Microseismicity produced by cracks and collapses within a karstified rock mass as a tool for risk management: the case of the aqueduct of Rome (Italy)

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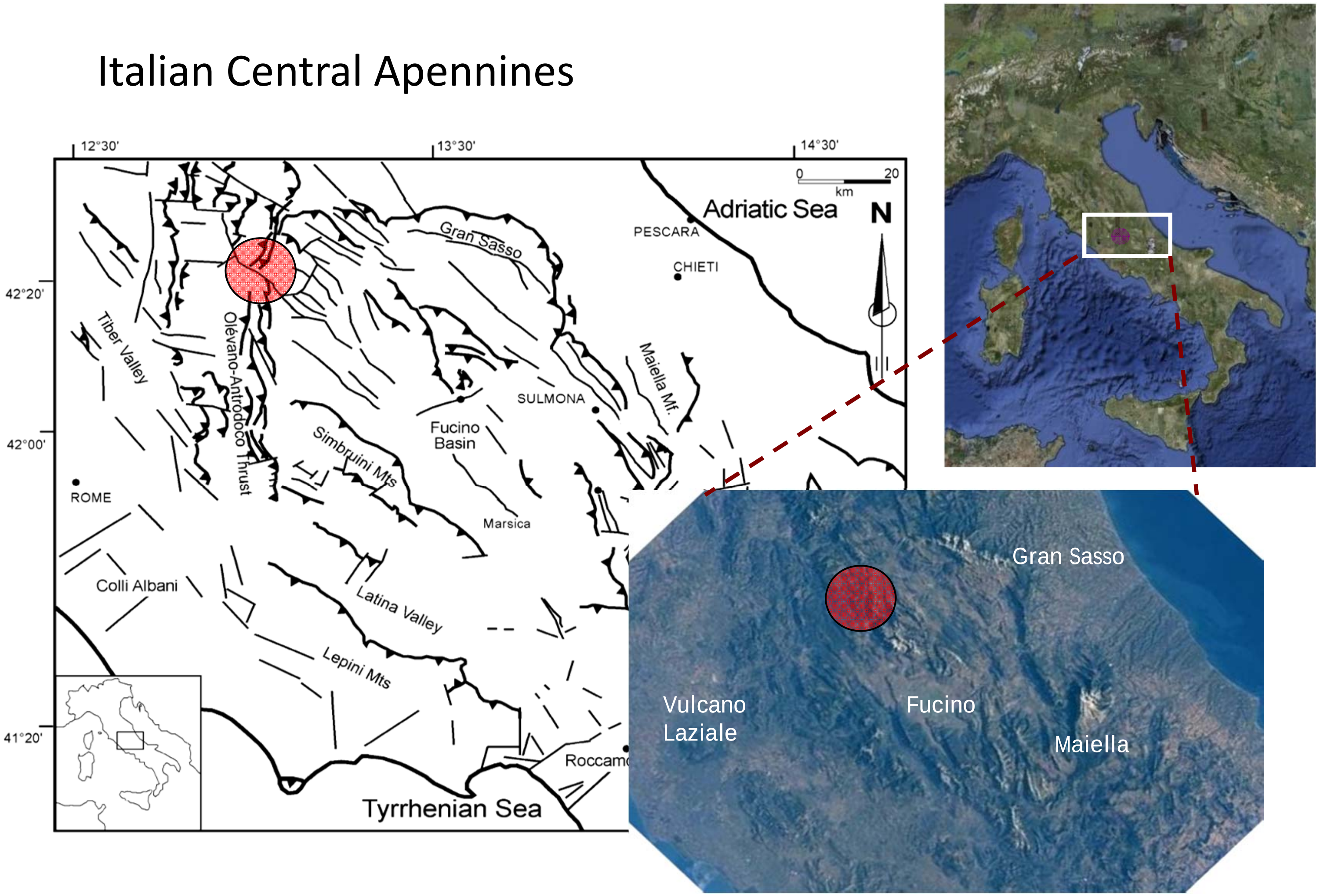
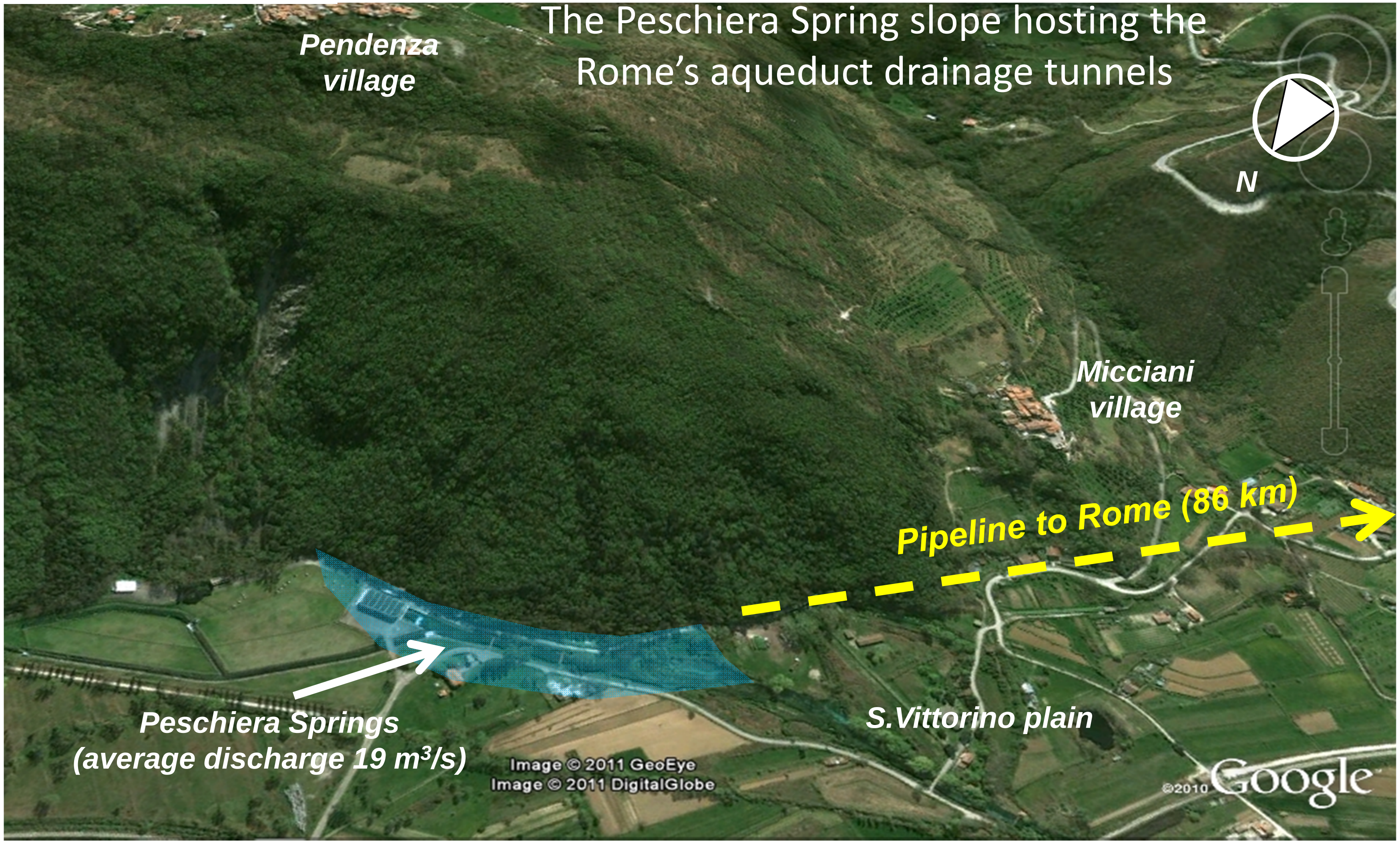
Seisms and Vibrations Laboratory

Champs sur Marne, Cité Descartes

Location of the site (Peschiera Springs Slope)

Italian Central Apennines




The Peschiera Spring slope hosting the
Rome's aqueduct drainage tunnels
Pendenza
village
N
Micciani
village
Pipeline to Rome (86 km)
Peschiera Springs
(average discharge 19 m3/s)
S.Vittorino plain
Image © 2011 GeoEye
Image © 2011 DigitalGlobe
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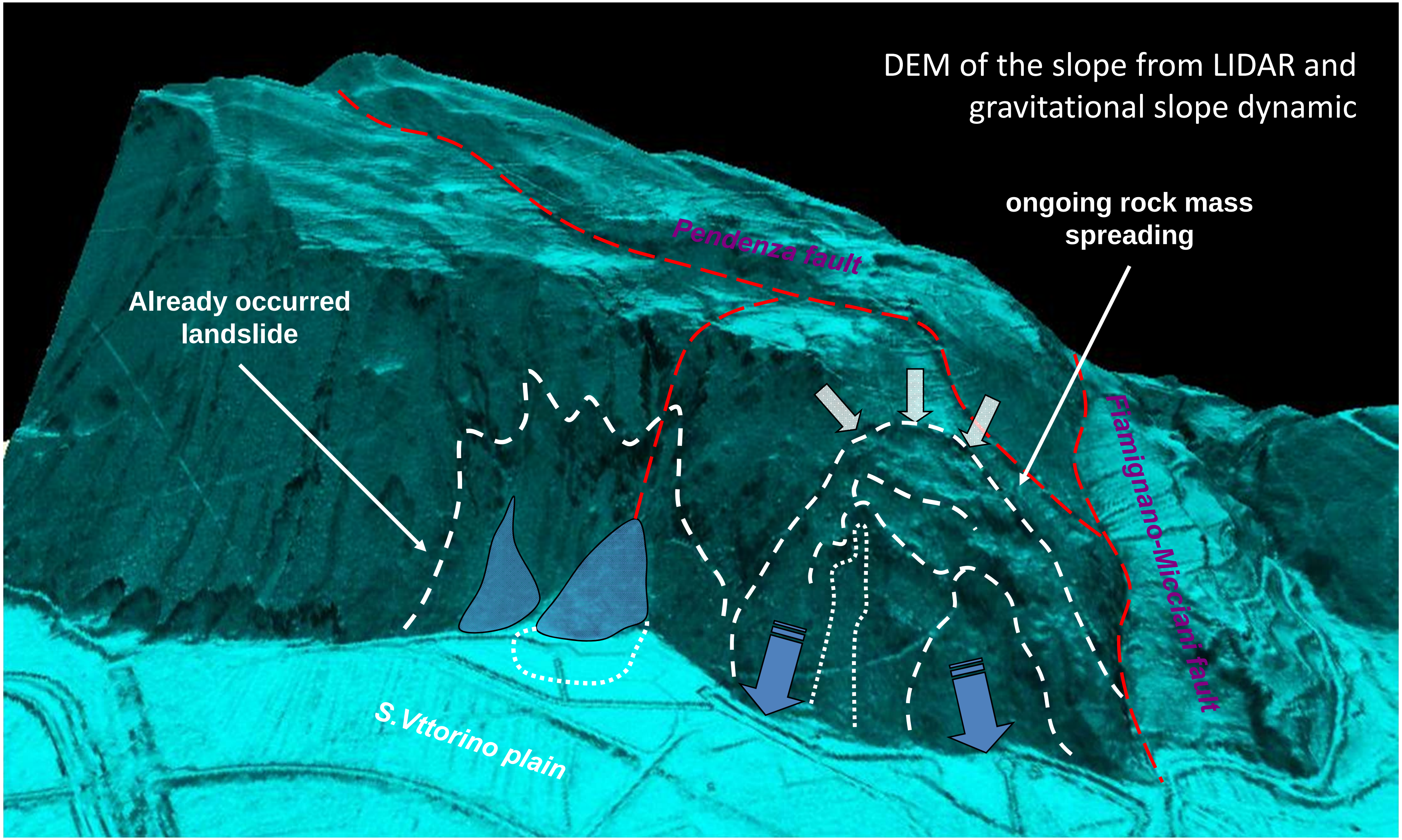
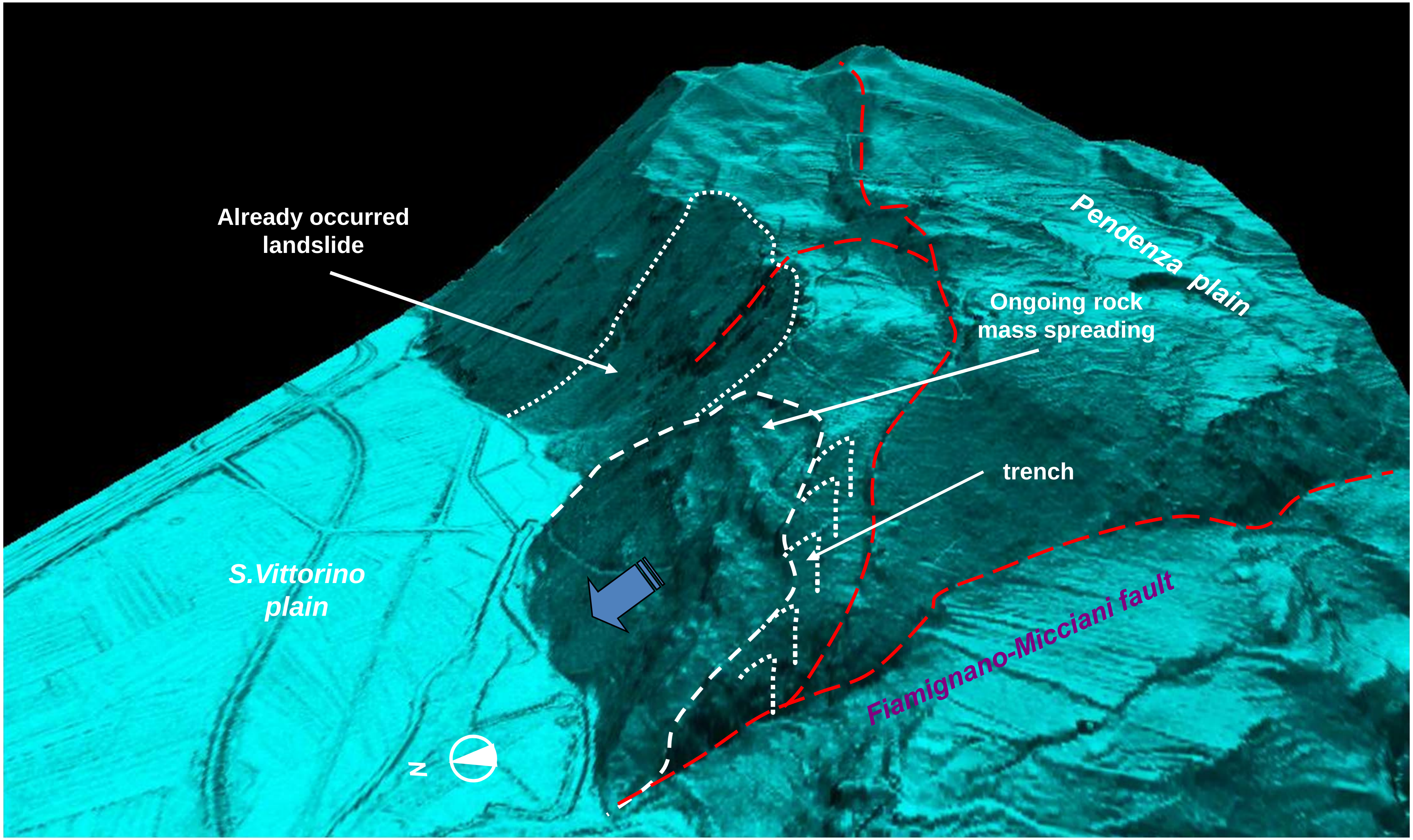
Motivations

- Ensure security of people working in the pipeline plant (i.e. Umbria-Marche 1997/ Colfiorito)

- Localization of the local events and estimation of the volumes involved in the processes generating the local events recorded

- Optimization of the economic resources for the reinforcement of the aqueduct


DEM of the slope from LIDAR and gravitational slope dynamic
ongoing rock mass spreading
Pendenza fault
Already occurred landslide
Flamignano-Micciani fault
S.Vttorino plain



Already occurred landslide
Pendenza plain
Ongoing rock mass spreading
trench
S.Vittorino plain
Fiamignano-Micciani fault
N

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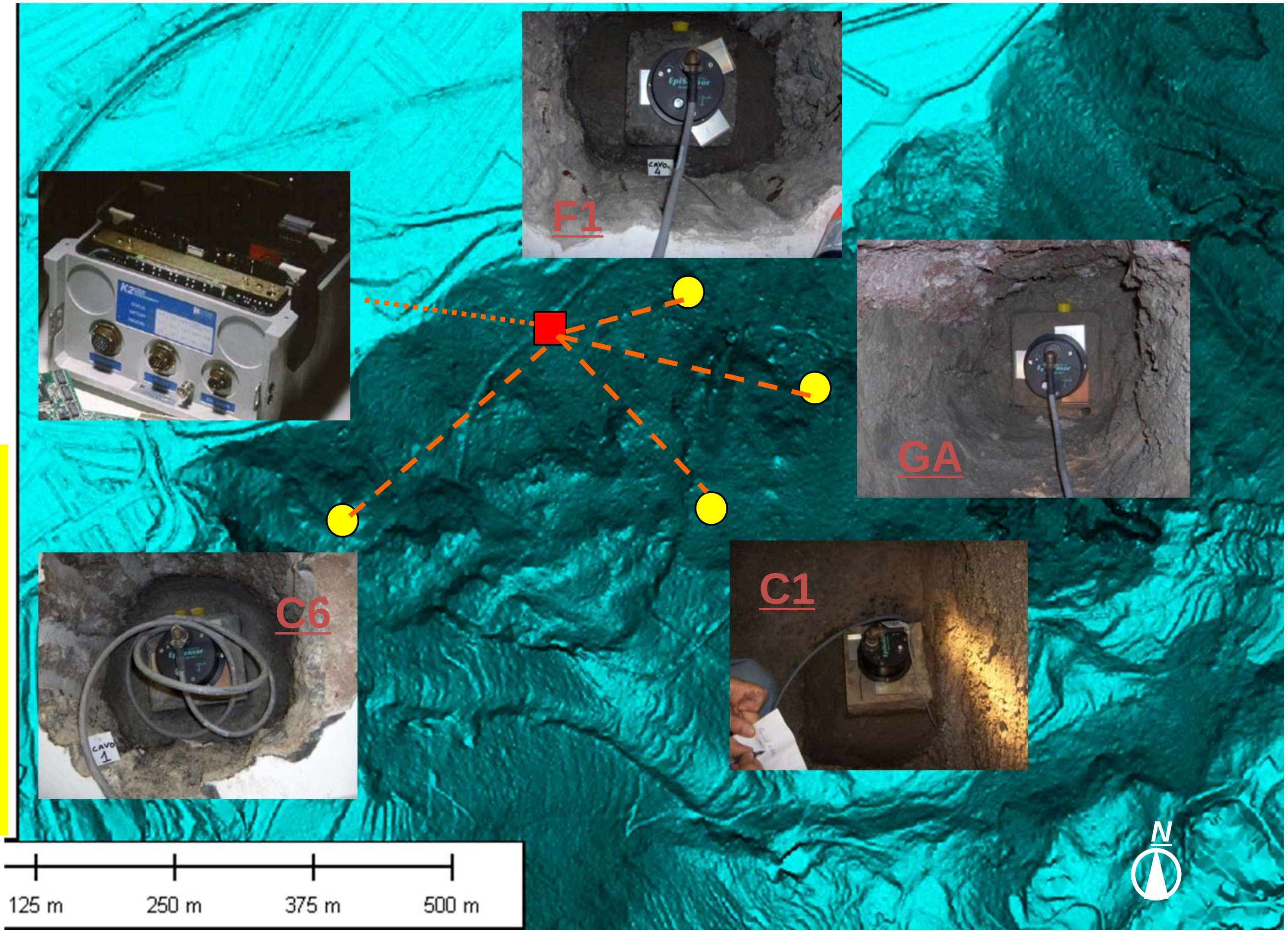
Sensors: KINEMETRICS EPISENSOR

Data logger: KINEMETRICS K2

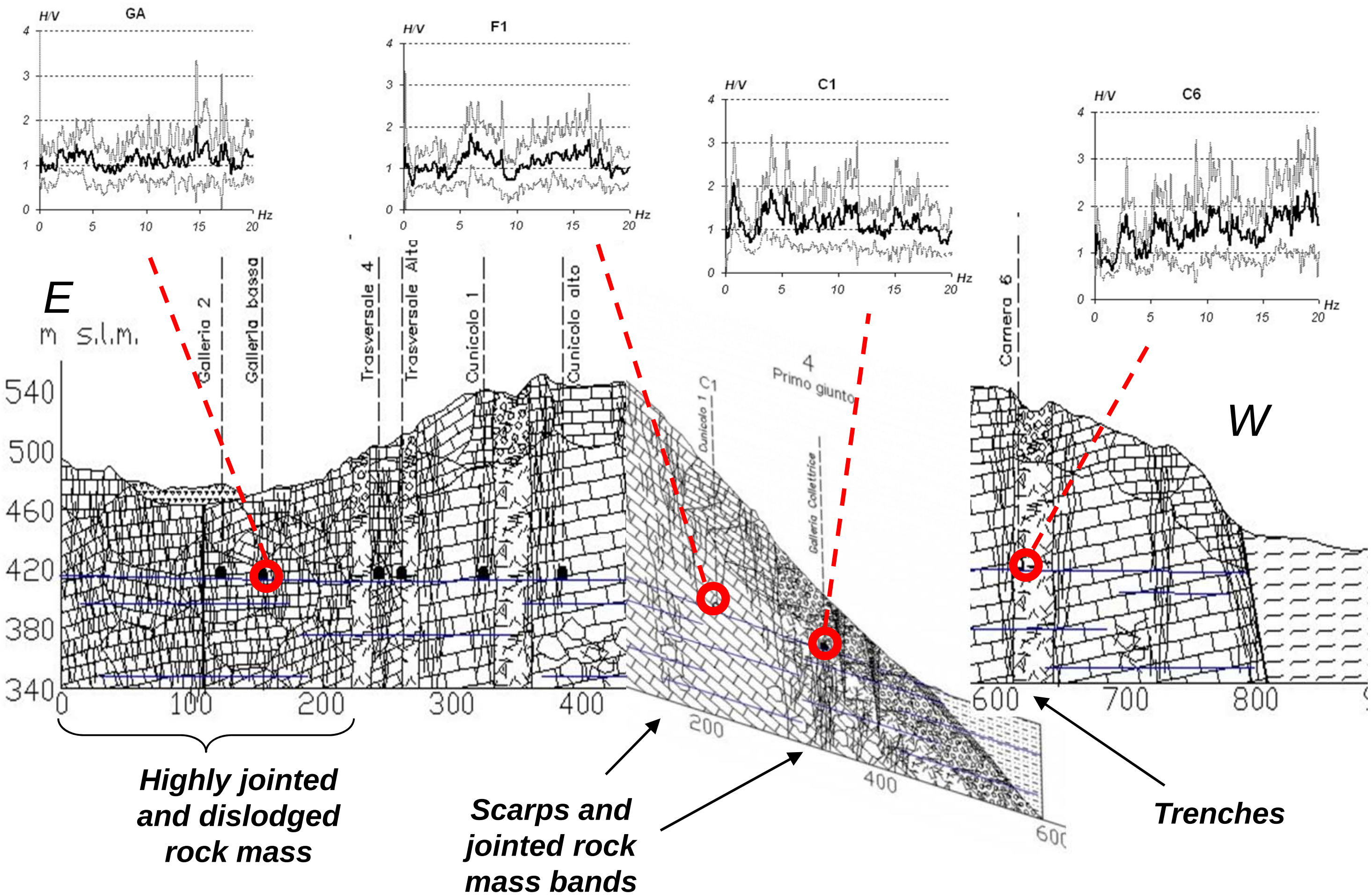
Interconnection: KINEMETRICS cable

Accelerometric network within the slope



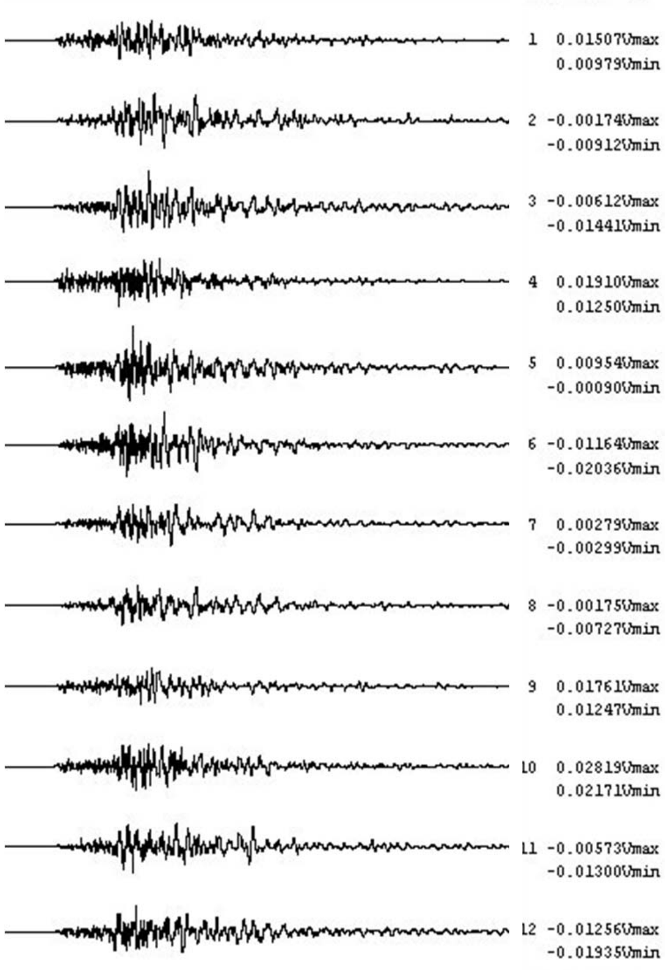
1) STA/LTA
2) Trigger on absolute amplitude
3) Others (filtering low/high frequencies)

Seismometric array: location of the recording stations and local stration amplification features

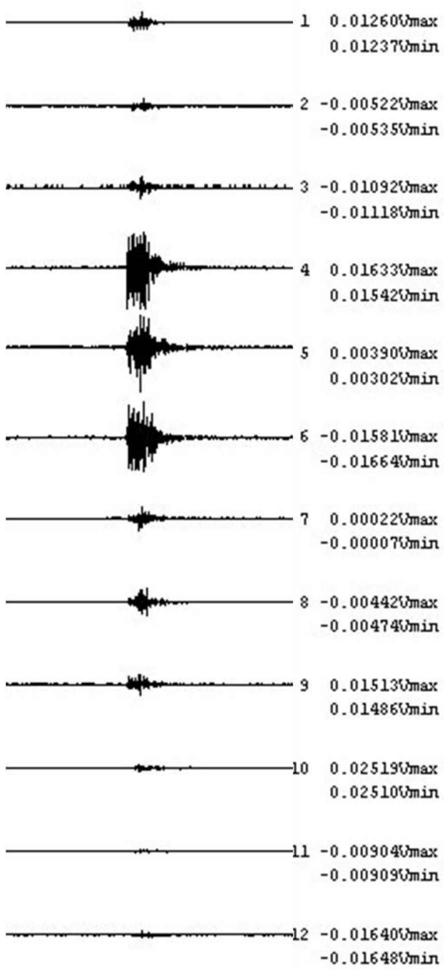


Typical seismic events recorded in the Peschiera Springs pipeline plant

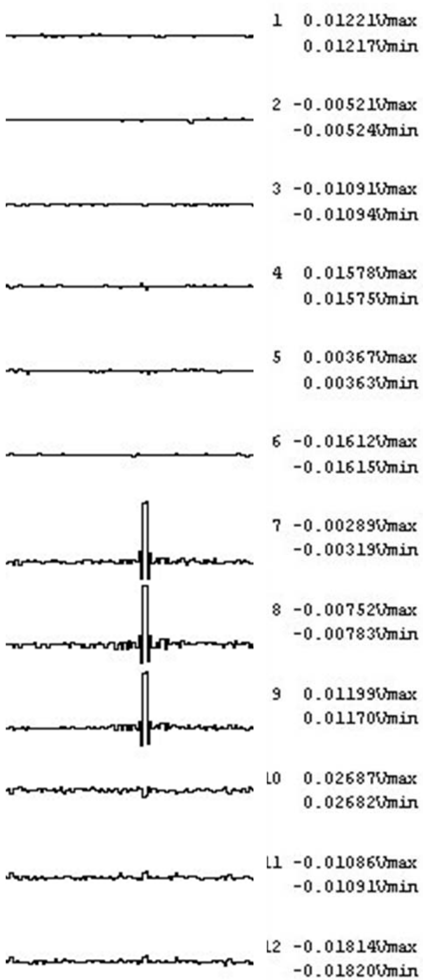
earthquake



crack

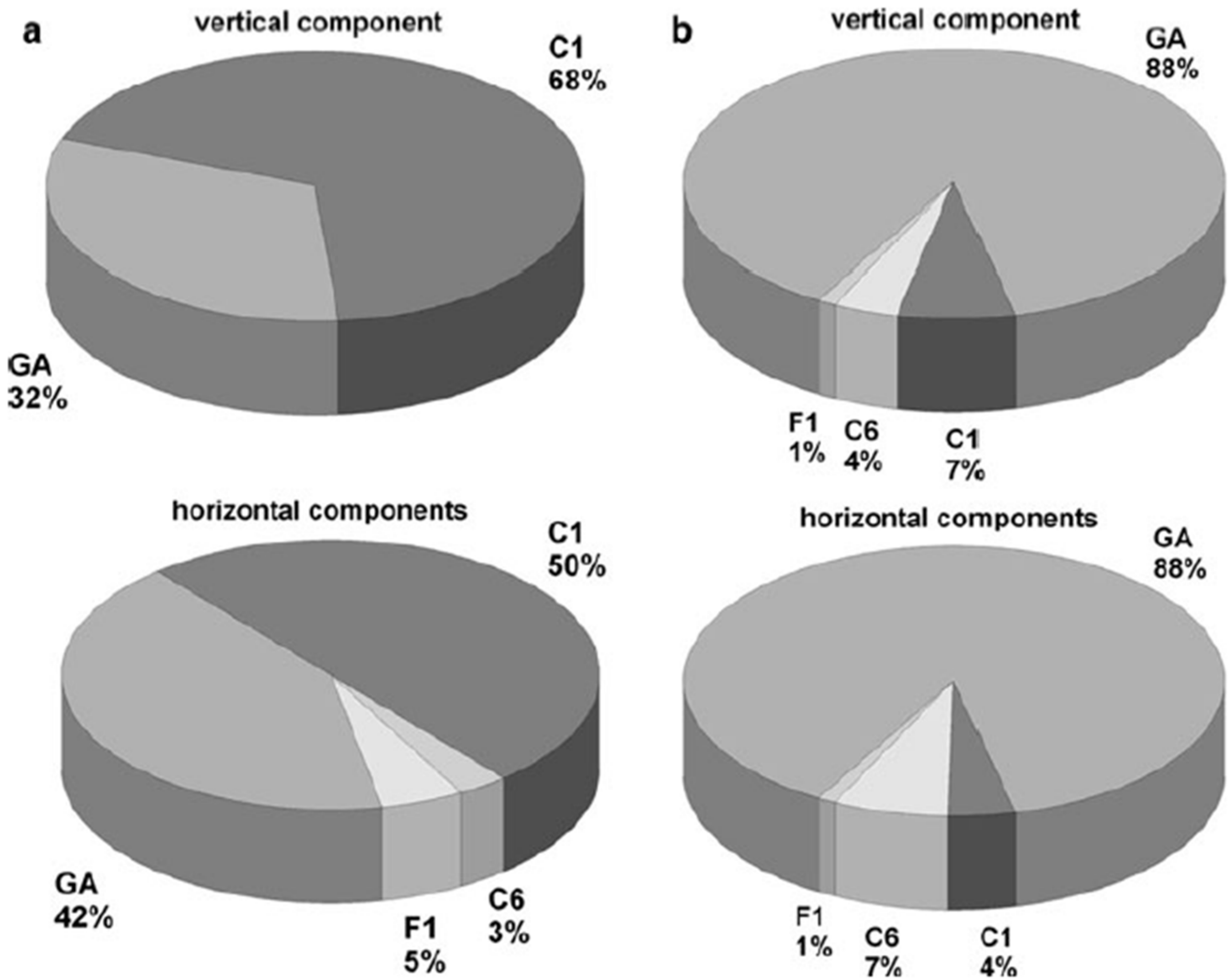


collapse

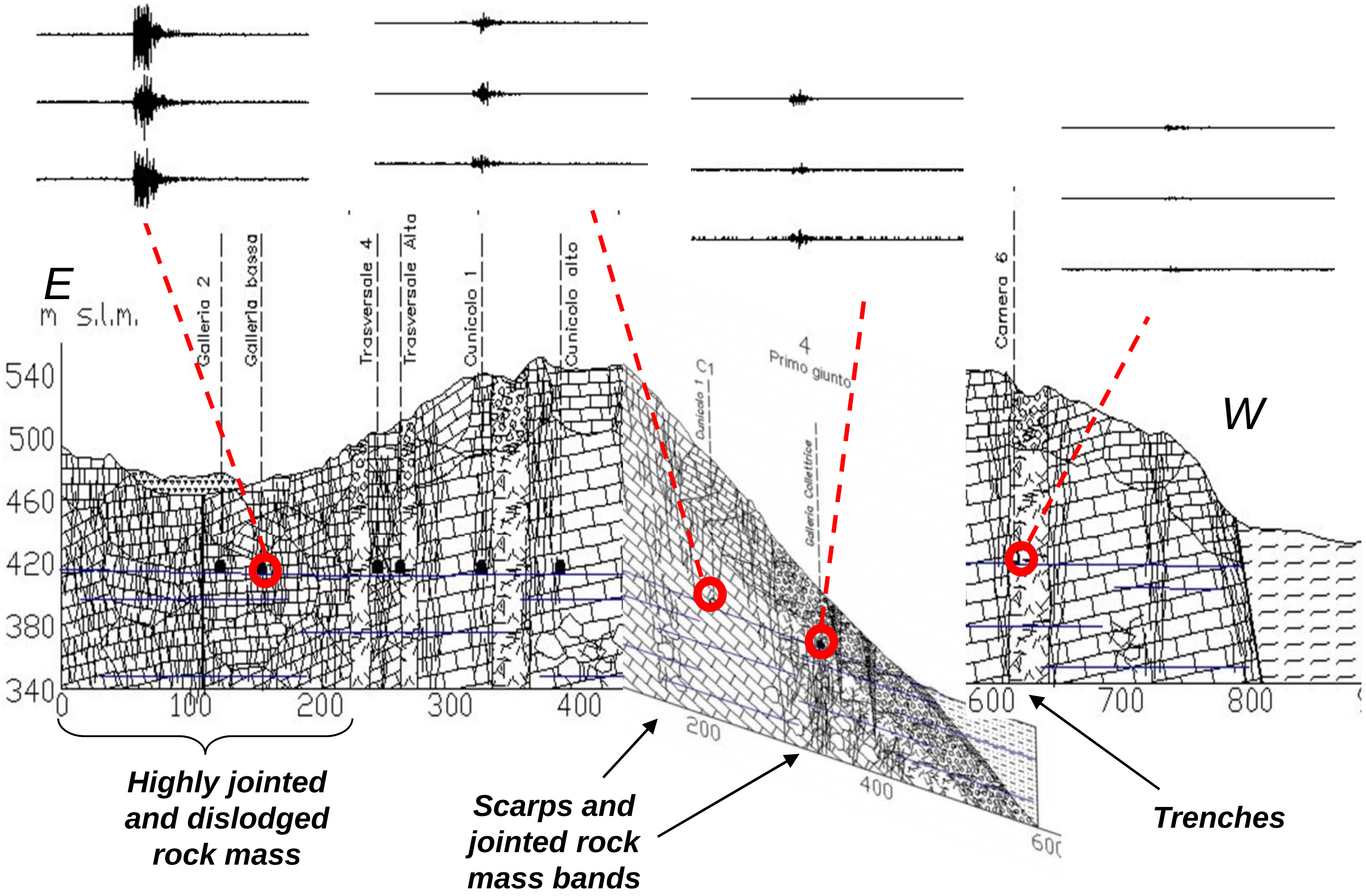


PGAmax distribution for a) collapses and b) cracks; no relevant differences appear for earthquakes.

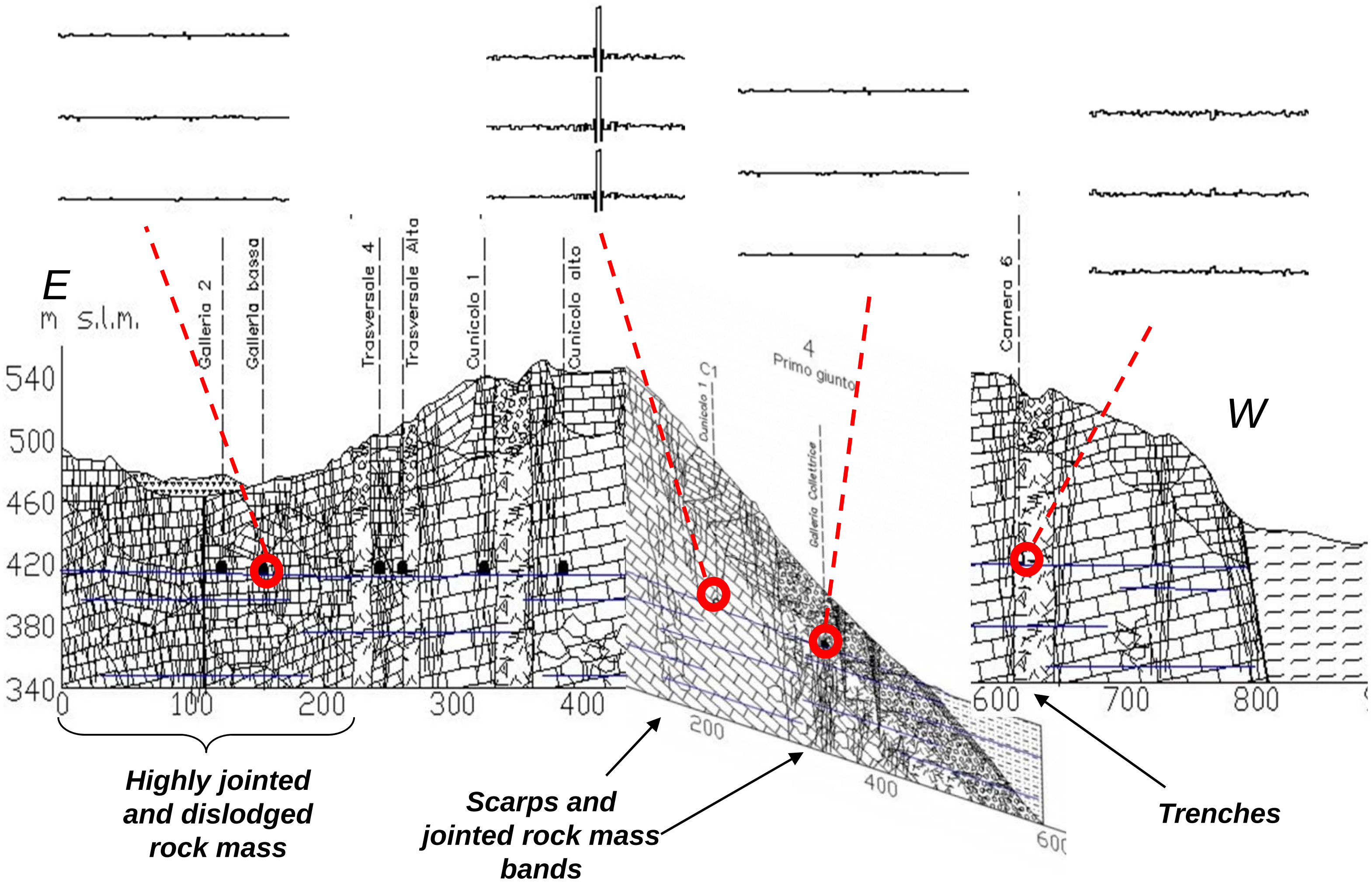
The most of the underground events occur in the eastern part of the slope where many cavities are also present

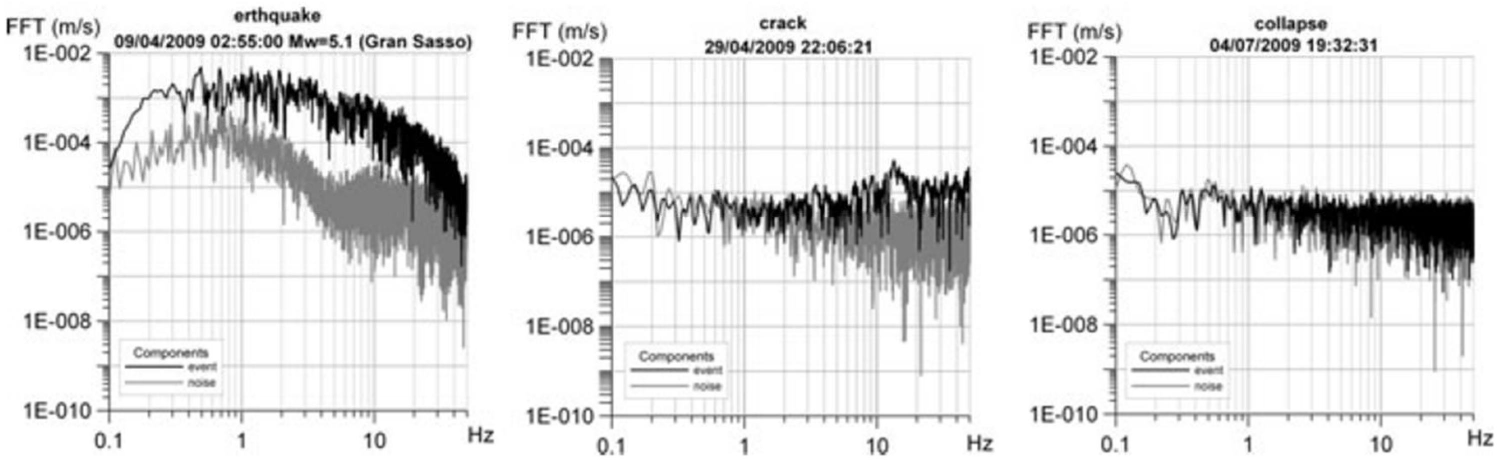


Location of the hypogeous events: pattern of attenuation (microearthquake event)

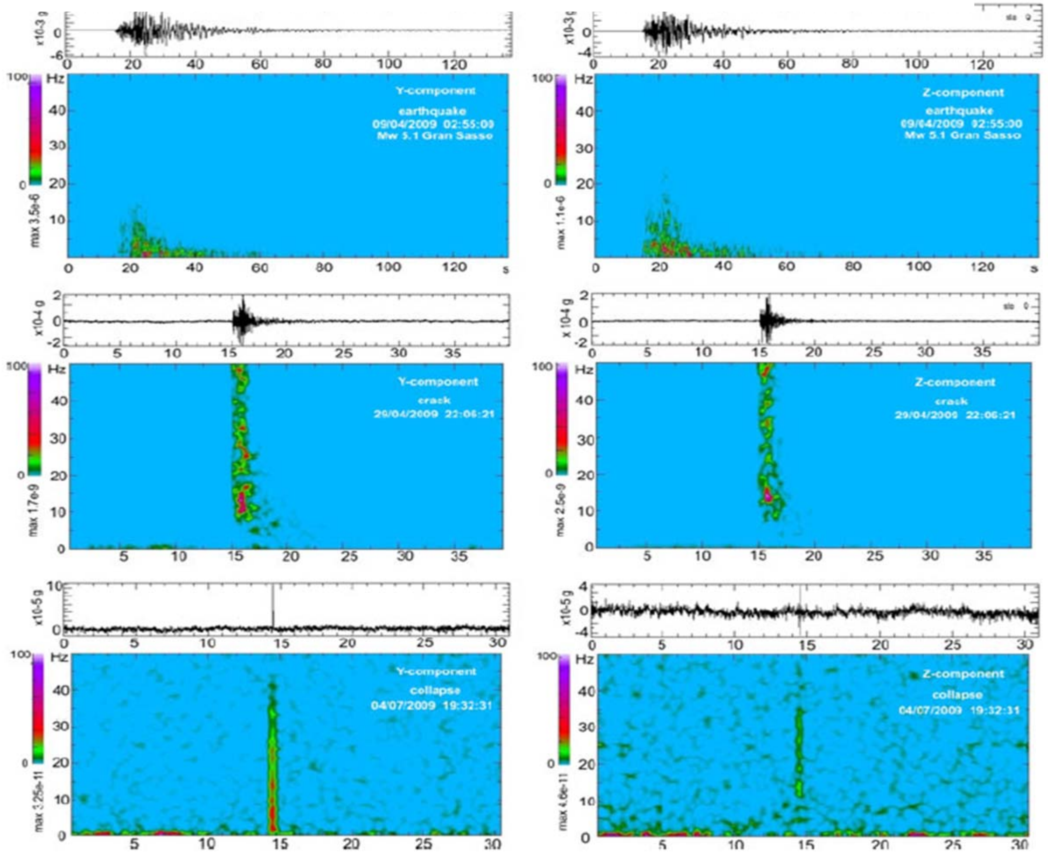


Location of the hypogeous events: pattern of attenuation (collapse event)





FFTs and spectrograms for the 3 kind of events recordable in the Peschiera pipeline plant.



No relevant spectral differences exist between the underground events and the normal standard noise level.

Spectrograms can put in evidence different durations for the recorded events.

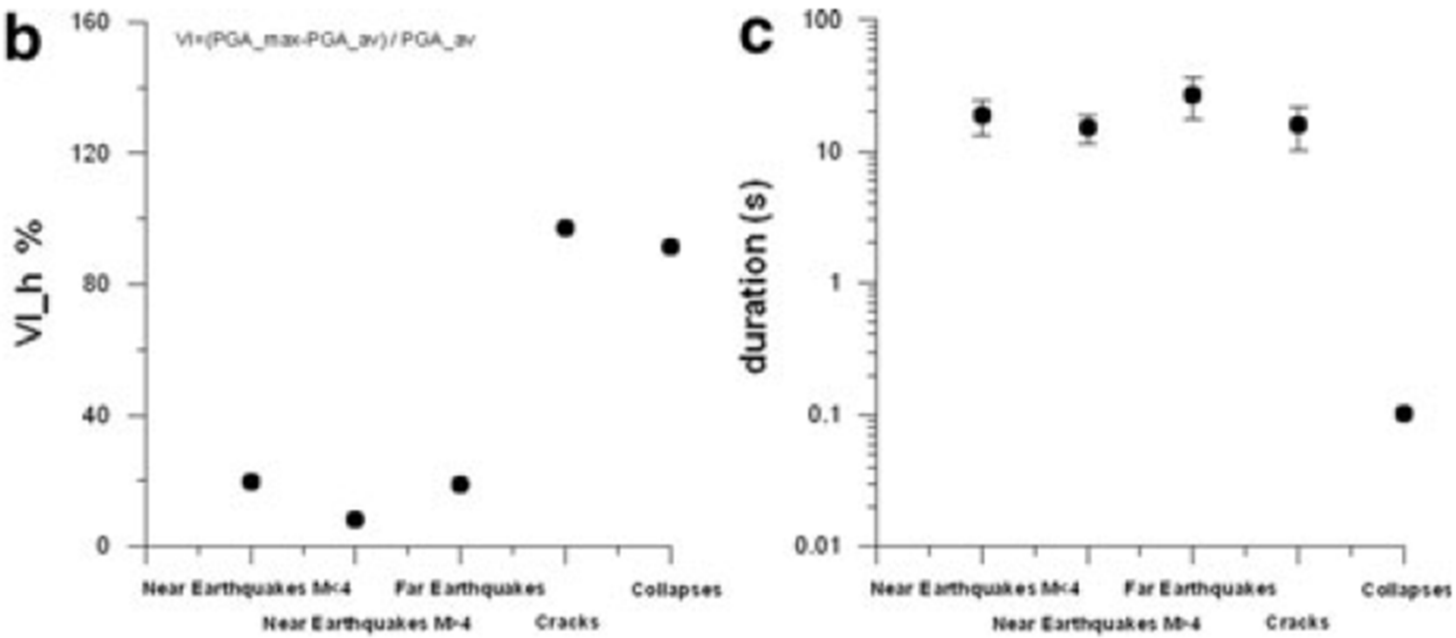
1) How to distinguish earthquakes from other local events ?

Far Field Earthquakes have shown a very low variability of the PGA among the recordings stations; this variability is summarized by VI.

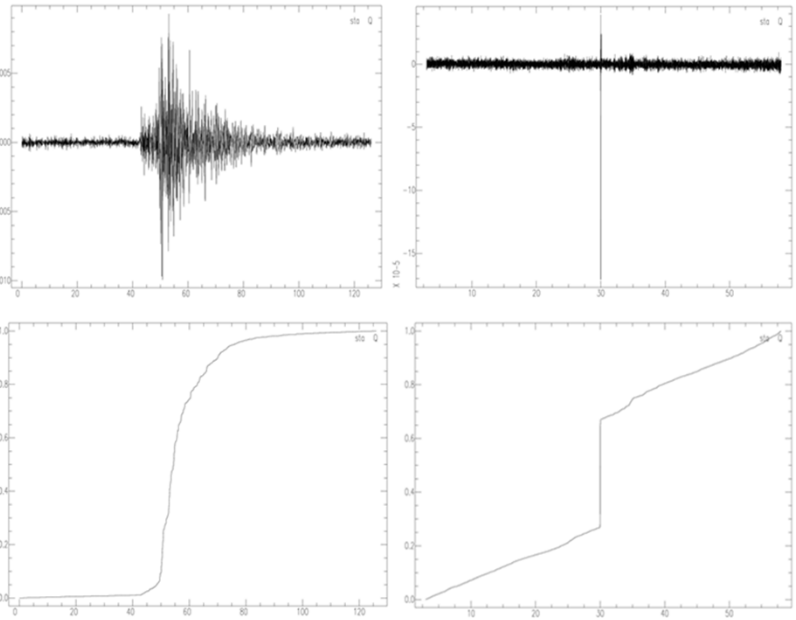
$$VI = \left(\left(PGA_{max} - PGA_{average}\right)/PGA_{average}\right) \times 100$$

2) How to distinguish between the 2 different hypogeneous/local events?

The duration can be used to separate cracks from collapses.



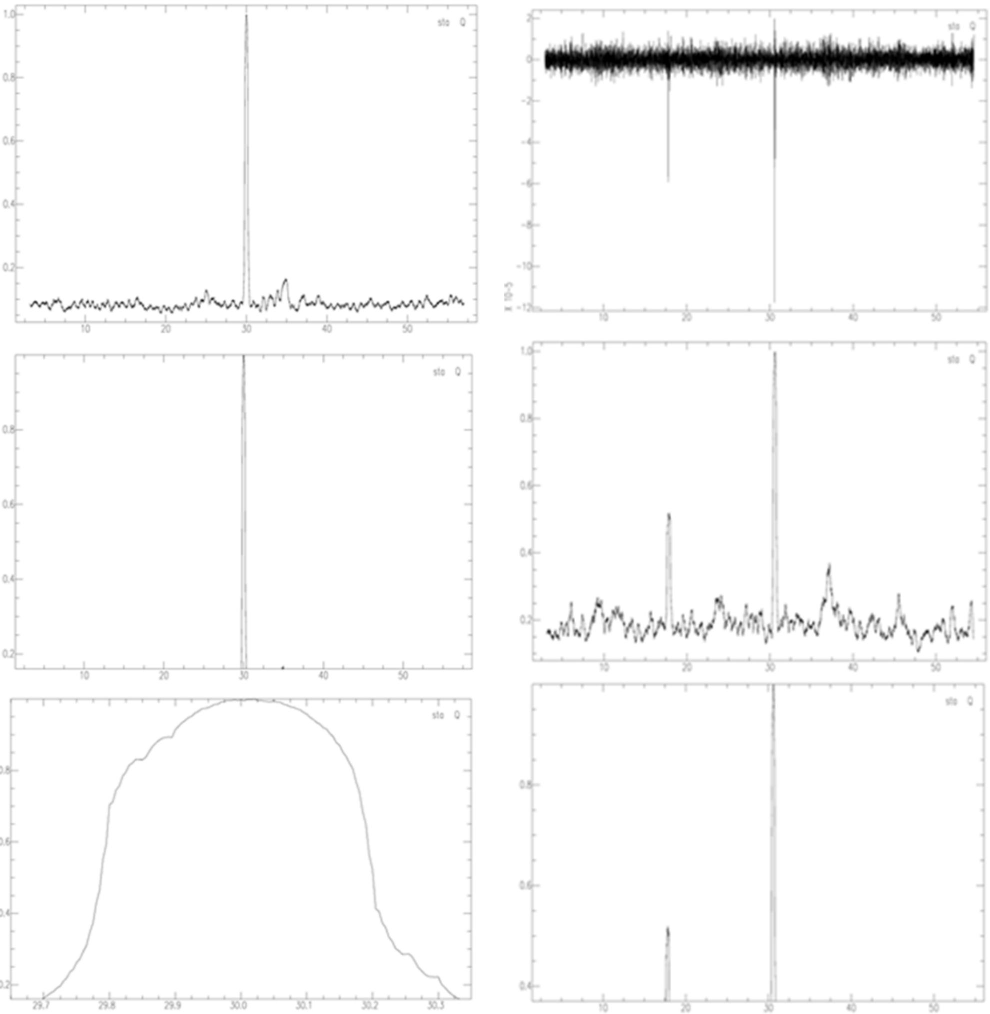
Duration of the events



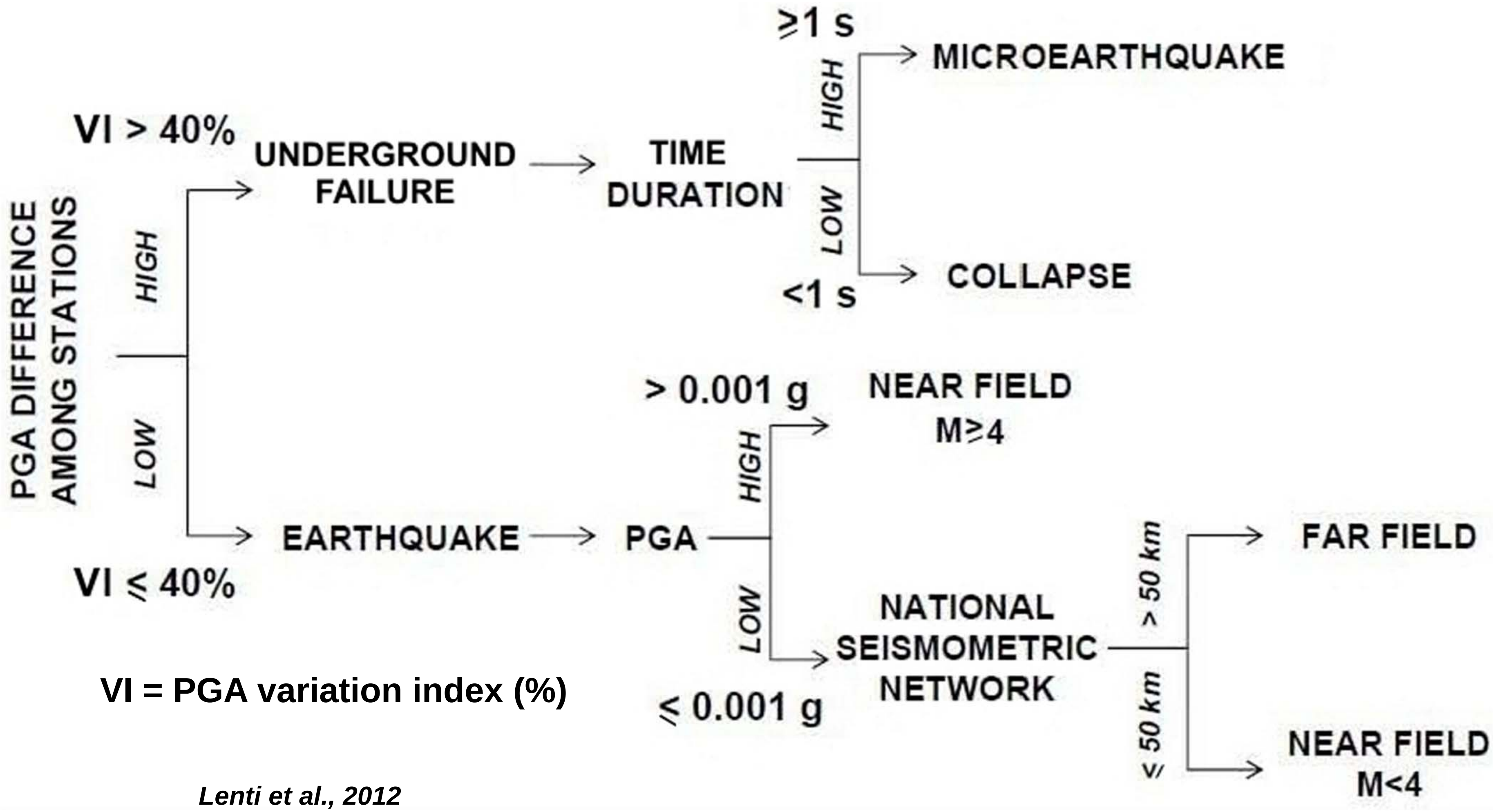
The duration based on the Arias Intensity does not work for very short events

$$AI = \frac{\pi}{2g} \int_0^{T_{file}} a^2(t) dt$$

The duration is defined on the base of the Hilbert Transform for the “short events”



Automatic detection of the recorded events



VI = PGA variation index (%)

Lenti et al., 2012

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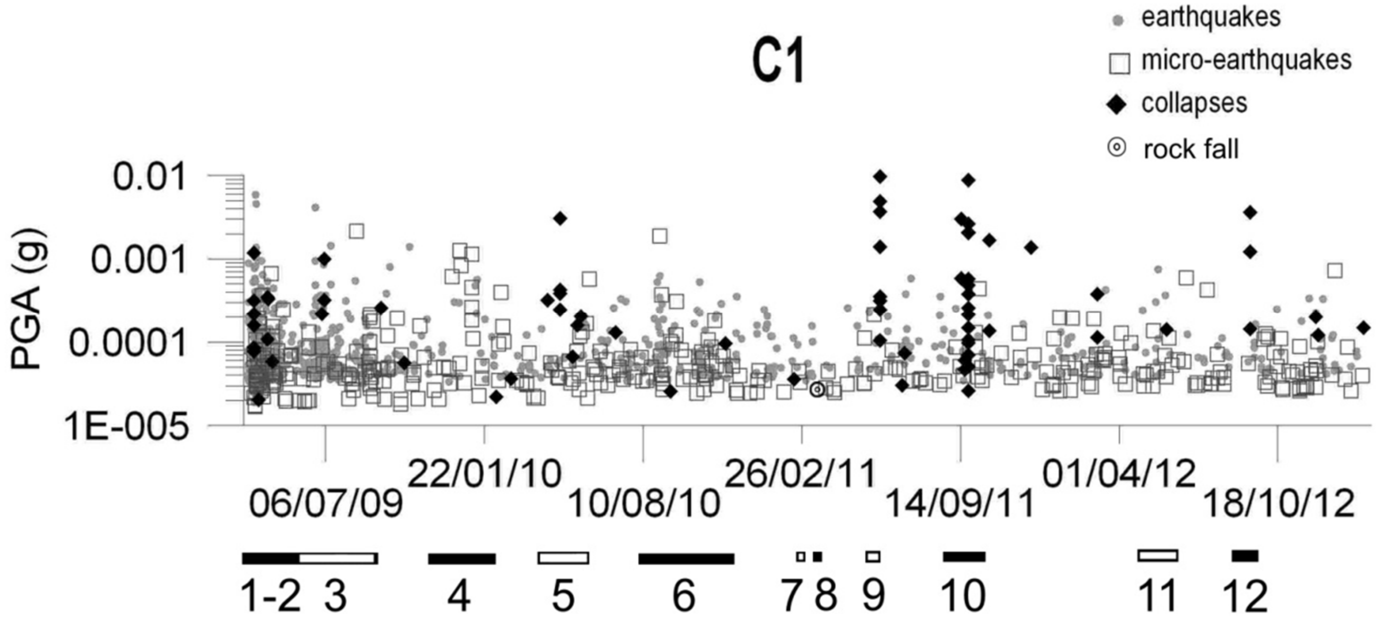
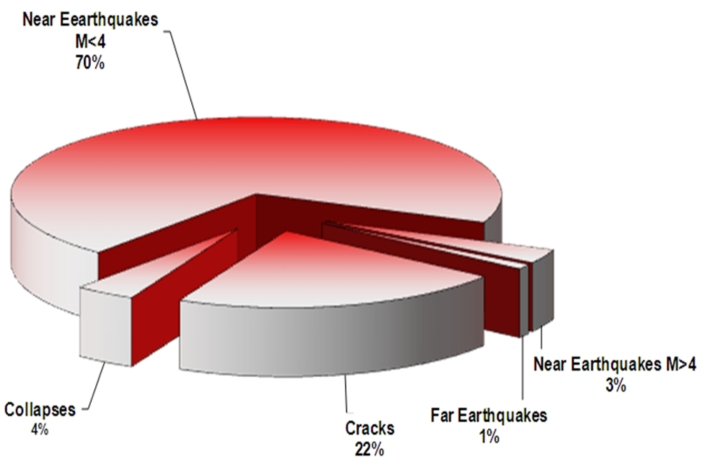


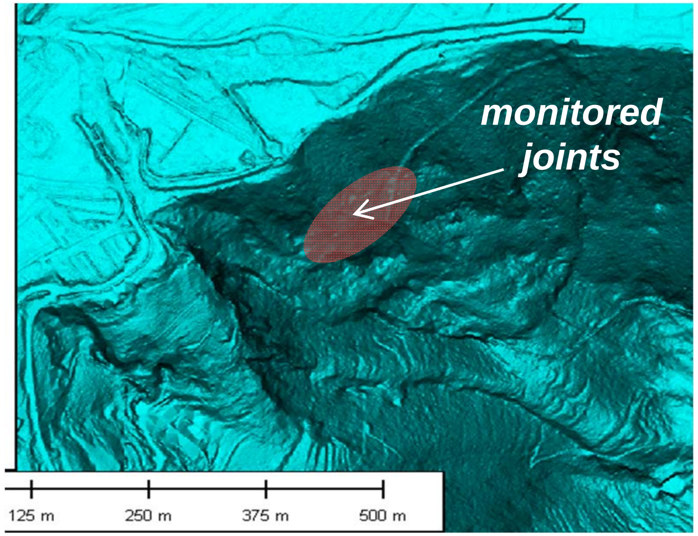
1471 seismic events

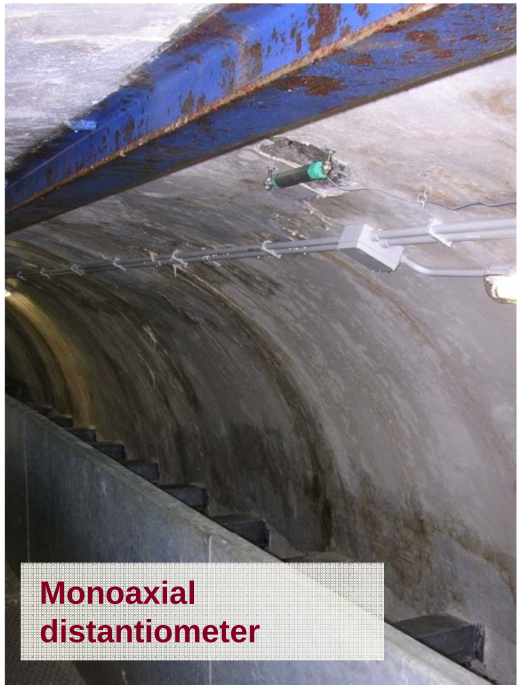
990 earthquakes
391 microearthquakes
91 collapses



1) 2009 L'Aquila seismic sequence, 2) the 2009 Valle dell'Aterno - Gran Sasso – Monti della Laga sequence; 3) the 2009 Reatini mountains sequence; 4) a micro-earthquake sequence; 5) the April 2010 micro-earthquake sequence due to collapses; 6) the 2010 Reatini mountains sequence; **7) the 11 March 2011 Japan teleseismic event**; 8) a rock-fall event of approximately 100 m^3 occurred on 2011 from a scarp located on the slope surface; 9) the June 2011 micro-earthquake sequence; 10) the September 2011 micro-earthquake sequence due to 15 collapses occurred within approximately half an hour; 11) the Emilia seismic sequence; **12) the September 2012 micro-earthquake sequence due to underground collapses**.


Traixially arranged
distantiometers

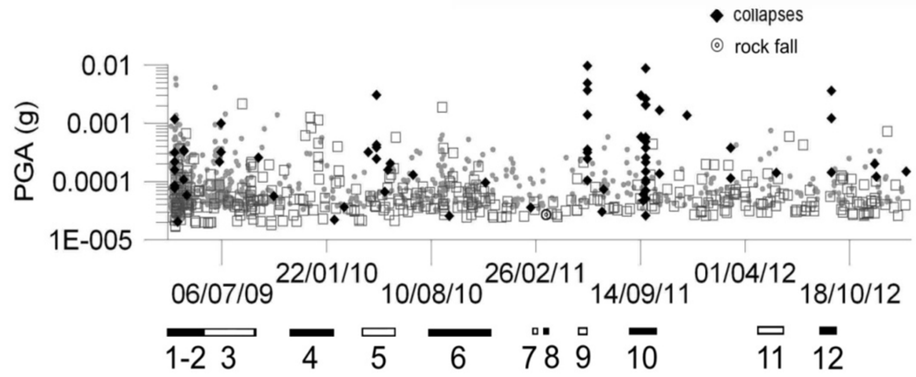

monitored
joints
125 m
250 m
375 m
500 m

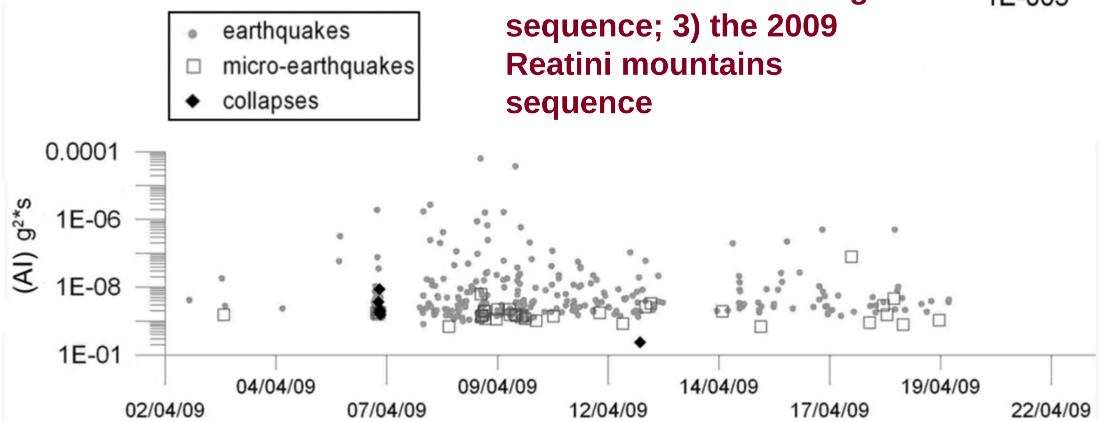

Monoaxial
distantiometer

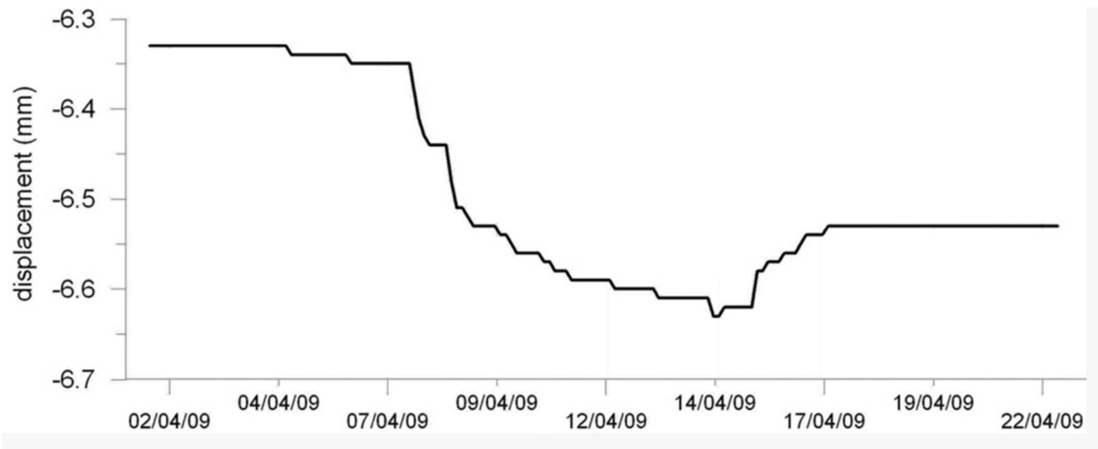

Estensimeter

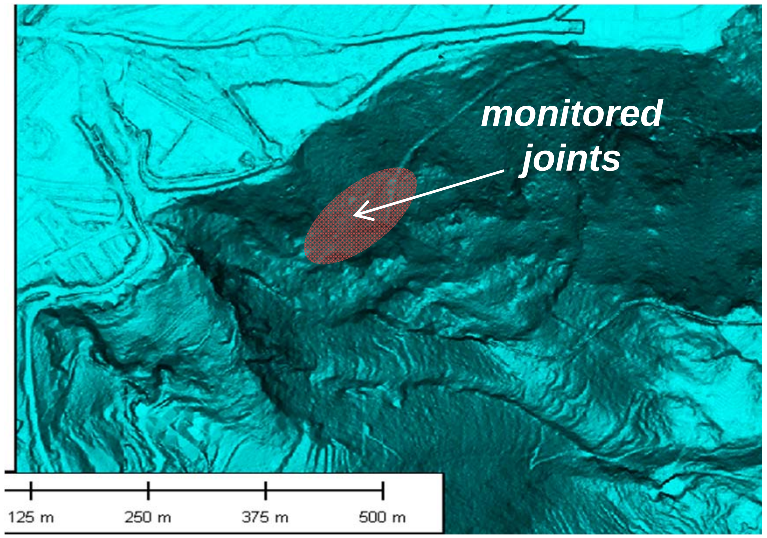

Traixially arranged
distantiometers

1) 2009 L'Aquila seismic sequence, 2) the 2009 Valle dell'Aterno - Gran Sasso – Monti della Laga sequence; 3) the 2009 Reatini mountains sequence









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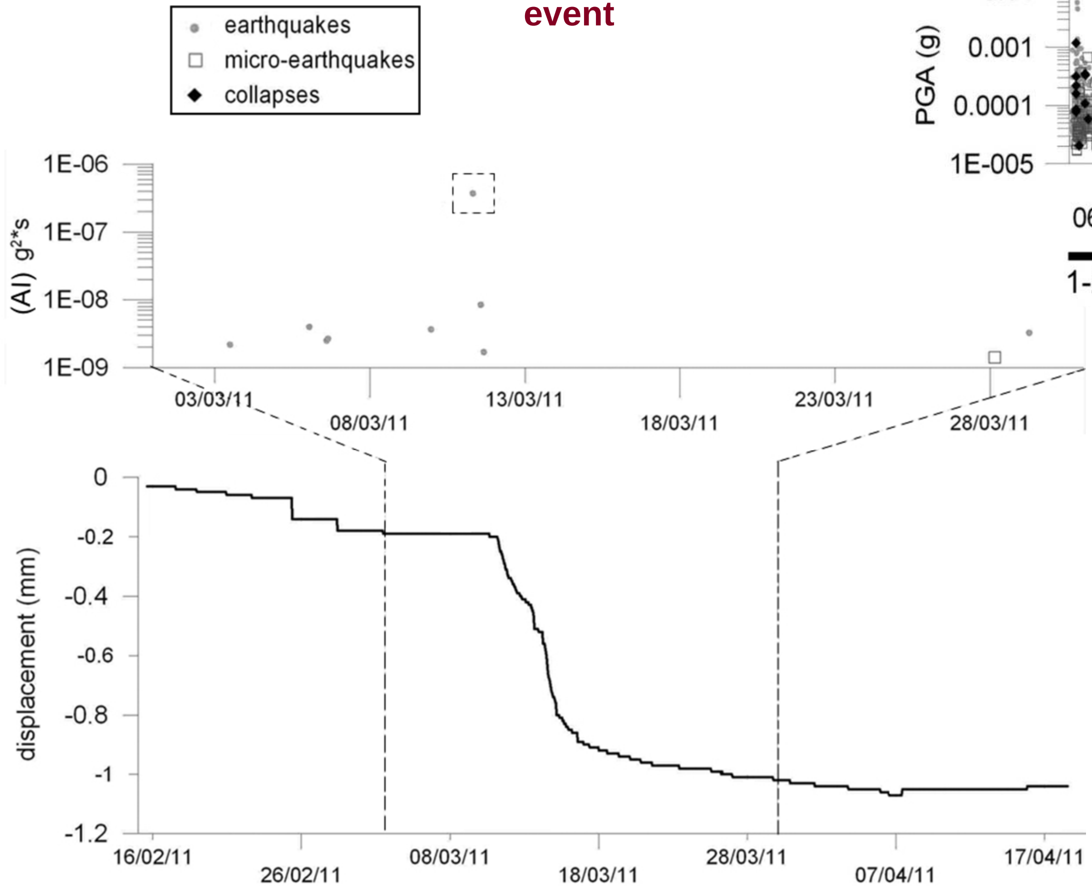
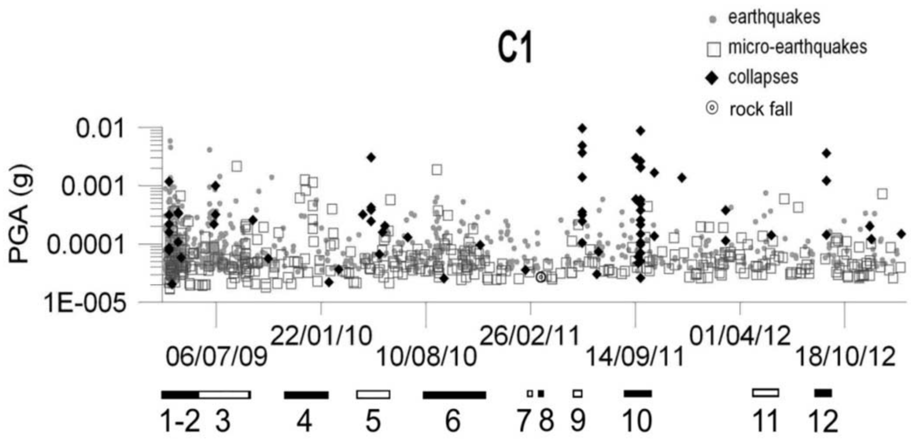
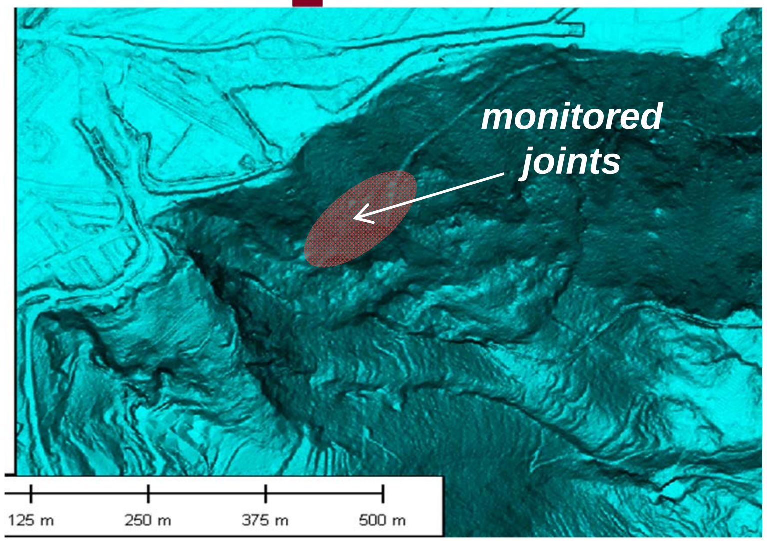
the 11 March 2011 Japan teleseismic event







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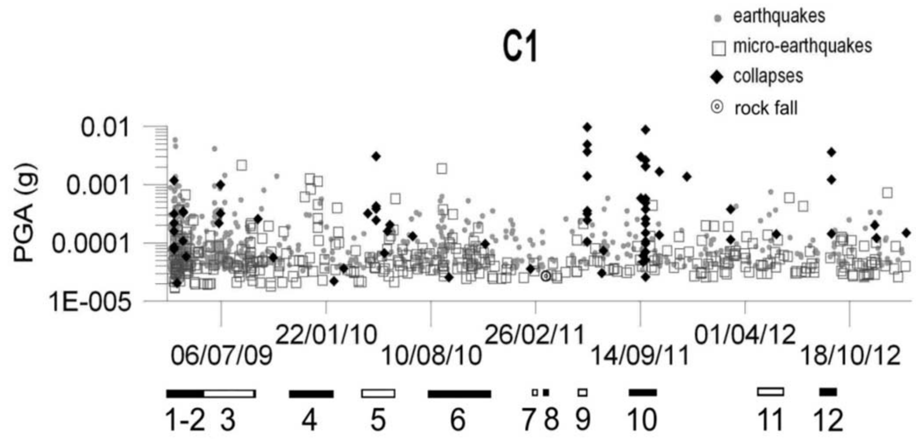
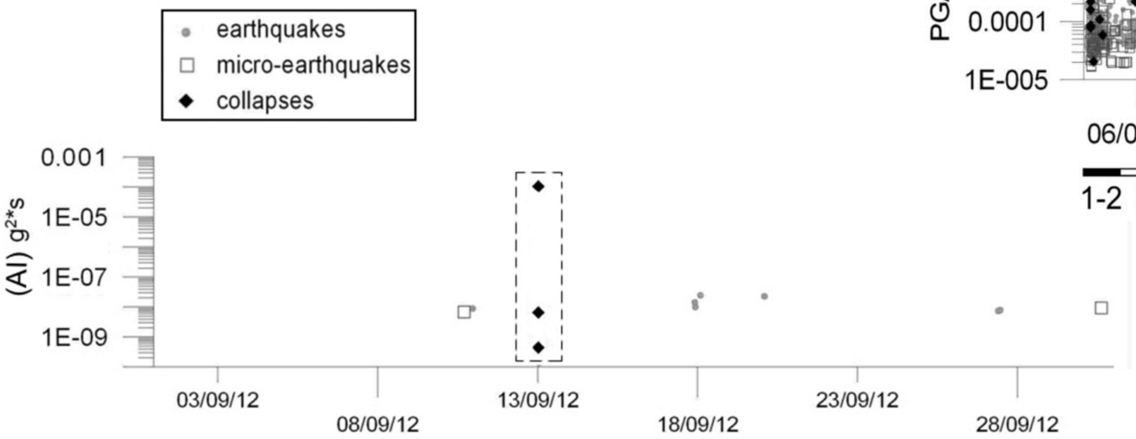
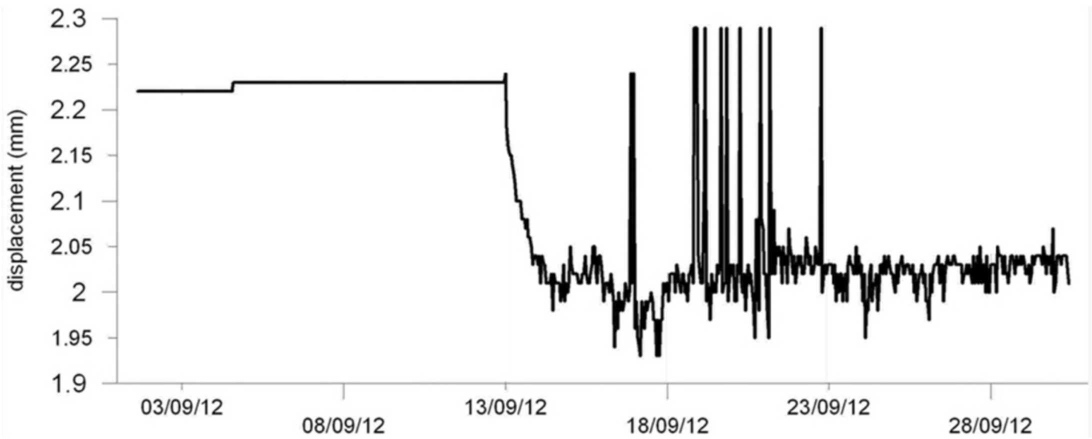
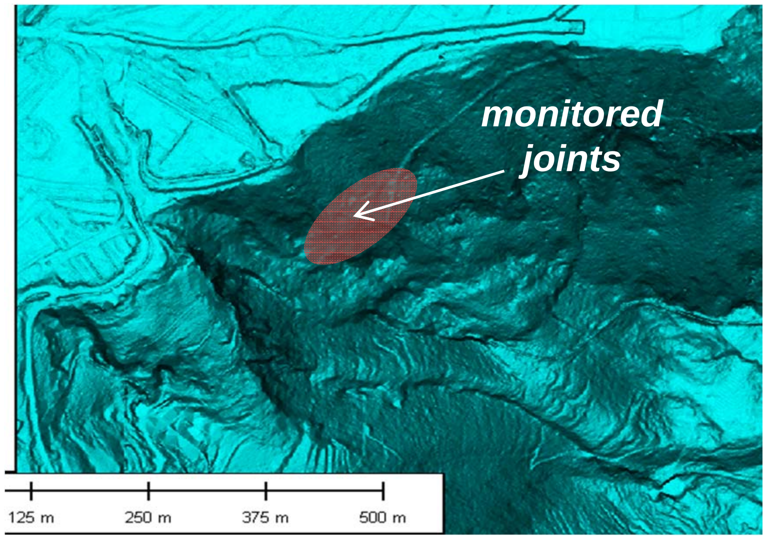
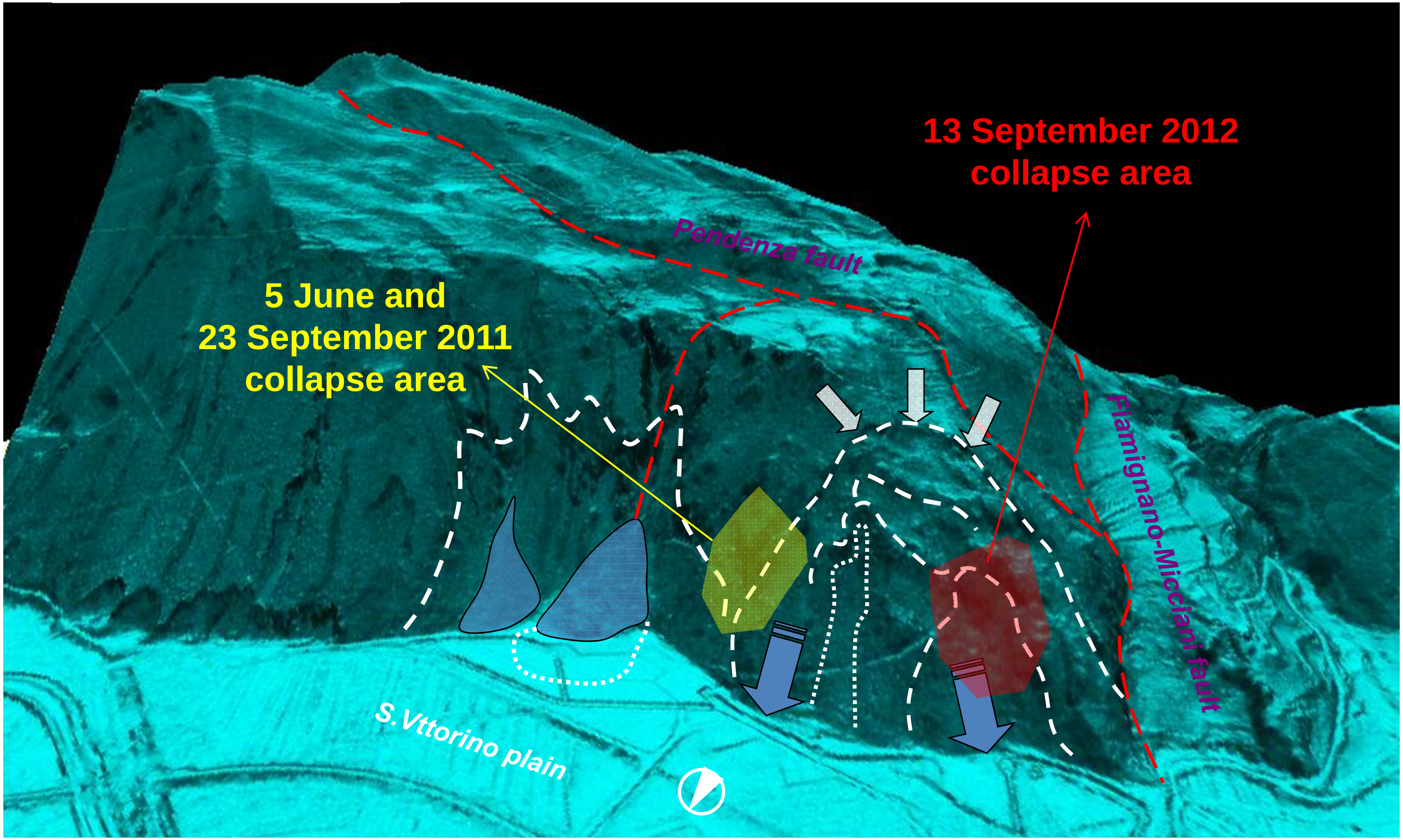
the September 2012 micro-earthquake sequence due to underground collapses











13 September 2012
collapse area
Pendenza fault
5 June and
23 September 2011
collapse area
Flamignano-Micciani fault
S.Vttorino plain

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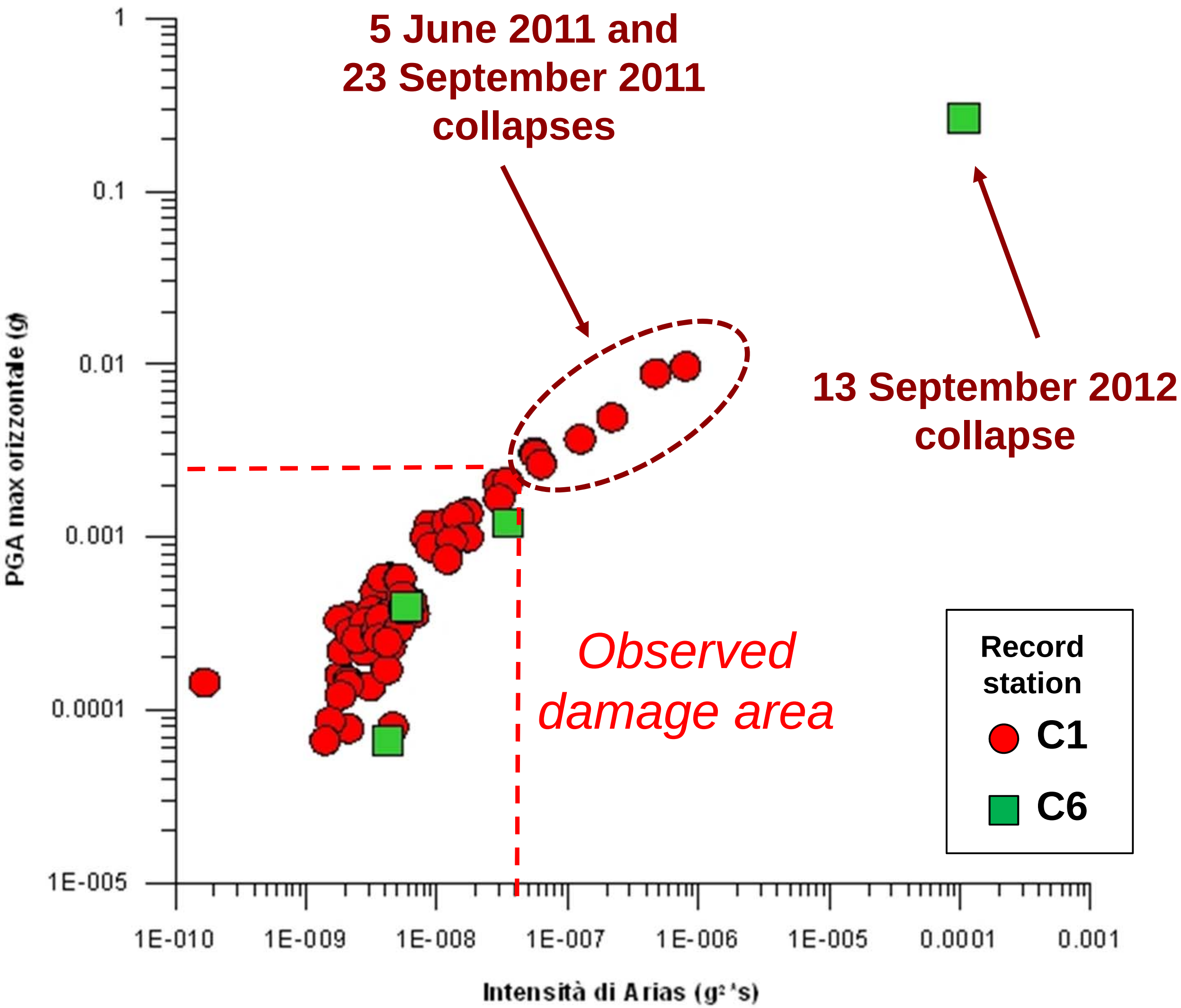
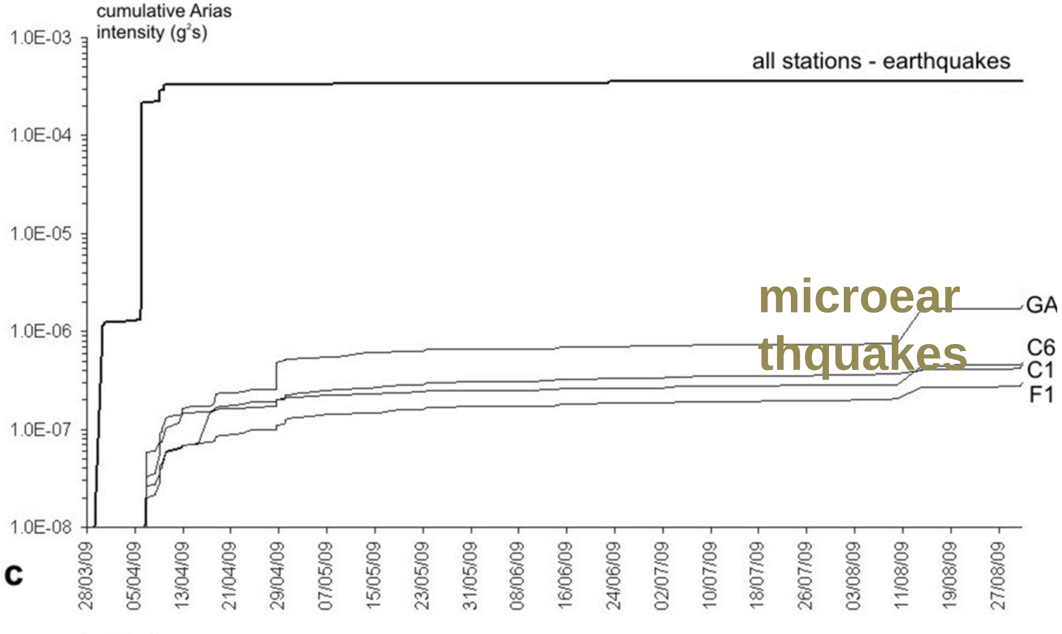
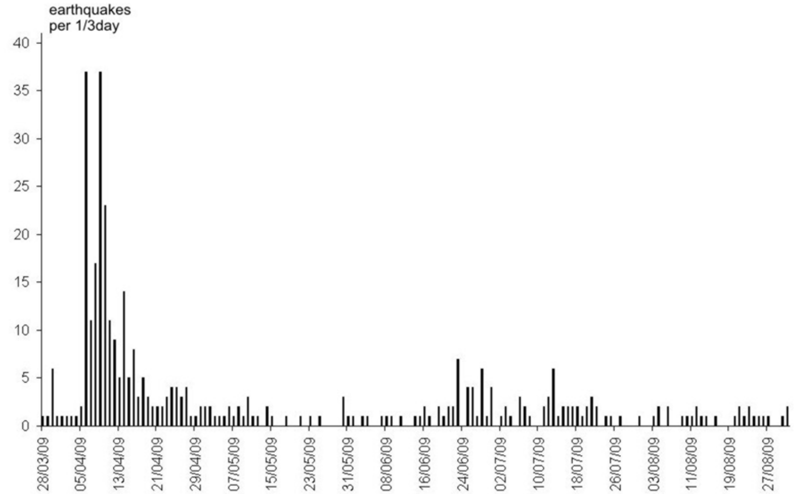
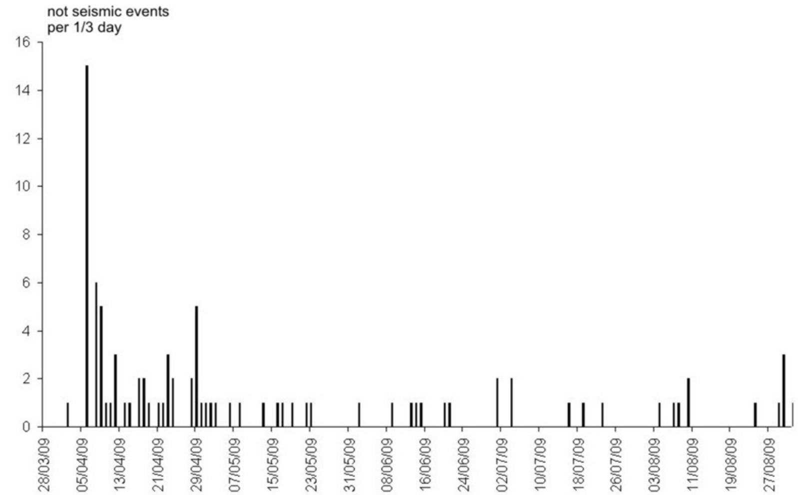


Prevision based on the “rate of effect occurrence” as well as on the “frequency of occurrence”



from Lenti et al., 2012

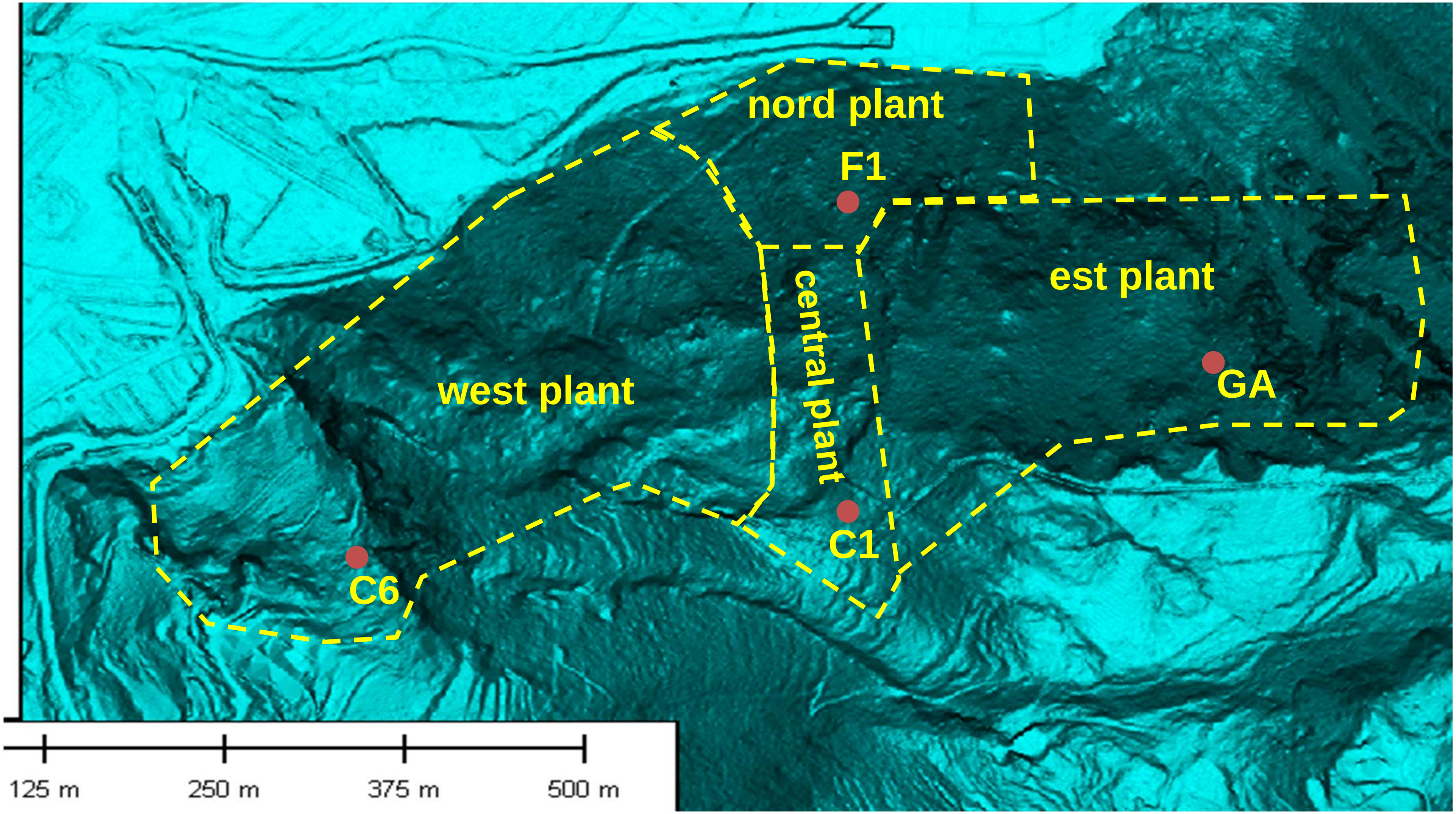




3 levels for the rate of AI:

Regressive, progressive and trasgressive corresponding to a decreasing, stationnarity and increasing failure hazard (Szwedzicki 2001, 2003)

Monitoring system: zonation and accelerometric stations

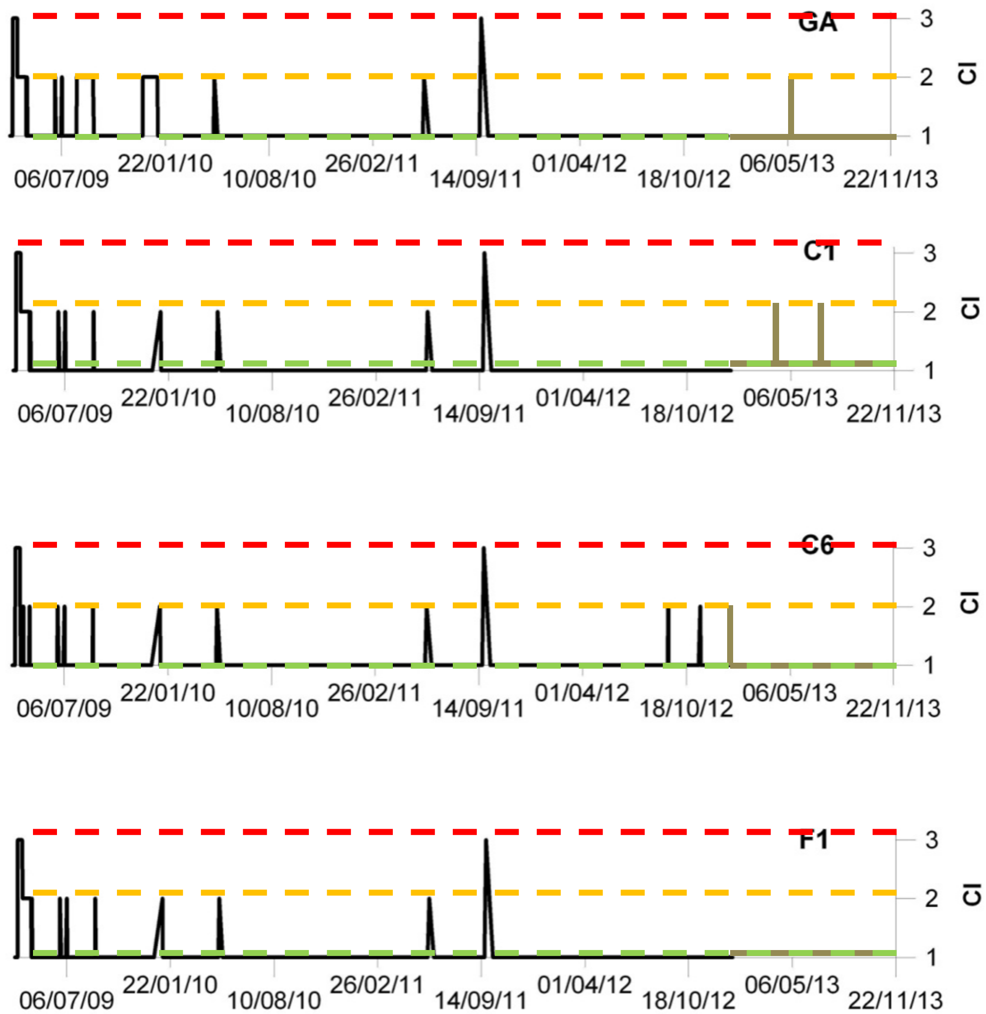


“Alarm strategy” based on the Control Index (CI(P,t))

“Alarm strategy” based on the Control Index (CI(P,t))

Earthquake frequency (event/day)	Micro-earthquake frequency (event/day)	FI_er/me(P,t)
0-10	0-3	0
11-20	4-10	1
>20	>10	4
Energy rate (g^2)		**EI(P,t)**
$\leq 10^{-3}$		0
$10^{-3}/10^{-2}$		1
$\geq 10^{-2}$		4
Alarm level	**FI(P,t) + EI(P,t)**	**CI(P,t)**
Ordinary	0	1
Alert	1-3	2
Emergency	4-12	3

CI(P,t) derived from FI(P,t)+EI(P,t)



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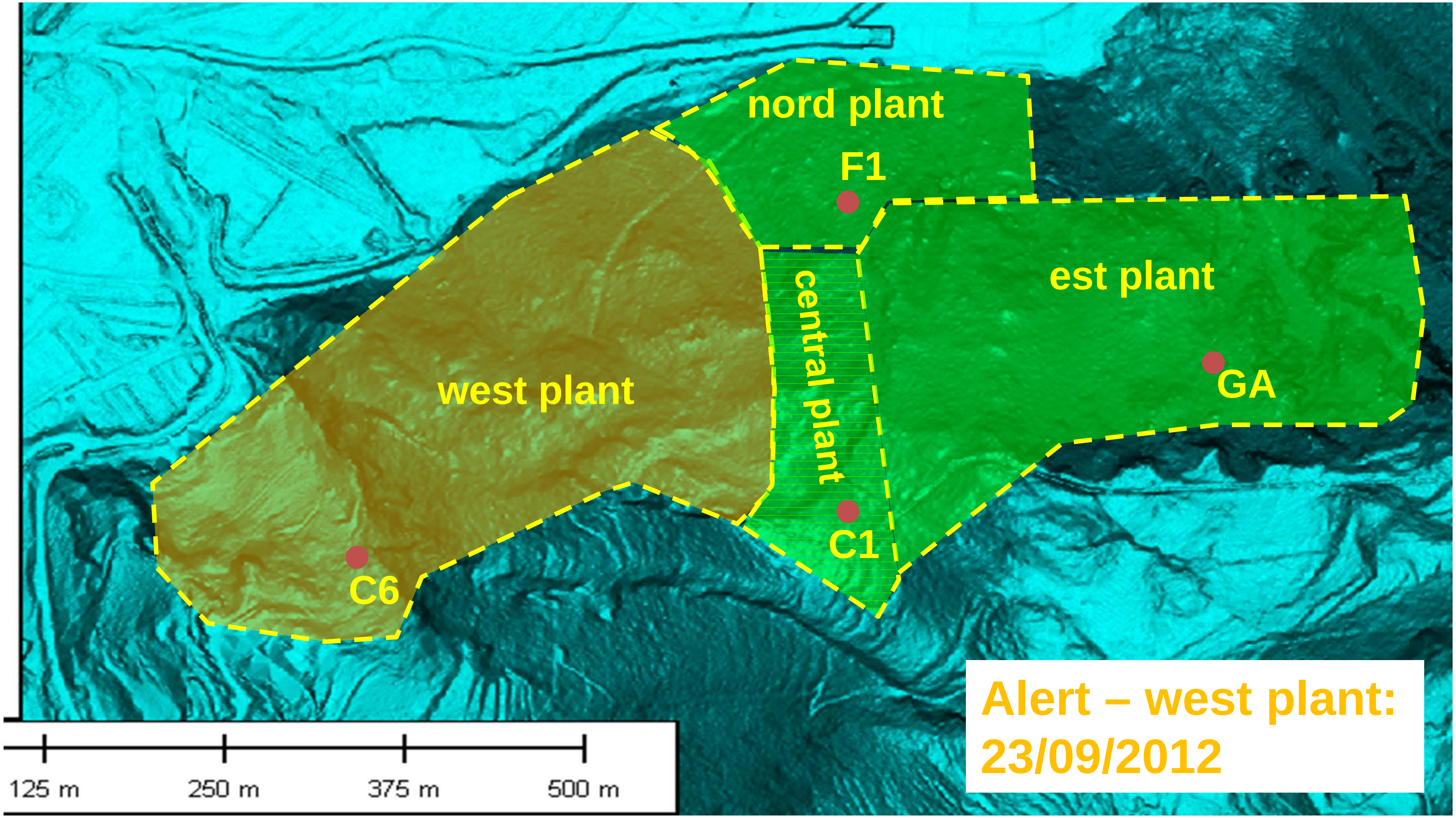
Monitoring system: plant zones and accelerometric stations



Conclusion

- **Characterization of the typology of different events**
- **Back analysis on the entire database to establish correlations between events and damage (displacements and fractures)**
- **Development of an automatic system of warning on phase de validation**

Perspectives

- Micro-accelerometers for localization of the underground events with negative Mw (?)
- Estimation of the volumes generating underground events (?) (correlation between frequency content, Mw and possible sliding surfaces of the involved volumes…)

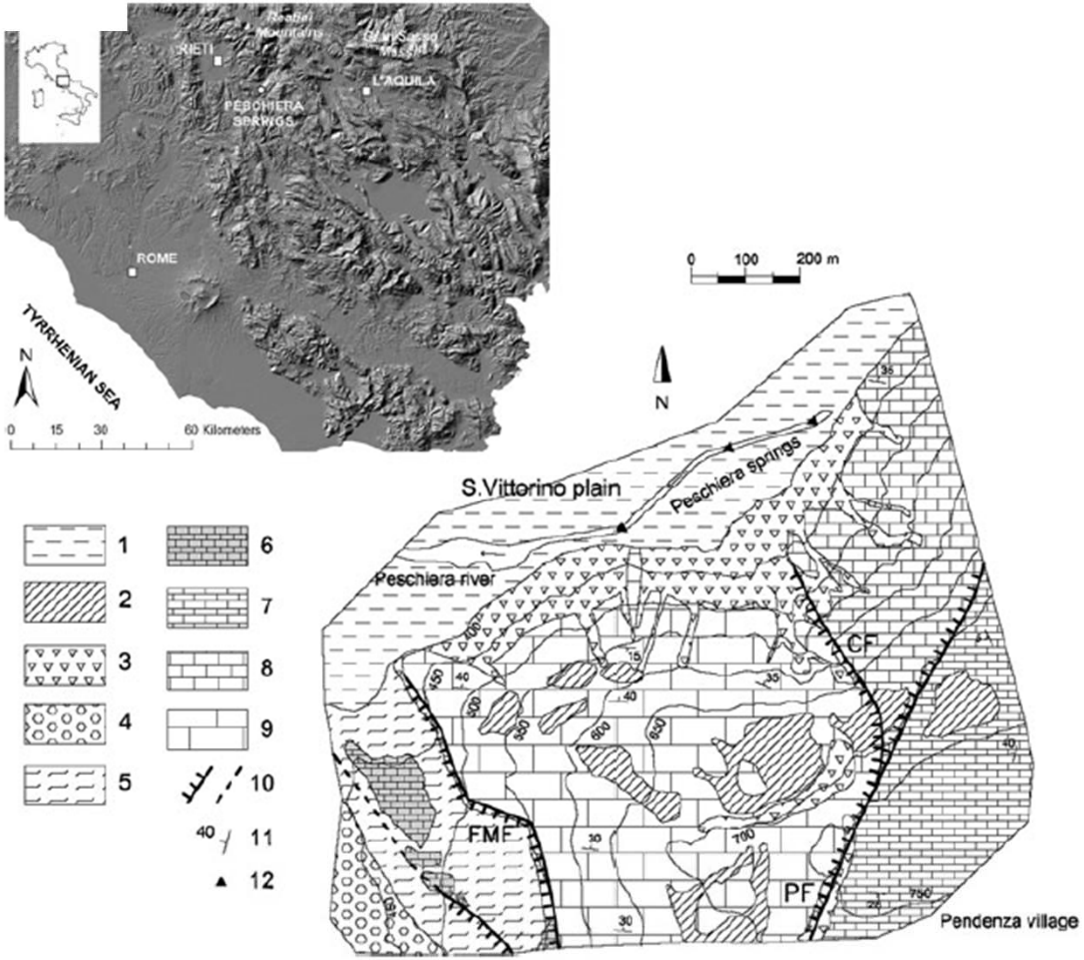


Fig. 2 Location and geological sketch of the Peschiera Springs slope: (1) Recent alluvial deposits of the Velino River; (2) Reddish soils; (3) Slope debris; (4) Gravel and conglomerate (*upper*-Pliocene and *lower*-Pleistocene parts); (5) Sandy-clayey flysch (*upper* Miocene); (6) Marly limestone (*upper* Cretaceous–lower Miocene); (7) Birdseye micritic limestone (*lower* Cretaceous); (8) Coral limestone (*upper* Malm); (9) Coral and echinoids limestone (Malm part); (10) Fault (*dashed* if estimated): *FMF* Fiamignano-Micciani Fault, *CF* Canalone Fault, *PF* Pendenza Fault; (11) Strike and dip of strata; and (12) Springs