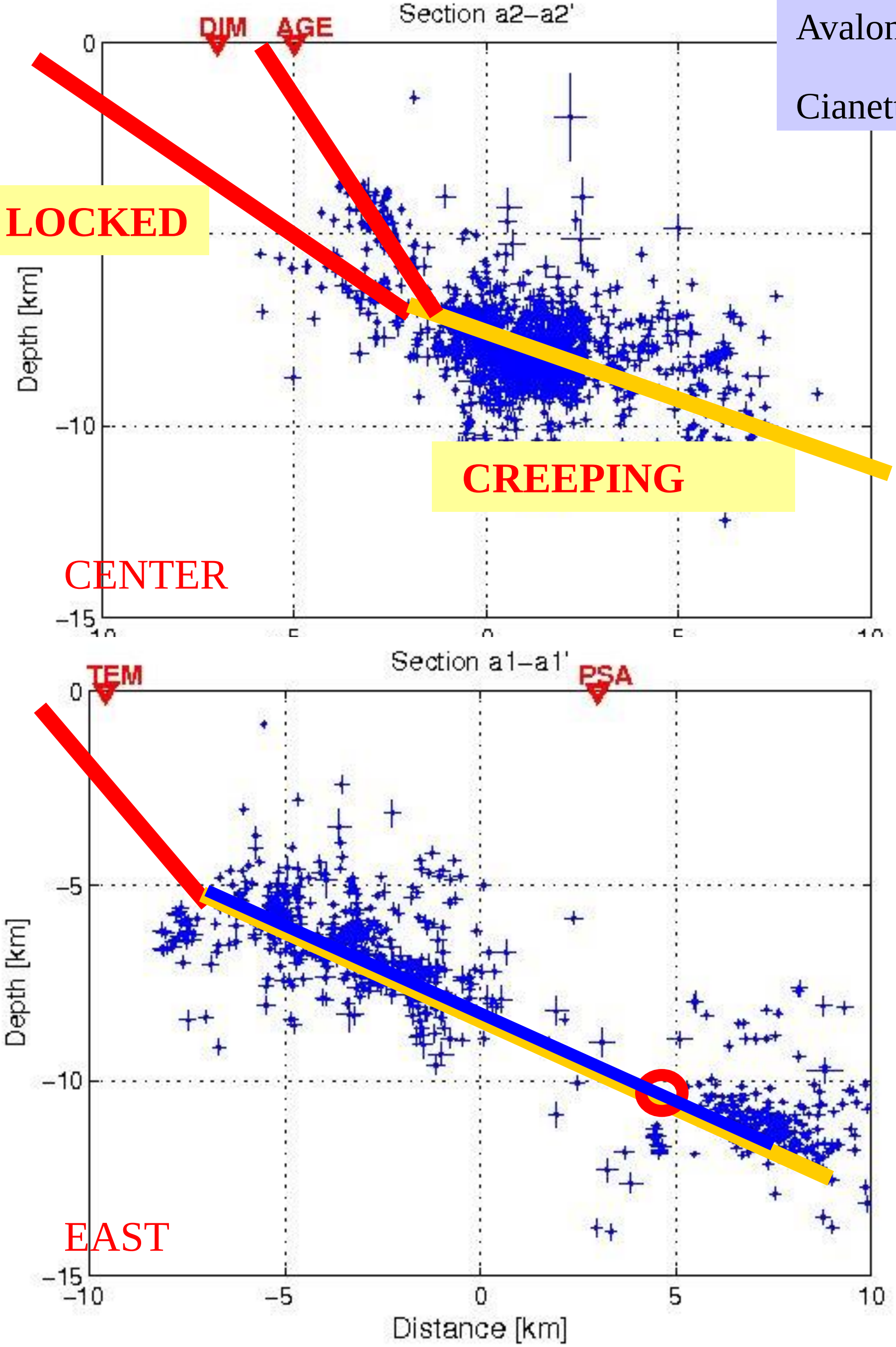
CRL



22°
Psatopyrgos F.
1995, Mw=6.2
Aigion F.
Patras
West Helike F.
373 BC
1861
East Helike F.
22°

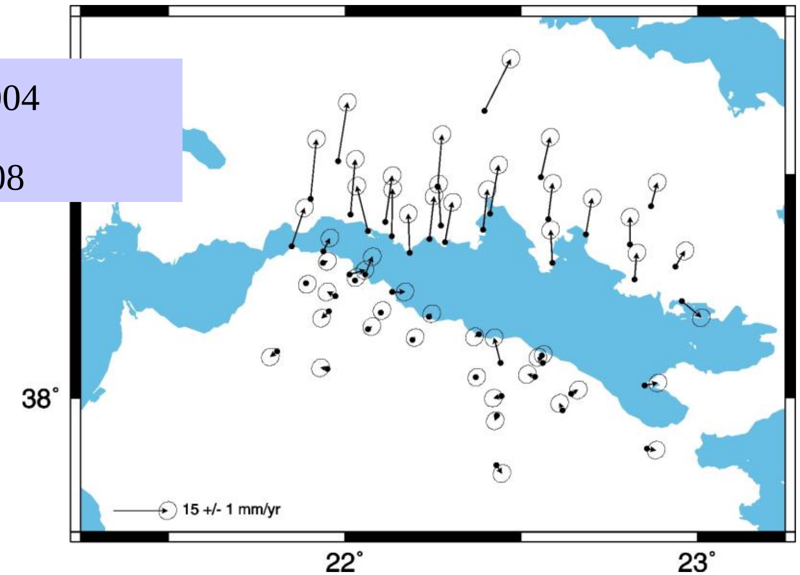


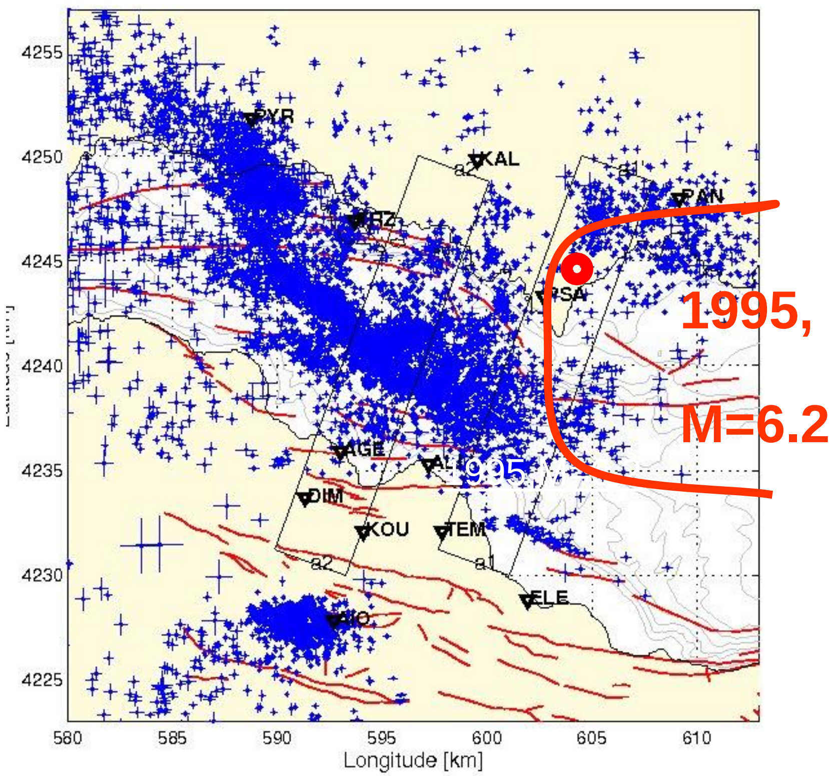
21.8°
22.0°
38.4°
38.2°
east area
1703?
1756?
1462?
1917
1580
1909
1965
Rio bridge
1714
1785
1804
1806
Psatopyrgos F.
1995, Mw=6.2
23
1748
1817
1888
Aigion F.
West Helike F.
Patras
373 BC
1861
East Helike F.
10 km



Avalone et al., 2004

Cianetti et al. 2008

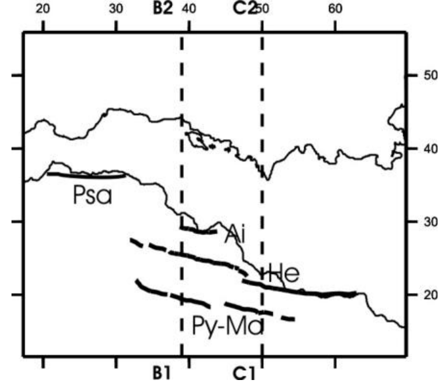




SEISMICITY 2001-2007

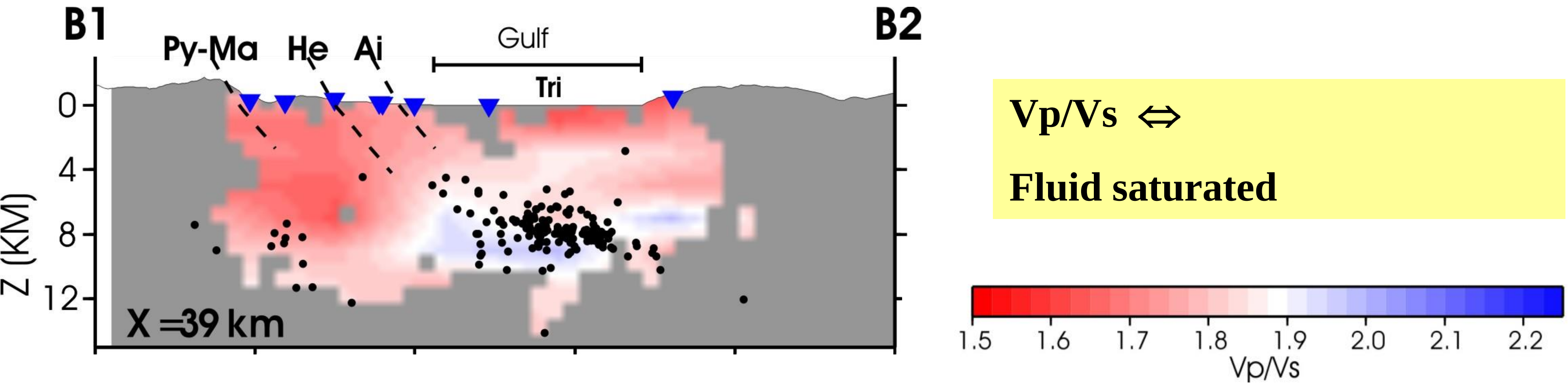
Corinth Tomography:

Rifting and fluids



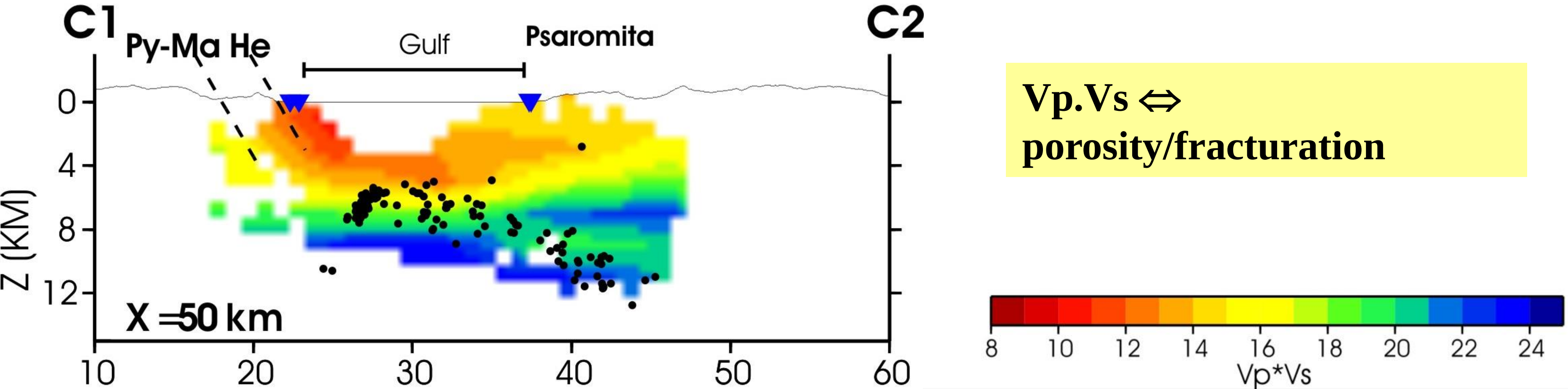
Latorre, 2004

Gautier et al. 2006



Vp/Vs ⇔

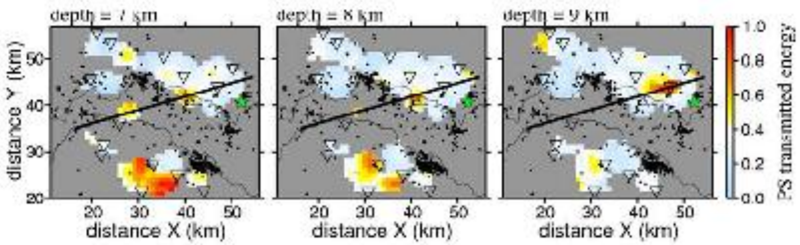
Fluid saturated



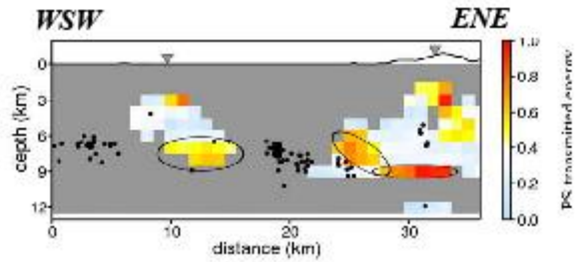
Vp.Vs ⇔
porosity/fracturation

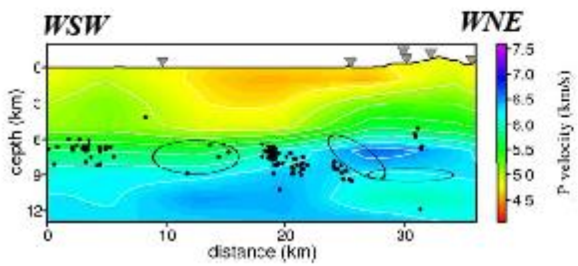
RESULTS

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

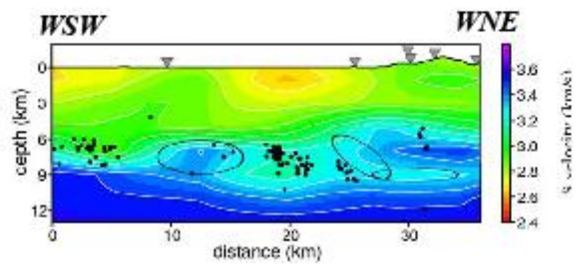


Vertical cross-section oriented 70° N





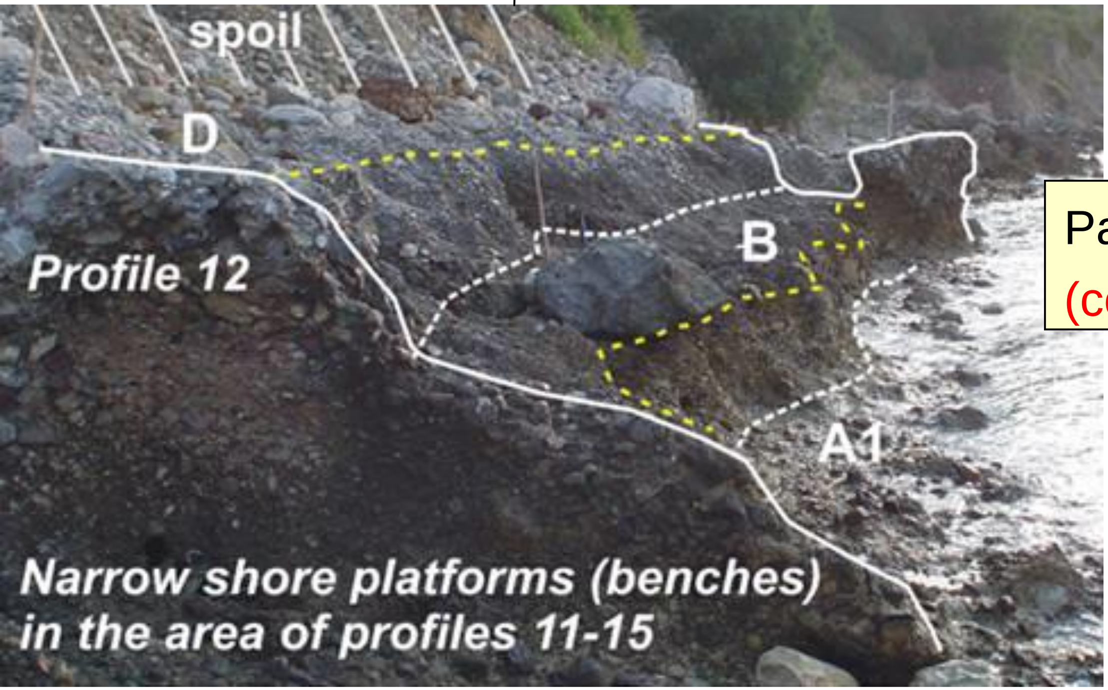
P velocity model



S velocity model

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

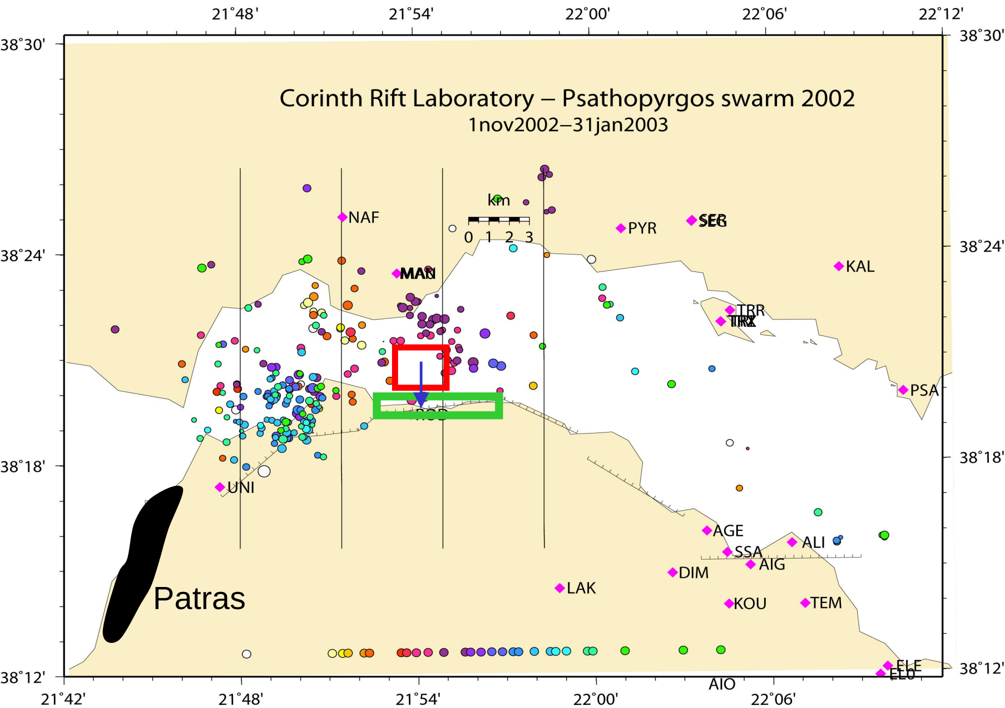
Psathopyrgos fault

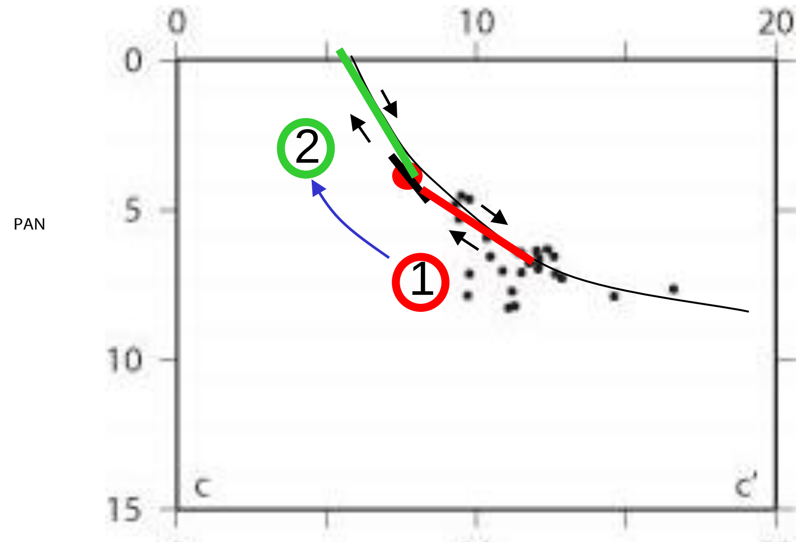


Paleoshoreline: 5 rapid uplift episodes (coseismic?) in 2000 years

Pantosti et al. 2007

Transient creep on the Psathopyrgos fault



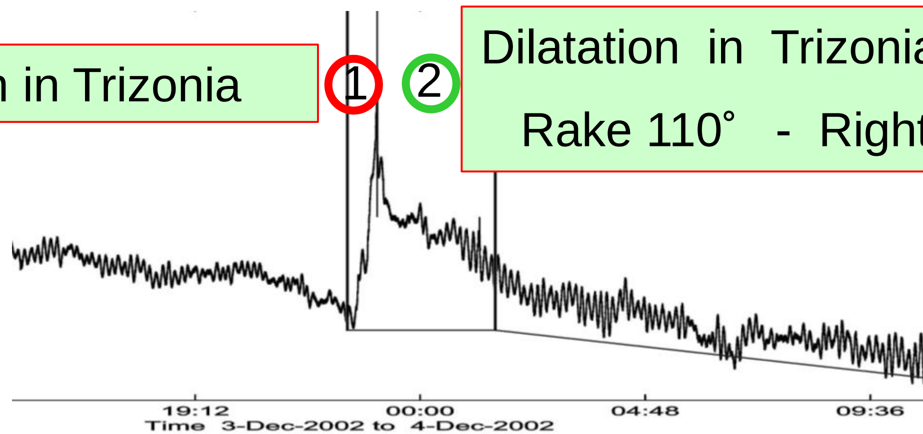


Aseismic slip - Δu=10 cm - Mw=5

Compression in Trizonia

Dilatation in Trizonia

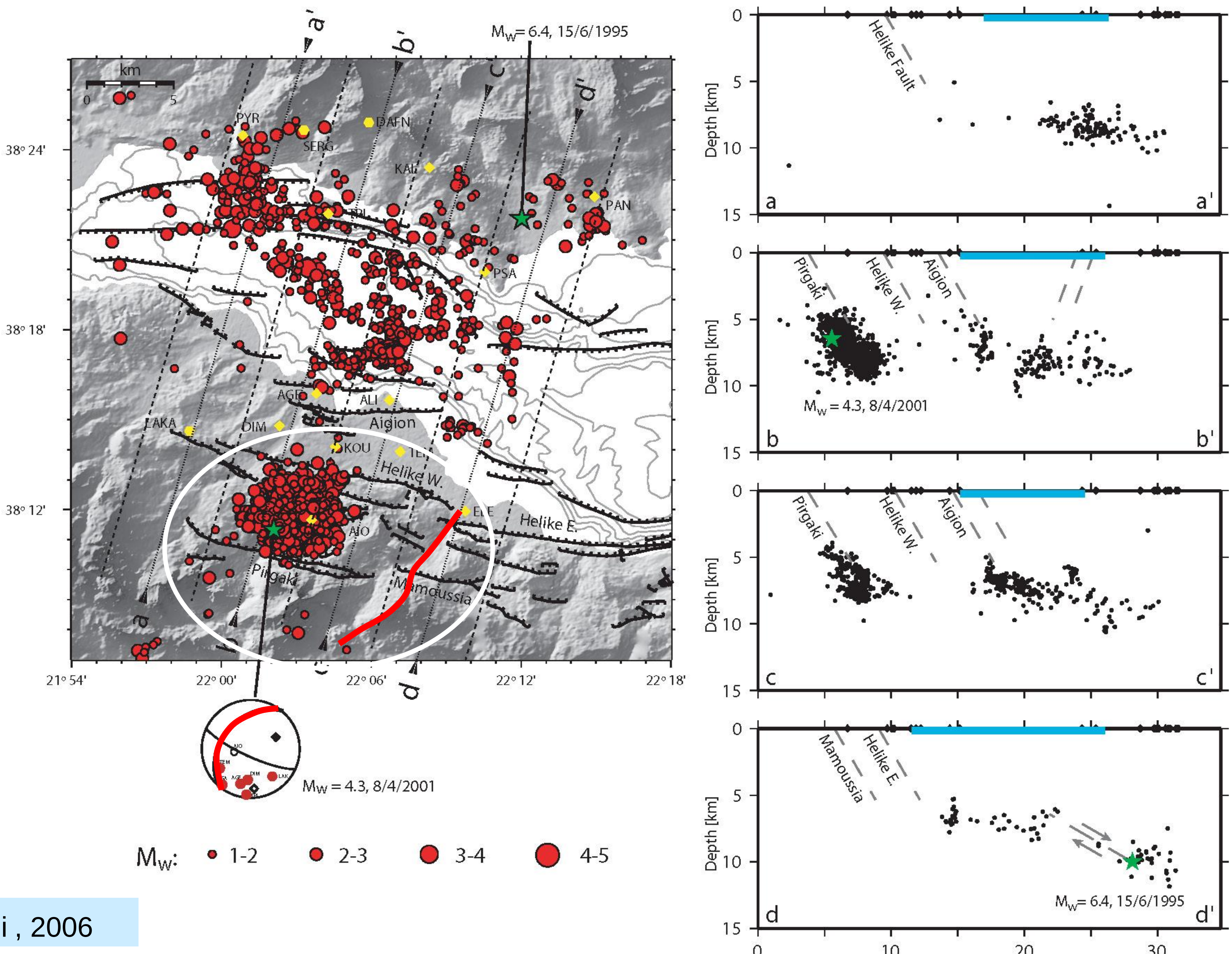
Rake 110° - Right-lateral



Bernard et al., 2008

2001 seismic swarm - 3 months - Mmax=4.2

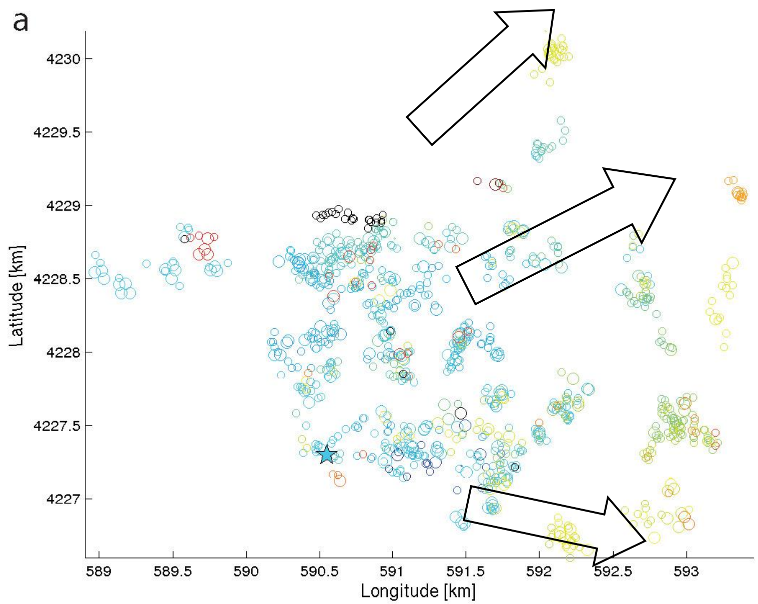
ancient fault - dip 45˚ NW - reactivated

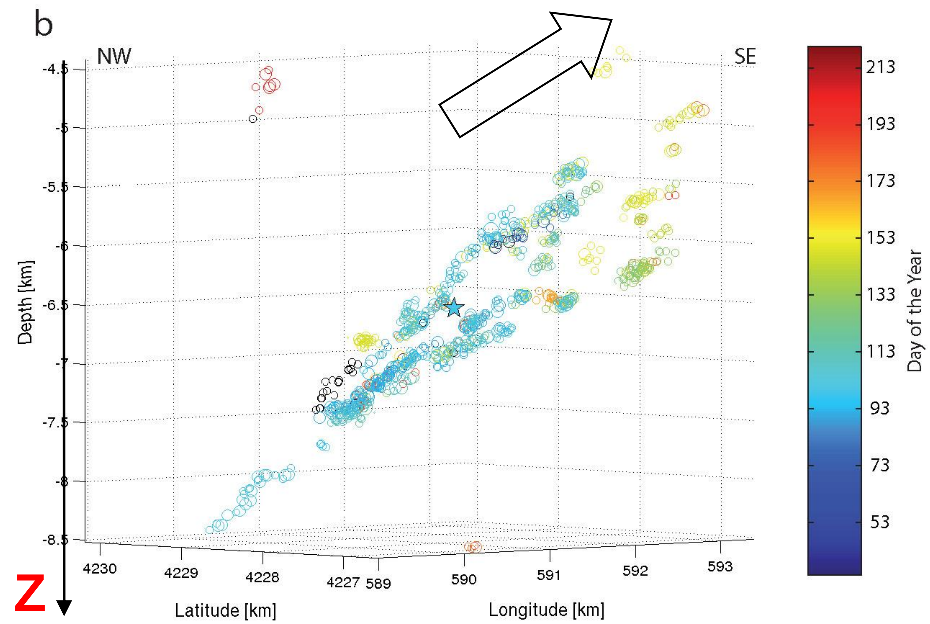


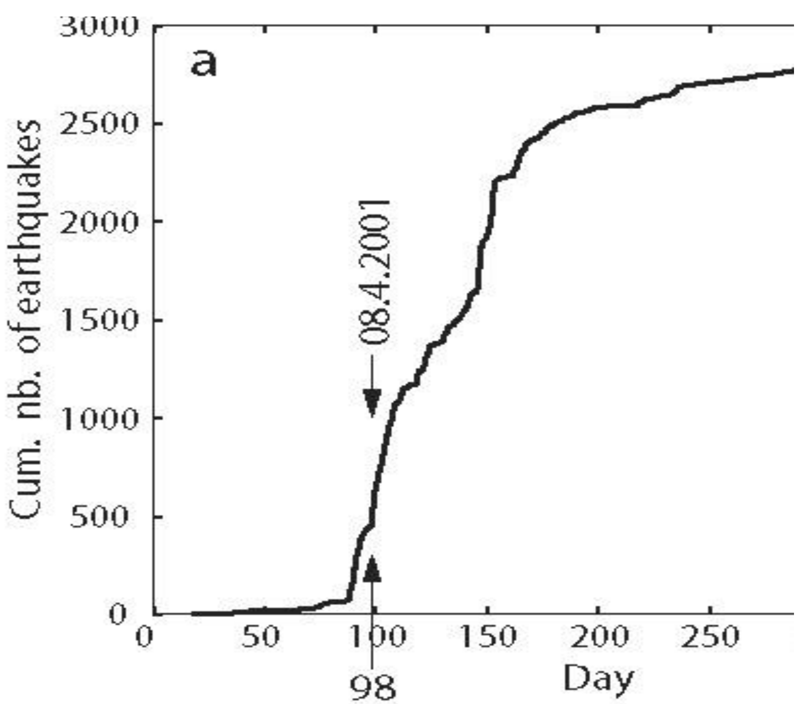
Pacchiani , 2006

Pacchiani, 2006

2001 seismic swarm: relocated multiplets







2 time scales of transient:

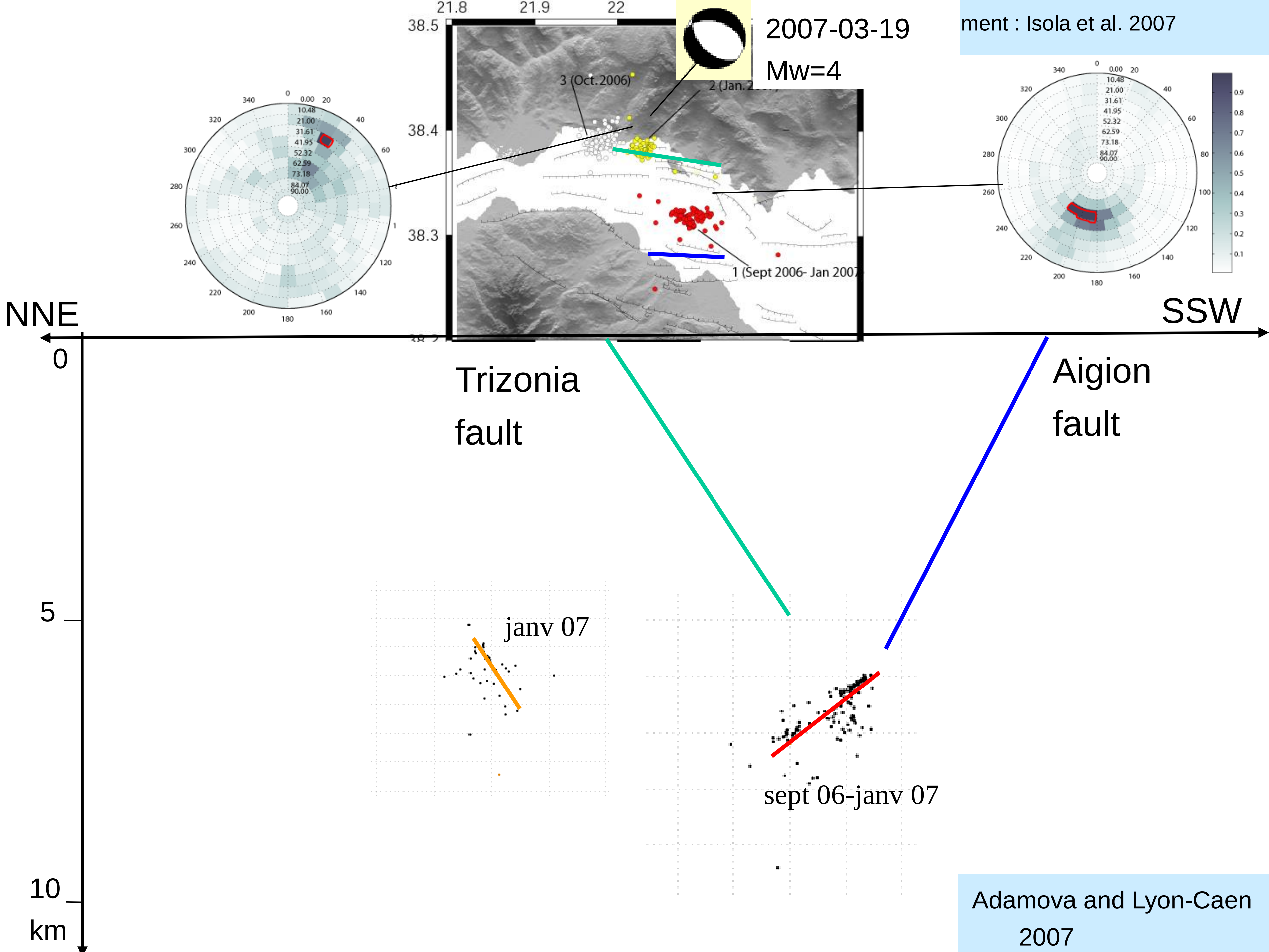
Week-month:

Upward migration :

pore pressure pulse?

Minute-day:

clustering Omori type


ment : Isola et al. 2007
2007-03-19
Mw=4
21.8
21.9
22
38.5
38.4
38.3
3 (Oct. 2006)
2 (Jan. 2
1 (Sept 2006- Jan 2007
NNE
SSW
0
5
10
km
Trizonia
fault
Aigion
fault
janv 07
sept 06-janv 07
Adamova and Lyon-Caen
2007

-**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

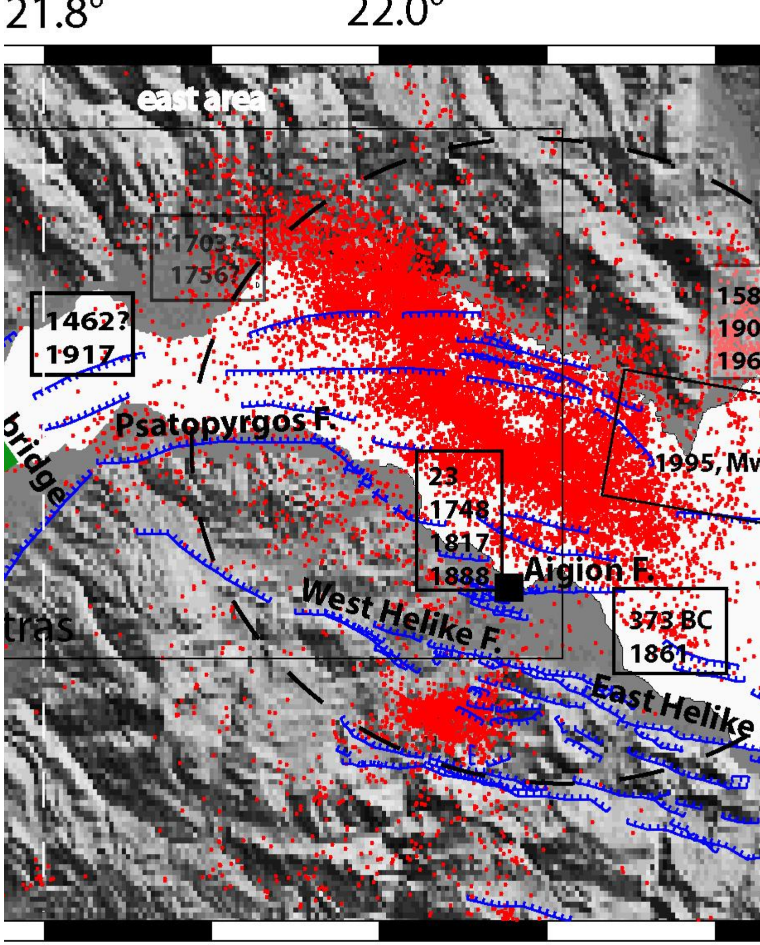
-**Failles obliques**

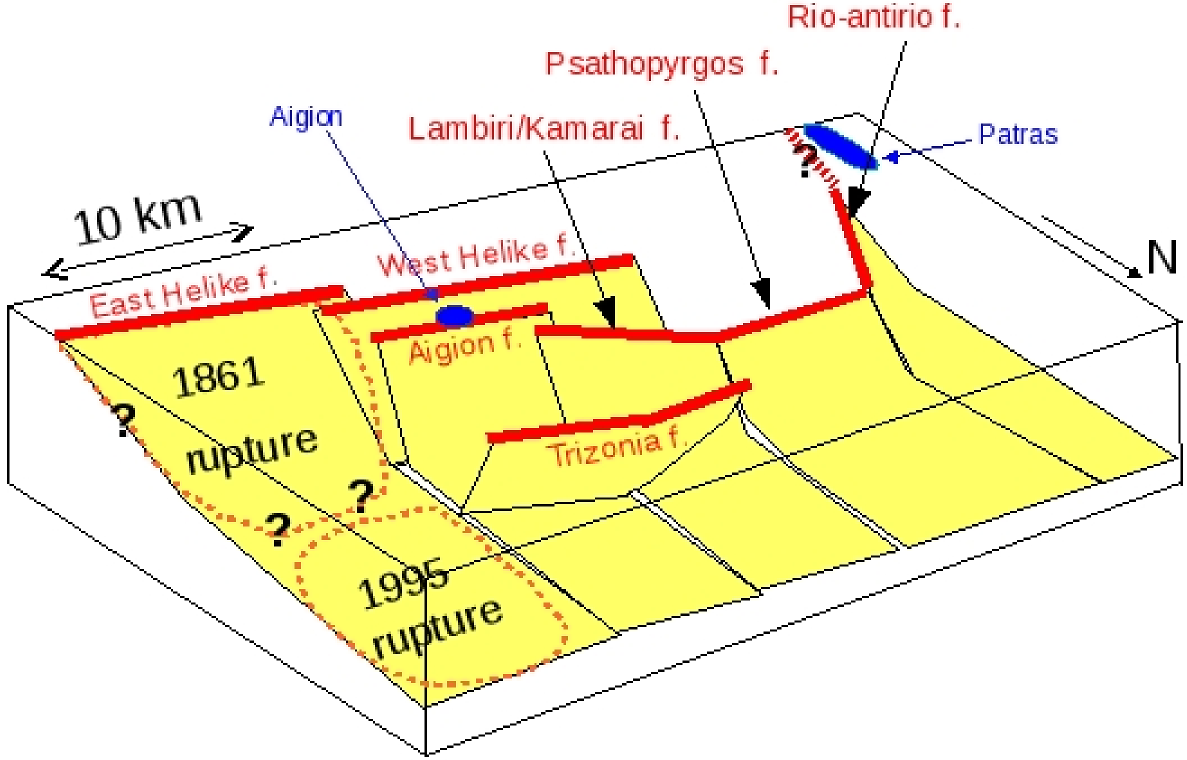
-faille de 2001: décrochante, 5-8 km, pendage NW, peut être liée à une structure majeure

-**Failles antithétiques:**

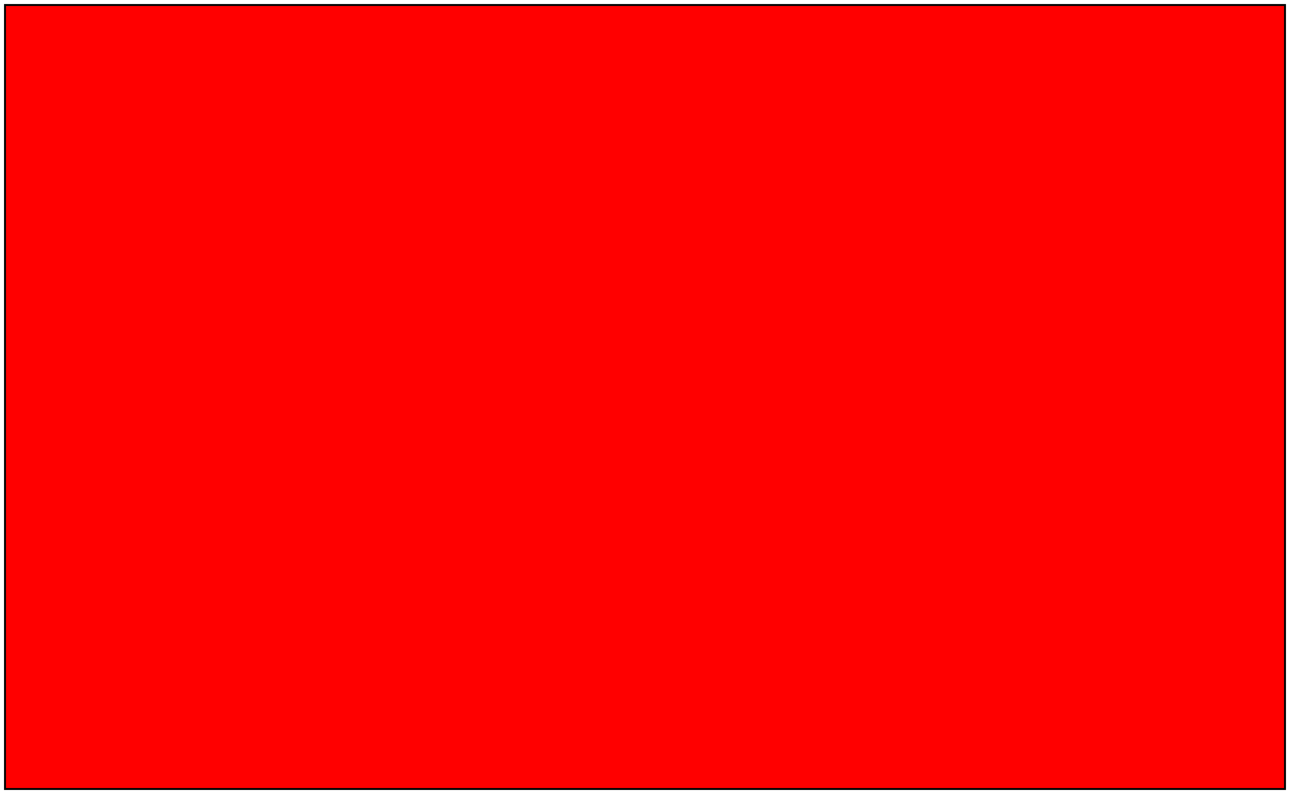
-- faille de Trizonia: activité diffuse vers 5 km, pas d'activité de multiplet

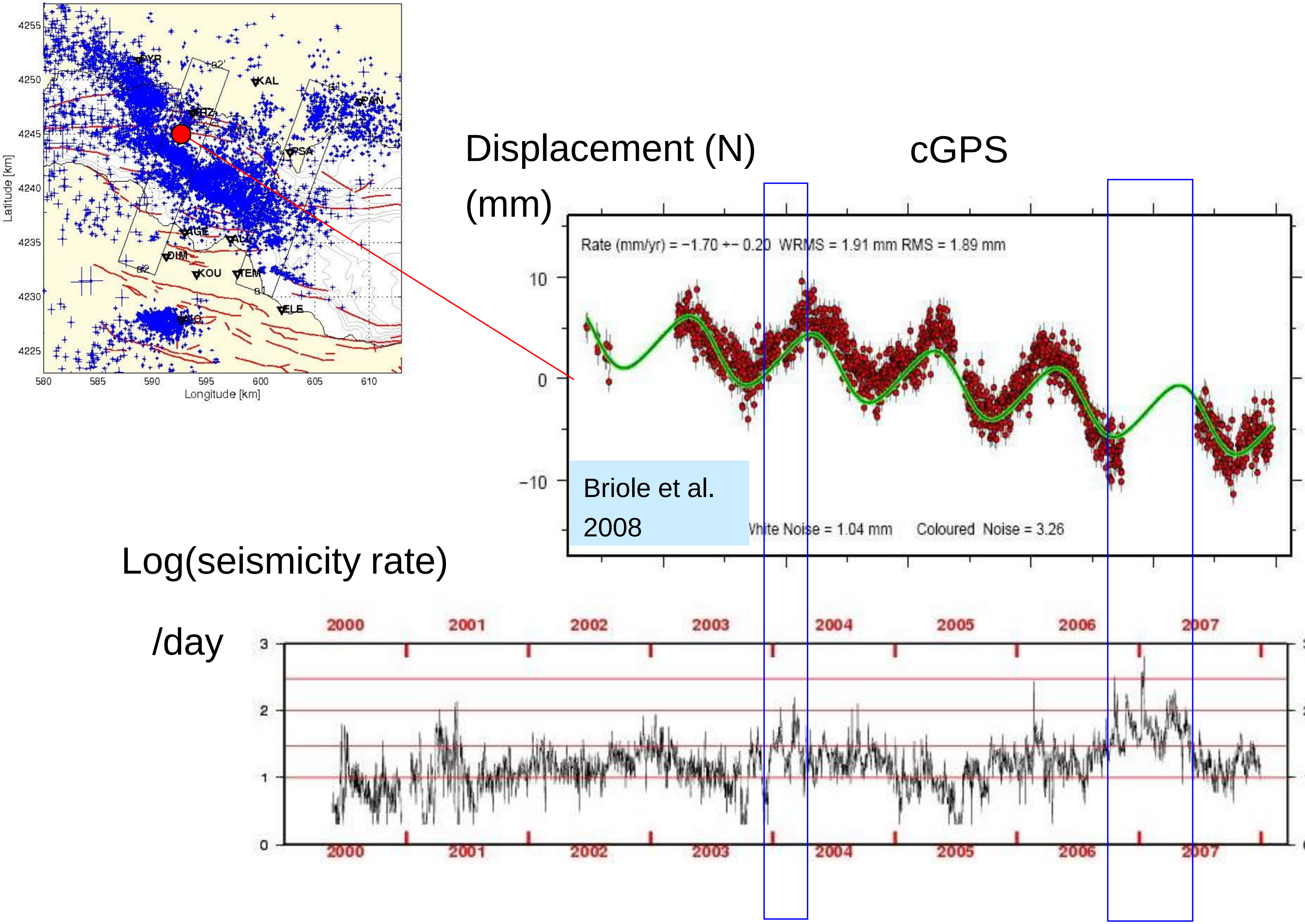
-- séisme de 2007: faille normale sous cote nord, plus au nord que Trizonia

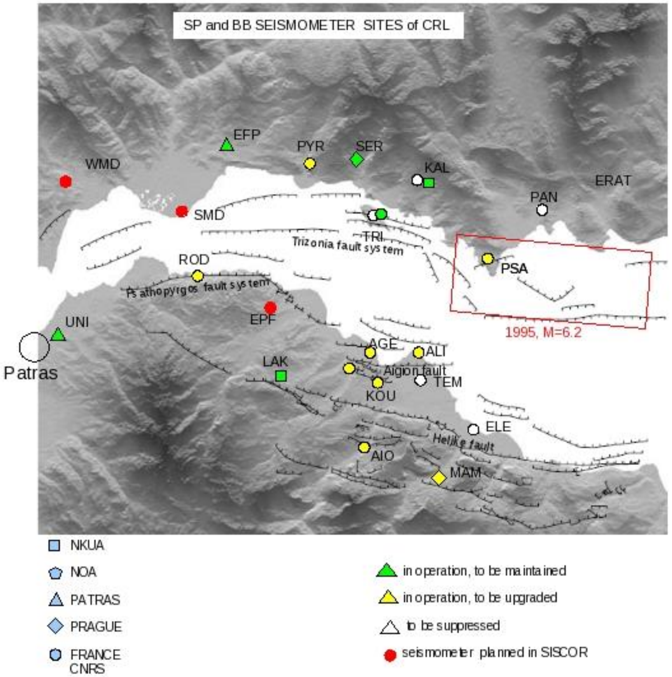


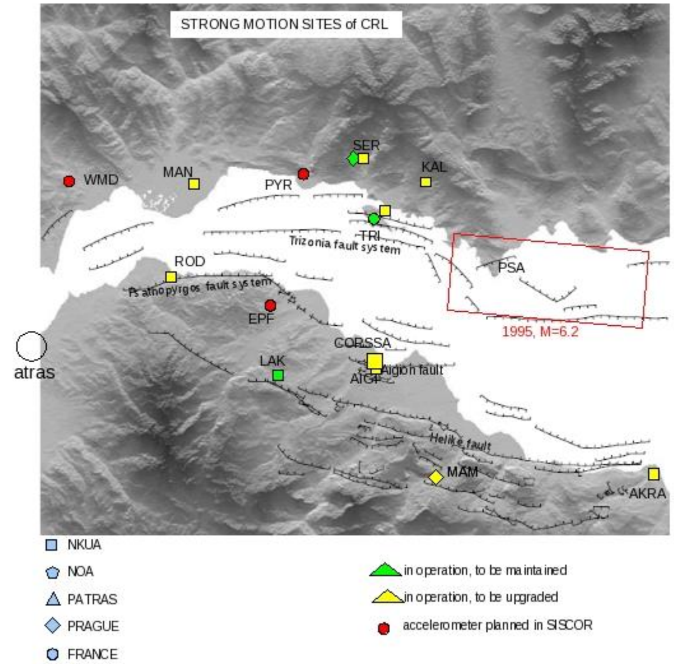


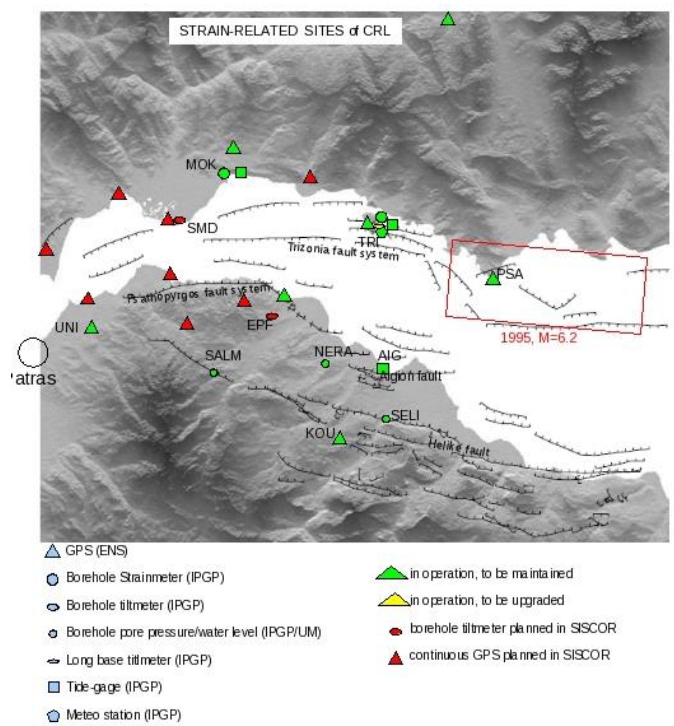
Rio-antirio f.
Psathopyrgos f.
Lambiri/Kamarai f.
Aigion
Patras
10 km
N
West Helike f.
East Helike f.
Aigion f.
1861
rupture
Trizonia f.
?
?
?
?
1995
rupture



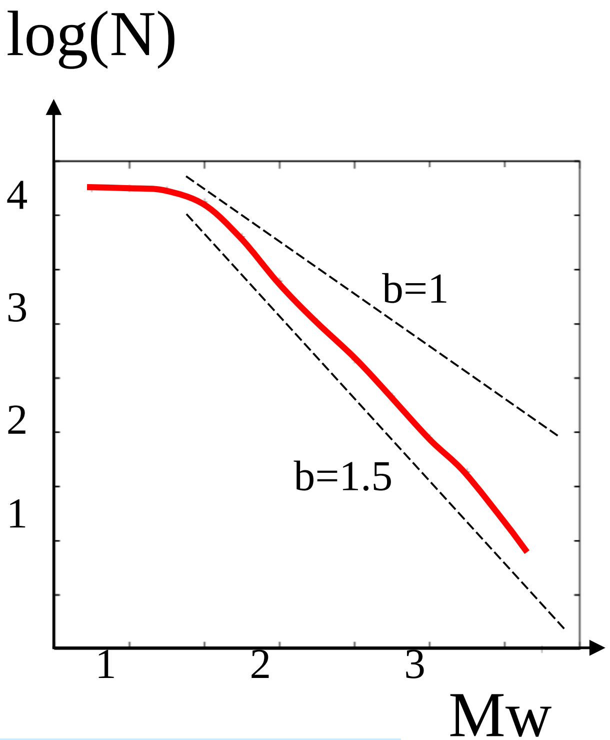

Displacement (N)
(mm)
cGPS
Rate (mm/yr) = −1.70 +− 0.20 WRMS = 1.91 mm RMS = 1.89 mm
10
0
−10
Briole et al.
2008
Coloured Noise = 3.26
Log(seismicity rate)
/day
2000 2001 2002 2003 2004 2005 2006 2007
3
2
1
0
Latitude [km]
Longitude [km]
4255 4250 4245 4240 4235 4230 4225
580 585 590 595 600 605 610
PYR
KAL
PAN
PSA
AGE
DIM
KOU
TEM
ELE


SP and BB SEISMOMETER SITES of CRL
EFP
PYR
SER
WMD
KAL
ERAT
PAN
SMD
TRI
Trizonia fault system
PSA
ROD
Psathopyrgos fault system
EPF
1995, M=6.2
UNI
Patras
AGE
ALI
LAK
Aigion fault
TEM
KOU
ELE
Helike fault
AIO
MAM
NKUA
NOA
PATRAS
PRAGUE
FRANCE CNRS
in operation, to be maintained
in operation, to be upgraded
to be suppressed
seismometer planned in SISCOR

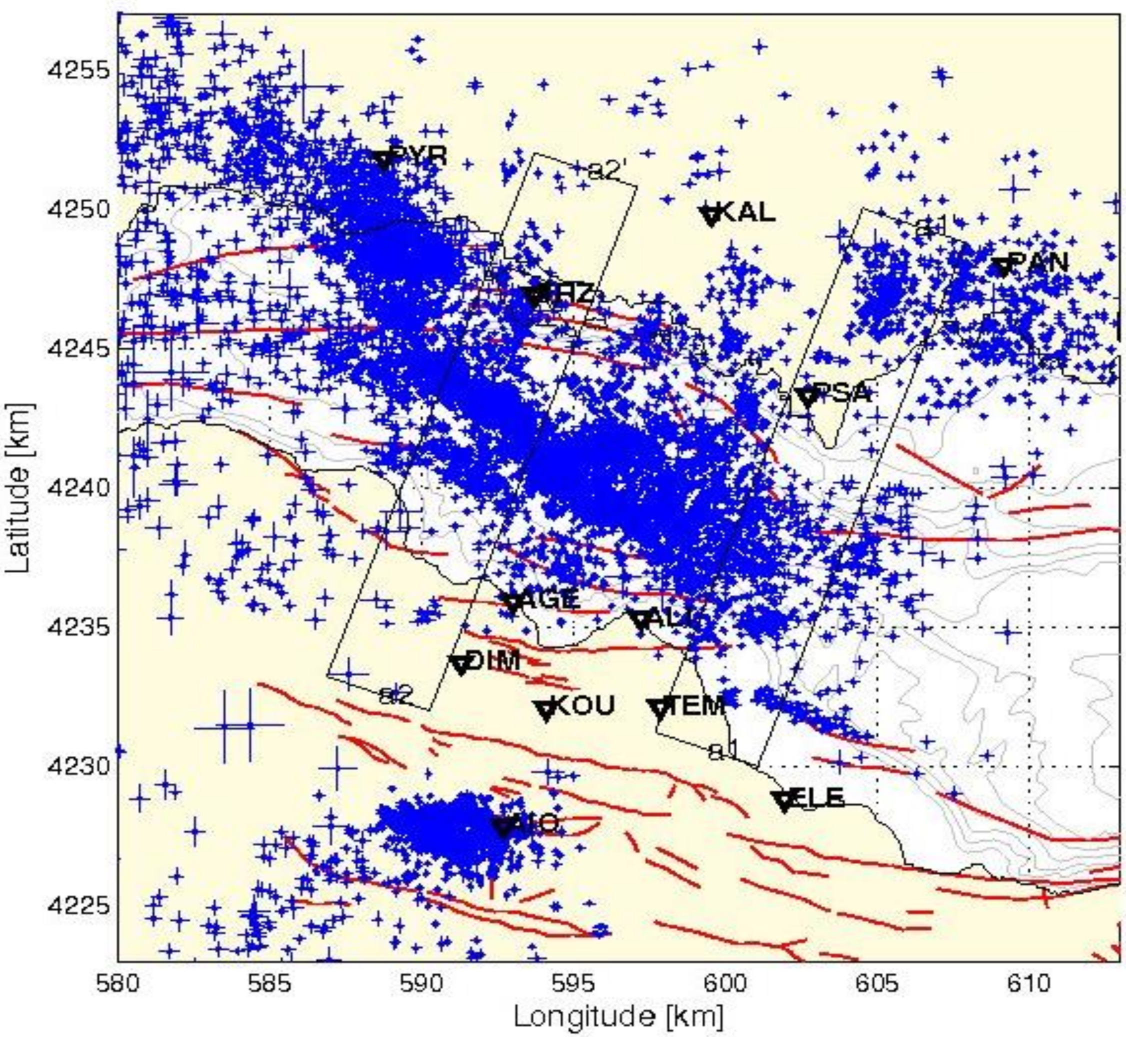

STRONG MOTION SITES of CRL
SER
WMD
MAN
KAL
PYR
TRI
Trizonia fault system
PSA
ROD
Psathopyrgos fault system
EPF
1995, M=6.2
atras
CORSSA
LAK
Aigion fault
AIG
Helike fault
MAM
AKRA
NKUA
NOA
PATRAS
PRAGUE
FRANCE
in operation, to be maintained
in operation, to be upgraded
accelerometer planned in SISCOR


STRAIN-RELATED SITES of CRL
MOK
SMD
TRI
Trizonia fault system
PSA
Psathopyrgos fault system
EPF
UNI
1995, M=6.2
atras
SALM
NERA
AIG
Aigion fault
SELI
KOU
Helike fault
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

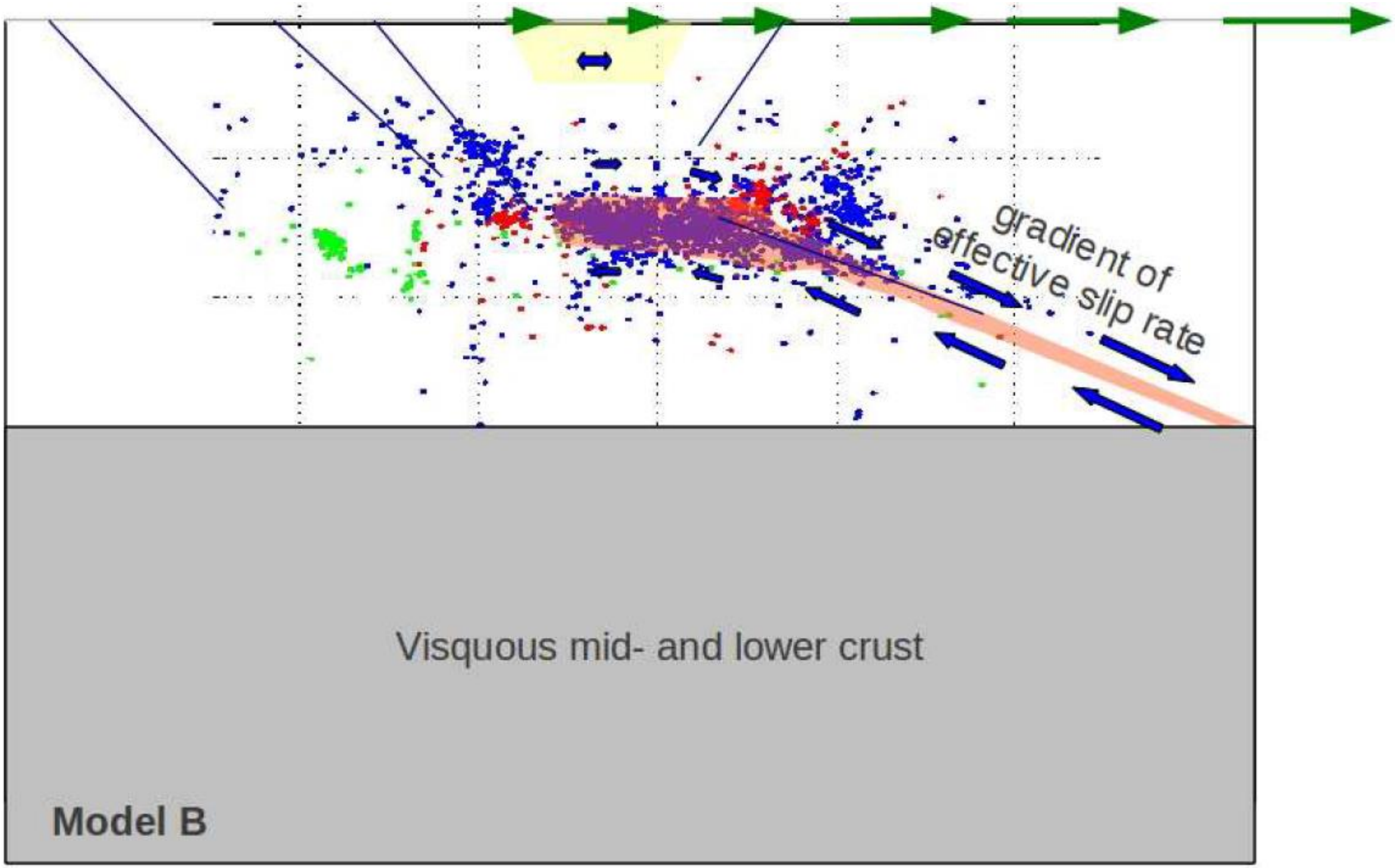


Pacchiani , 2006

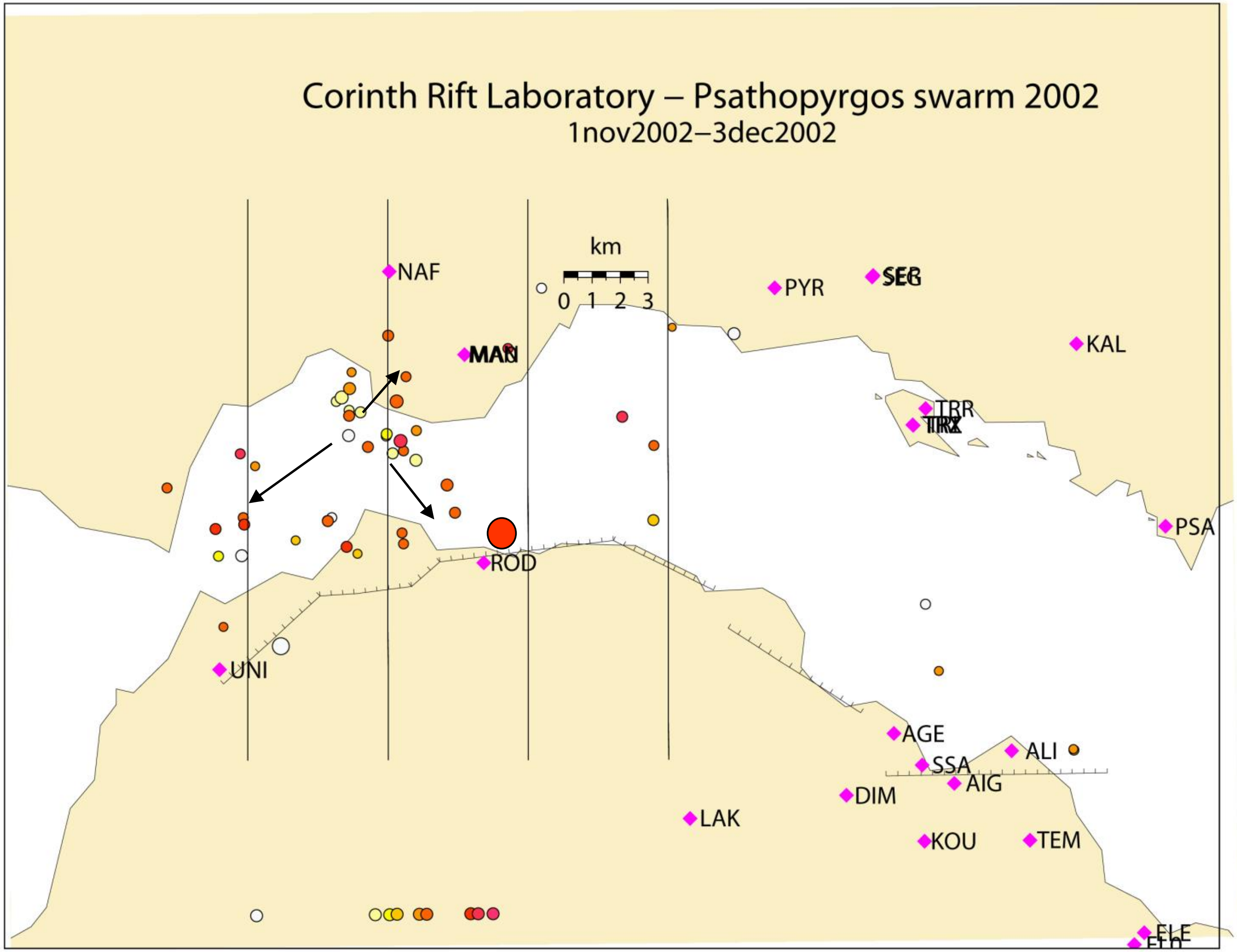


Lambotte, 2008

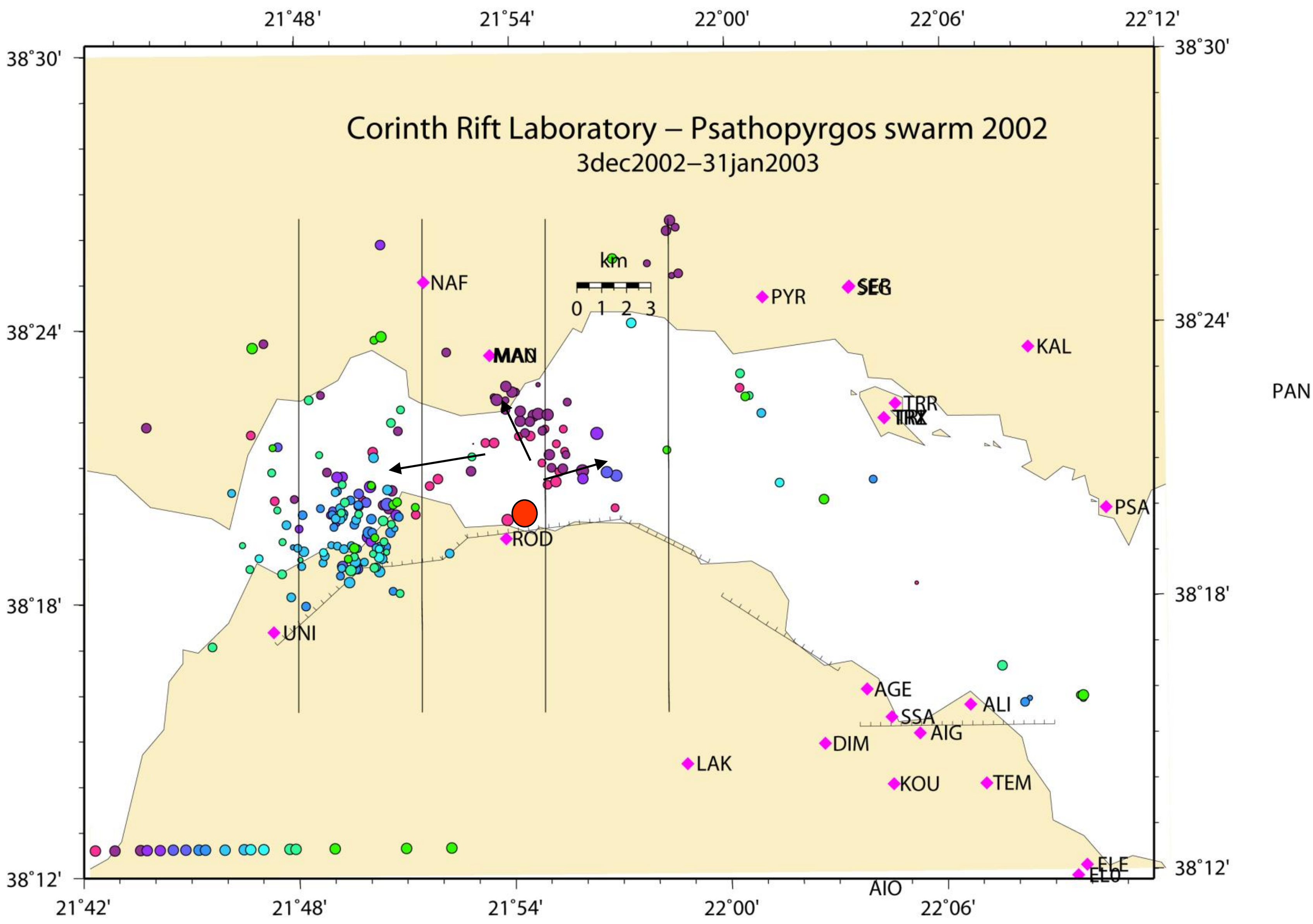
Detachment model with constant opening rate (remote) and constant friction

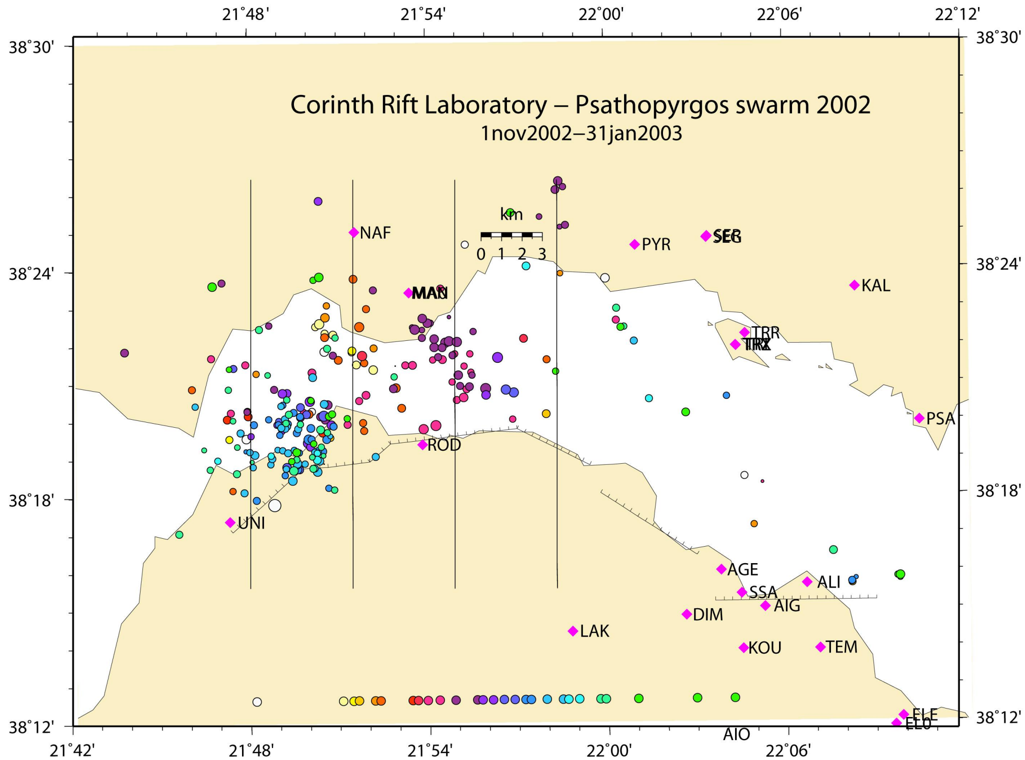


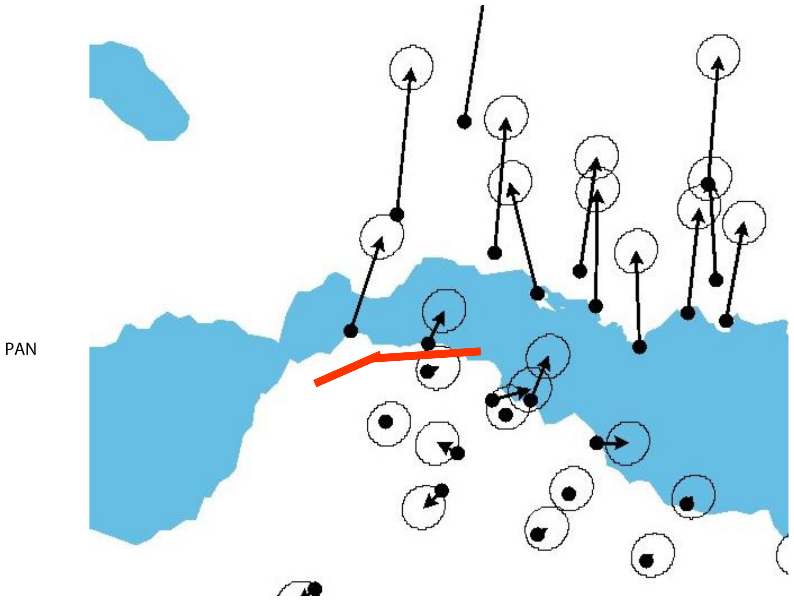
Before 3 december earthquake



After 3 december earthquake



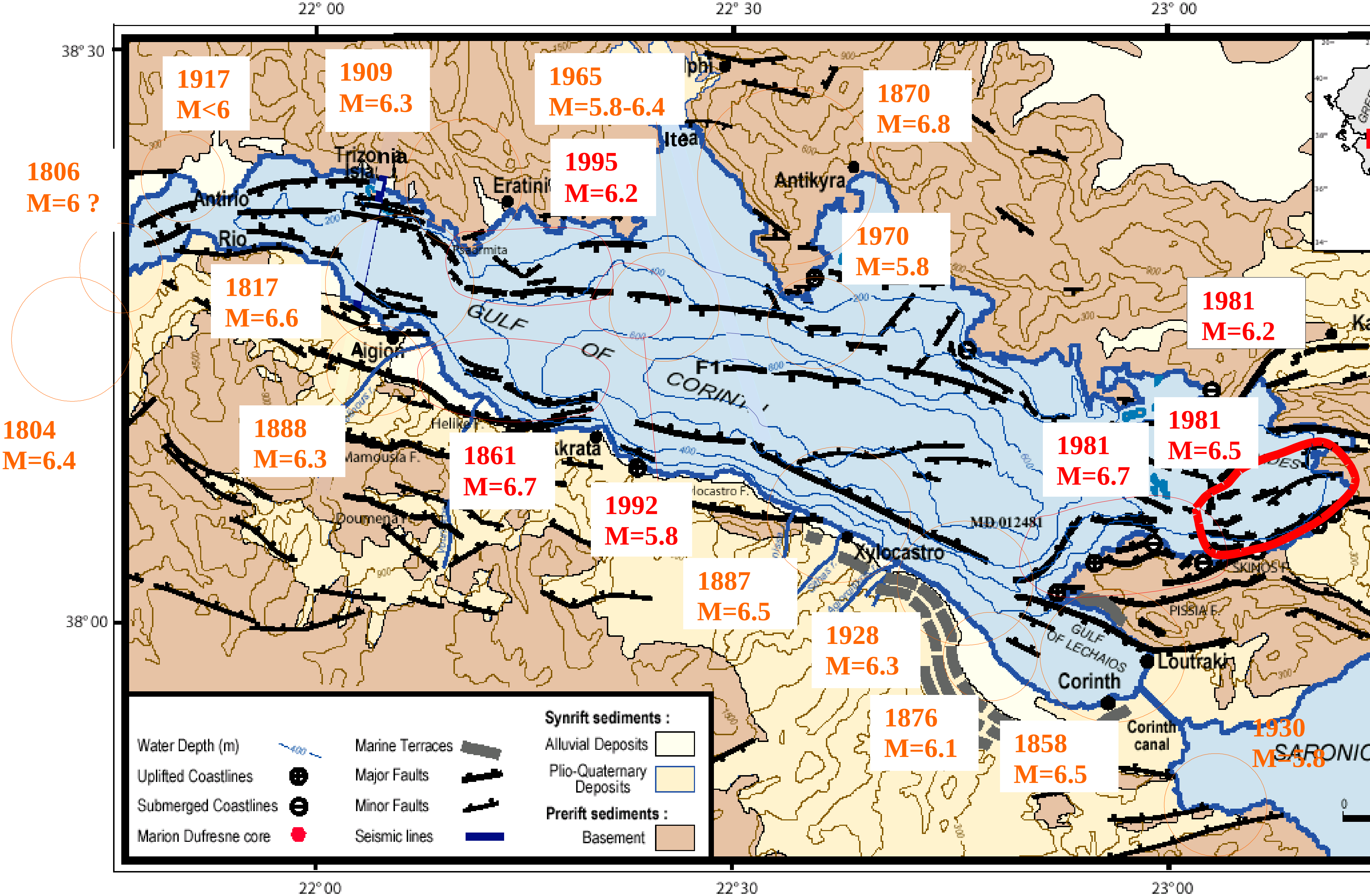




- No historical earthquakes (300 yrs)

- GPS >1.5 cm/yr

- creeping and seismic


22° 00
22° 30
23° 00
38° 30
38° 00
1917
M<6
1909
M=6.3
1965
M=5.8-6.4
1870
M=6.8
1806
M=6 ?
1995
M=6.2
1970
M=5.8
1817
M=6.6
1981
M=6.2
1804
M=6.4
1888
M=6.3
1861
M=6.7
1981
M=6.7
1981
M=6.5
1992
M=5.8
1887
M=6.5
1928
M=6.3
1876
M=6.1
1858
M=6.5
1930
M=5.8
Trizonia
Itea
Antikyra
Antirio
Rio
Eratini
Aigion
GULF OF CORINTH
F1
Xylocastro
Loutraki
Corinth
GULF OF LECHAIOS
Corinth canal
SARONIC
SKINOS F.
PISSIA F.
MD 012481
Water Depth (m)
Uplifted Coastlines
Submerged Coastlines
Marion Dufresne core
Marine Terraces
Major Faults
Minor Faults
Seismic lines
Synrift sediments :
Alluvial Deposits
Plio-Quaternary Deposits
Prerift sediments :
Basement
SSE
0

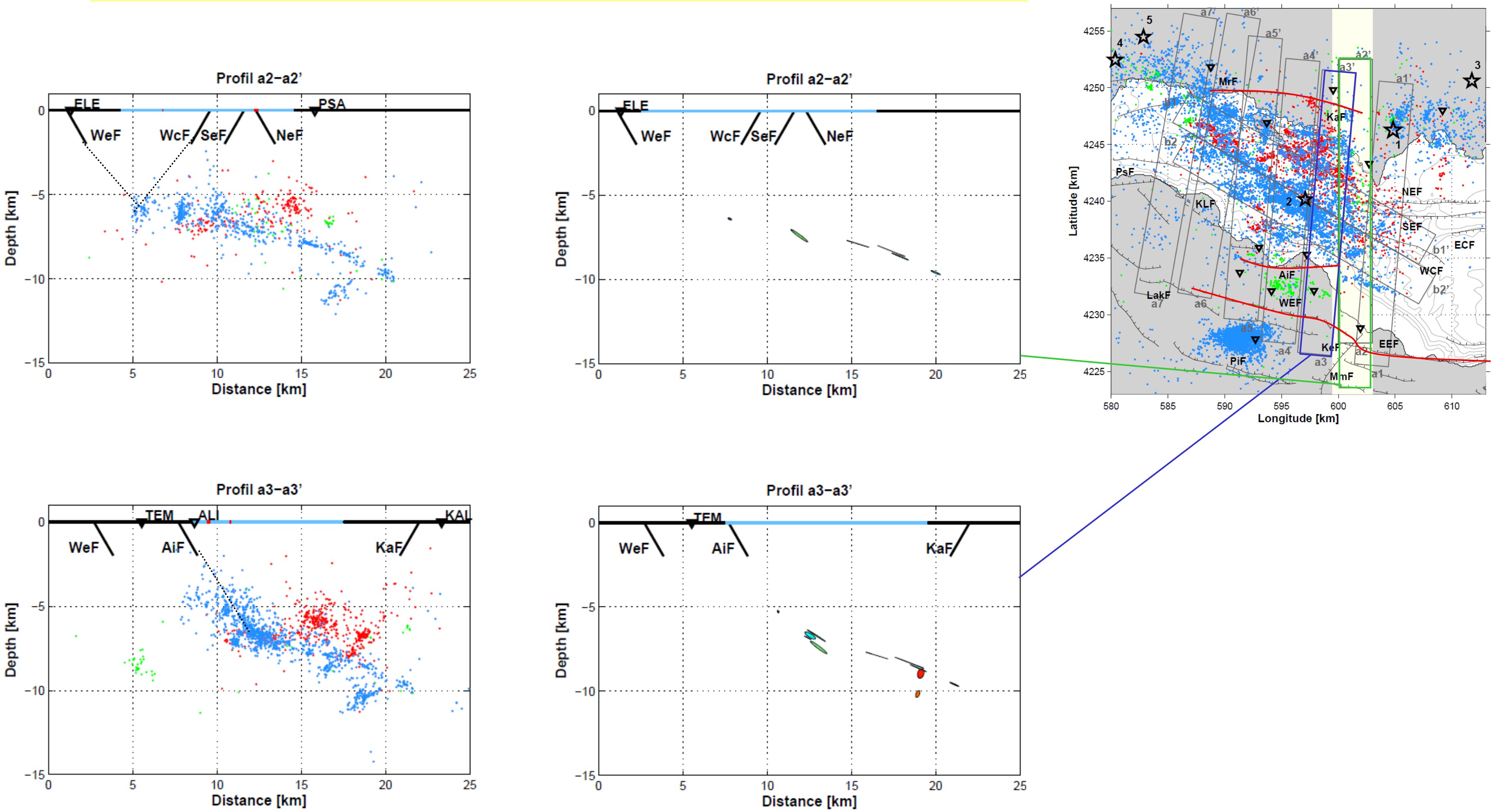
1800-2008

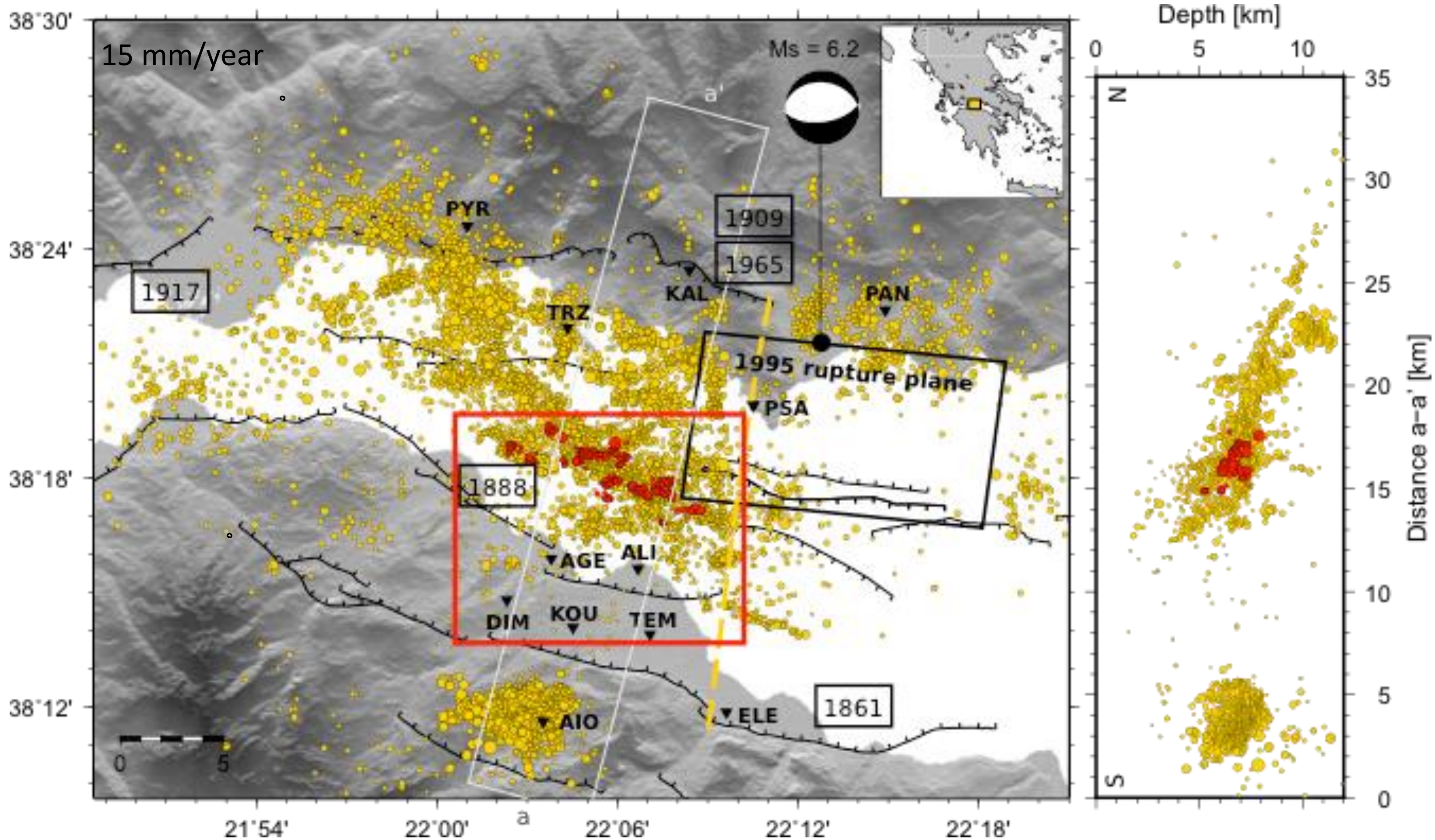
- Aigion et Helike faults
- antithetic faults (Kalithea)
- low dip seismogenic layer , dipping north but:

  1995 aftershocks are shallower (red)

  Some multiplets have larger dip

  Active structures below the layer





15 mm/year
Ms = 6.2
PYR
TRZ
KAL
PAN
PSA
1909
1965
1917
1888
1861
1995 rupture plane
AGE
ALI
DIM
KOU
TEM
AIO
ELE
a'
a
0
5
38°30'
38°24'
38°18'
38°12'
21°54'
22°00'
22°06'
22°12'
22°18'
Depth [km]
Distance a–a' [km]
N
S

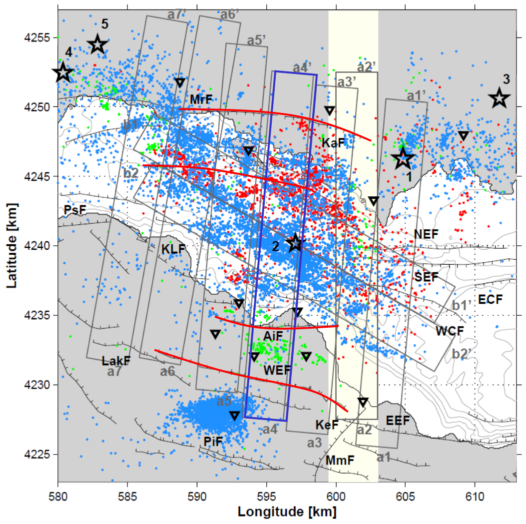
- Aigion fault: activity at 3 km, partial creep?

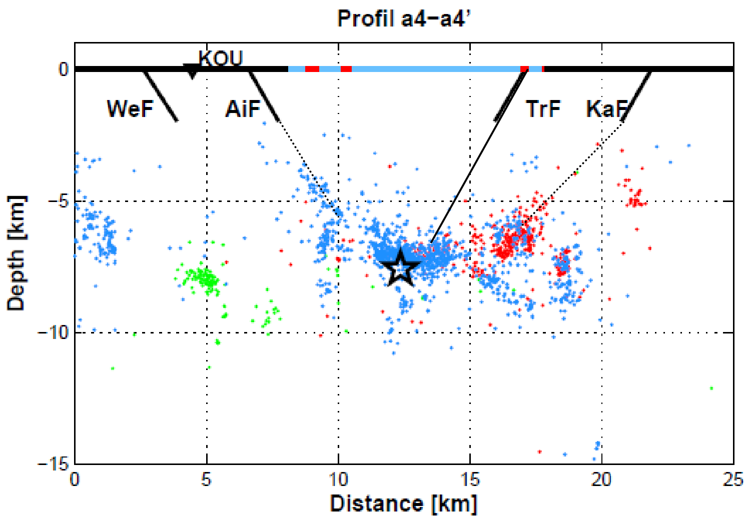
-- West Helike Fault : silent

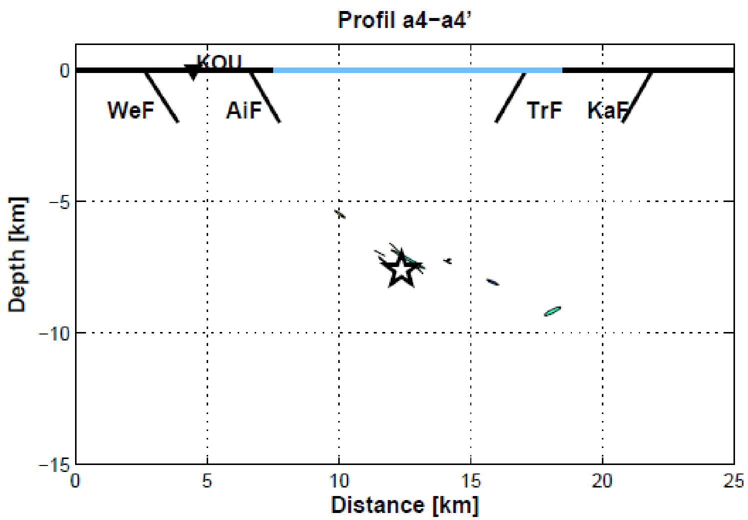
- Trizonia fault, antithetic: silent

- Kalithea fault: deep activity?

+ complex structure of the seismogenic « layer »

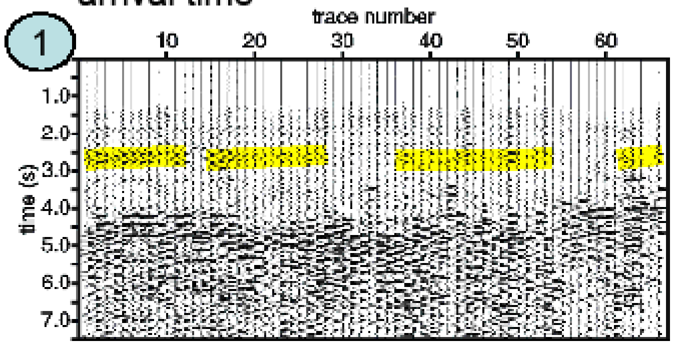




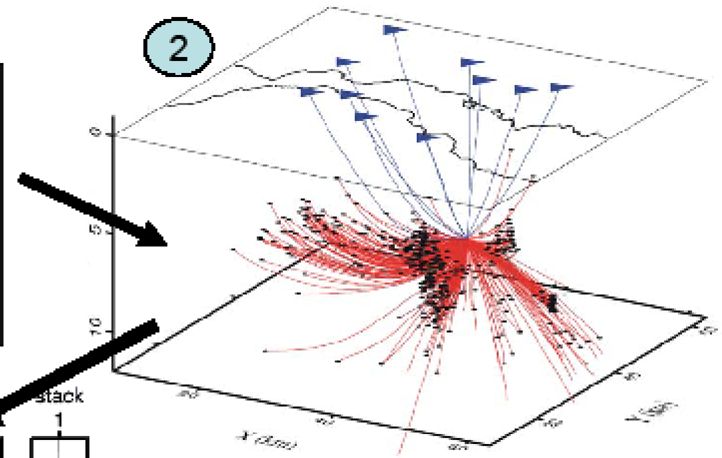


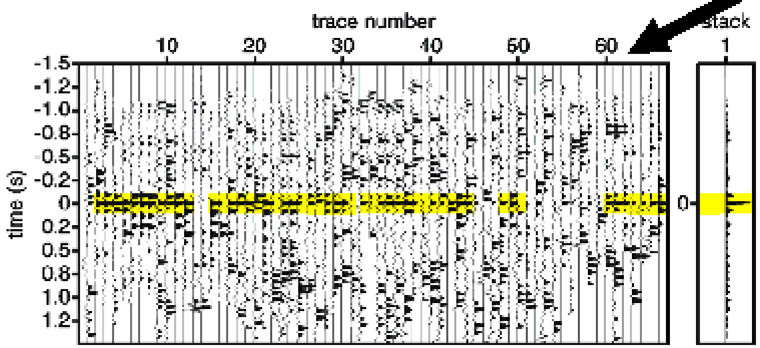
Example on real data

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

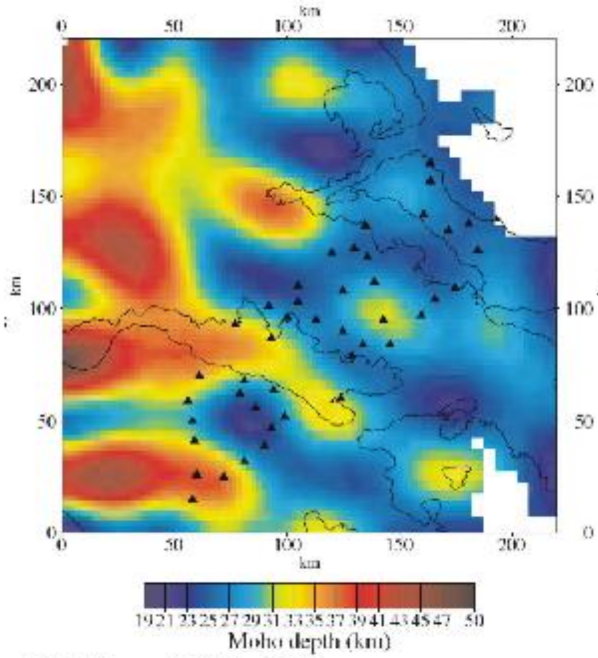


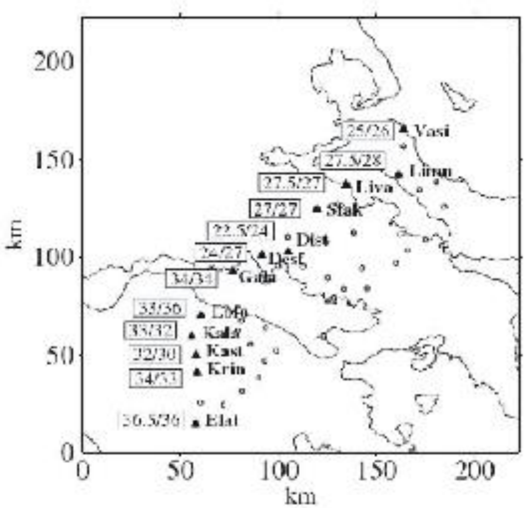


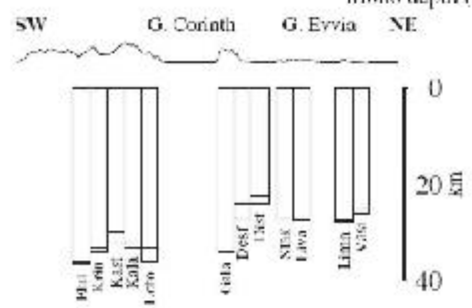
3

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

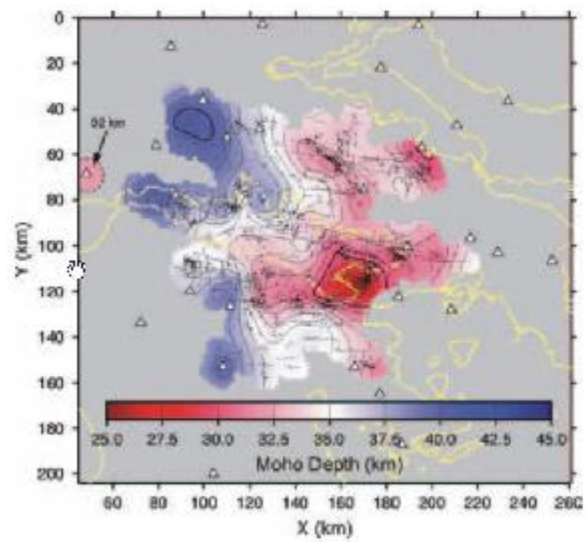
Inversion de données gravimétriques
Comparaison à la tomographie
aux fonctions récepteur





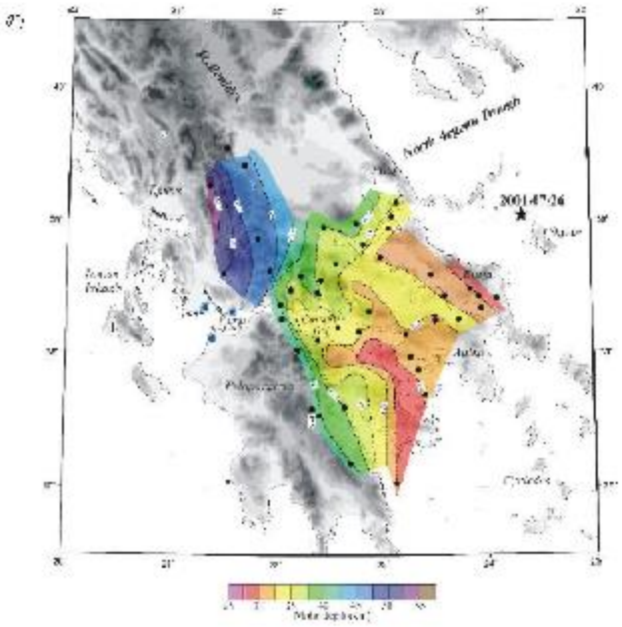


Tiberi et al., Geophys..J.Int., 2001



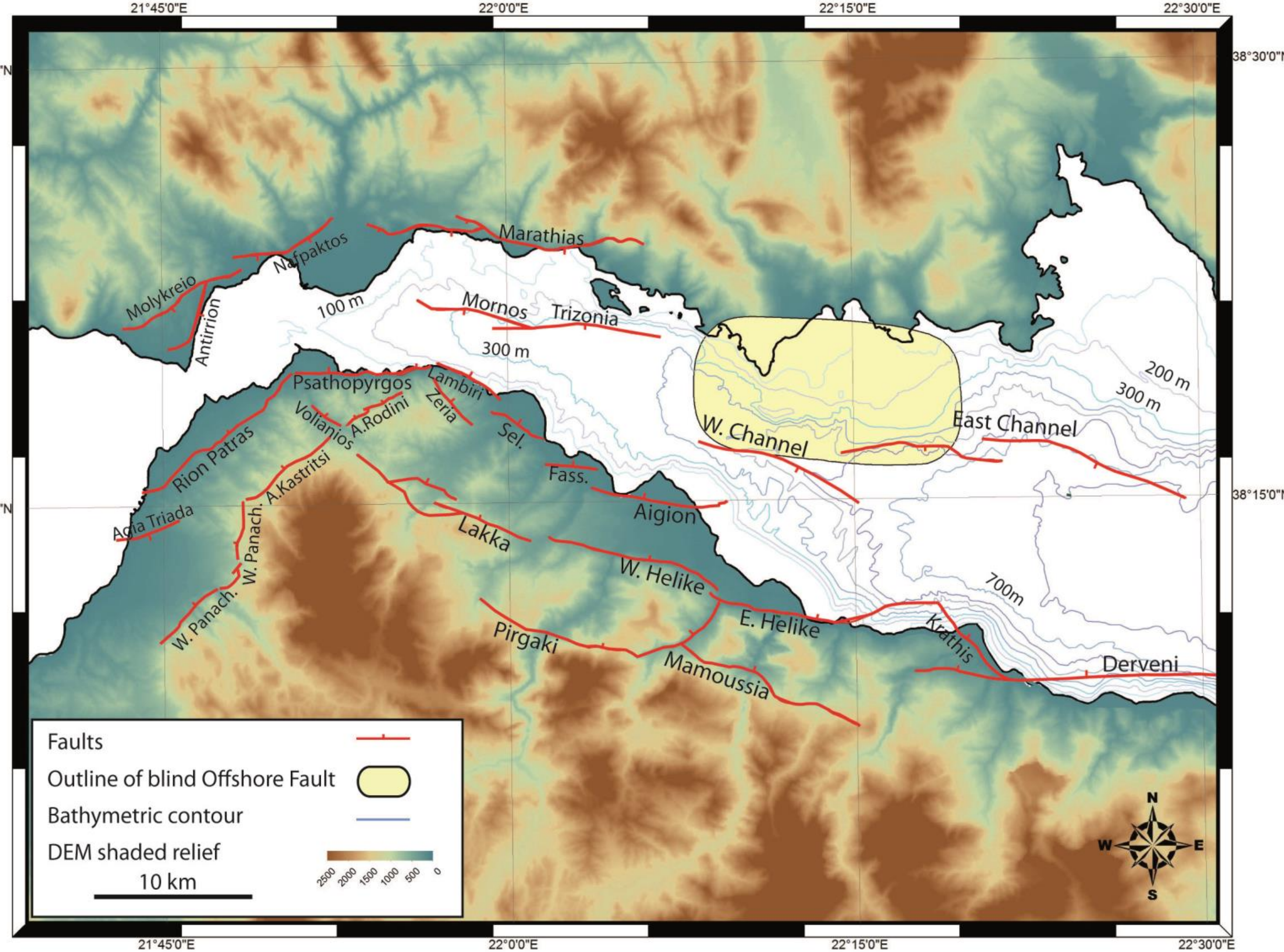
Moho obtenu par tomographie 2D des temps de réflexion PmP

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

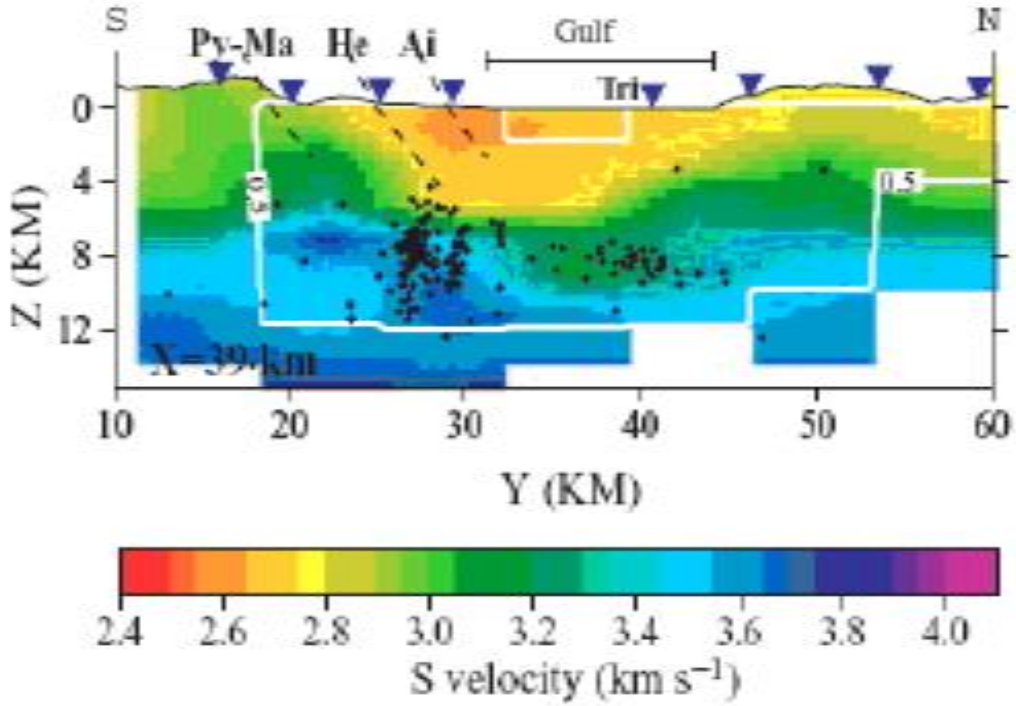


Extension du modèle avec des Pn

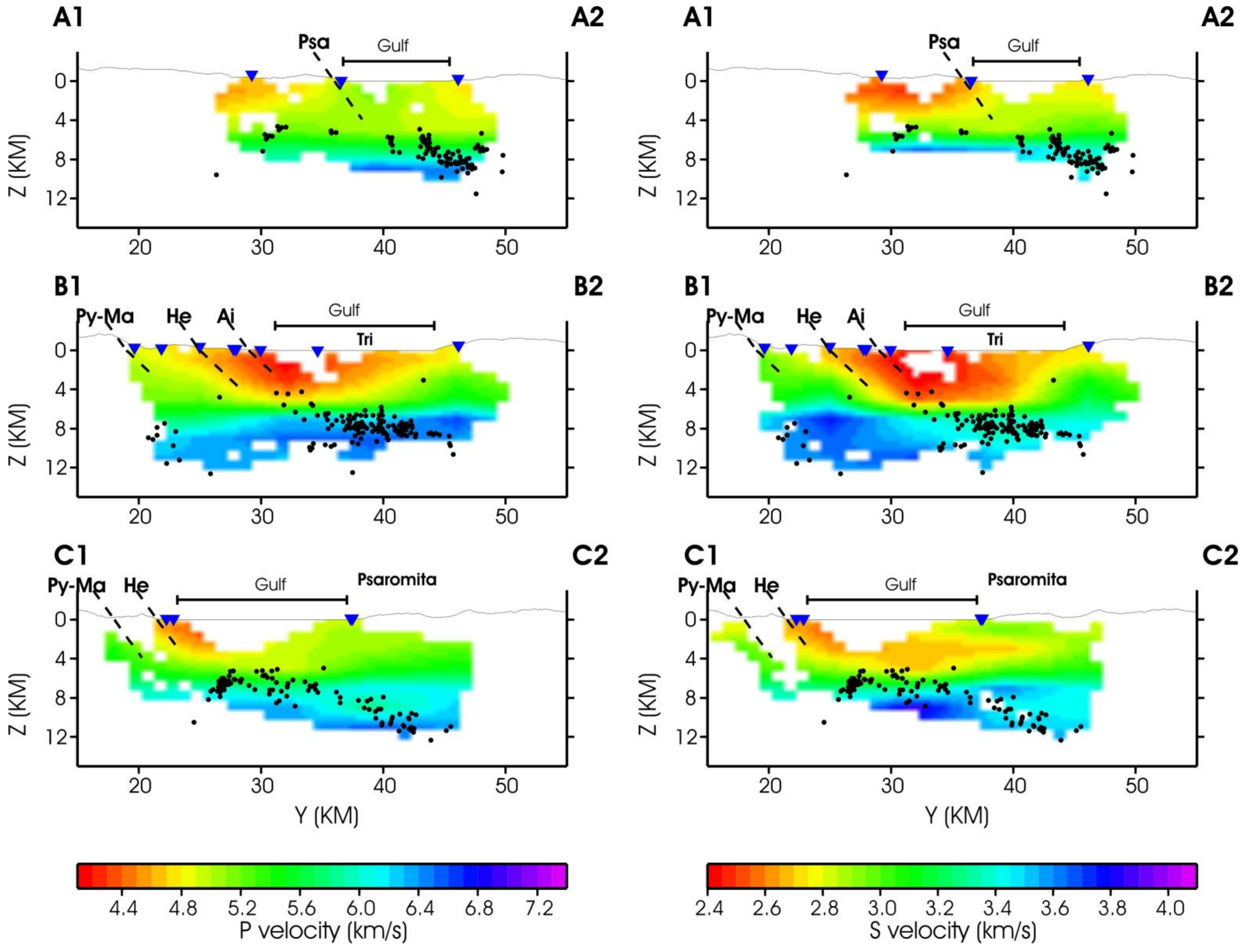
Sachpazi et al., Tectonophys. 2007

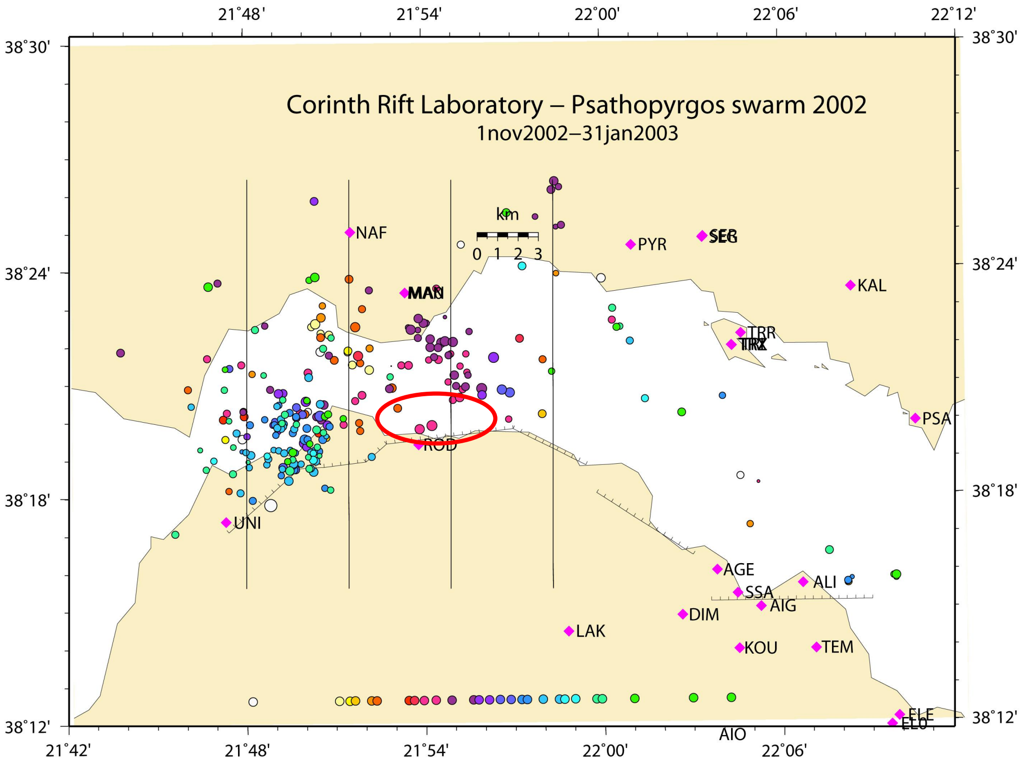


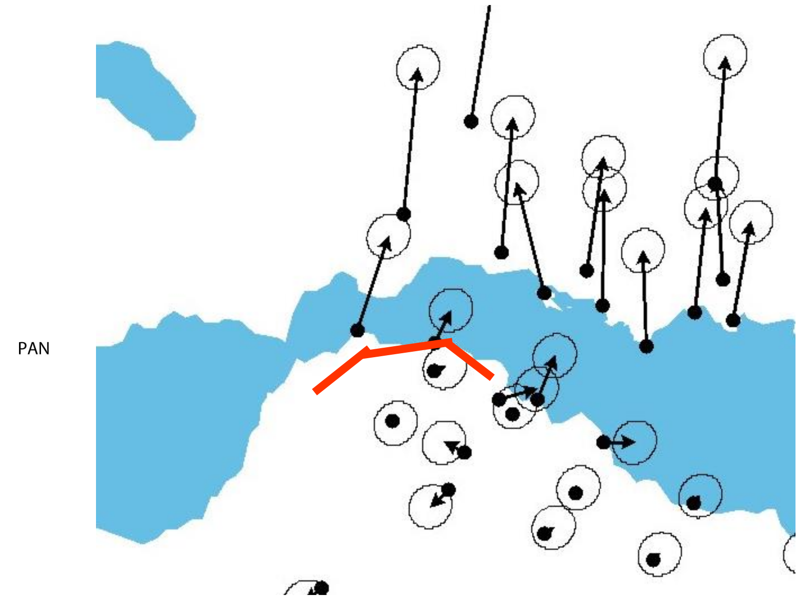
21°45'0"E
22°0'0"E
22°15'0"E
22°30'0"E
38°30'0"N
38°15'0"N
Marathias
Nafpaktos
Molykreio
Antirrion
100 m
Mornos
Trizonia
300 m
Psathopyrgos
Lambiri
Zeria
Volianios
A.Rodini
Sel.
Rion Patras
A.Kastritsi
W. Panach.
Fass.
Aigion
Agia Triada
Lakka
W. Helike
E. Helike
Pirgaki
Mamoussia
Krathis
Derveni
700m
W. Channel
East Channel
200 m
300 m
Faults
Outline of blind Offshore Fault
Bathymetric contour
DEM shaded relief
10 km
2500
2000
1500
1000
500
0
N
S
E
W



S
N
Py-Ma
He
Ai
Gulf
Tri
0.5
0.5
X=39 km
Z (KM)
Y (KM)
0
4
8
12
10
20
30
40
50
60
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
4.0
S velocity (km s⁻¹)


A1
A2
Psa
Gulf
B1
B2
Py-Ma
He
Ai
Gulf
Tri
C1
C2
Py-Ma
He
Gulf
Psaromita
Z (KM)
Y (KM)
P velocity (km/s)
S velocity (km/s)





Avalone et al. 2004

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

1990-2001:
Creep from GPS
1.5 cm/yr