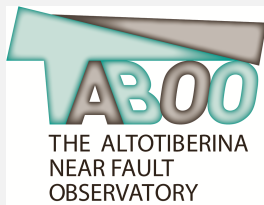


Mixed-mode slip behavior of the Altotiberina LANF System (Italy)

Through high-resolution earthquake locations and Repeating Events

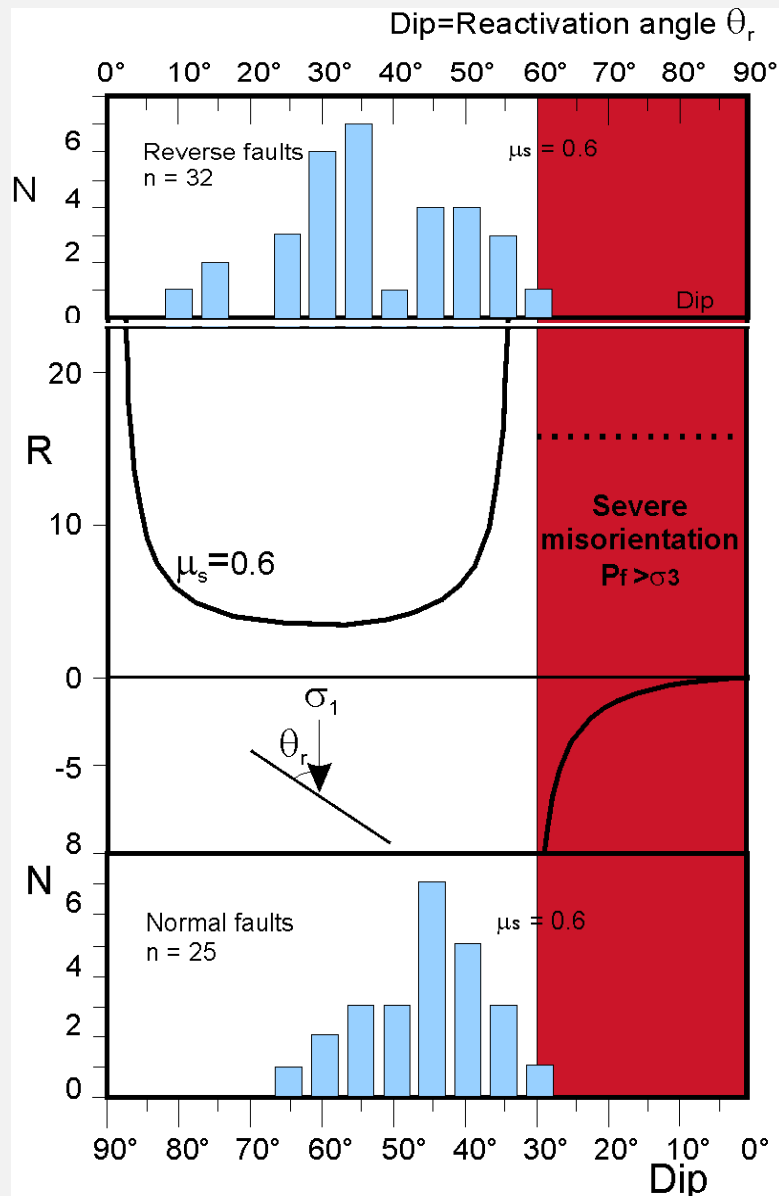
*Luisa Valoroso*¹, *Lauro Chiaraluce*¹, *Raffaele Di Stefano*¹, and **The AltotiBerina near Fault ObservatOry (TABOO) working group.**

1: Istituto Nazionale di Geofisica e Vulcanologia, Centro Nazionale Terremoti



Cargese, Corsica, 4 October 2017

LANF enigma



$$R = \frac{\sigma_1 - P_f}{\sigma_3 - P_f} = \frac{1 + \mu_s \cot \theta_r}{1 - \mu_s \tan \theta_r}$$

Classical Anderson-Byerlee frictional fault mechanics (one principal stress is vertical and faults with $0.6 < \mu_s < 0.85$) **predicts no slip** on LAF (dip $< 30^\circ$).

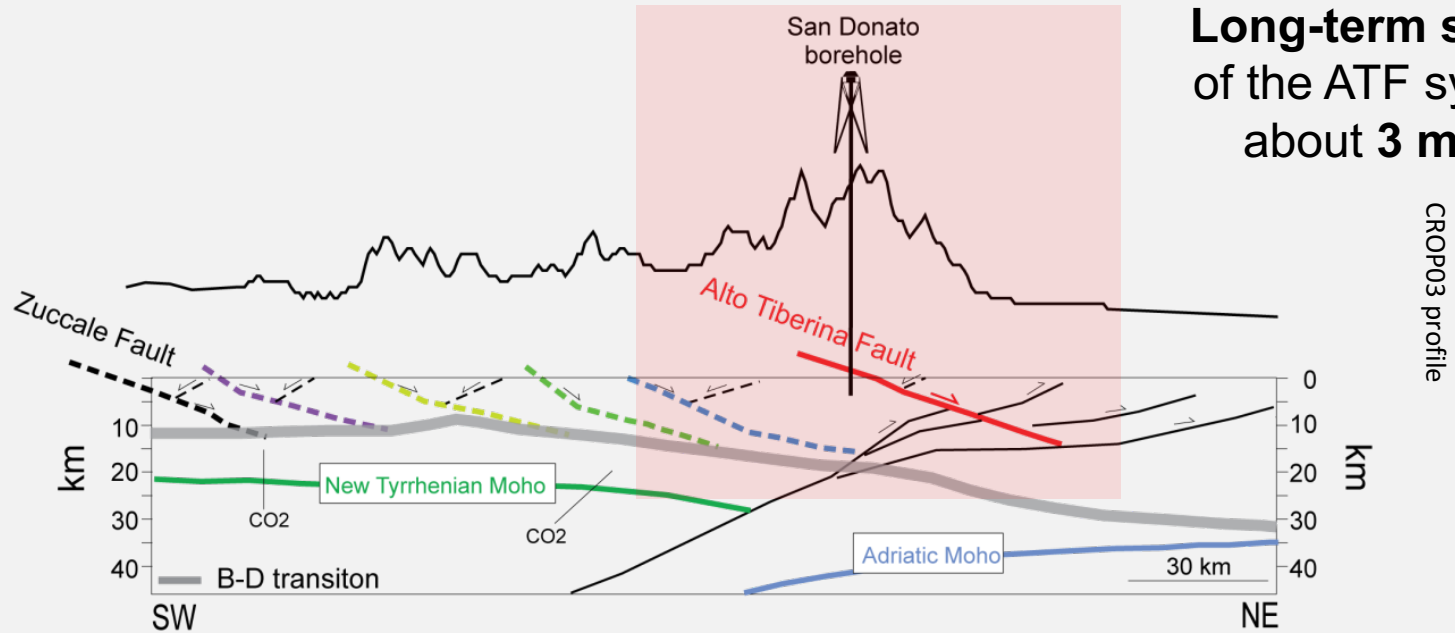
This is consistent with the observed dip-range of moderate and large dip-slip earthquakes ($M > 5.5$) identified using positively discriminated focal mechanisms.

LANF enigma

- ✓ Can eqks nucleate on **LANF** (dip < 30°)?
- ✓ How do **LANF** accommodate extension of continental crust (i.e., *seismic vs aseismic* slip-behaviour)?
- ✓ What about their seismic hazard?

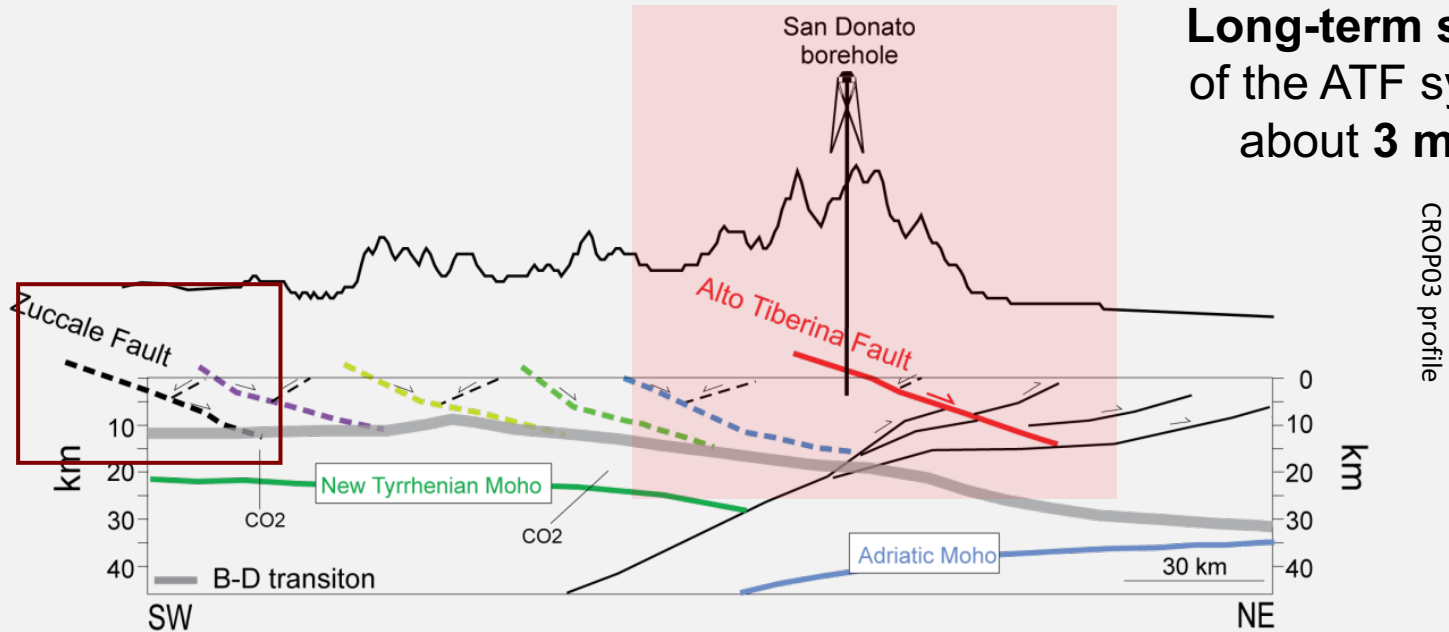
Northern Apennines

**Long-term slip-rate
of the ATF system is
about 3 mm/yr.**

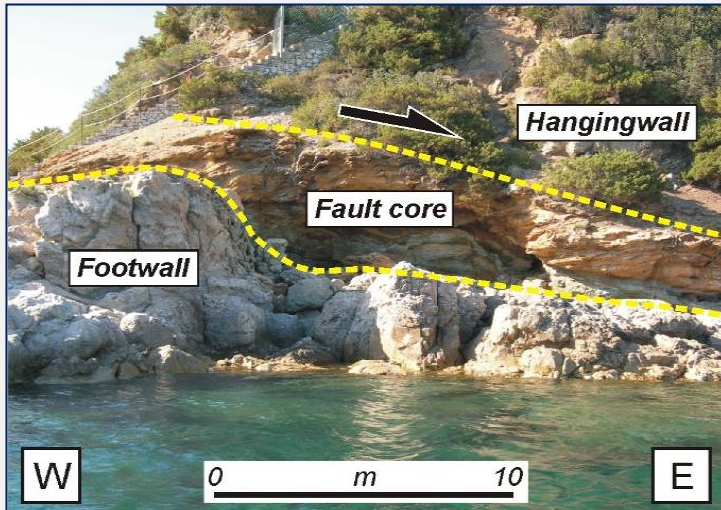


Northern Apennines

**Long-term slip-rate
of the ATF system is
about 3 mm/yr.**



Zuccale Fault

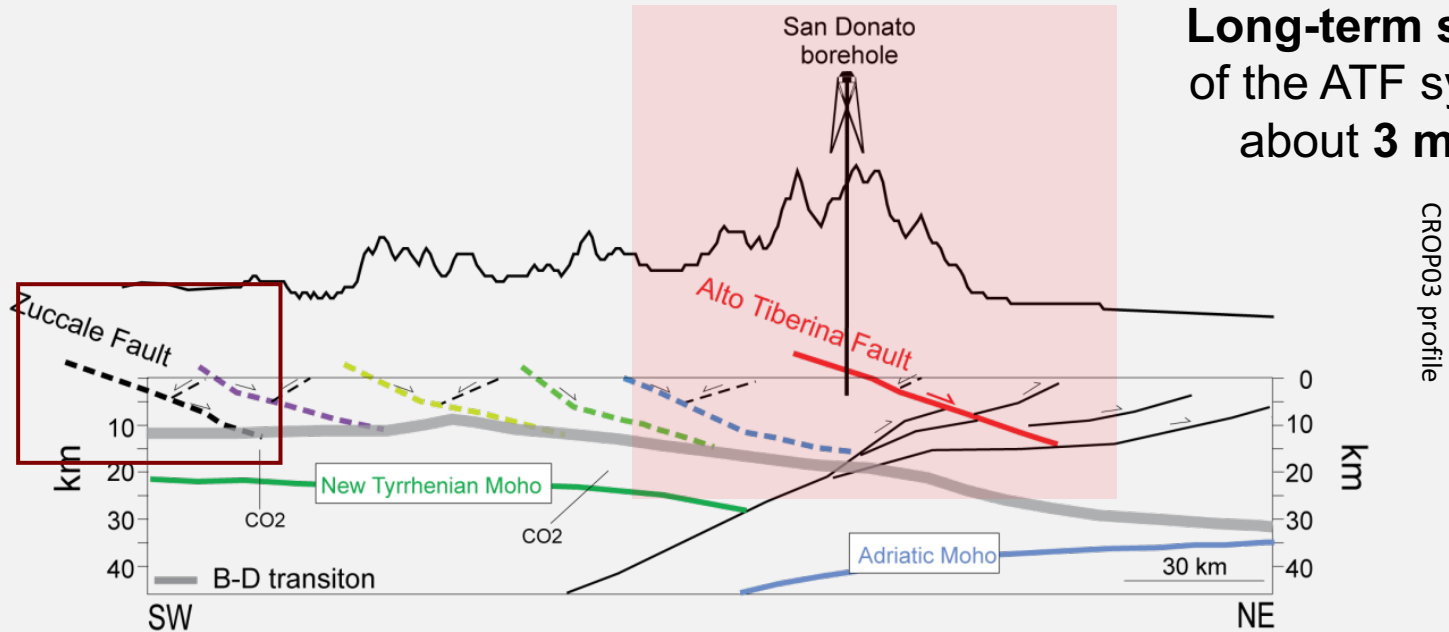


Both velocity strengthening &
velocity weakening materials in
the LANF fault core of the
exhumed analogue of the ATF

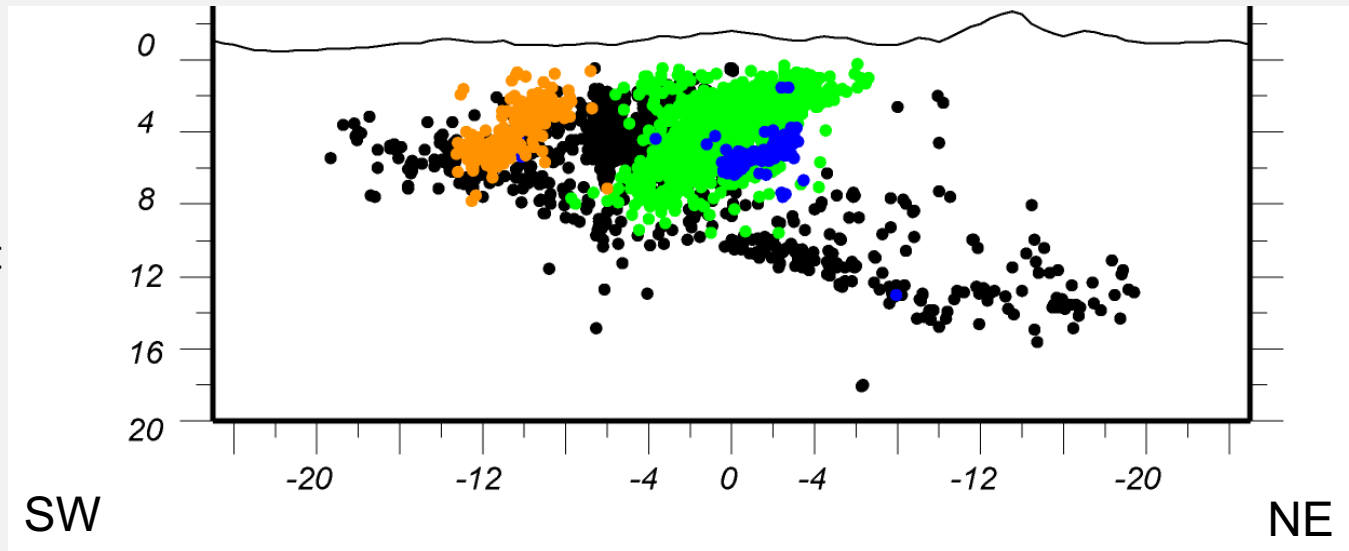
Smith et al., 2007 JSG;
Collettini et al., 2011 EPSL

Northern Apennines

**Long-term slip-rate
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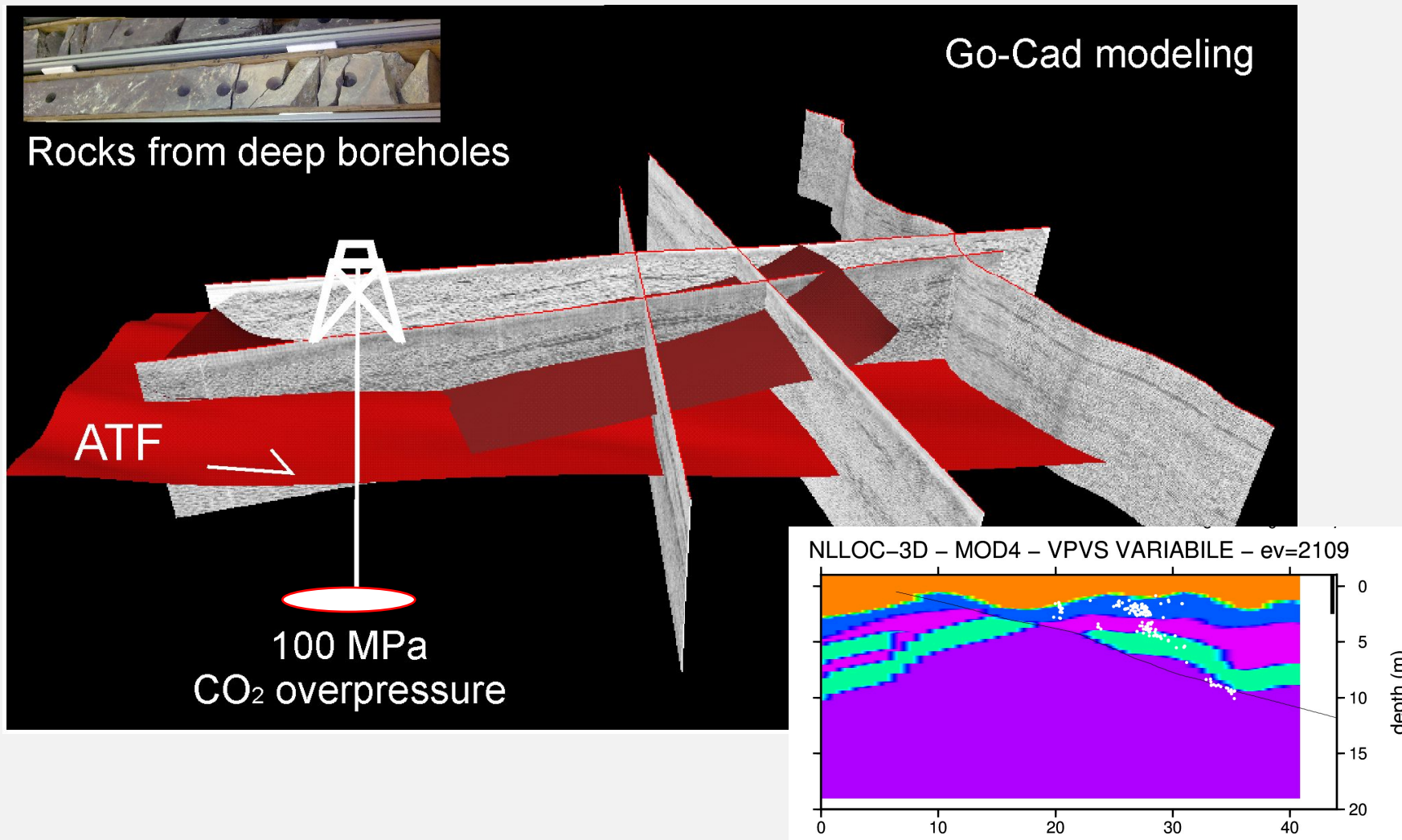


2000-2001
temporary
experiment



Available geophysical data

Borehole data, rock samples and 300 km of seismic reflection profiles are available to identify fault rock types, fault geometry and fluid pressure condition, at depth.



The **A**lto ti**B**erina near fault **O**bservat**O**ry (TABOO)

- Observation systems:

- Seismic network:

24-SP, 18-BB, 12-SM.

- HRcGPS network: 18.

- Geochemical stations: 4 (Radon).

- Electromagnetic stations: 1 (ELF and VLF).

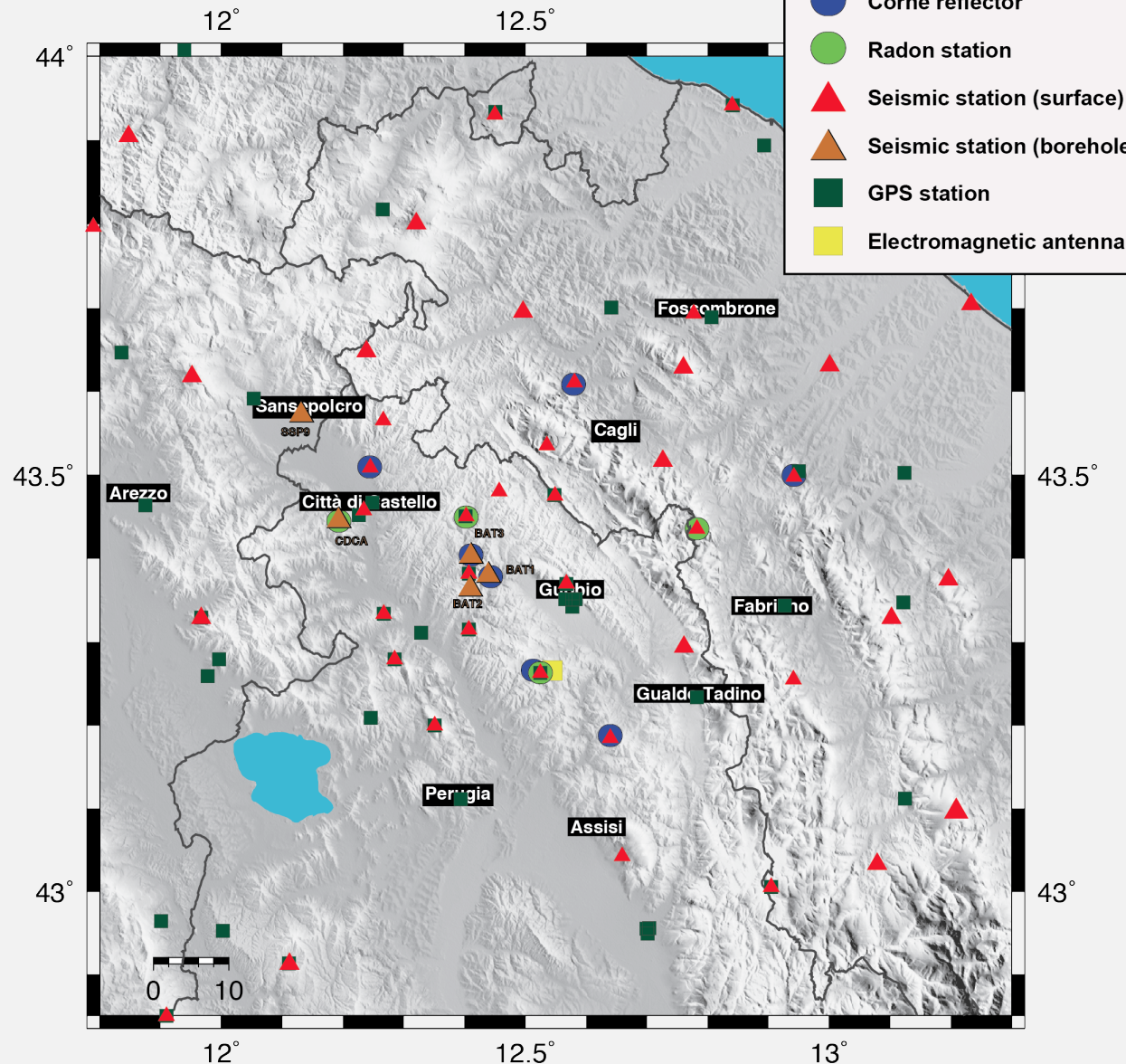
- 5 shallow boreholes (~250 m) instrumented with SP arrays.

- 6 corner reflectors.

- Future developments:

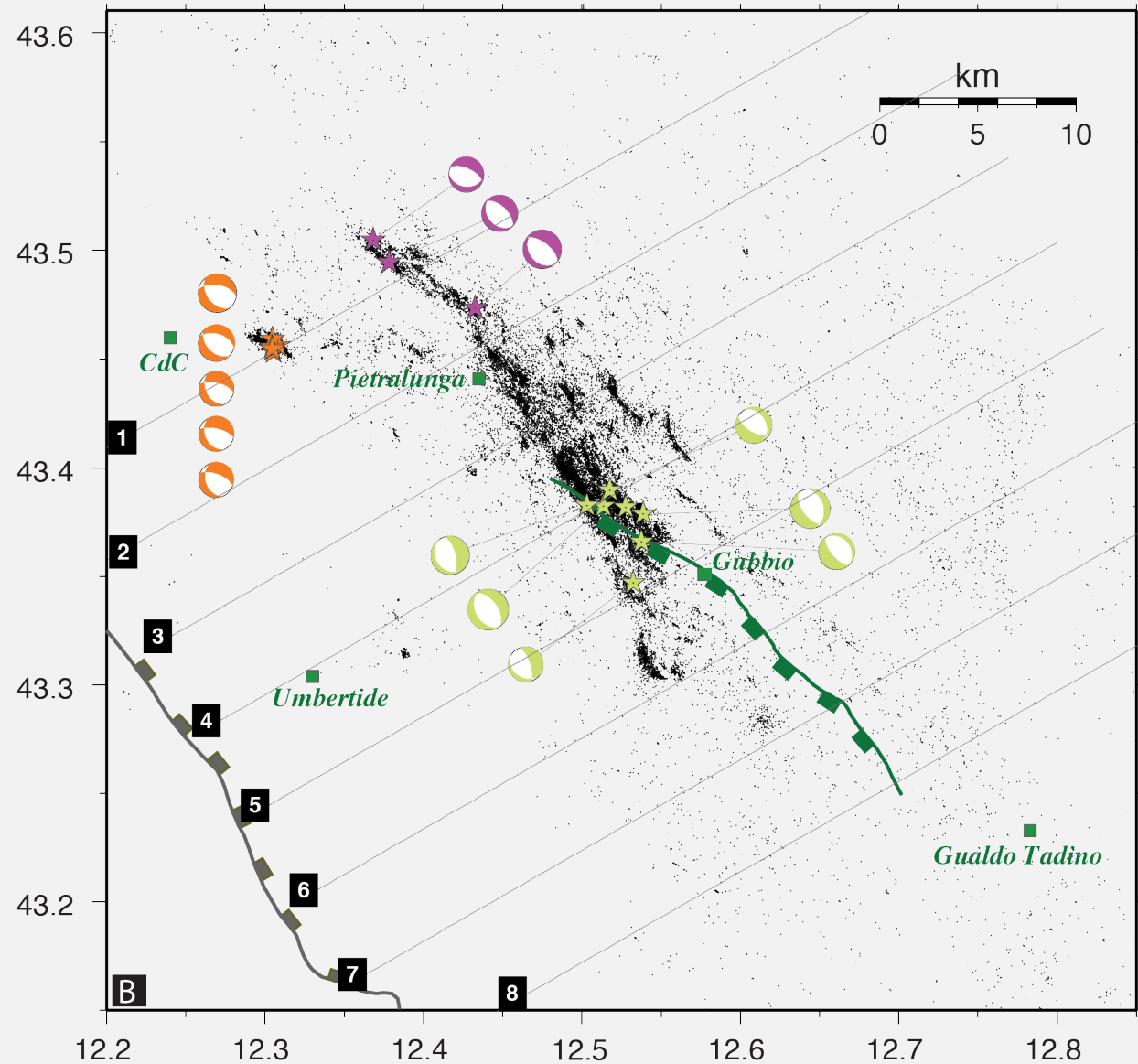
- Installation of 6 strain meters in shallow boreholes.

- Potential site for ICDP deep drilling.



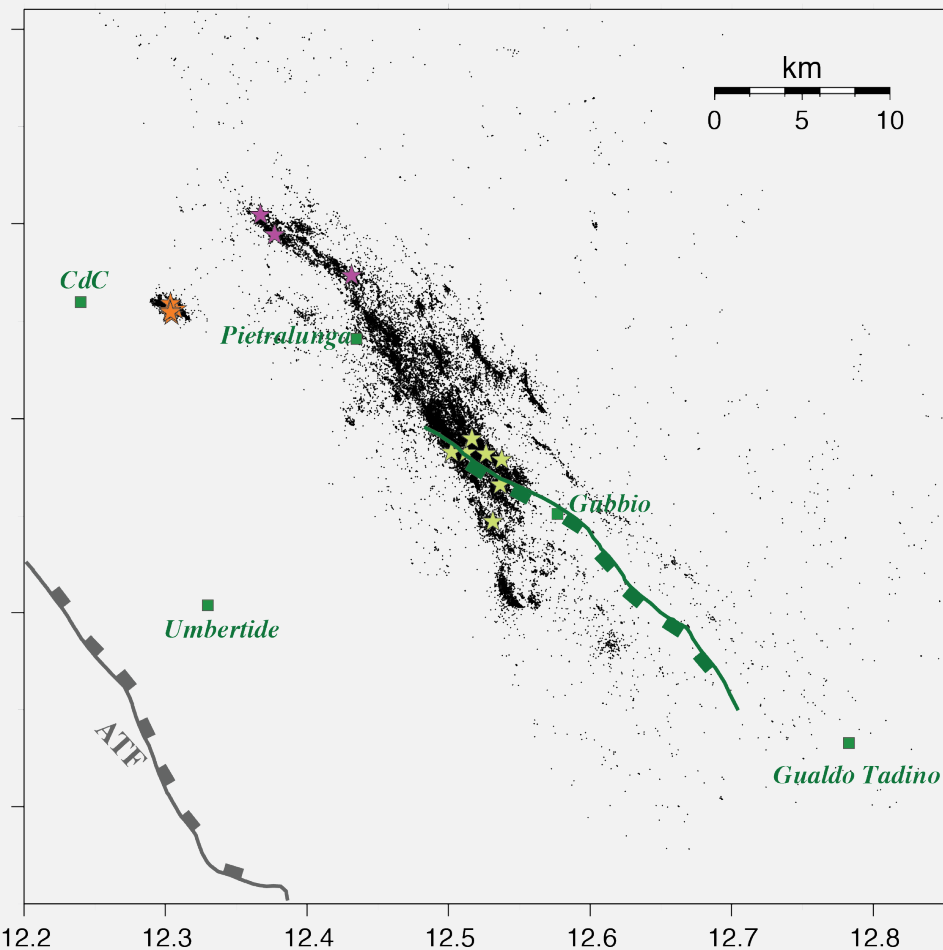
2010-2014 Earthquake catalogue

- High-resolution double-difference catalogue (Waldhauser and Ellsworth, 2000)
- 37,000 events
 M_W max= 3.9
- 15 $M_W > 3$
- $M_C = 0.5 M_L$



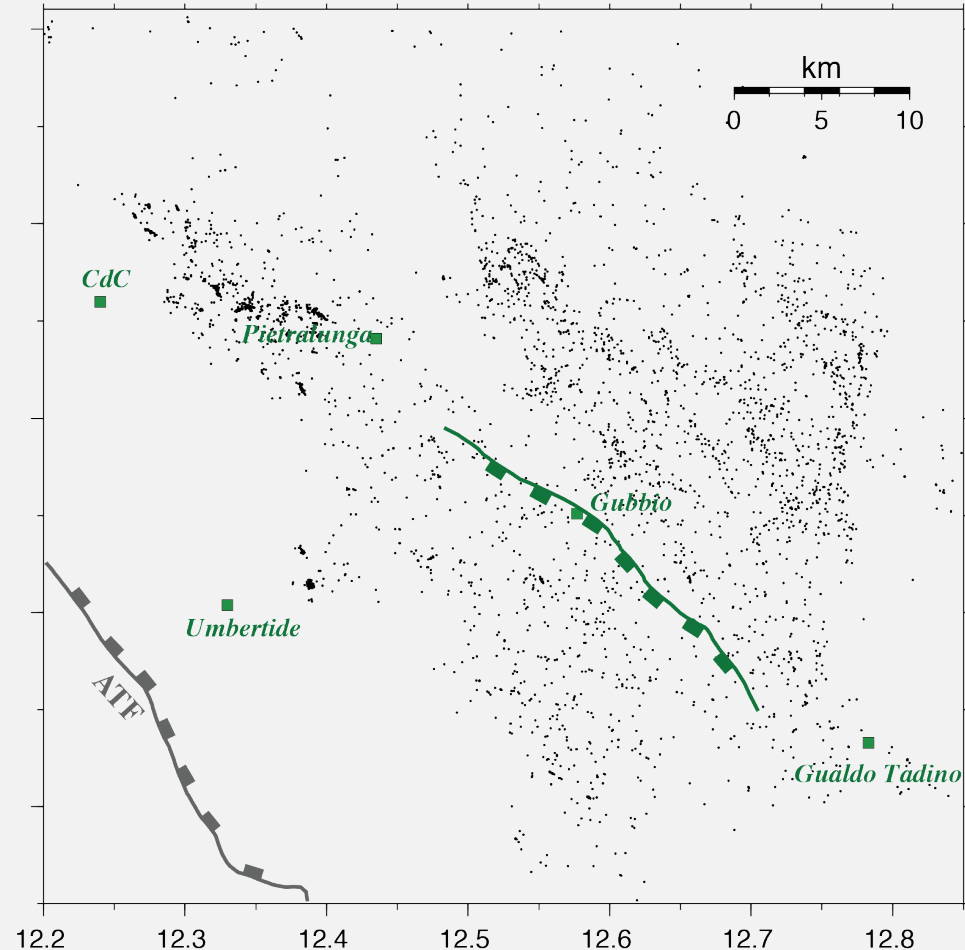
Hanging-wall vs On-Fault seismicity

ATF hanging-wall



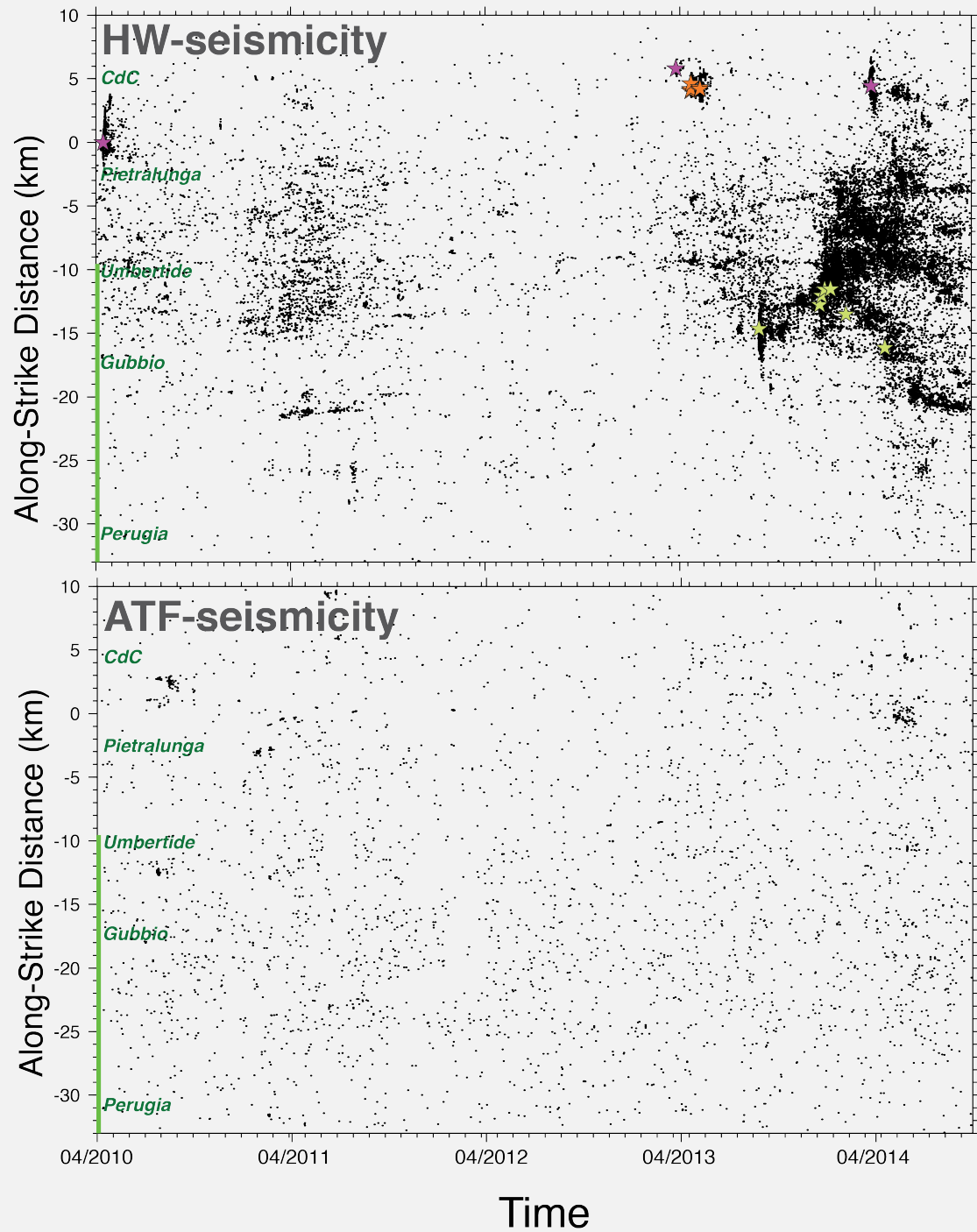
32 k events

ATF on-fault



3685 events (10% of the whole dataset)
 $M_L < 2.4$

Space-Time Evolution



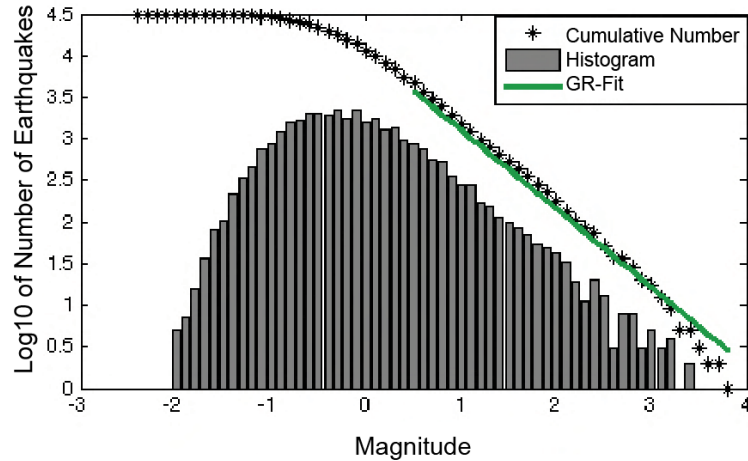
Hanging-wall vs On-Fault seismicity

ATF hanging-wall

Completeness Mag MBS = 0.5

b-value MBS = 0.94 (0.01)

B-value=0.94 (± 0.01)

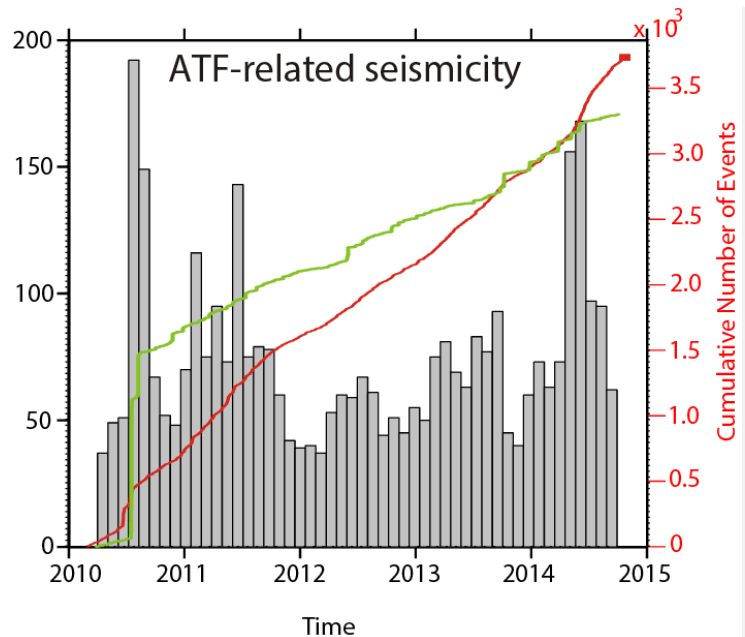
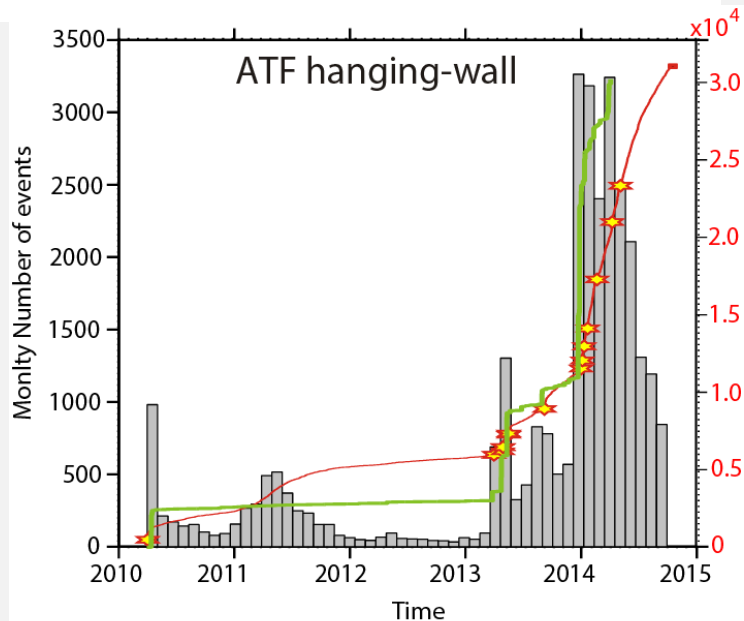
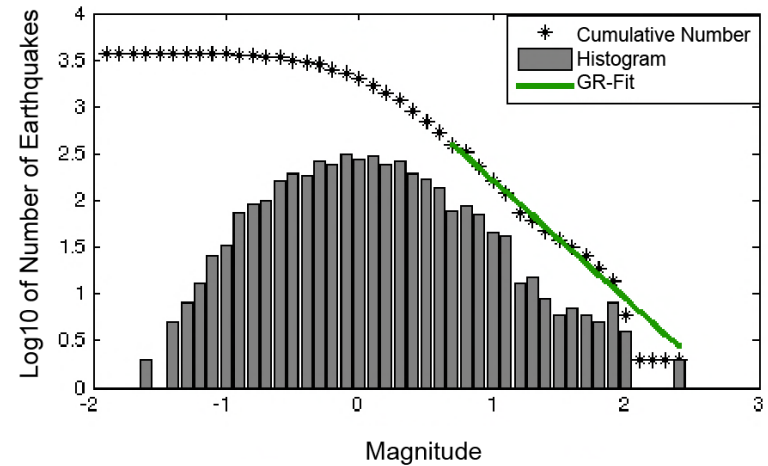


ATF-related seismicity

Completeness Mag MBS = 0.7

b-value MBS = 1.27 (0.06)

B-value=1.27 (± 0.06)



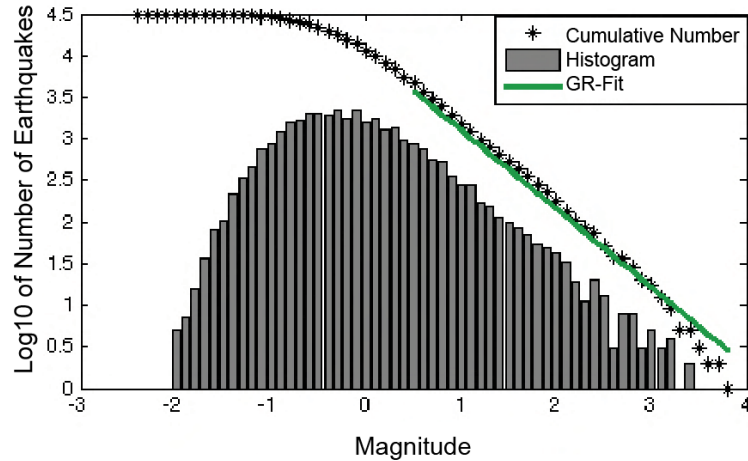
Hanging-wall vs On-Fault seismicity

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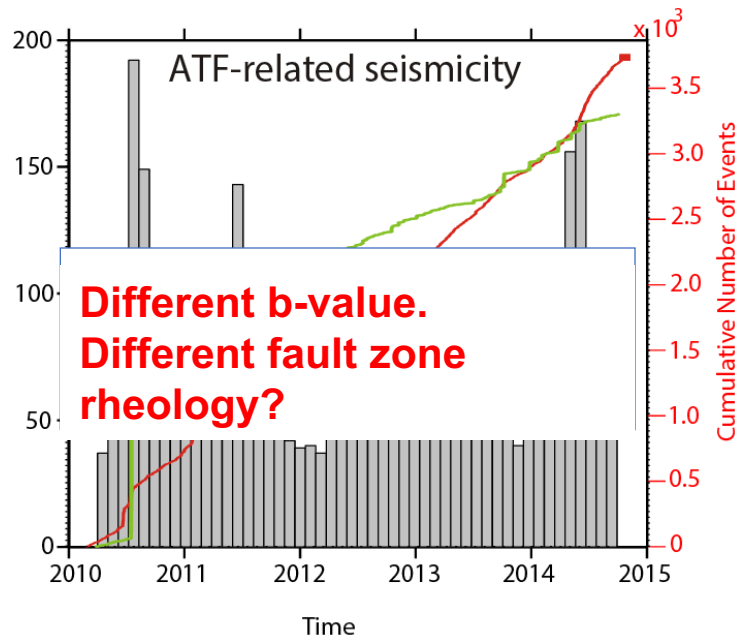
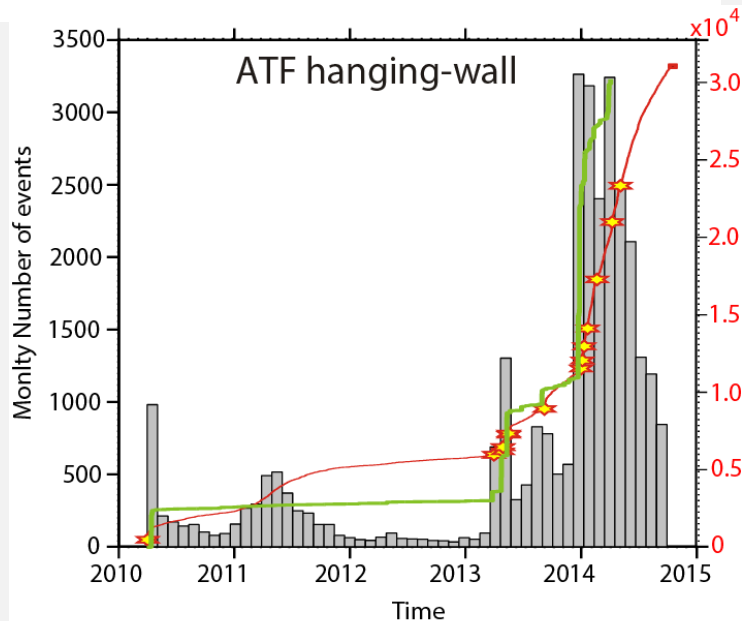
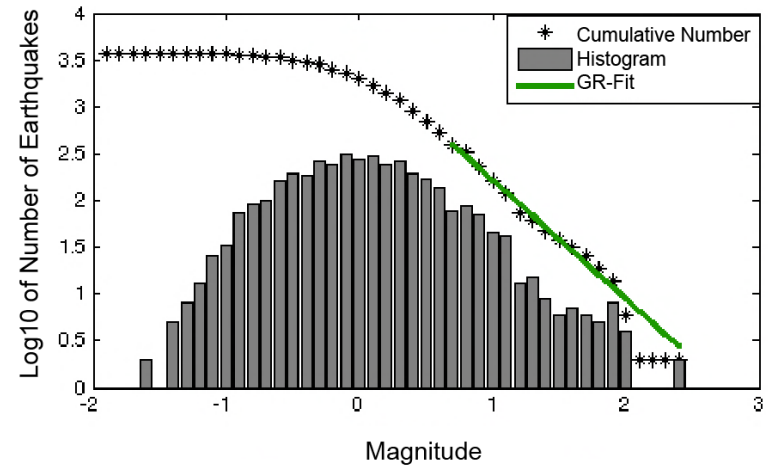


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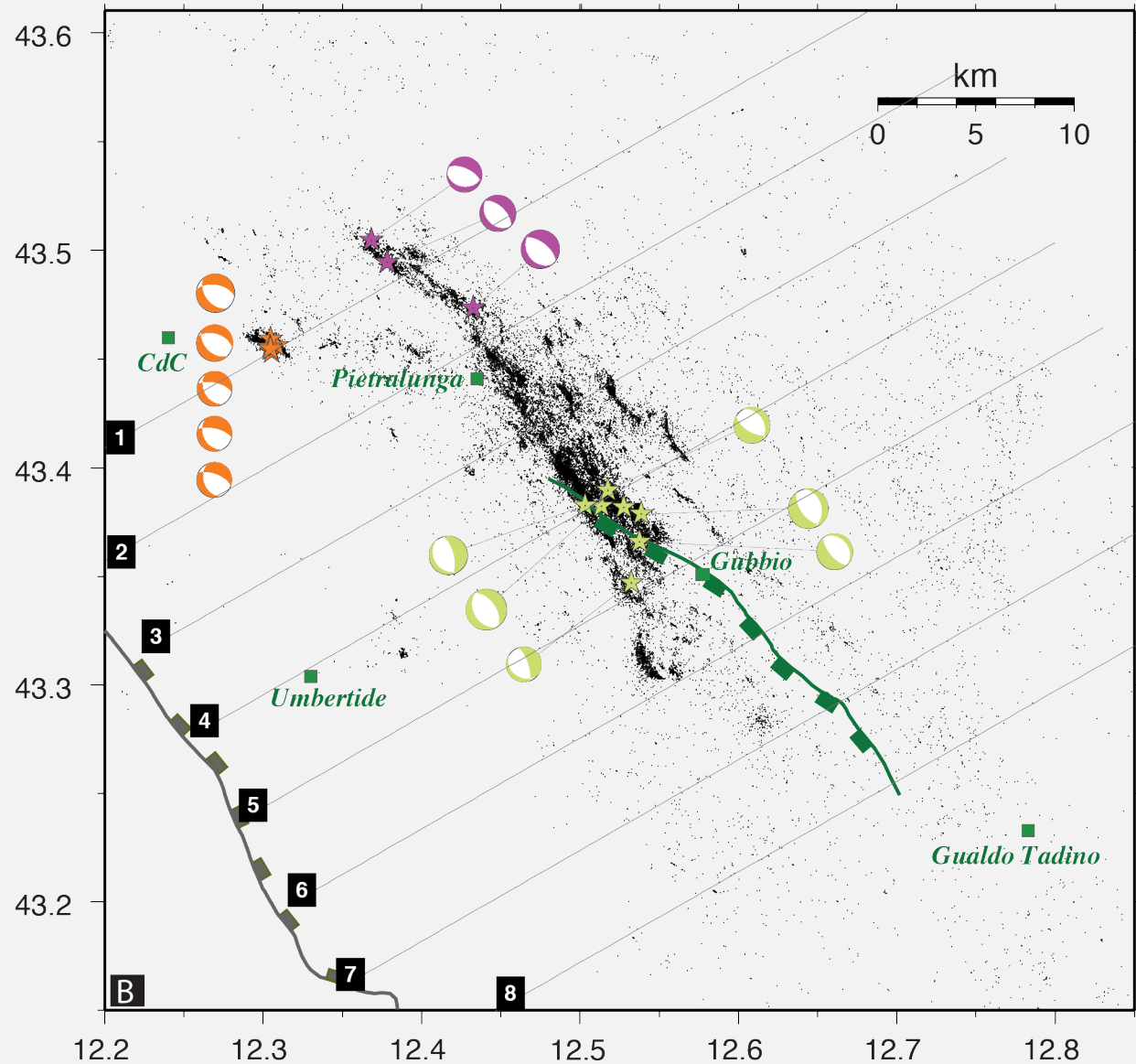
B-value=1.27 (± 0.06)



**Different b-value.
Different fault zone
rheology?**

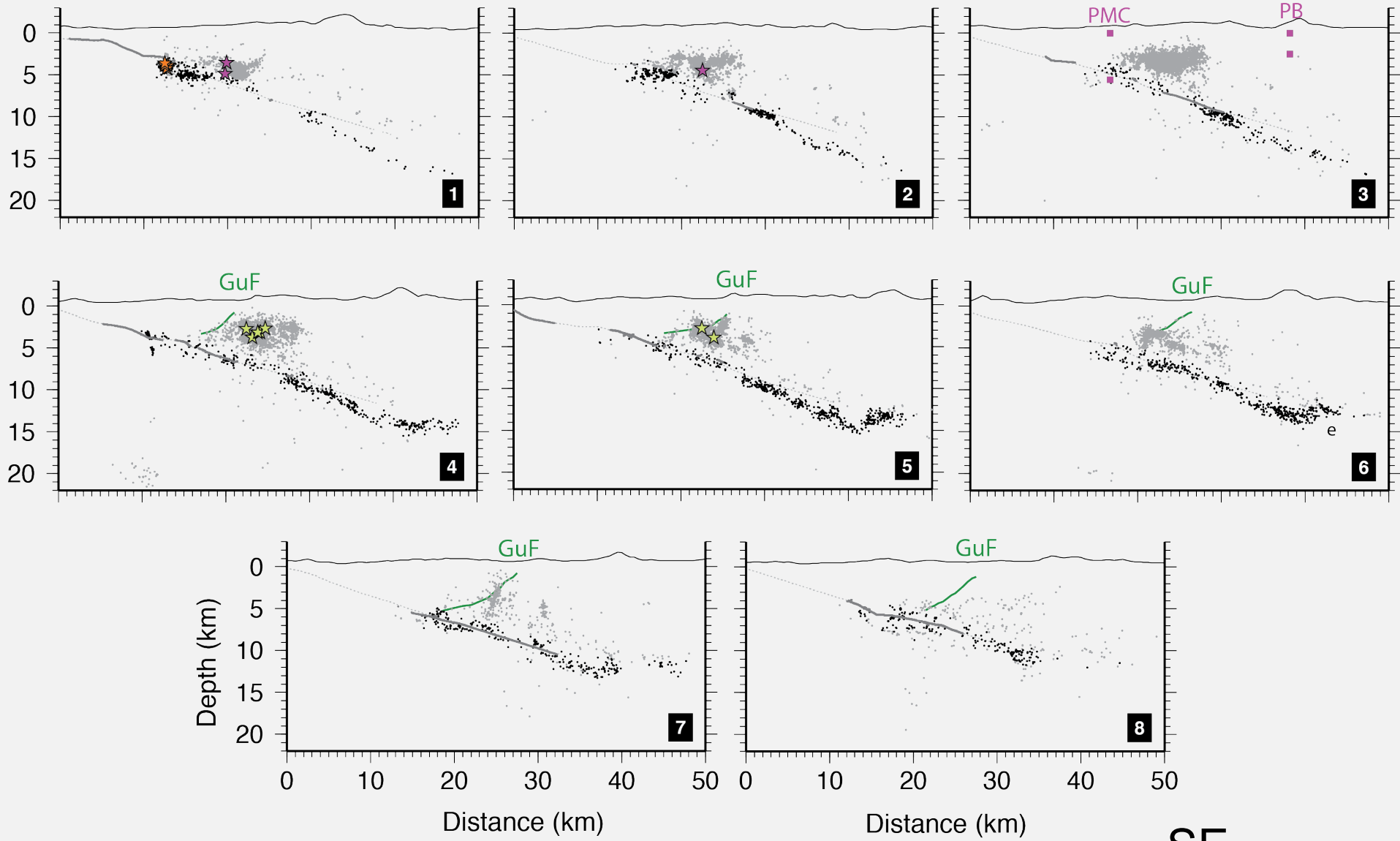
2010-2014 Earthquake catalogue: Seismicity @ detph

5 km-spaced
cross-sections



Low-angle ATF: Fault Zone Structure

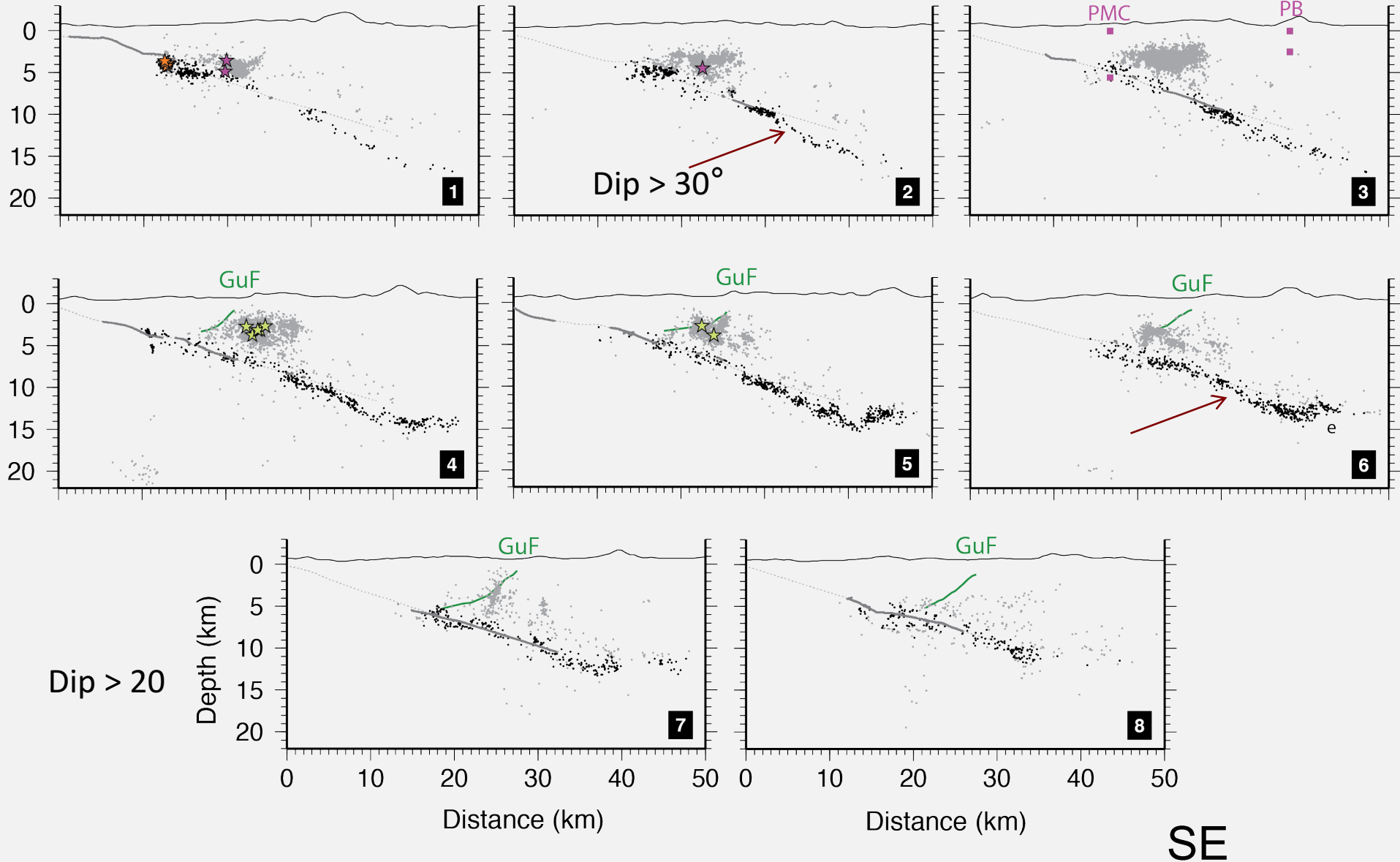
NW



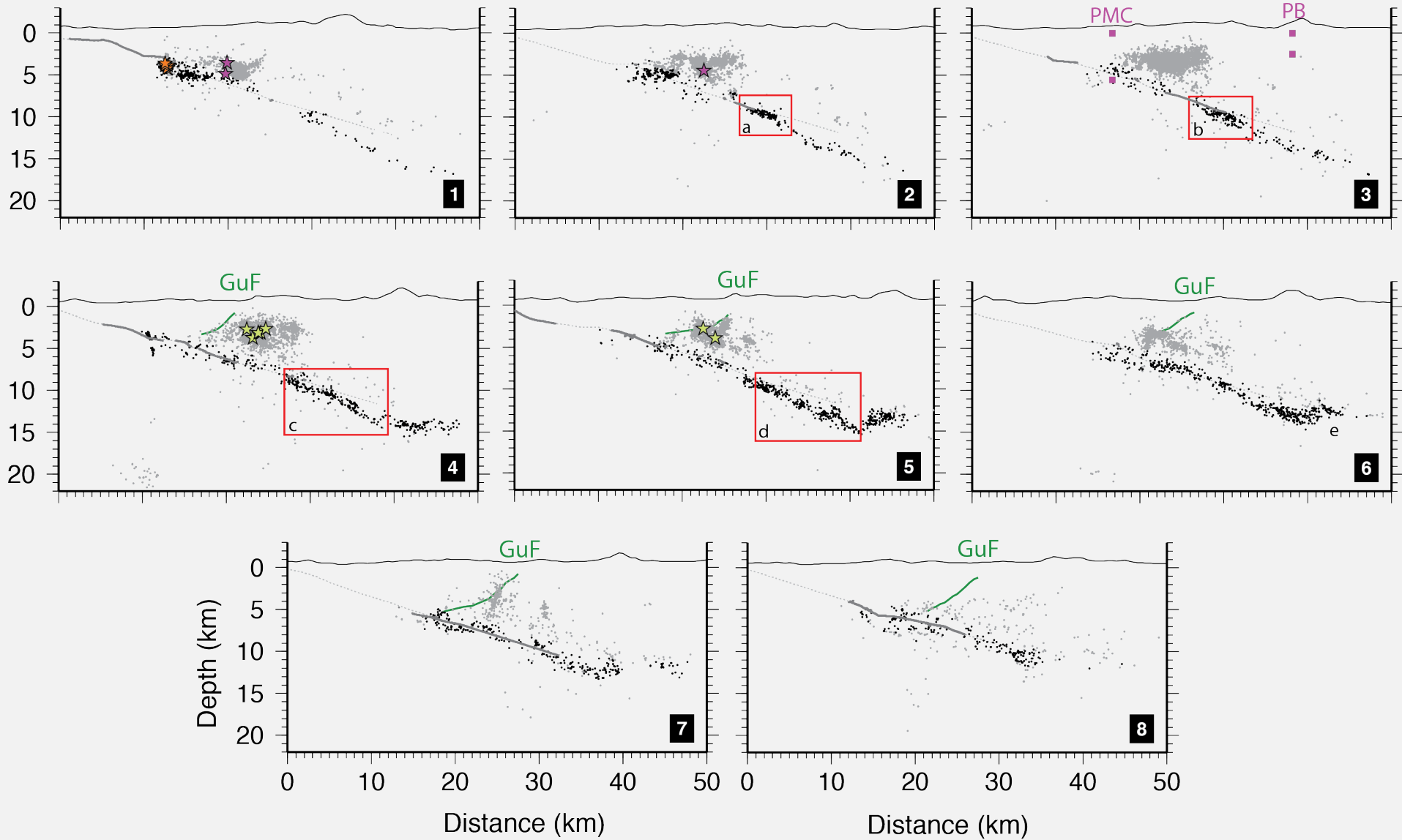
SE

Low-angle ATF: Fault Zone Structure

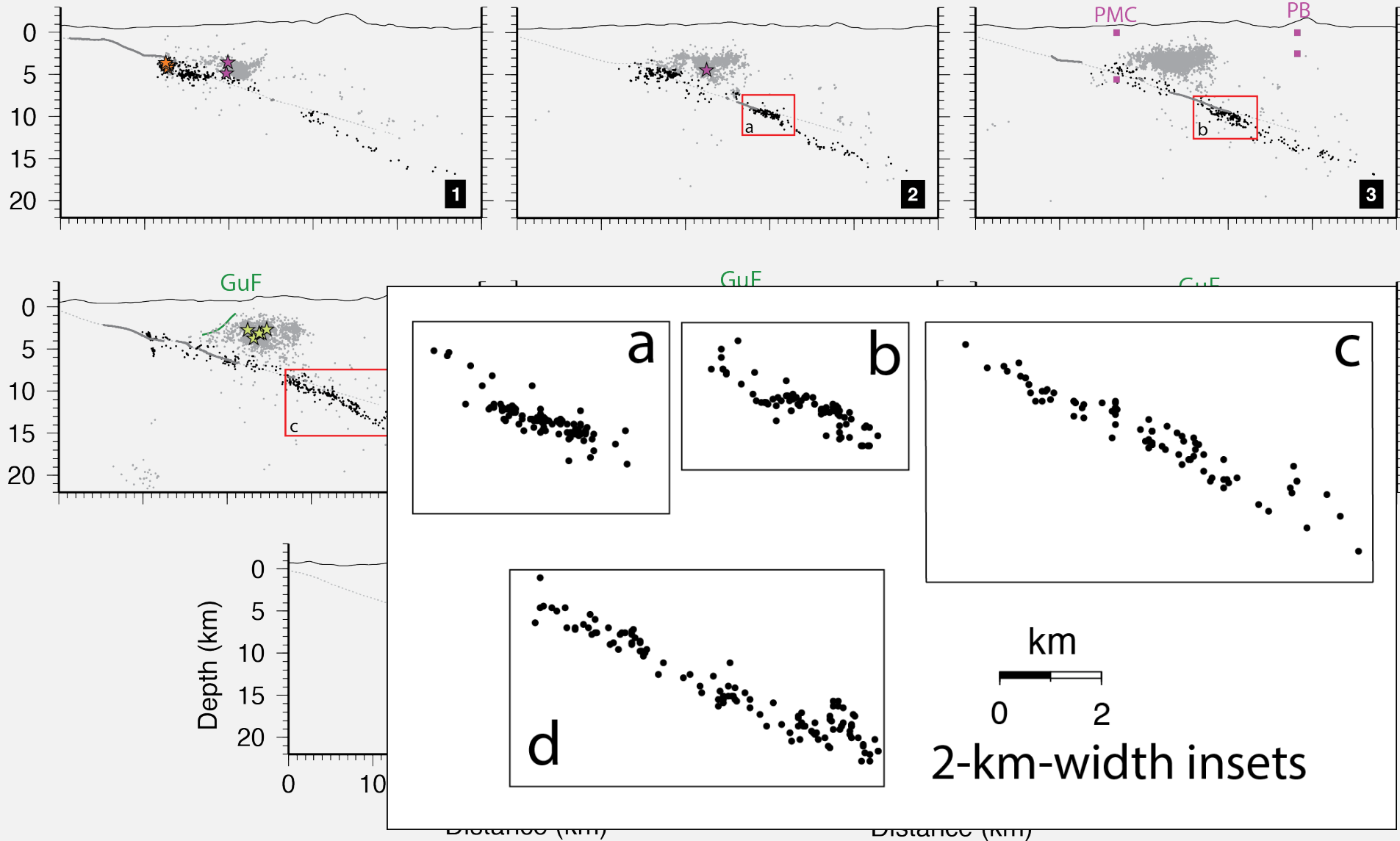
NW



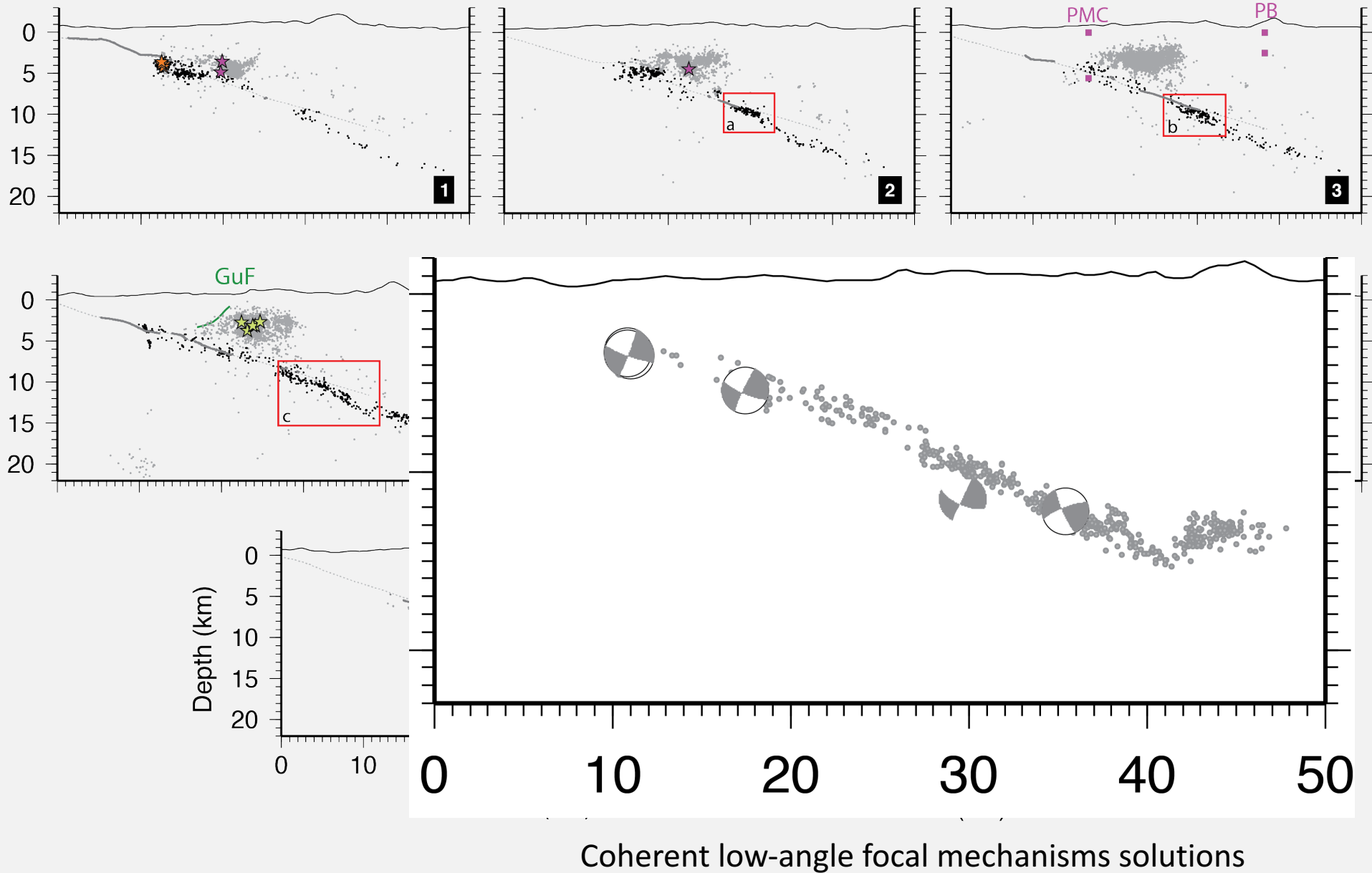
Low-angle ATF: Fault Zone Structure



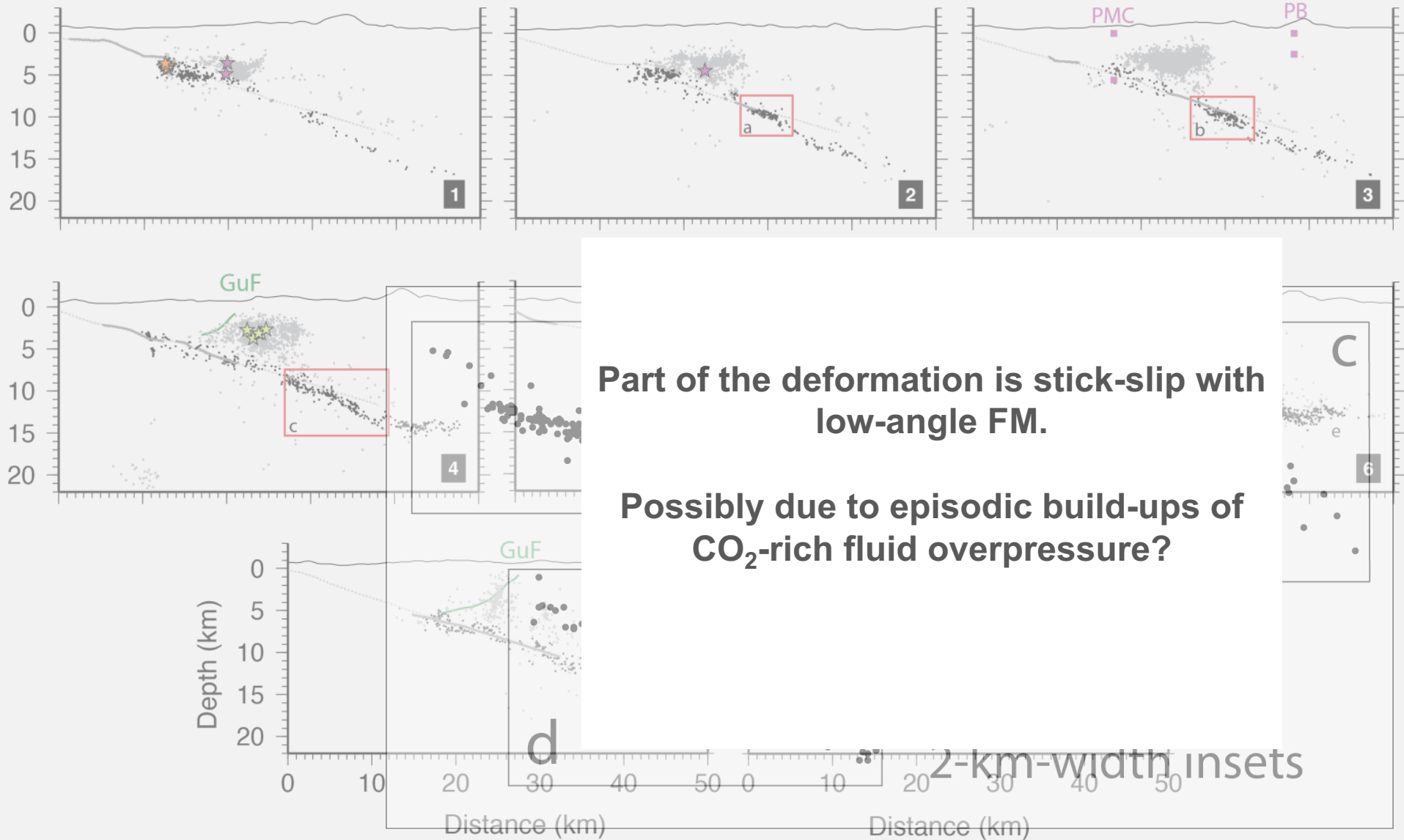
Low-angle ATF: Multiple slipping planes



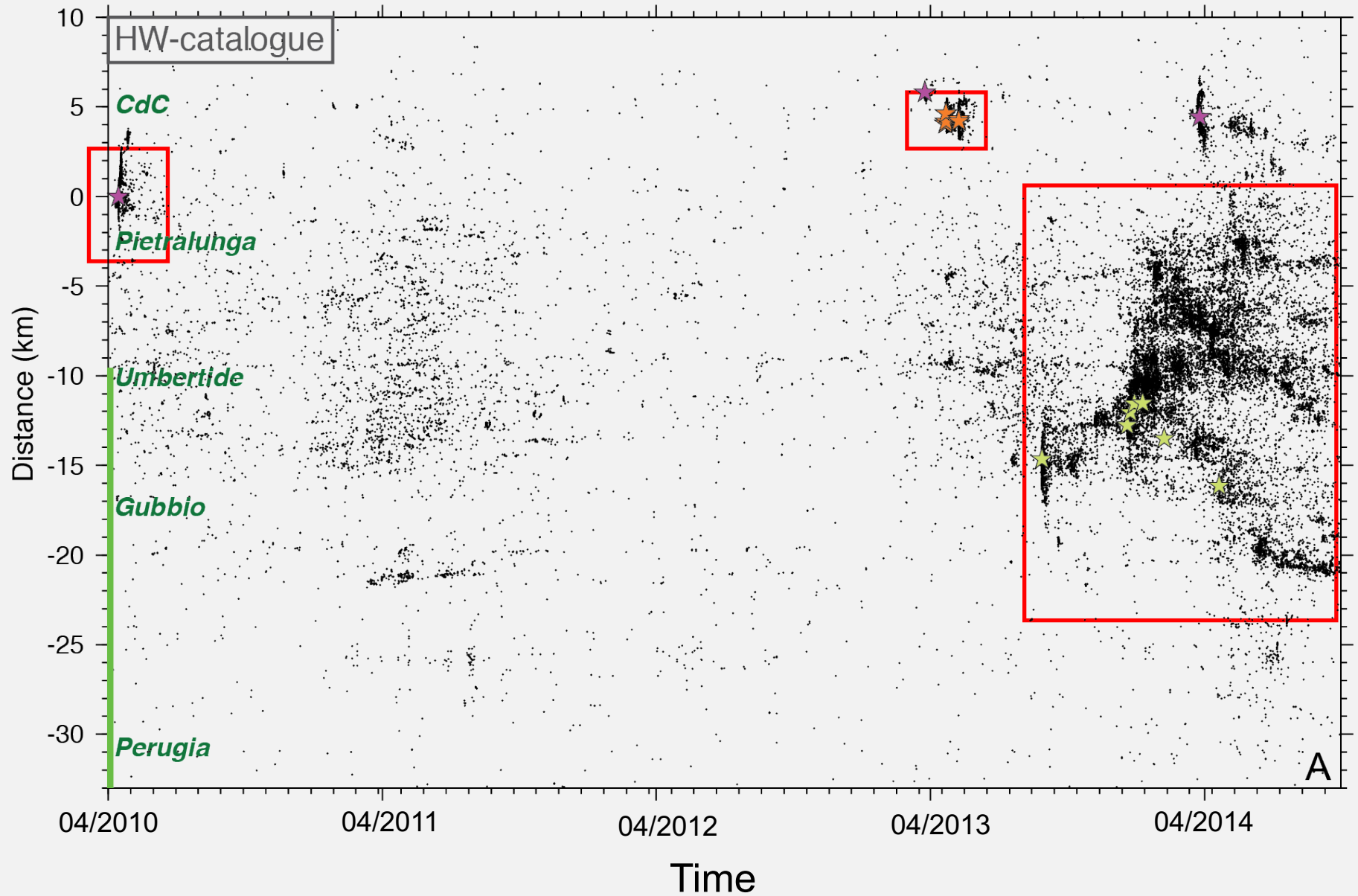
Low-angle ATF: Multiple slipping planes



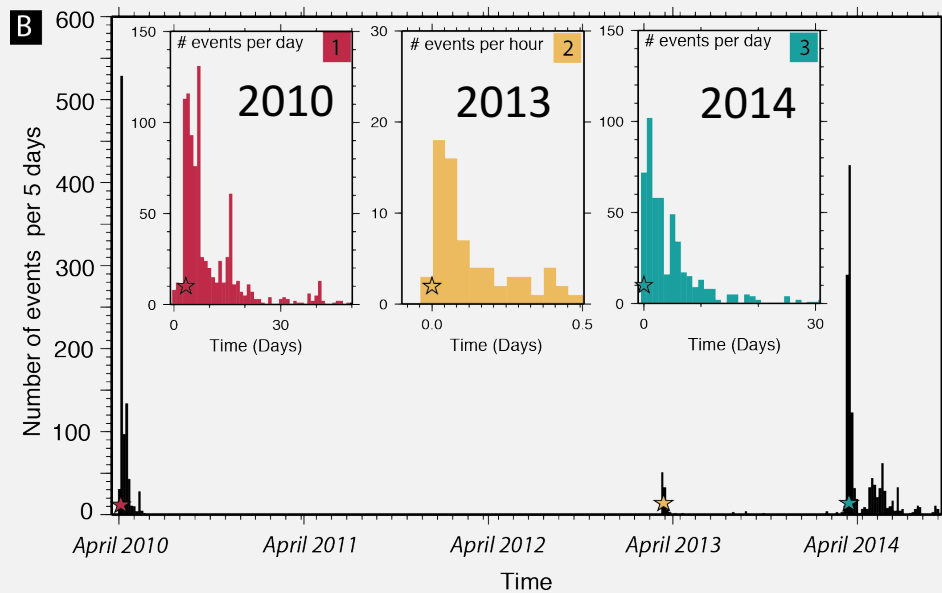
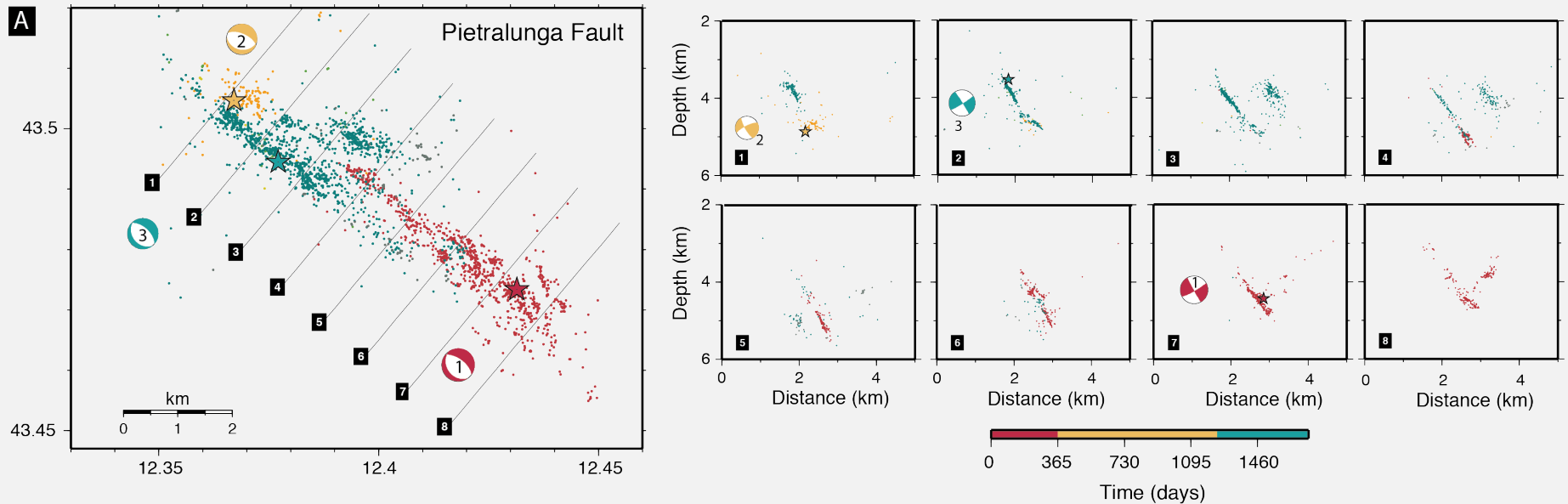
Low-angle ATF: Multiple slipping planes



Hanging-wall: Space-time diagram

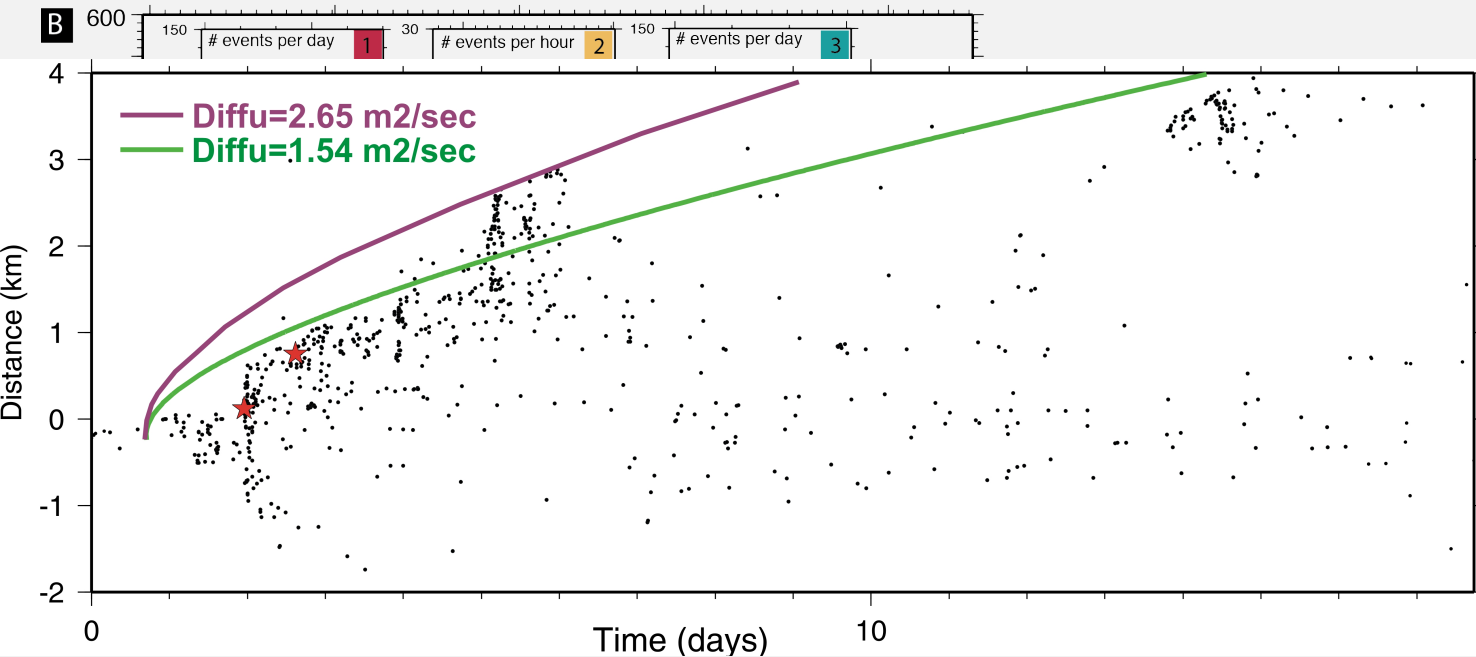
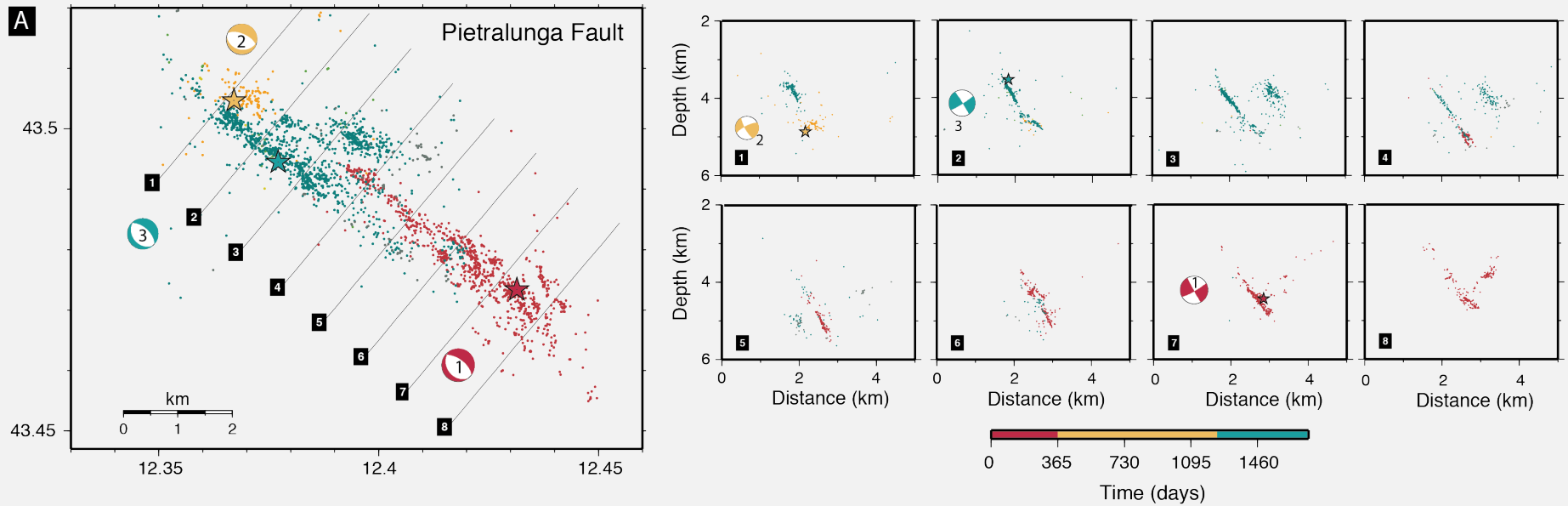


Pietralunga Seismic Sequence



- 3 minor seismic sequences:**
- following $M_w > 3$ events
 - Omori-like decay
 - activity moves toward previous unbroken areas

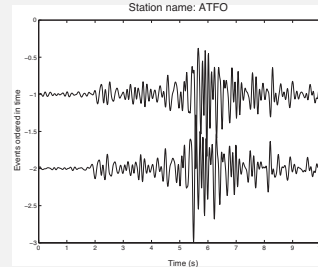
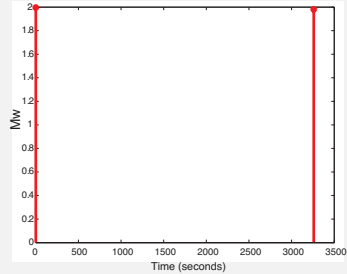
Pietralunga Seismic Sequence



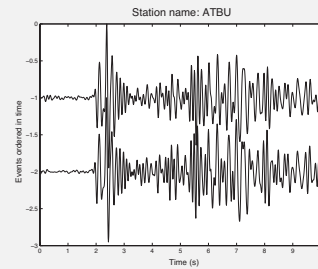
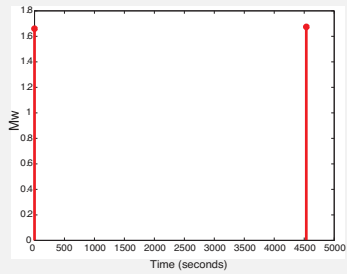
**Migration
speed of 0.5
km/day**

**Slip behaviour along
the low-angle ATF?**

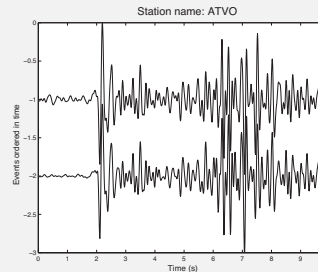
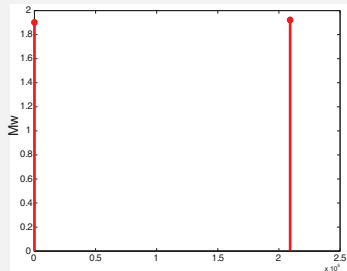
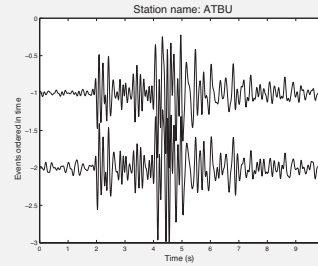
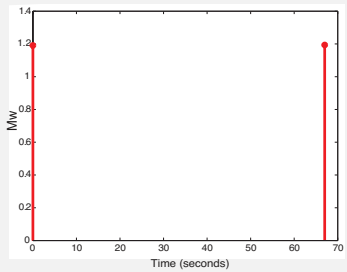
Clusters of Similar (Repeating?) Events along the ATF



- ✓ **97 clusters** including 300 events
- ✓ **90% of coherency at 5 stations**
- ✓ **8% of the total ATF-seismicity**

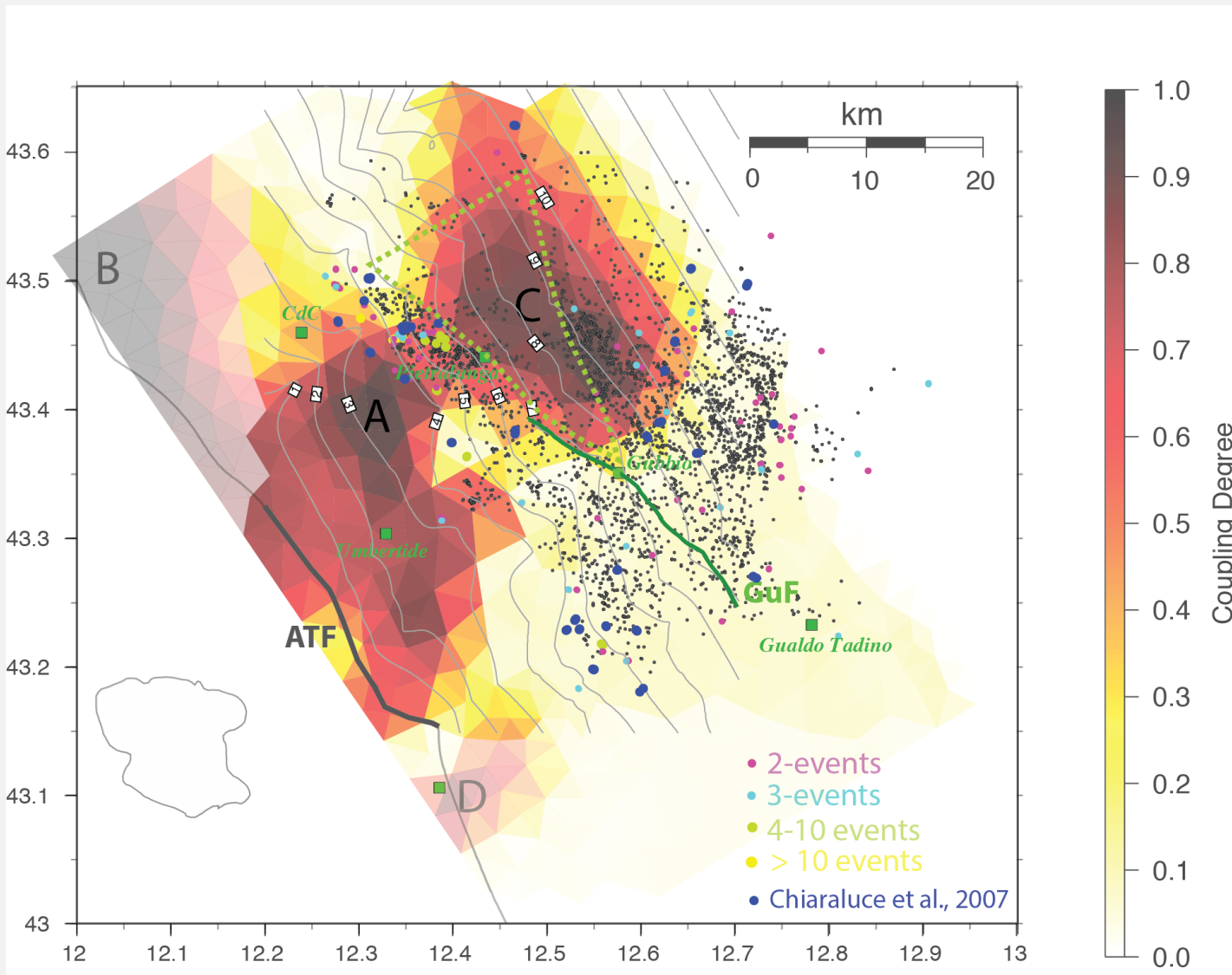


- ✓ **60% of the clusters are doublets**
- ✓ **Similar magnitude**
- ✓ **Short inter-event-time (1 day)**



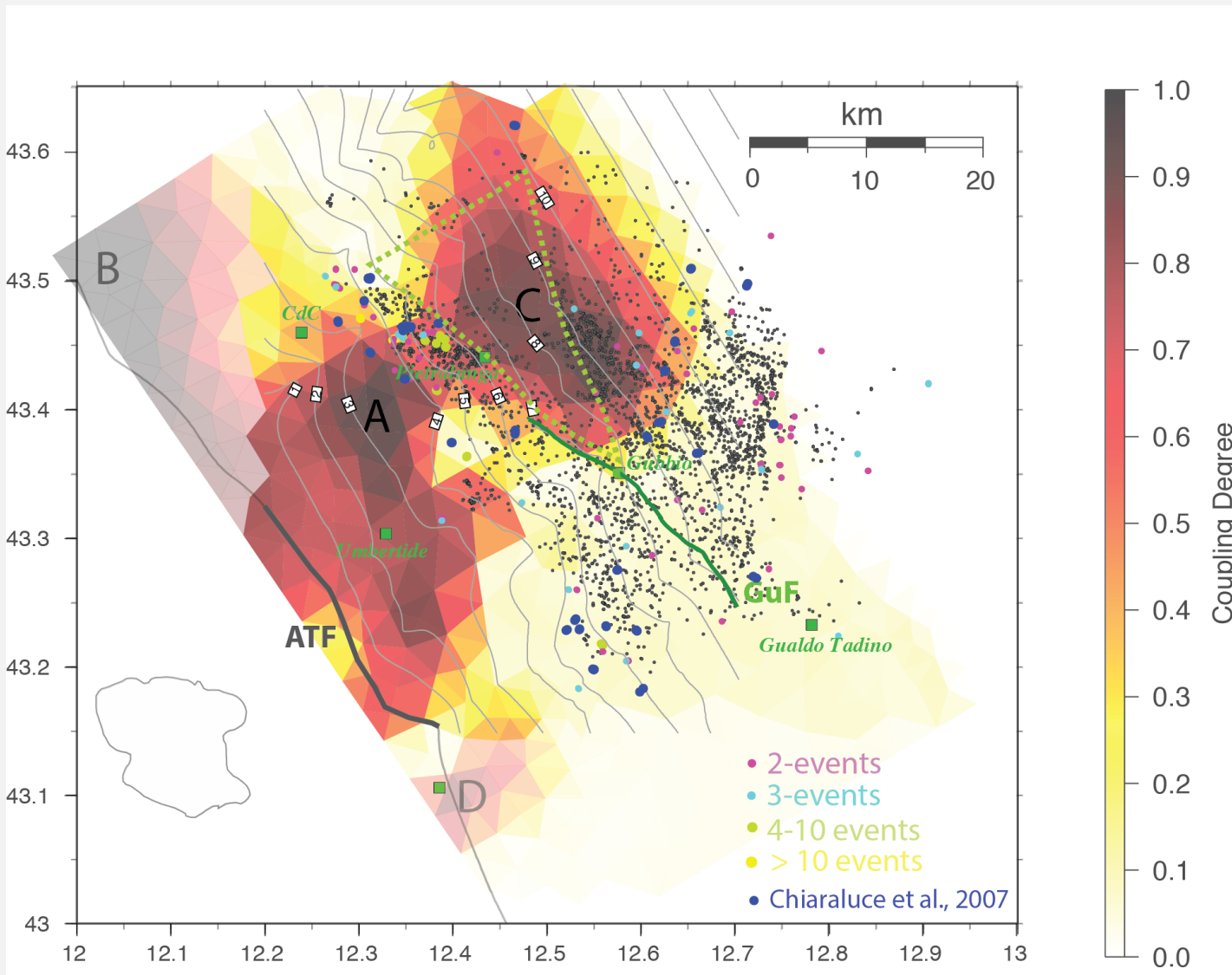
Time (s)

Spatial variation of frictional behaviour along the ATF



- ✓ Creeping below 5 km
- ✓ 1.7 mm/yr slip-rate

Spatial variation of frictional behaviour along the ATF

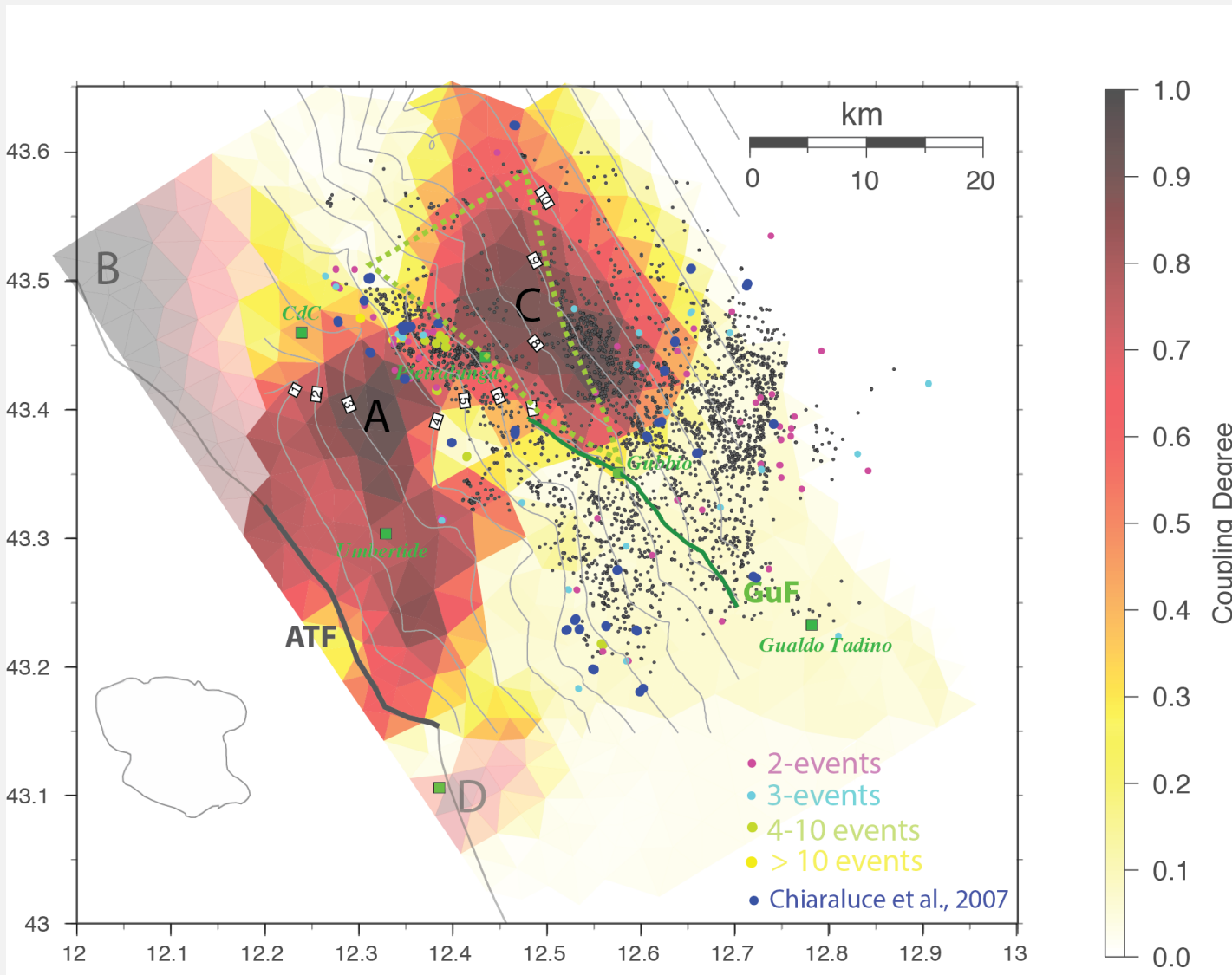


✓ Creeping below 5km

✓ 1.7 mm/yr slip-rate

Seismic M_0 30% of the Geodetic M_0

Spatial variation of frictional behaviour along the ATF



✓ Creeping below 5km

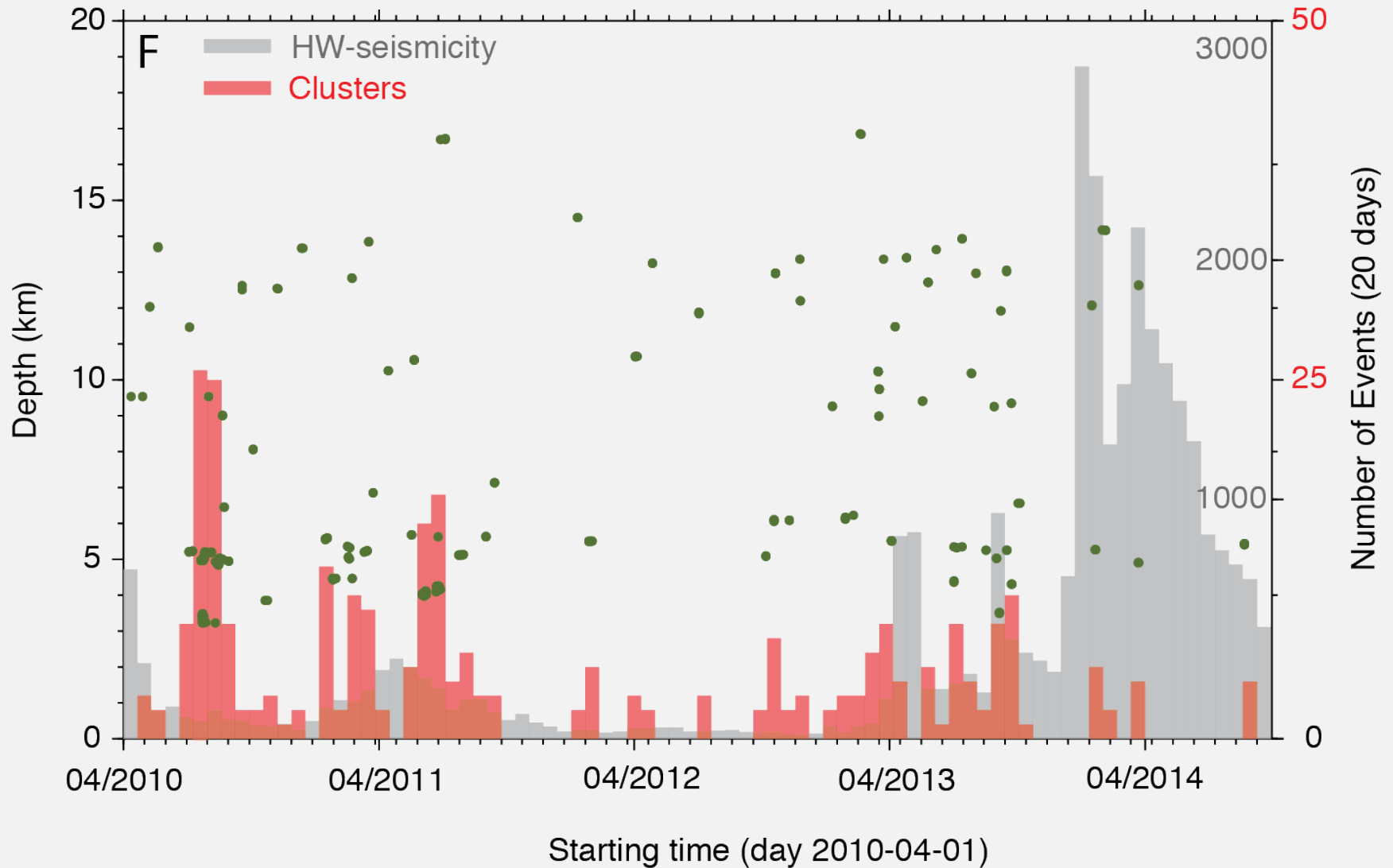
✓ 1.7 mm/yr slip-rate

Seismic M_0 30% of
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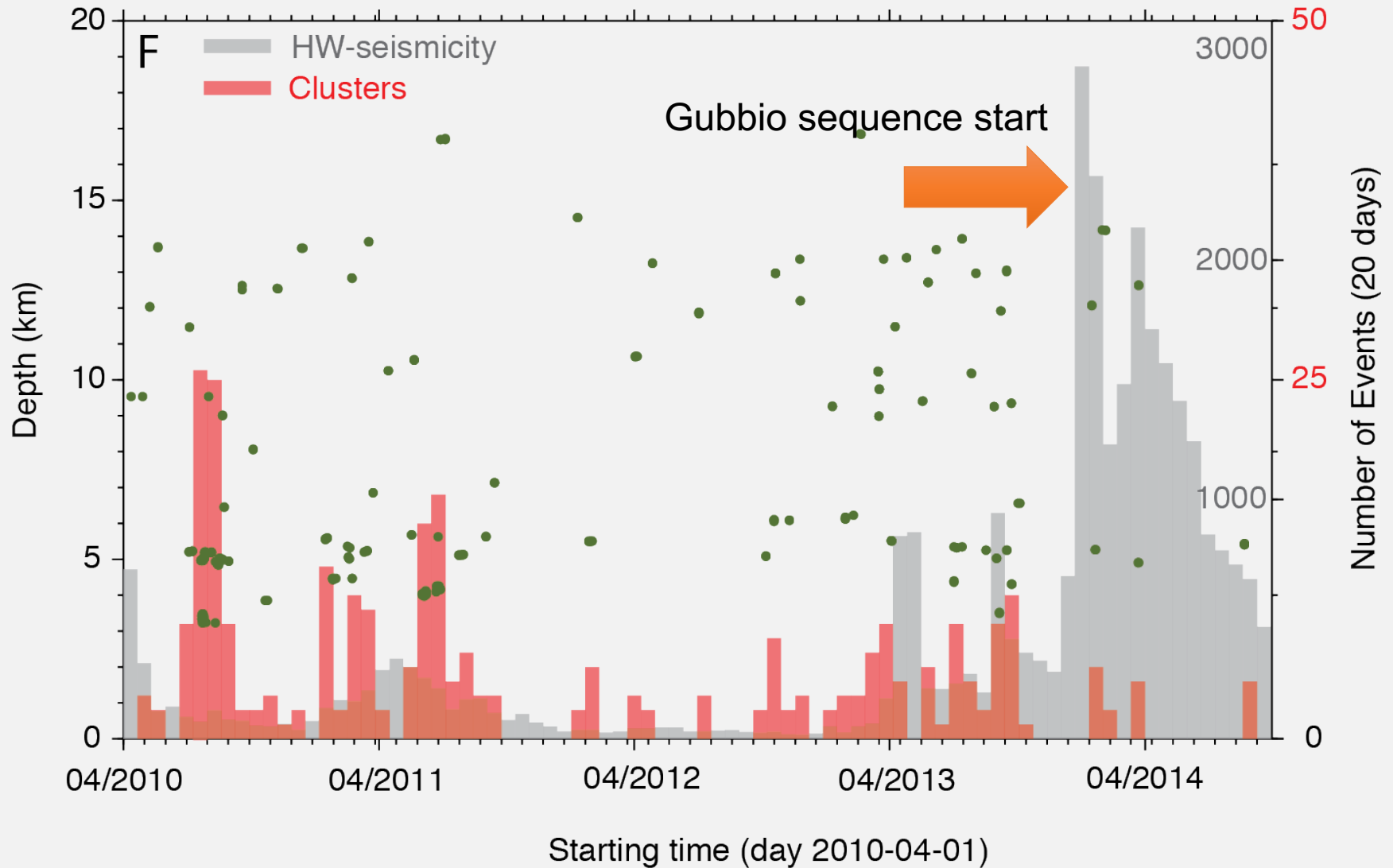
**Aseismic
deformation**

How is the strain partitioned within the **fault system**?



The rate of occurrence of RE seems to be synchronous with the ATF-HW seismic release → **creeping guiding the strain partitioning?**

How is the strain partitioned within the **fault system**?



The rate of occurrence of RE seems to be synchronous with the ATF-HW seismic release → **creeping guiding the strain partitioning?**

In Summary...

- Kinematically consistent micro-seismicity does occur along the **active LANF** within a crustal volume with vertical σ_1 and high-fpf (CO_2)
- **High-angle HW faults** are activated by **multiple M3+** seismic sequences, showing migrating from one fault segment to another.
- The low-angle ATF shows a mixed-mode (stick-slip & stable-sliding) slip-behavior.
- Aseismic slip is suggested by:
 - seismic M_0 about 30% of the geodetic M_0
 - clusters of RE occur within **creeping** portions around asperities.
- RE seismic rate seems synchronous with the ATF-HW seismic release, thus suggesting that the **creeping** may **guide** the **strain partitioning** along the ATF-HW faults.

Thank you!