Possible Unslipped Segments in the M. Vettore Fault System. The case of August-October 2016 (Mw 6.5) earthquakes in central Italy

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UNICT GEOmatica - Laboratory

Scientific Leader

G. De Guidi

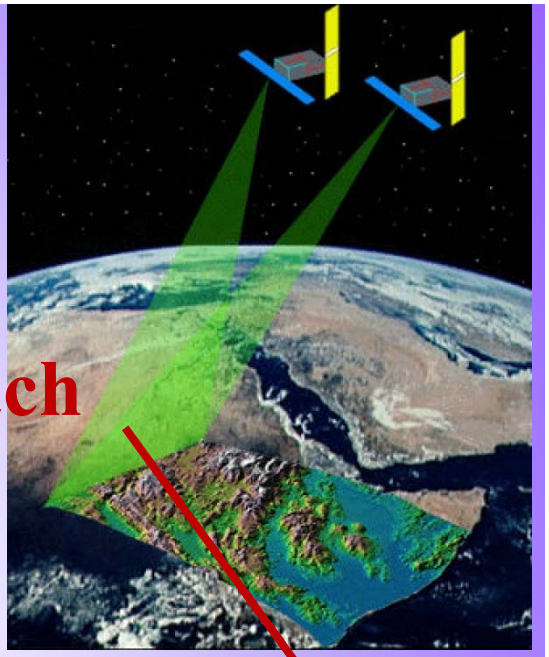
Since 2014, the Catania DSBGA has initiated a project for the training of a GEOmatica laboratory. This team should be able to manage geological emergency, in any part of Italy, in maximum 36 hours to monitoring, with highly technological instrumentation (GNSS, Drone, Total Station and dedicated software), the post critical phases of hydrogeological disaster, seismic and volcanic events.

Multidisciplinary approach

TOPOGRAPHIC MEASUREMENT

MORPHO-STRUCTURAL SURVEY

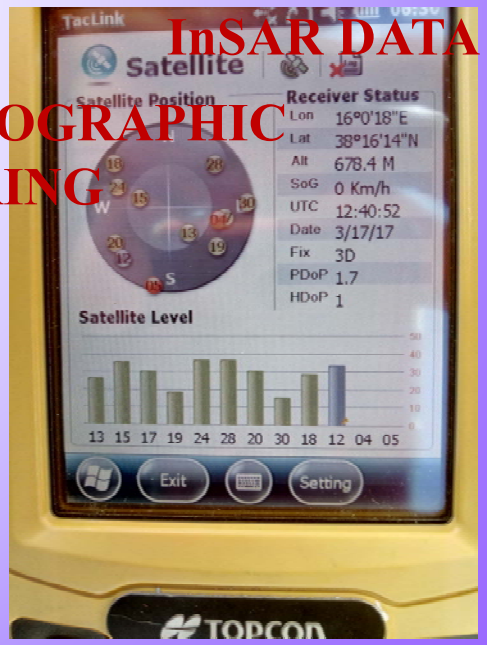
LASER SCANNING



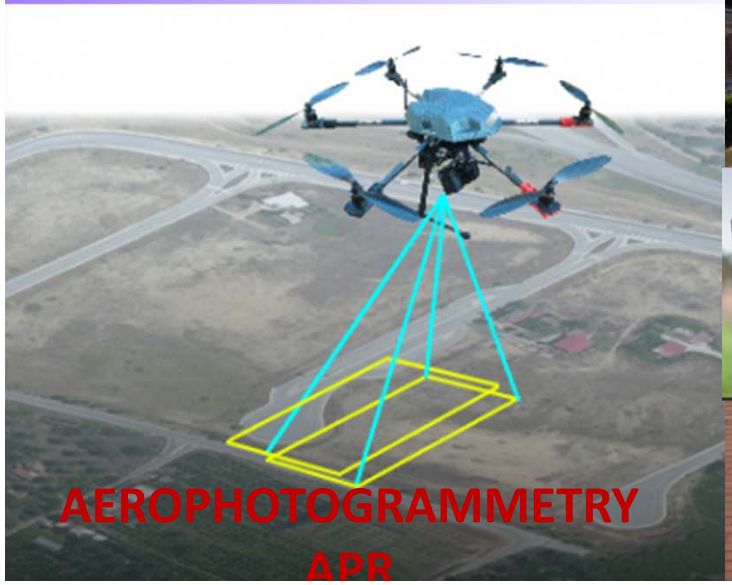
INTERFEROMETRIC SAR

GEOSTRUCTURAL ANALYSIS

GEODETIC - TOPOGRAPHIC MONITORING



InSAR DATA

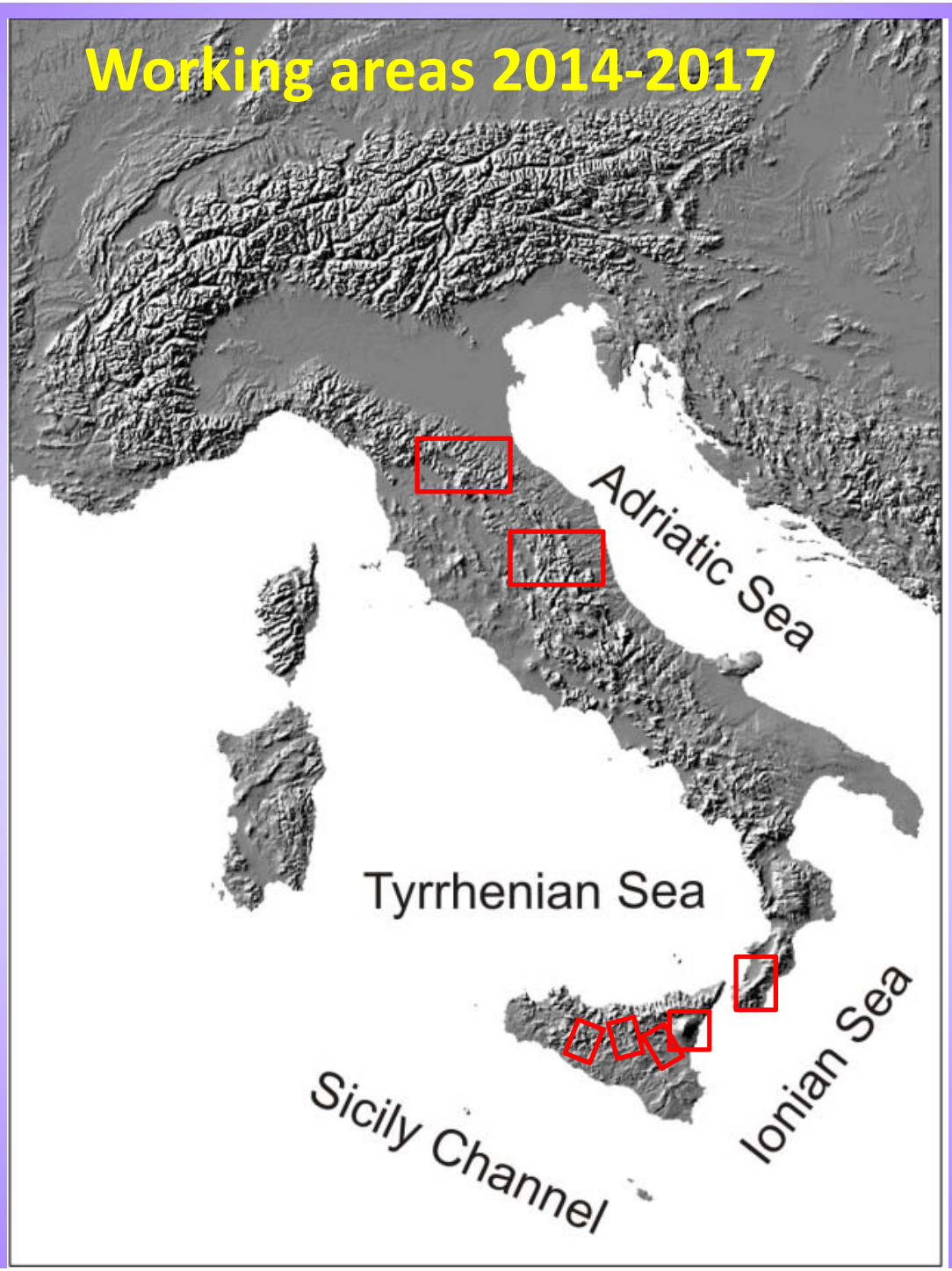


AEROPHOTOGRAMMETRY

APR

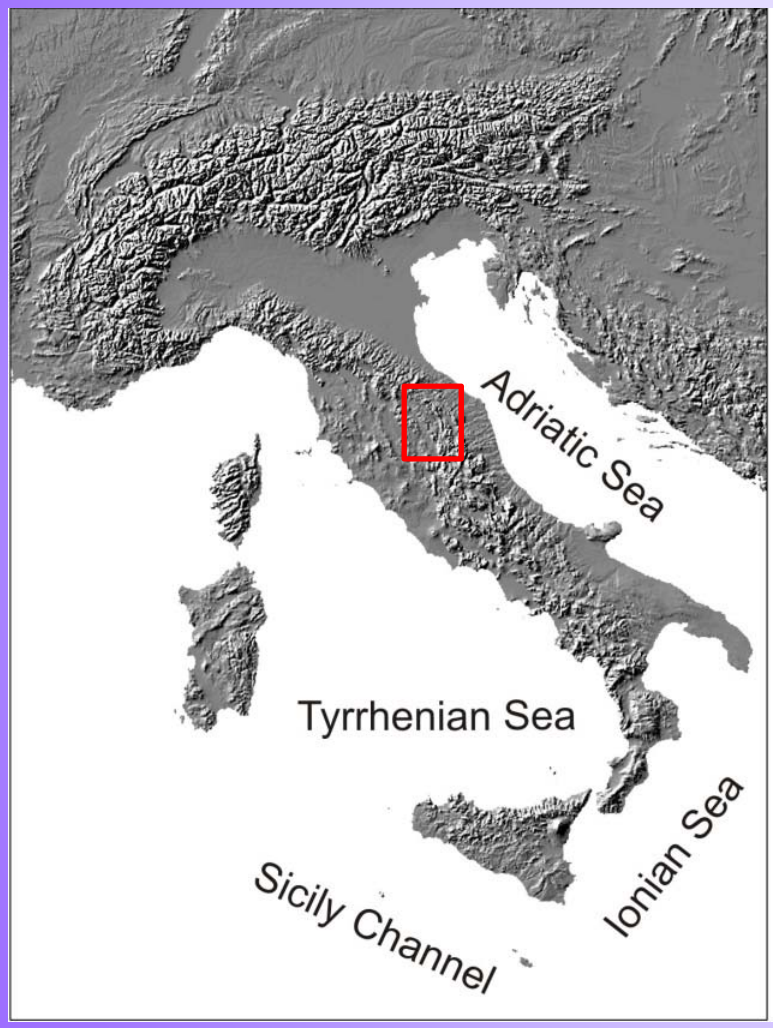
G.N.S.S.

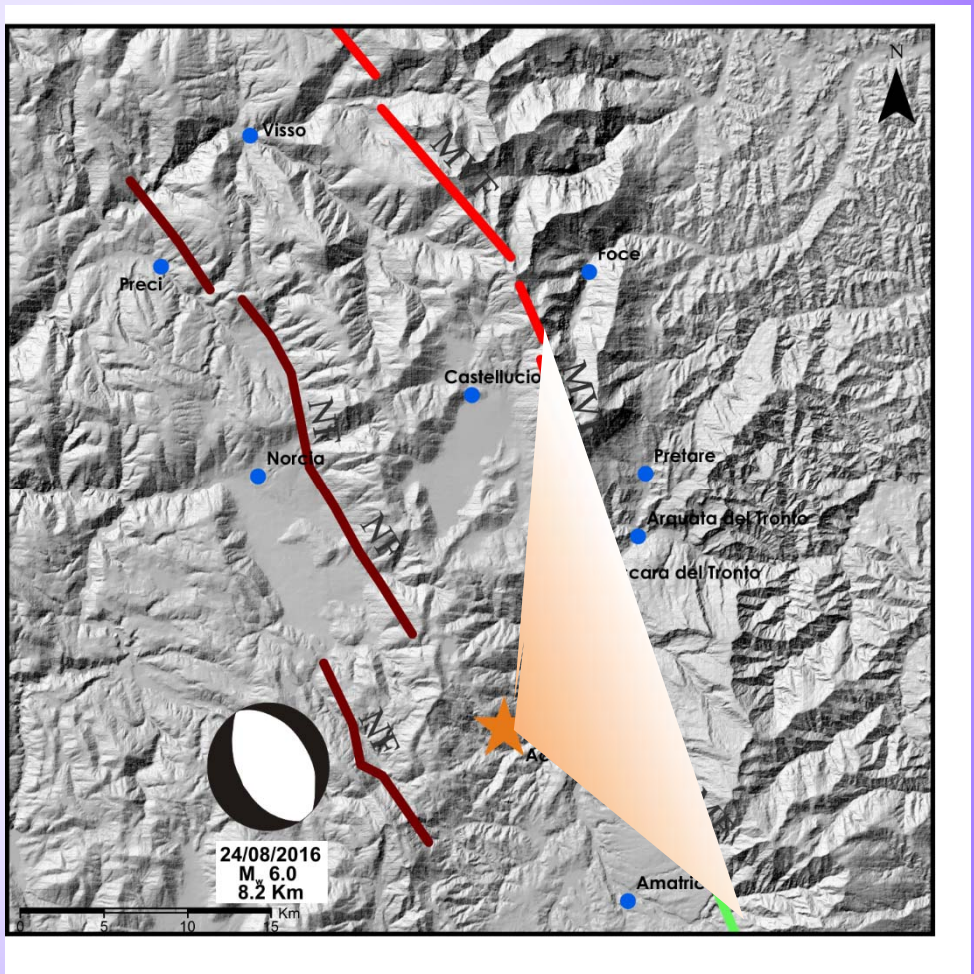
Working areas 2014-2017



Central Apennines

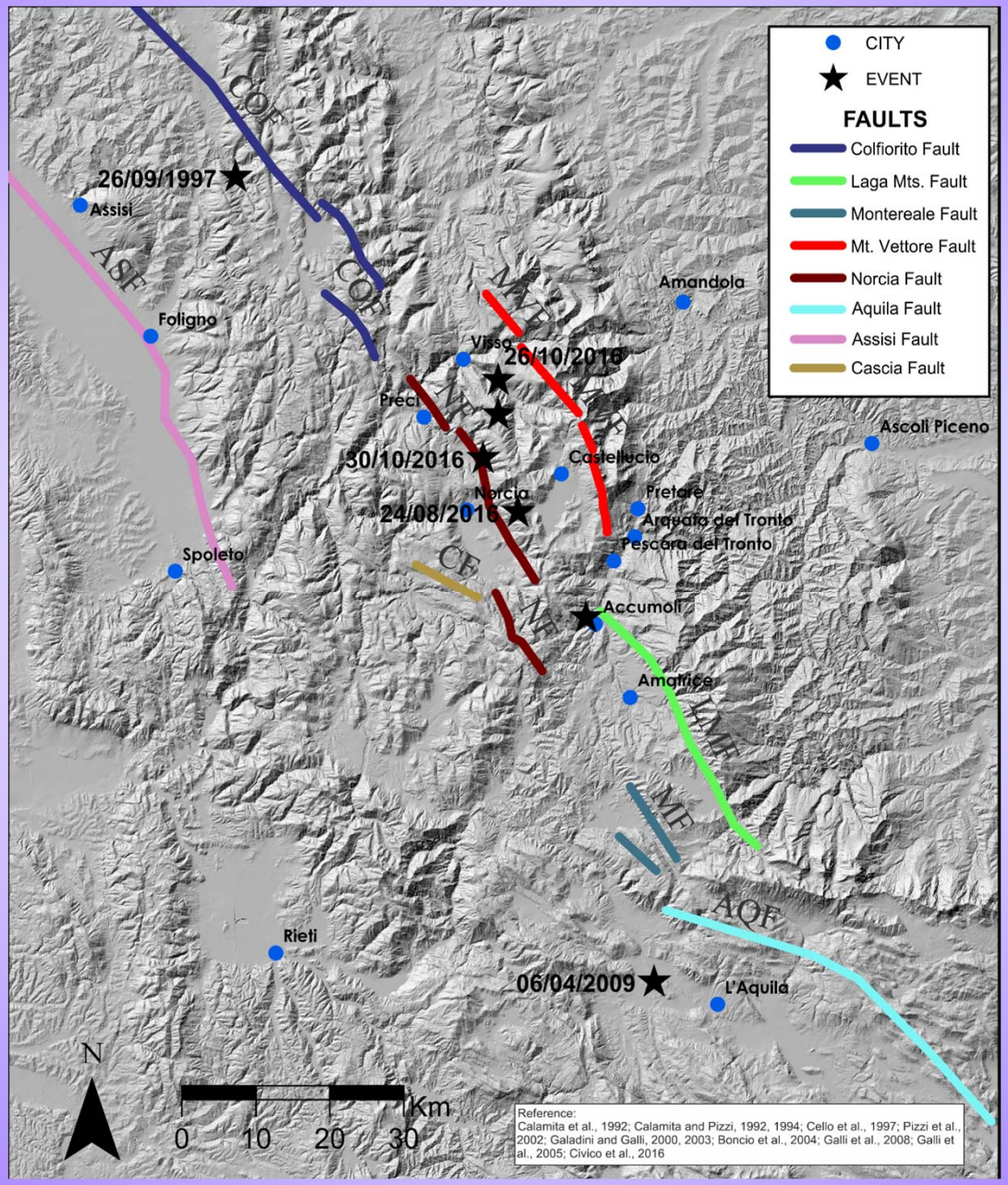
Co-seismic displacement on August 24 (Mw 5.9) earthquake in central Italy





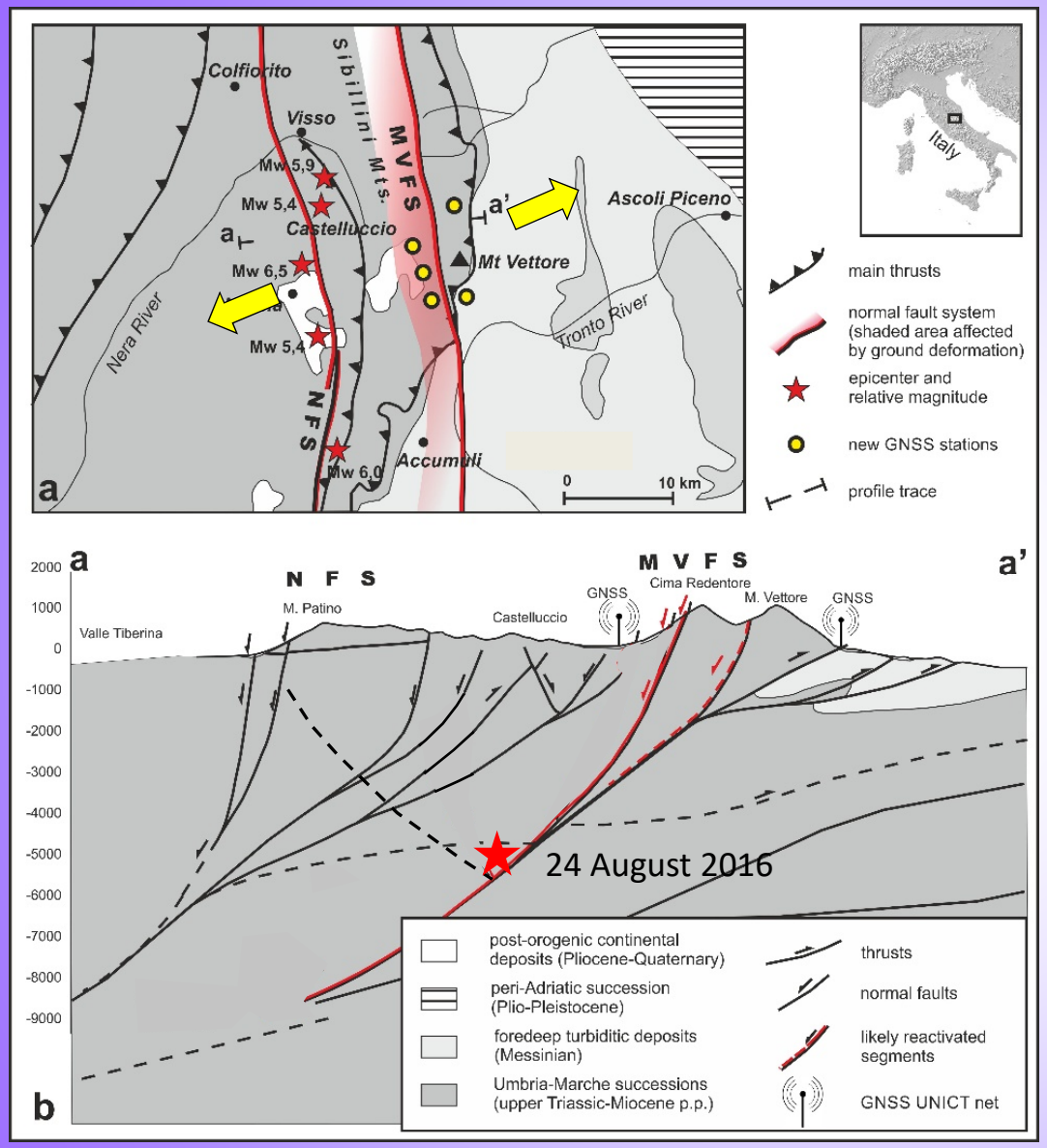
Depth =5 km; Strike=155 ; 331; Rake =-87 ; -93
Dip =49 ; 41; Mo =1.07e+25; Mw =5.96 (http://cnt.rm.ingv.it/tdmt)

Simplified seismotectonic map of central Apenines



Simplified seismotectonic map of central Apenines and geological profile across the epicentral area

(de Guidi et al. 2017)

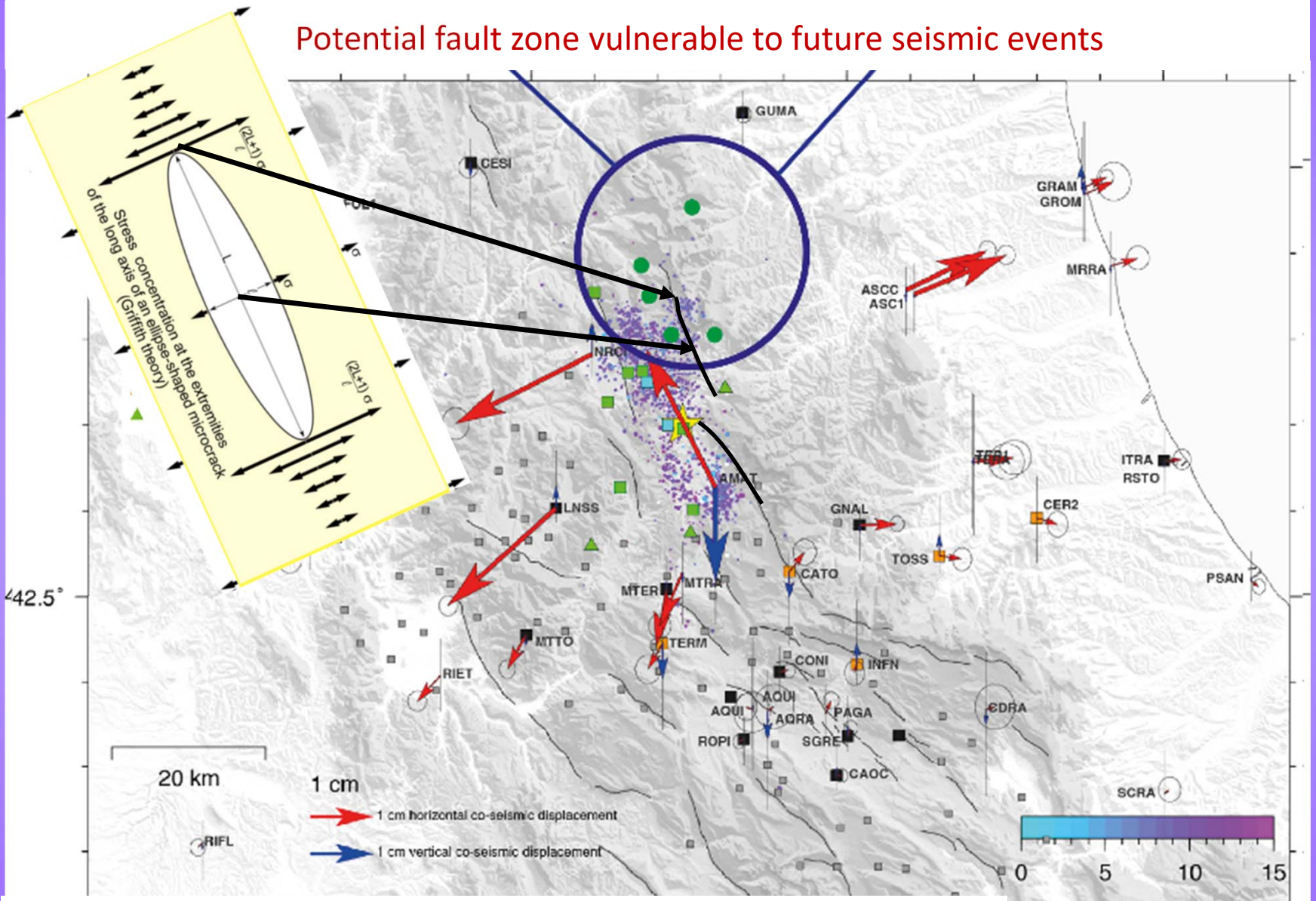


Yellow arrows indicate Quaternary Tectonic regime and Geometry of structure domines

The location of the major event is from GdL INGV (2016), while the main geostructural features from Pierantoni et al. (2013) and Mantovani et al. (2011) have been modified.

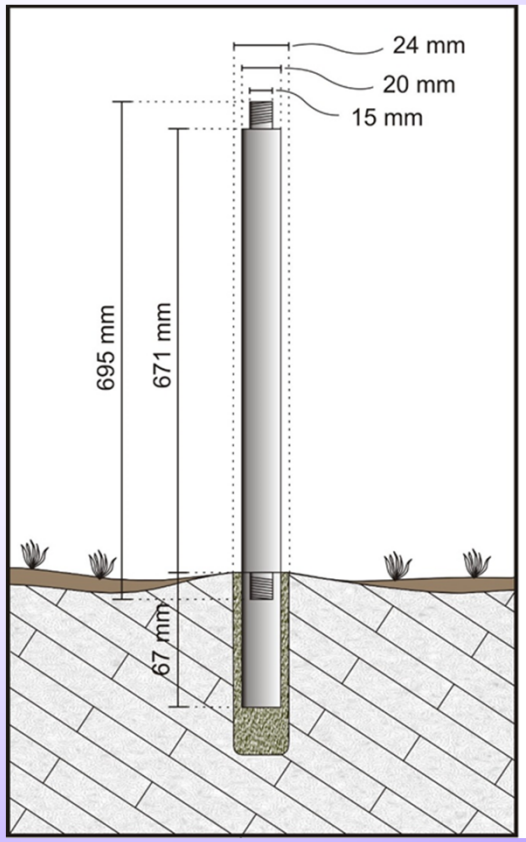
Geodetic and seismotectonic map view

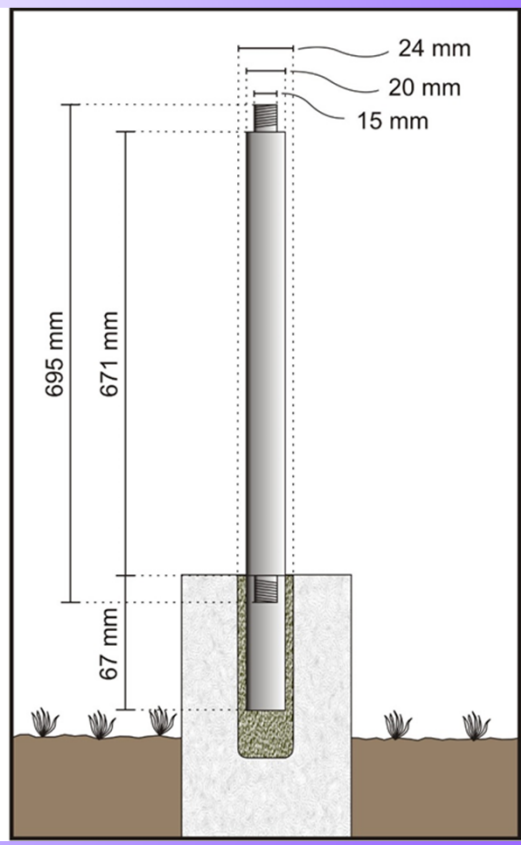
Potential fault zone vulnerable to future seismic events



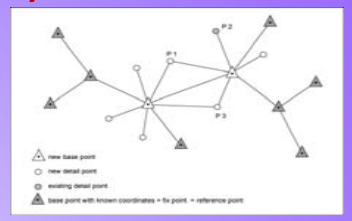
Horizontal (red arrows) and vertical (blue arrows) consensus co-seismic displacements (with 68% confidence errors), and the local UniCT GPS network. The aftershocks of 24 August, Mw D 6:0 main event (yellow star) are coloured as afunction of depth (from http://iside.rm.ingv.it)

The building of Benchmark and a first set of measurements carried out during a first campaign (30 September and 2 October 2016)

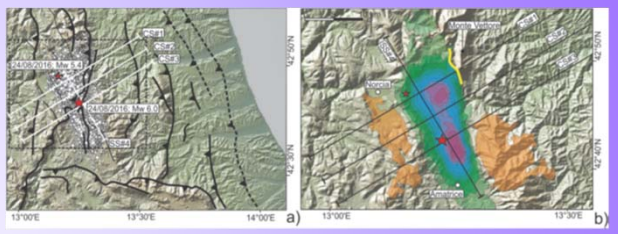




The planning and building criteria (GNSS network stations)



- the distribution of IGM; RING; CAGEONET; DPC; ISPRA permanent and discrete measurement benchmark;

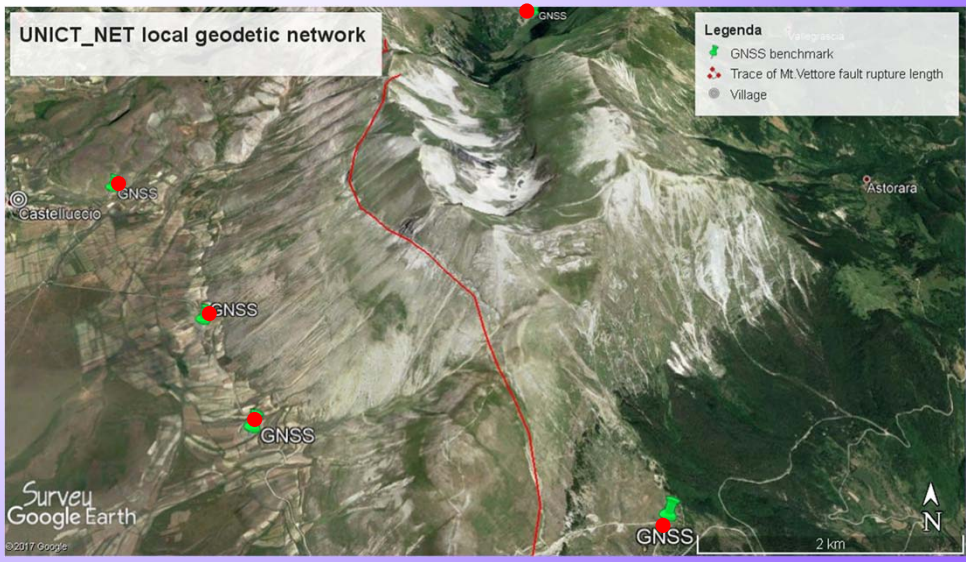


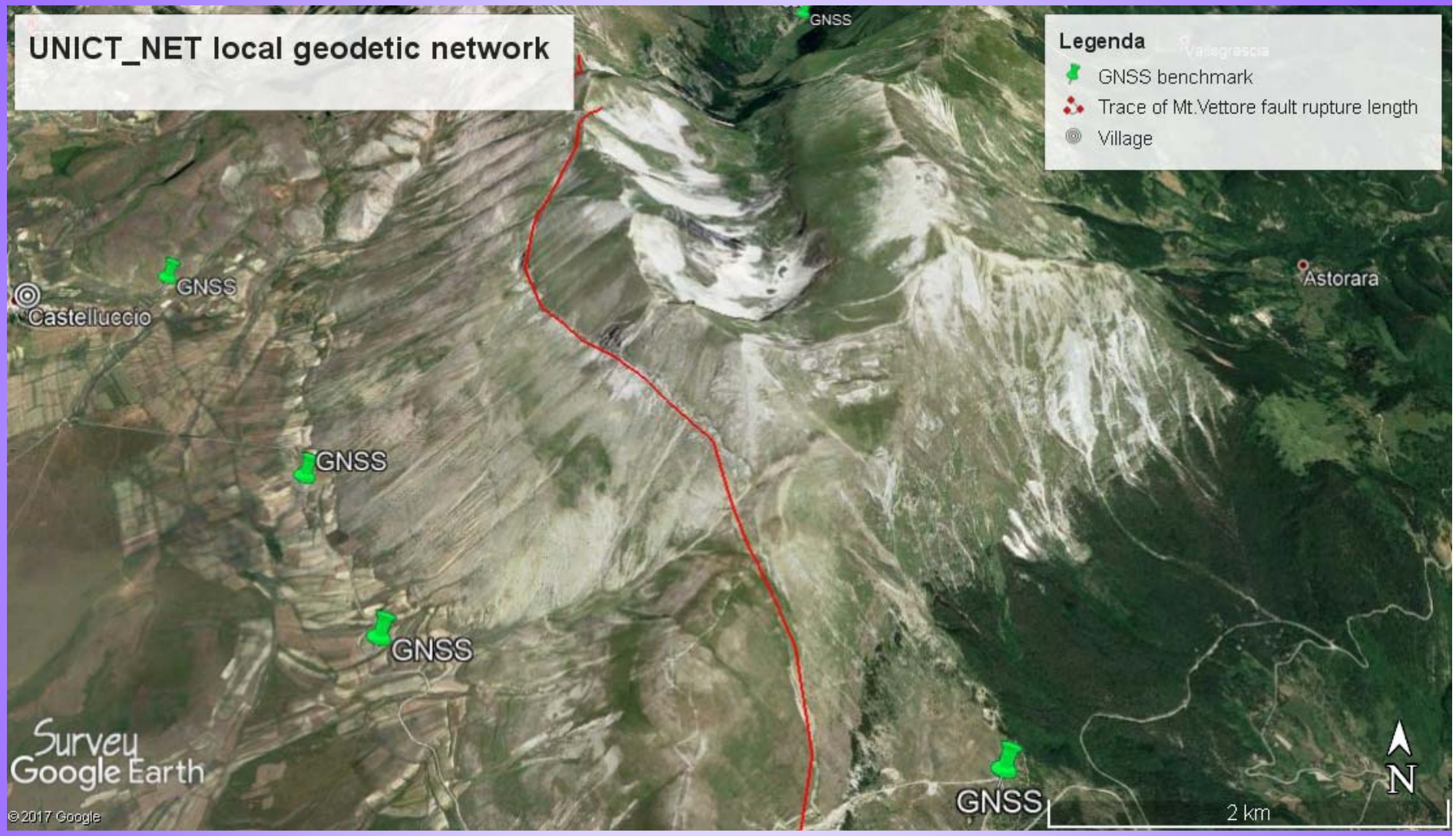
- seismotectonic setting of the area;
- surface and deep geometry of the major faults;

- the lack of possible gravitational instabilities in both static and dynamic conditions

Reconstructing the principal deformation zone which developed as a consequence of the 24 August event

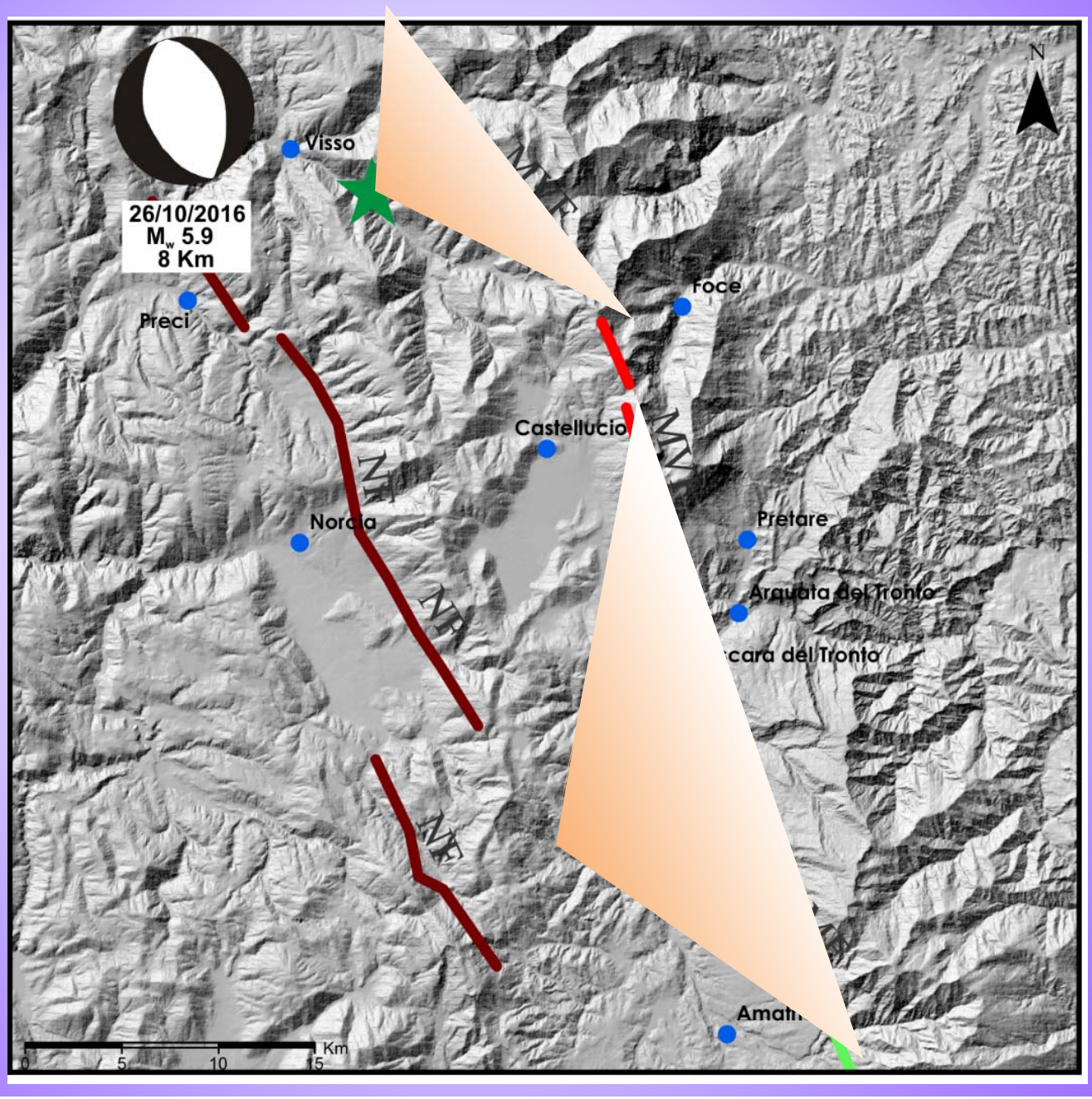
- much closer to the epicentral area than the existing ones belonging to other networks;
- characterized by equivalent distances from the reactivated Mt Vettore fault segments;
- within a distance of 30 km from the closest permanent network points that have been not affected by deformation, therefore allowing a rigorous elaboration during the post-processing phases



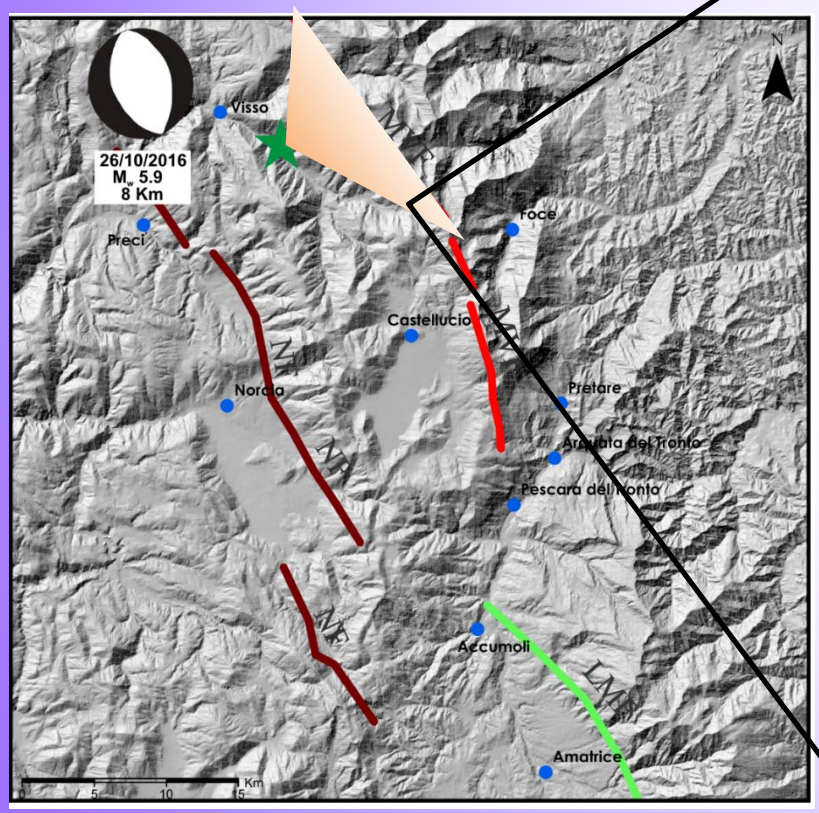

UNICT_NET local geodetic network
Legenda
GNSS benchmark
Trace of Mt.Vettore fault rupture length
Village
GNSS
Castelluccio
Astorara
Valegrascia
2 km
N
Surveu
Google Earth
©2017 Google

October 26 2016 (Mw 5.9), earthquakes

Depth =6 km
Strike=159 ; 344
Rake =-93 ; -87
Dip =47 ; 43
Mo =7.38e+24
Mw =5.85



Active deformation during October 29 field trip; 24 our before the 6.5 Mw earthquake



Active deformation during October 29 field trip; 24 our before the 6.5 Mw earthquake

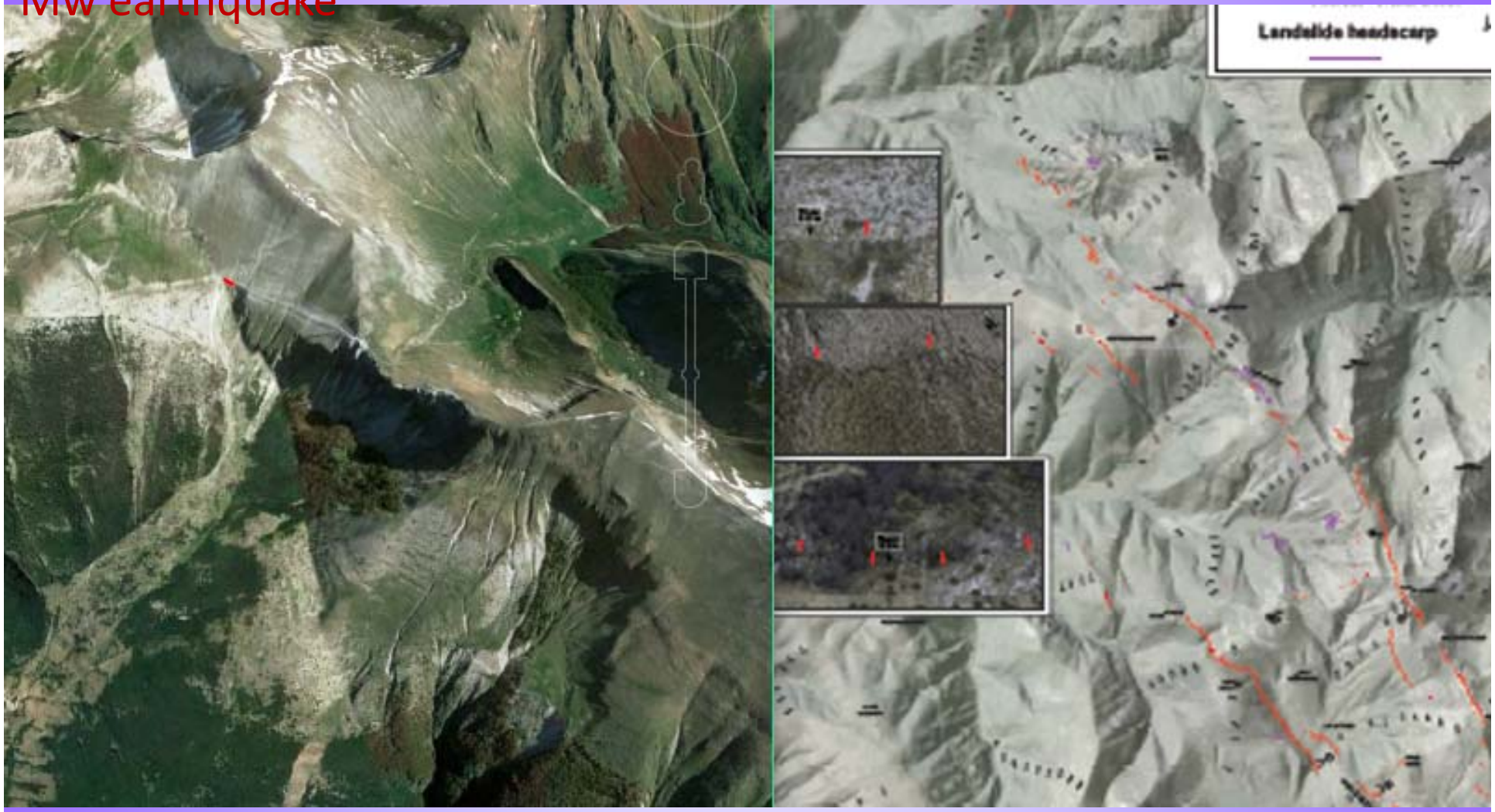
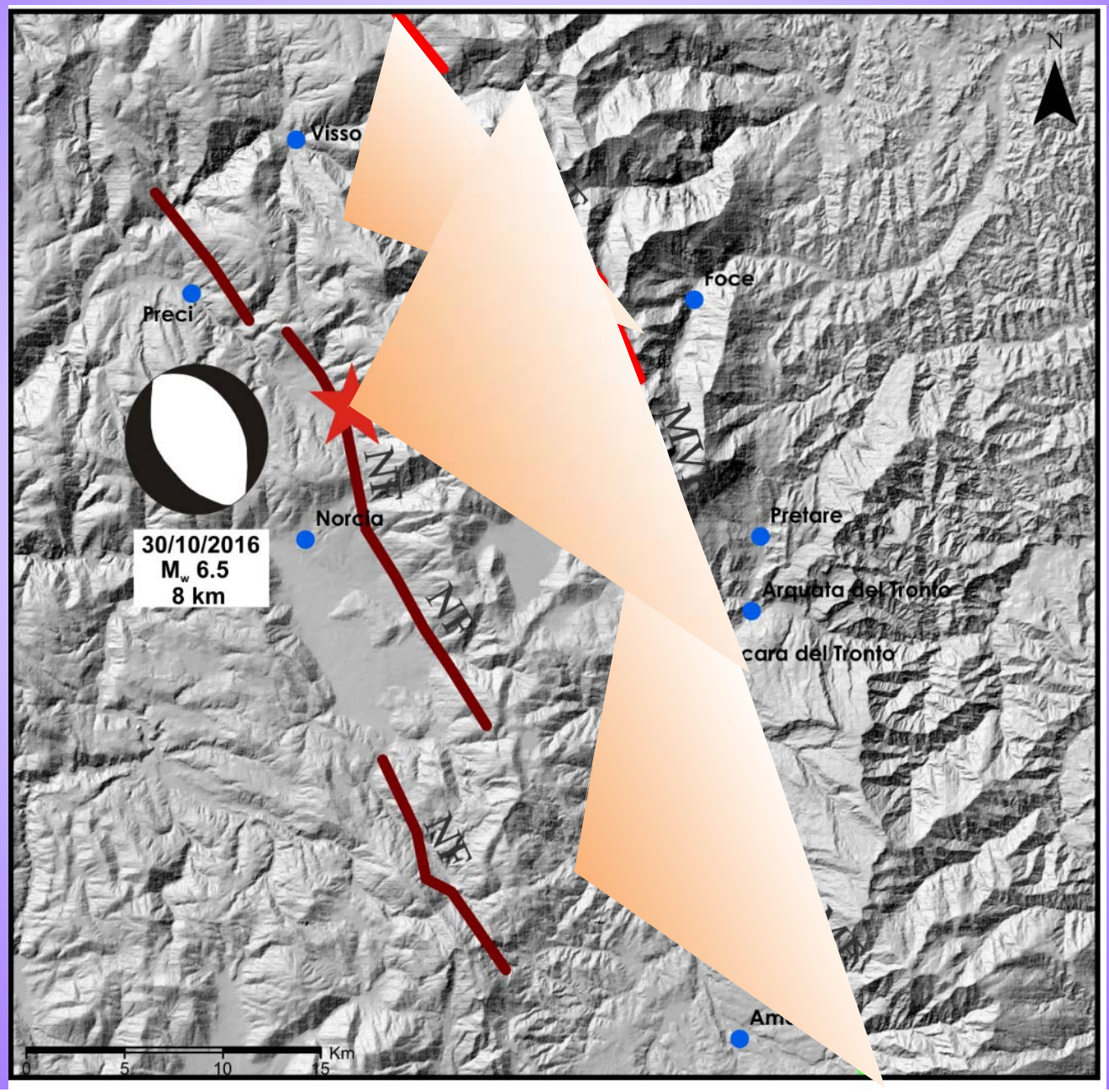
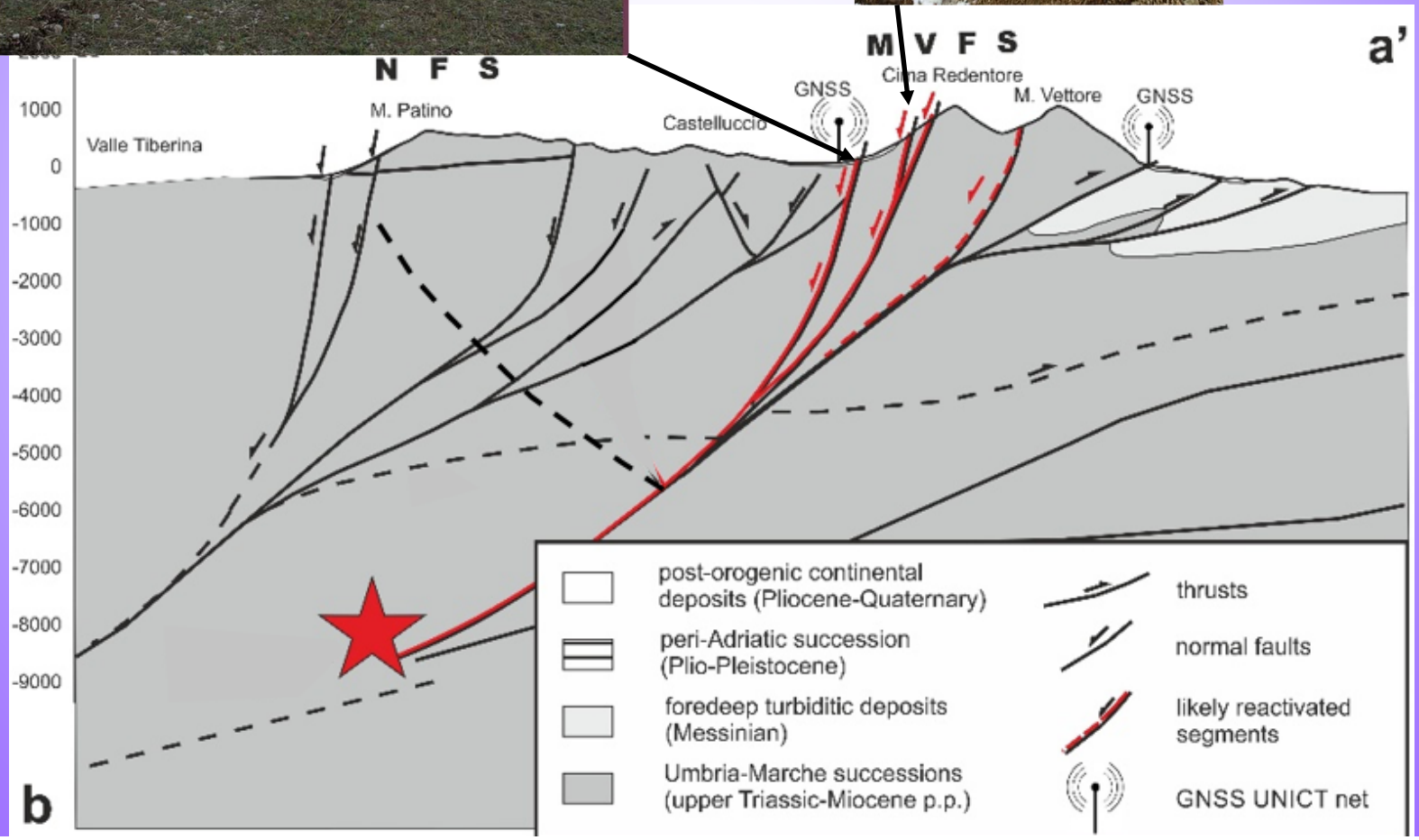


FIGURA DA GOOGLE HEART CON RIQUADRO GENERALE

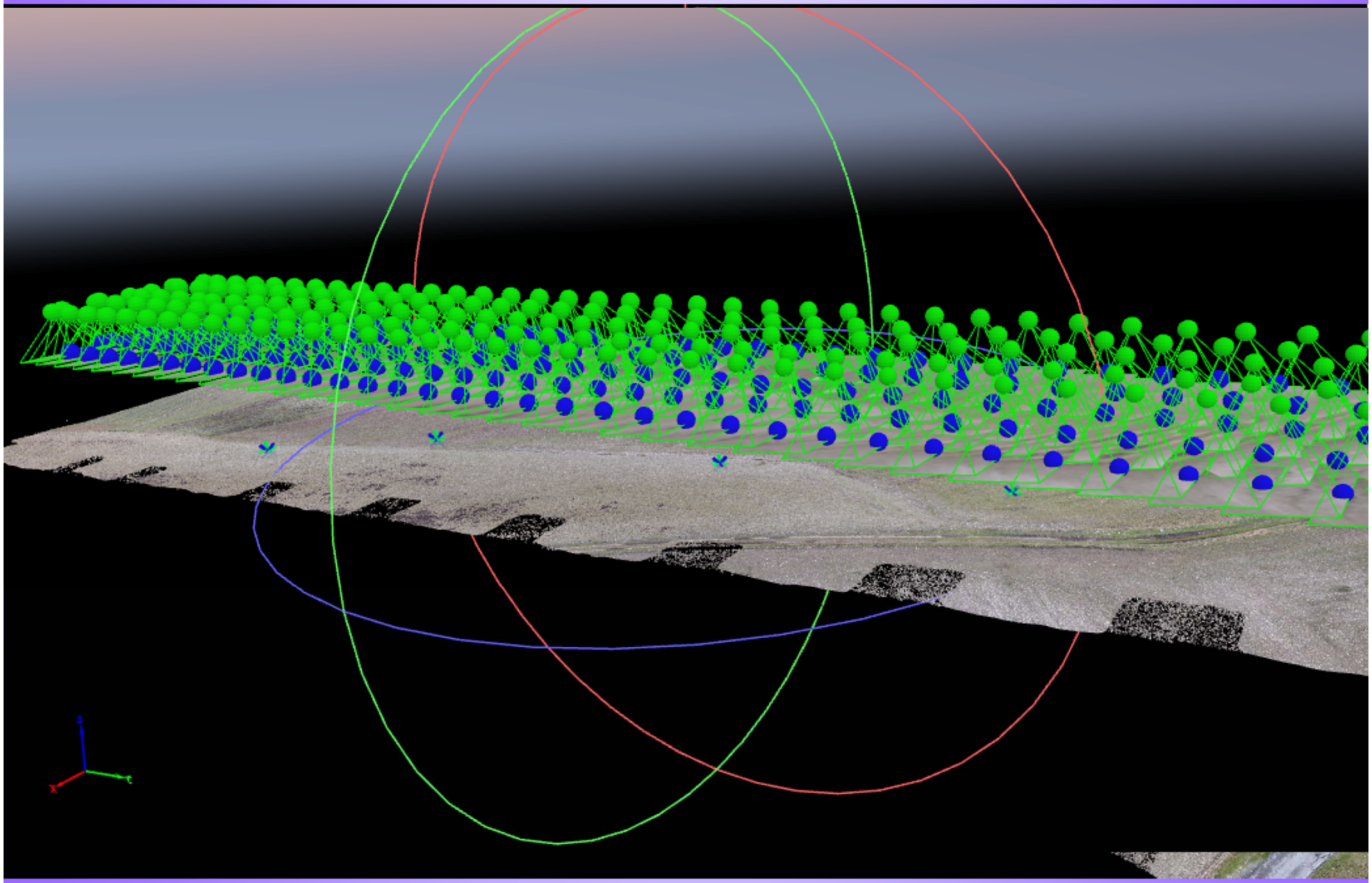
October 30 2016 (Mw 6.5), earthquake



Set of measurements carried out during a second campaign (10, 14 November 2016)

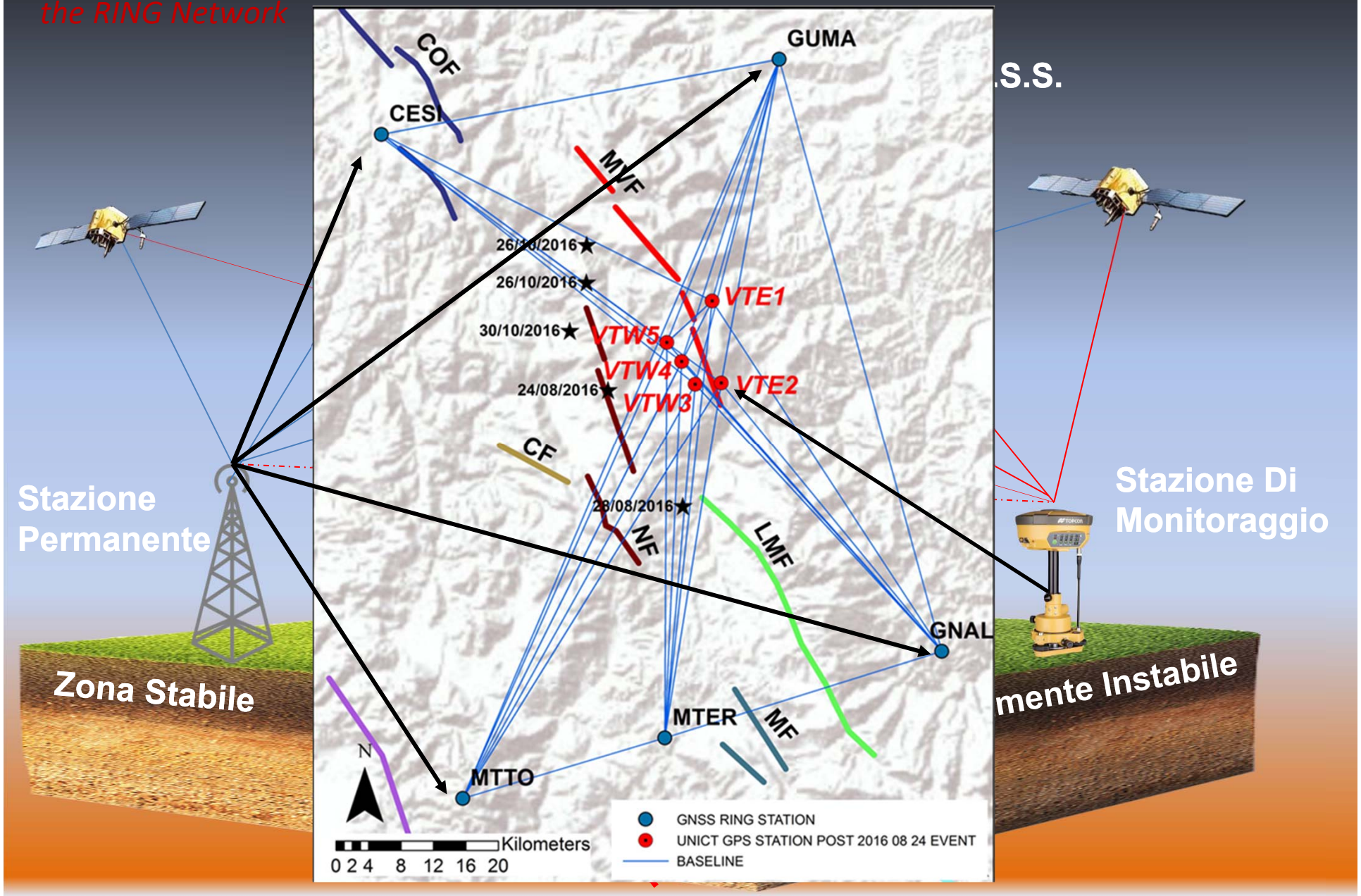


Rilievo aerofotogrammetrico mediante tecnologia drone

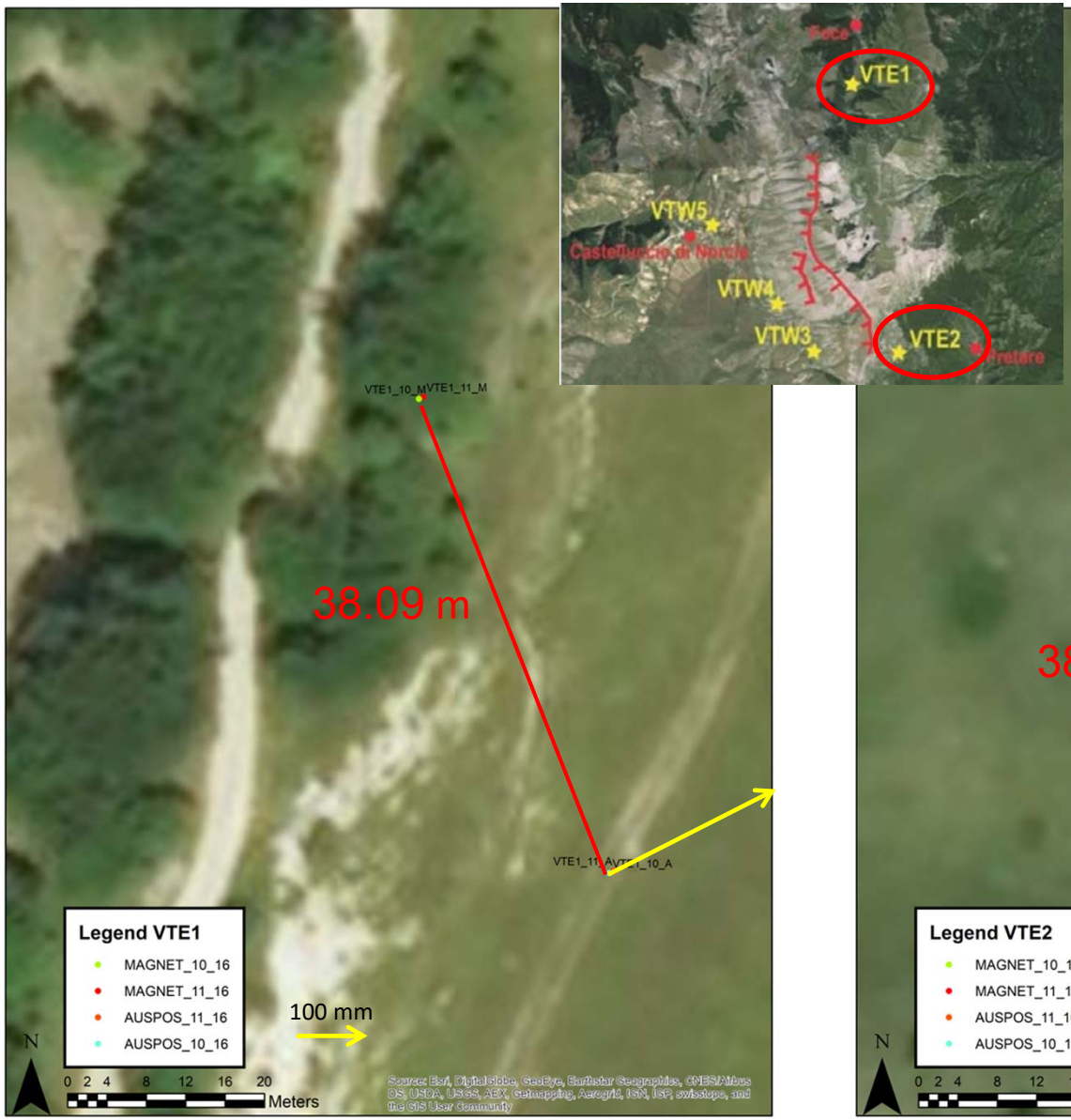


Metodologia di rilevamento

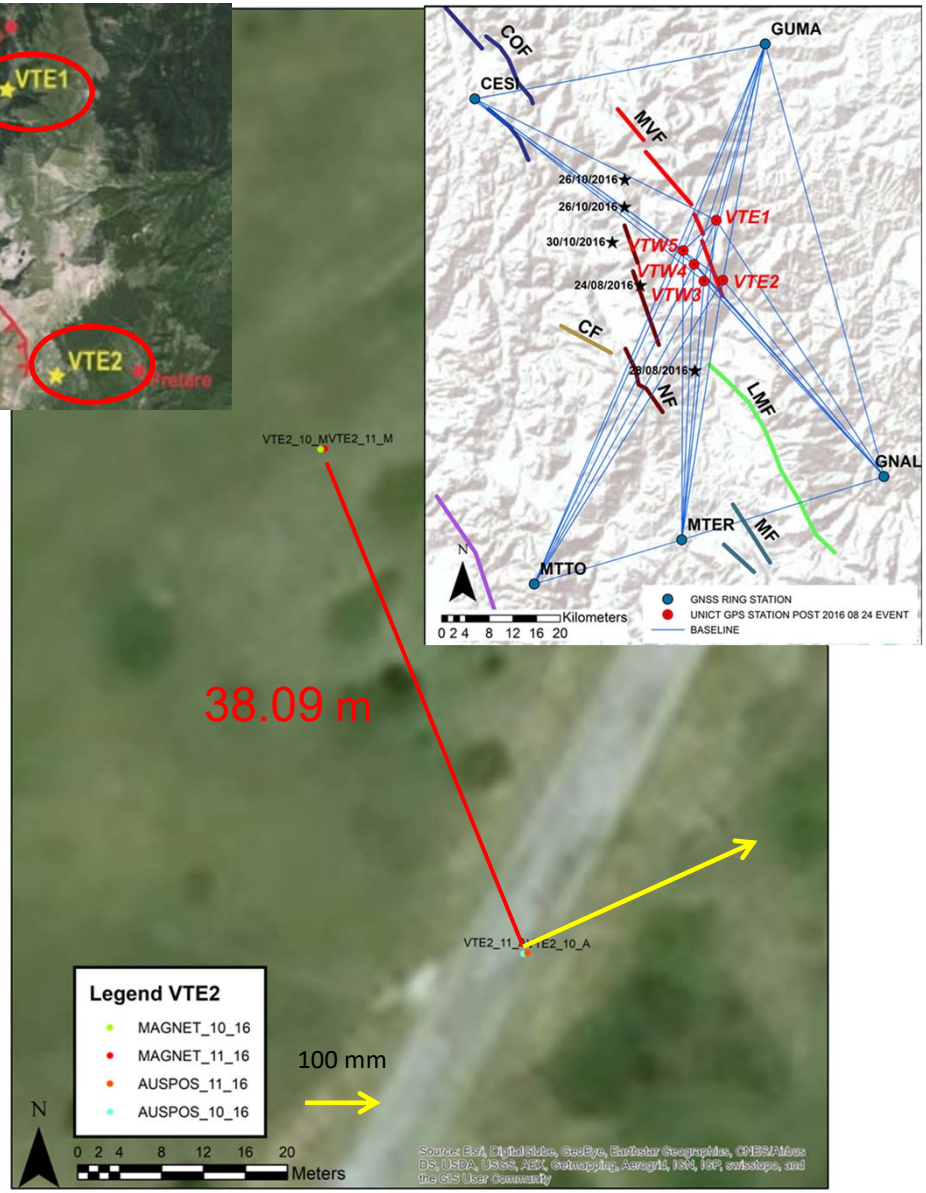
Baselines obtained by combining the new GNSS UNICT stations with selected GNSS ones from the RING Network



Stazione VTE1

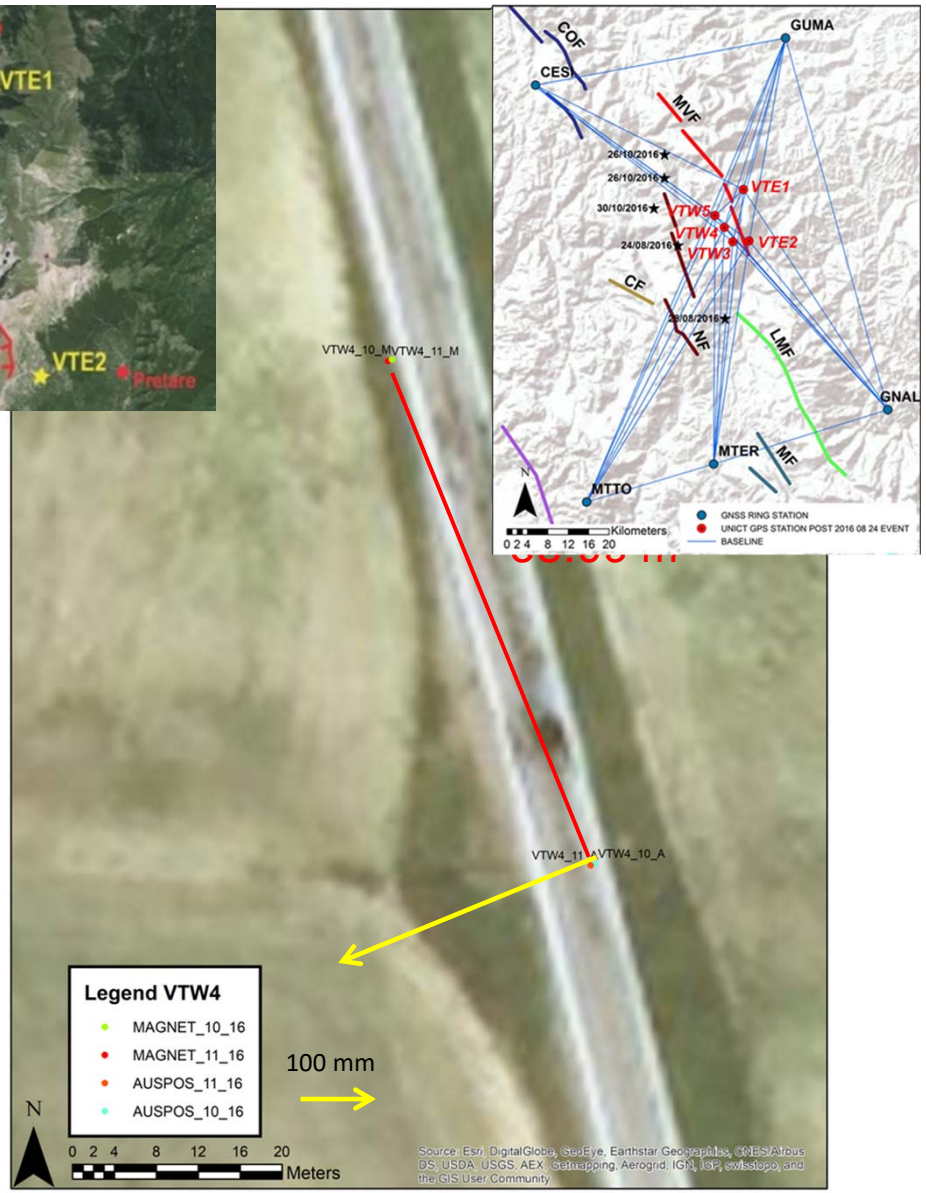


Stazione VTE2

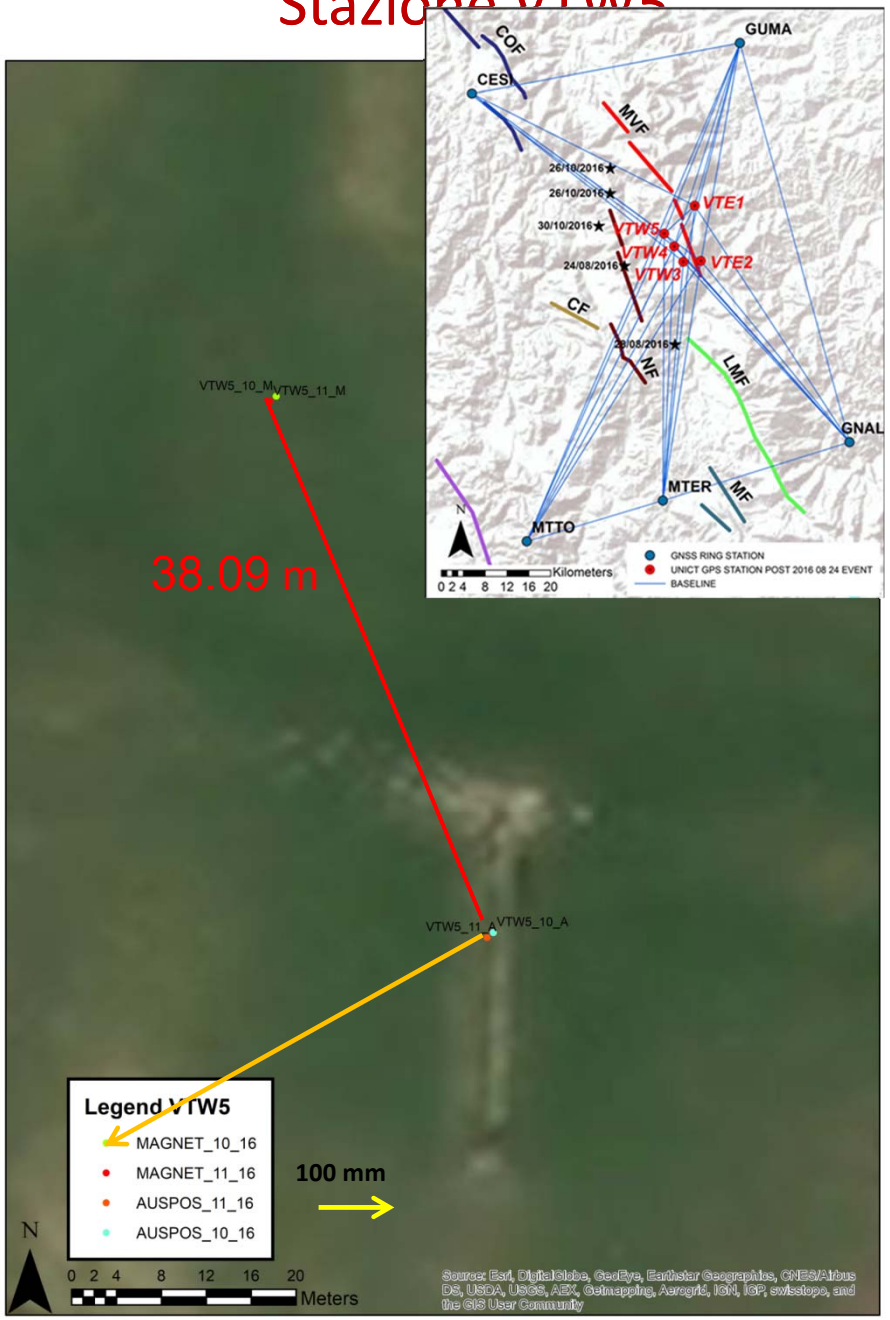


Stazione VTW3

Stazione VTW4



Stazione VTW5



Scarto misure

	VTE1	VTE2	VTW3	VTW4	VTW5
MAGNET	354.4mm	294mm	273.9mm	308.6mm	538.6mm
AUSPOS	358.2mm	308.1mm	0	320.5mm	532.2mm
Scarto	3.8mm	14.1mm	0	11.9mm	6.4mm

The data from survey-mode GNSS stations have been downloaded and processed using TOPCON magnet analysis software, evaluating co-seismic solutions and comparing them with AUSPOS web-based online services for GPS data processing (Ocalan et al., 2013)

Post-processed data result

ID	Station	Longitude	Latitude	$disp_{N-S}$	$disp_{E-W}$	$disp_{UP}$	unc_{N-S}	unc_{E-W}	unc_{UP}
VTE1	FOCE_SENTIERO	13°15′57.45166″	42°51′57.04340″	141	312	29	15.5	16.5	44.0
VTE2	PRETARE	13°16′33.20959″	42°47′56.56780″	60	282	67	19.0	16.5	46.0
VTW3	QUARTUCCIOLO	13°14′46.41153″	42°47′56.57032″	198	26	−349	15.5	14.5	36.0
VTW4	COLLE_CURINA	13°13′55.01245″	42°48′59.62491″	102	288	−769	15.5	15.0	36.0
VTW5	CASTELLUCCIO_VALLE	13°12′56.20423″	42°49′54.89014″	353	418	−707	15.0	13.5	37.5

Nat. Hazards Earth Syst. Sci., 17, 1–8, 2017
https://doi.org/10.5194/nhess-17-1-2017

Natural Hazards and Earth System Sciences
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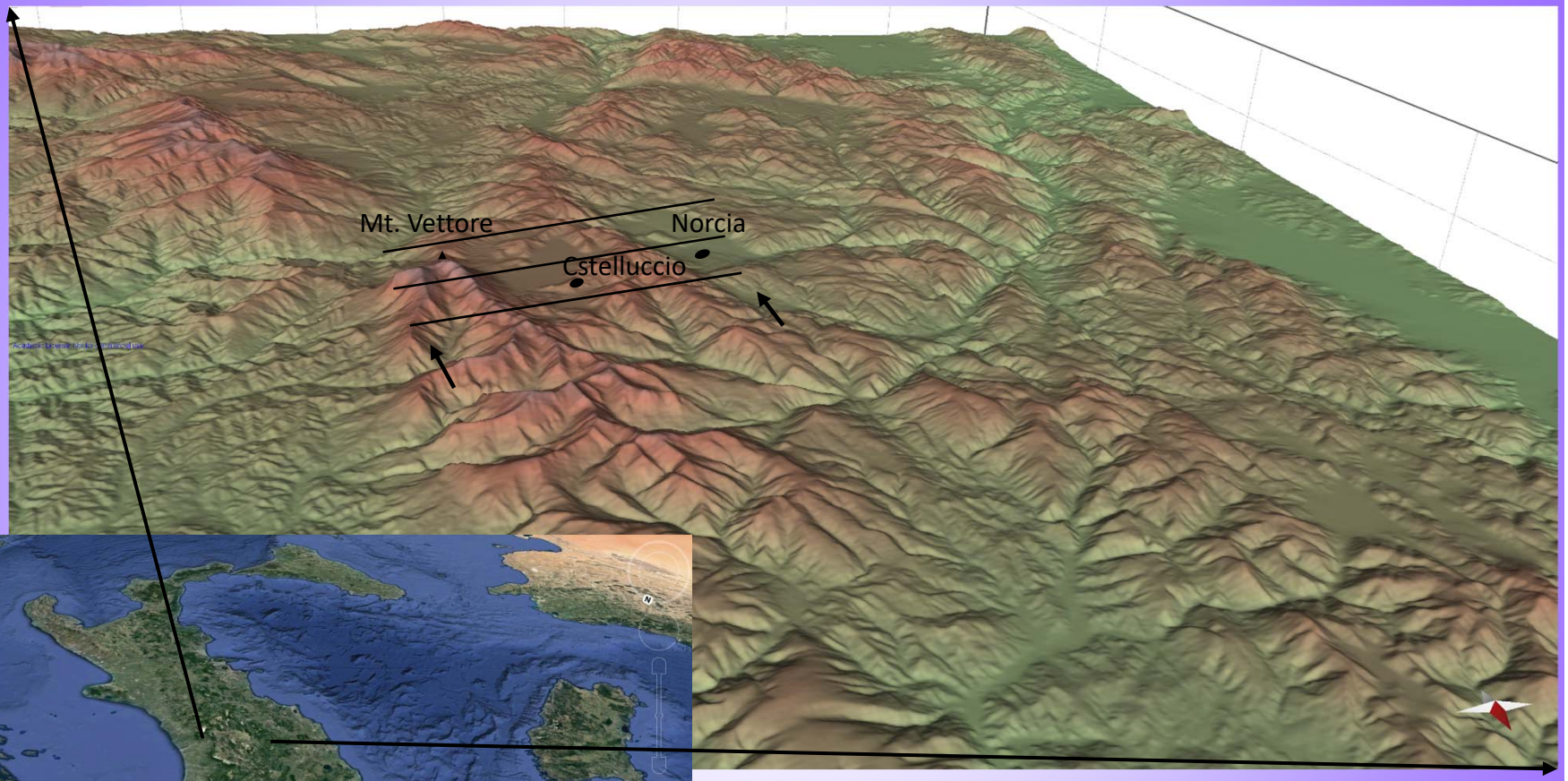
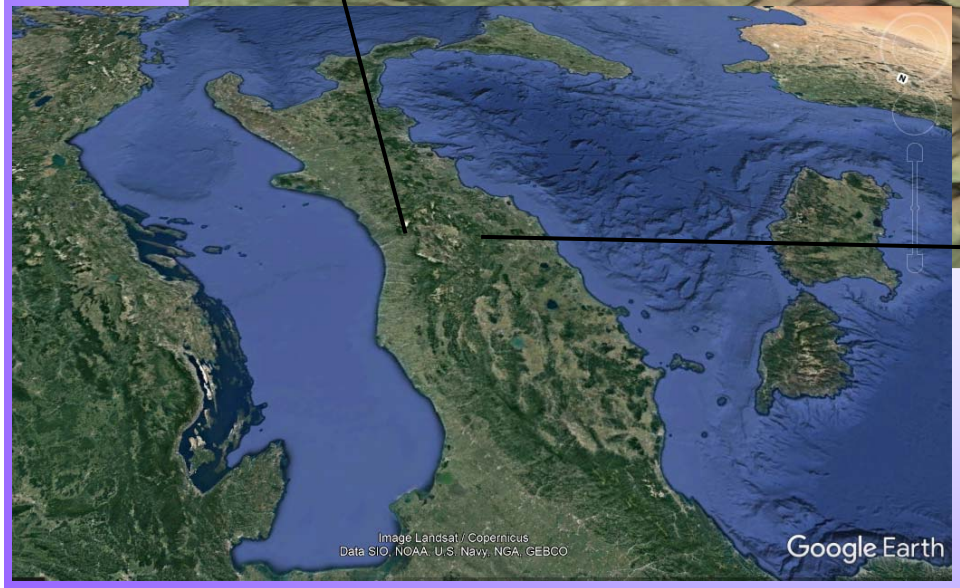
Brief communication: Co-seismic displacement on 26 and 30 October 2016 ($M_w = 5.9$ and 6.5) – earthquakes in central Italy from the analysis of a local GNSS network

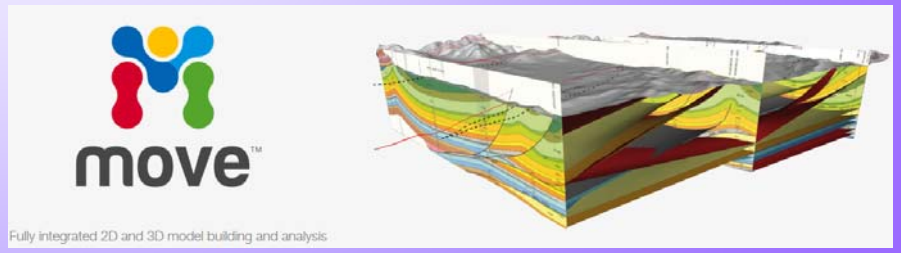
Giorgio De Guidi[1,2], Alessia Vecchio[1], Fabio Brighenti[1], Riccardo Caputo[3,4,5], Francesco Carnemolla[1], Adriano Di Pietro[1], Marco Lupo[1], Massimiliano Maggini[3,5], Salvatore Marchese[1], Danilo Messina[1], Carmelo Monaco[1,2], and Salvatore Naso[1]

[1]Department of Biological, Geological and Environmental Sciences, University of Catania, Catania, Italy
[2]CRUST, UR-UniCT, Catania, Italy
[3]Department of Physics and Earth Sciences, University of Ferrara, Ferrara, Italy
[4]Research and Teaching Center for Earthquake Geology, Tyrnavos, Greece
[5]CRUST, UR-UniFE, Ferrara, Italy

Move digital elaboration







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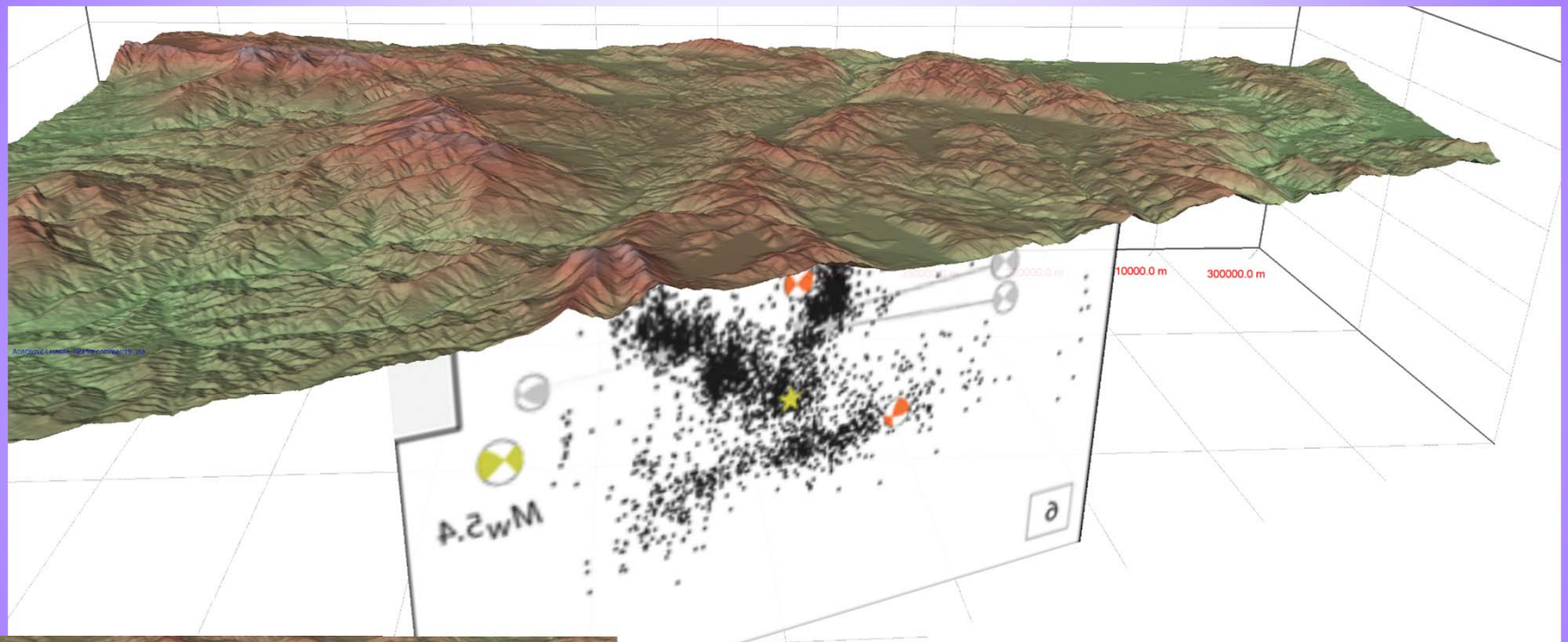
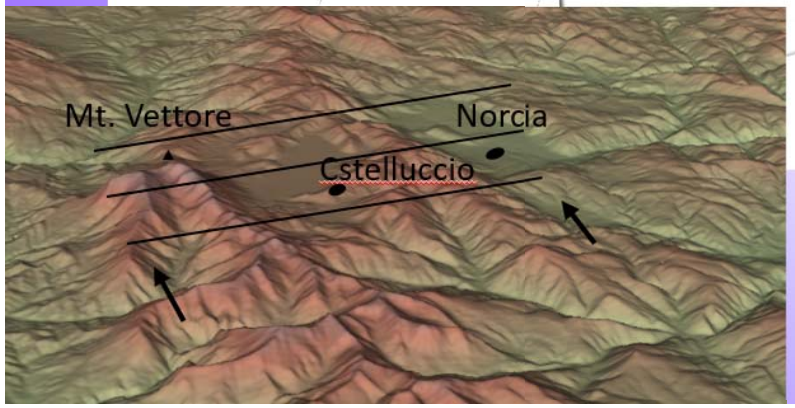
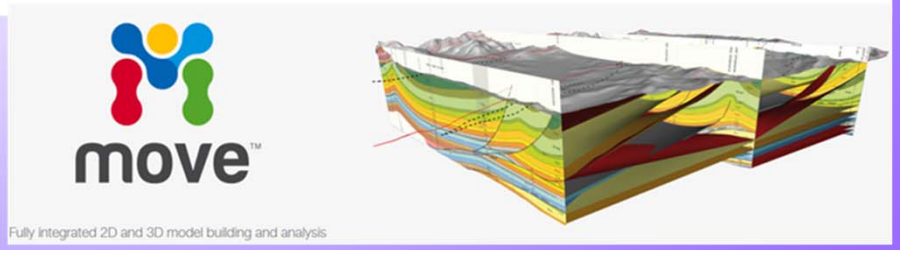


From Chiaraluce et al., 2017 modified





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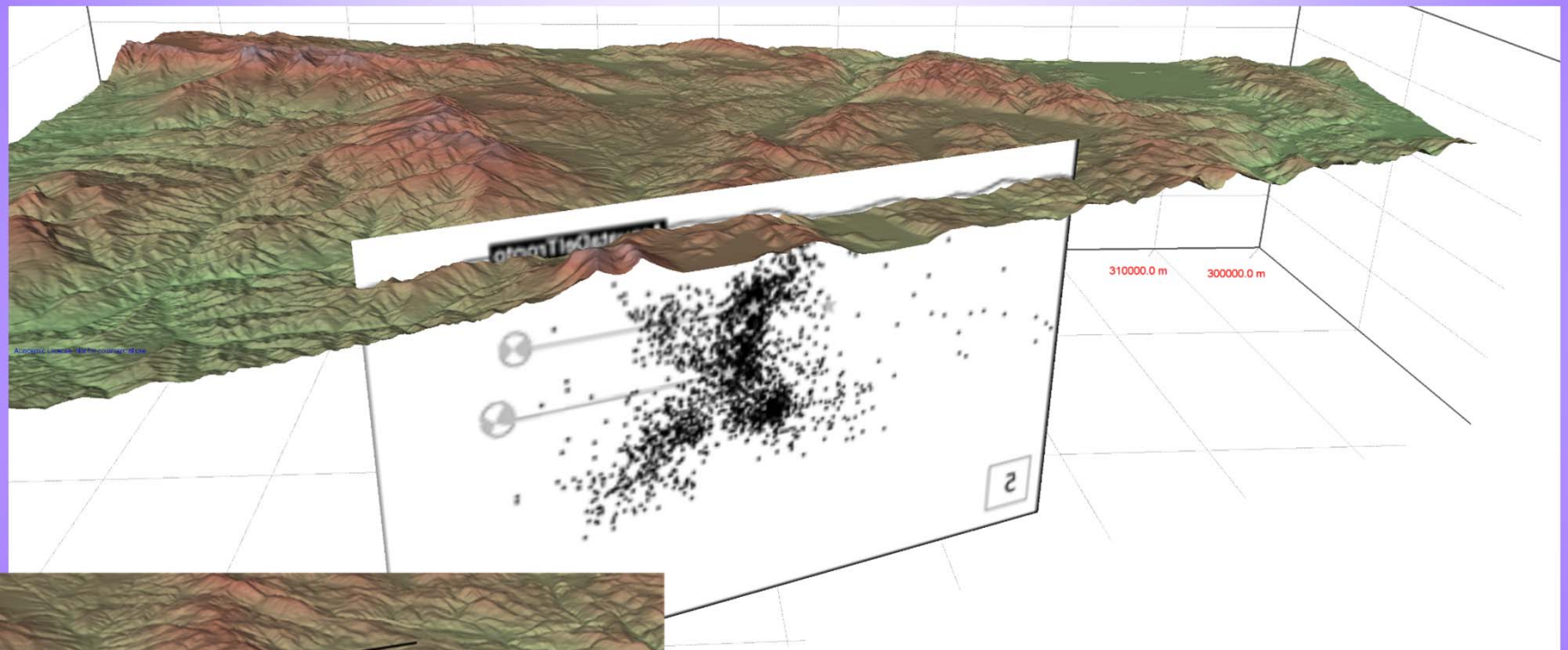

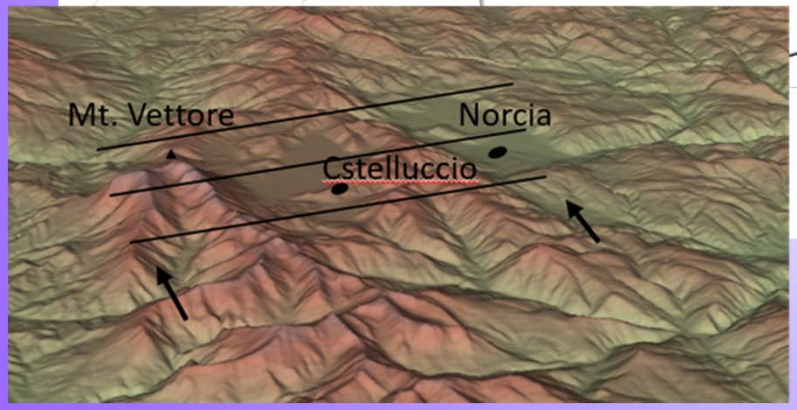

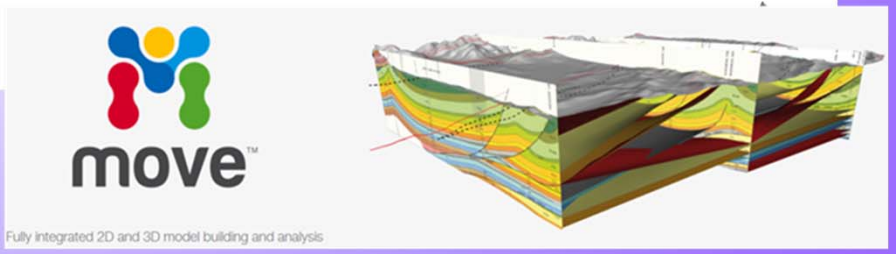

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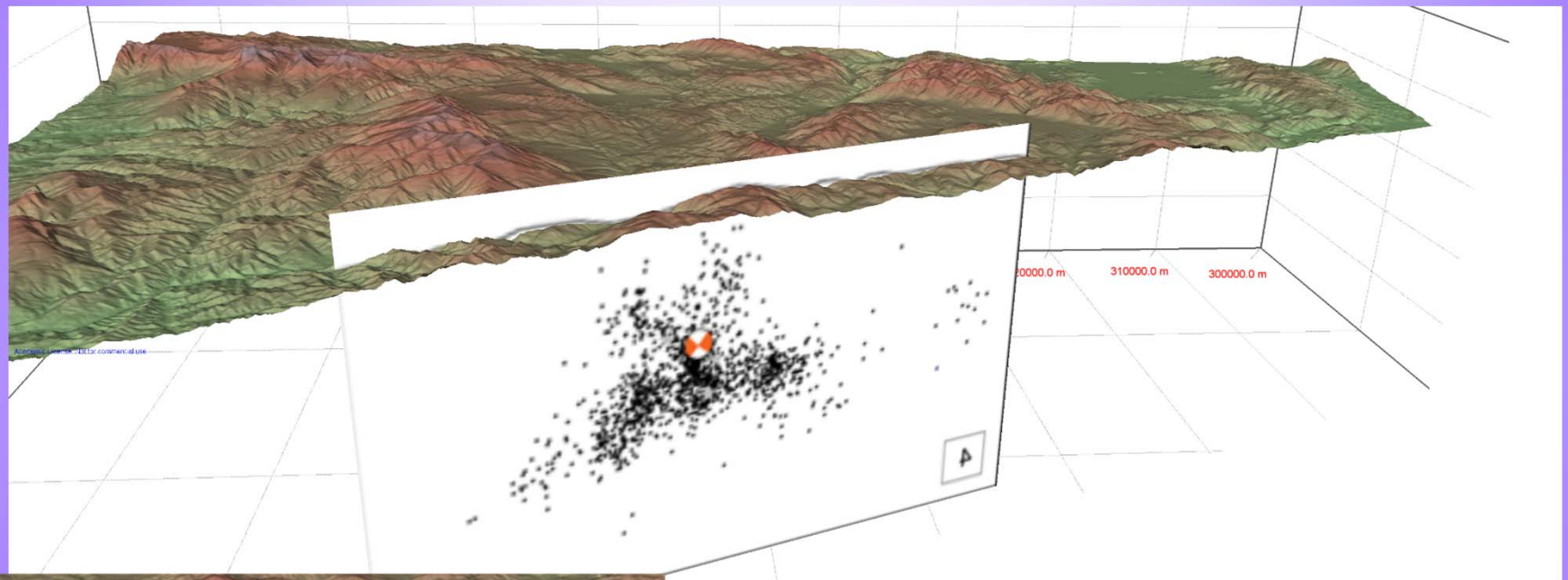
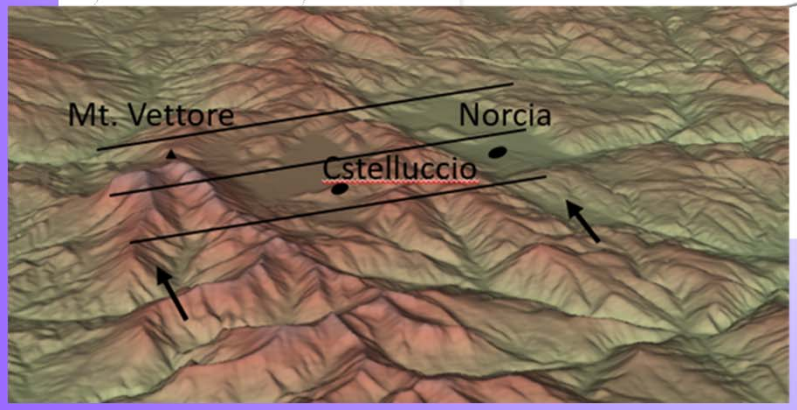
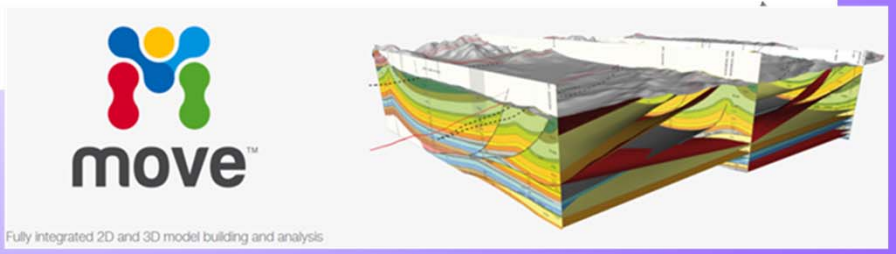
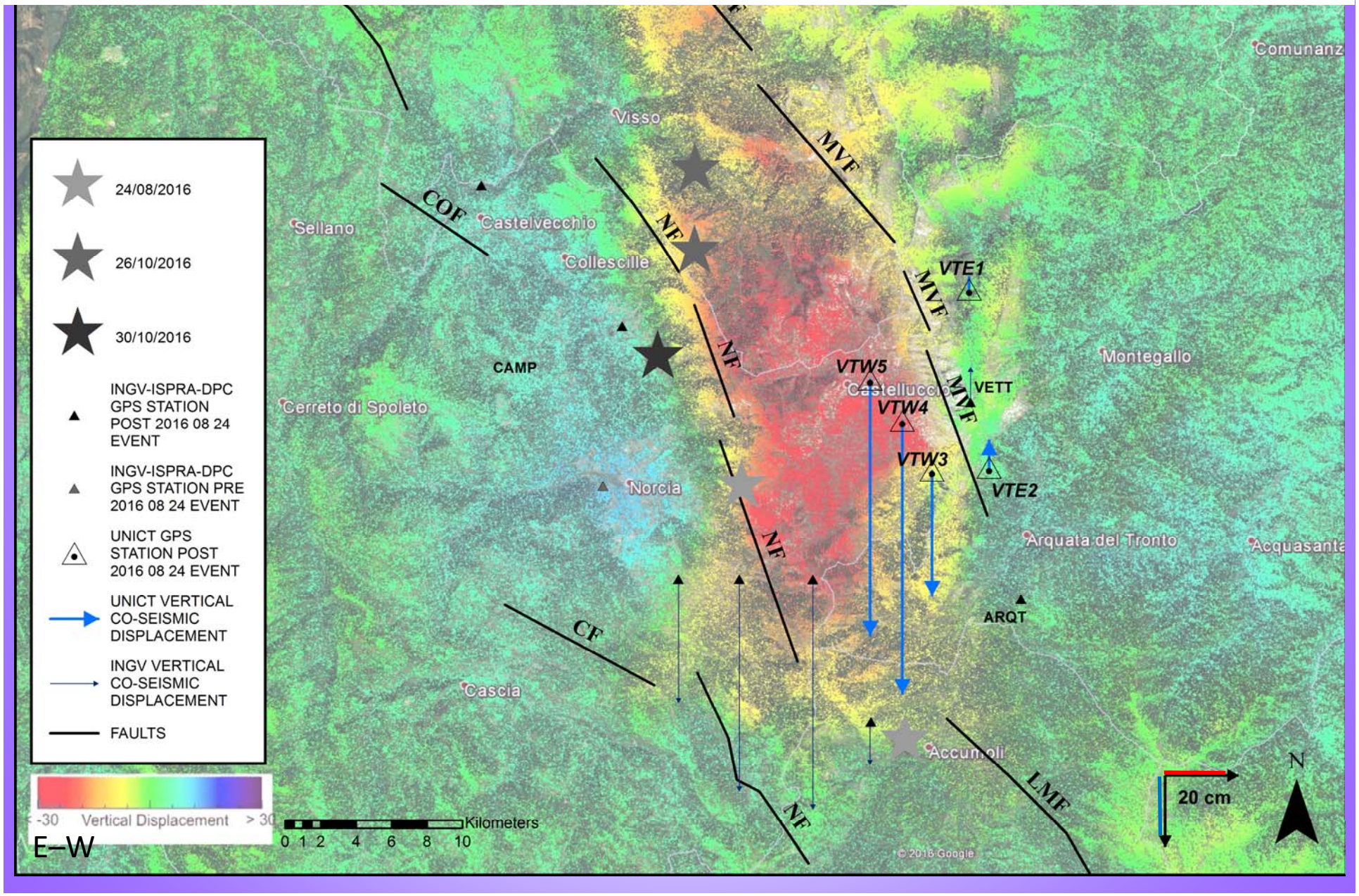


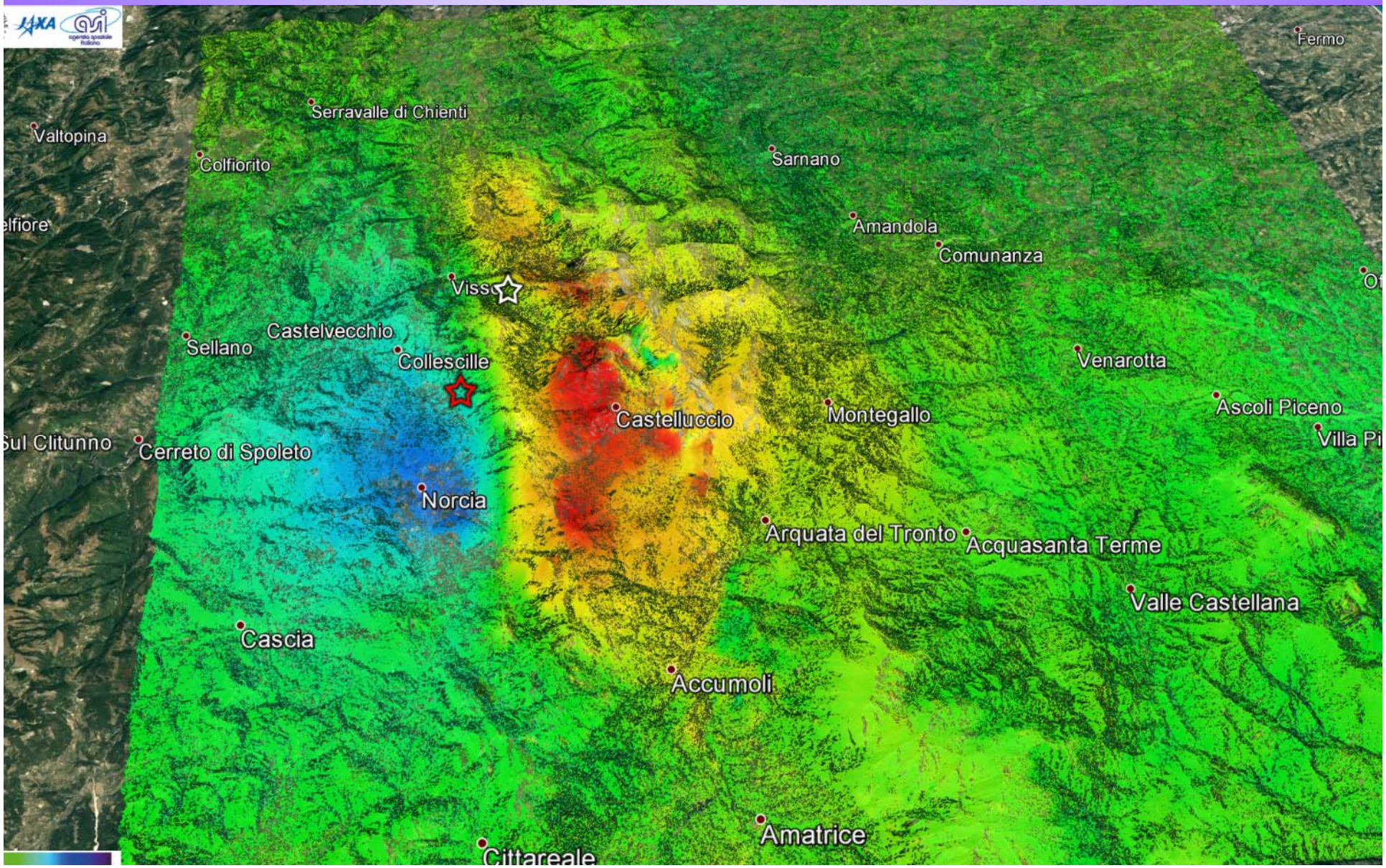




Colour-coded maps showing the E–W (a) and vertical (b) displacement distribution obtained by the DInSAR technique recorded on 26 October 2016 (pre-event images) and on 1 November 2016 (post-event images) (http://www.irea.cnr.it/index.php?option=com)

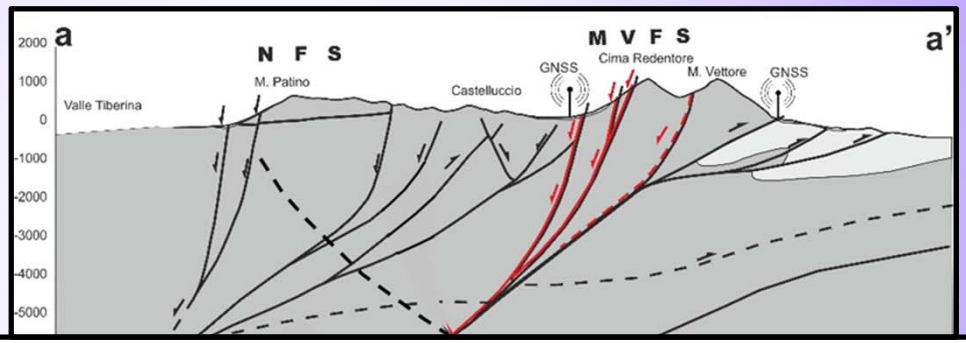


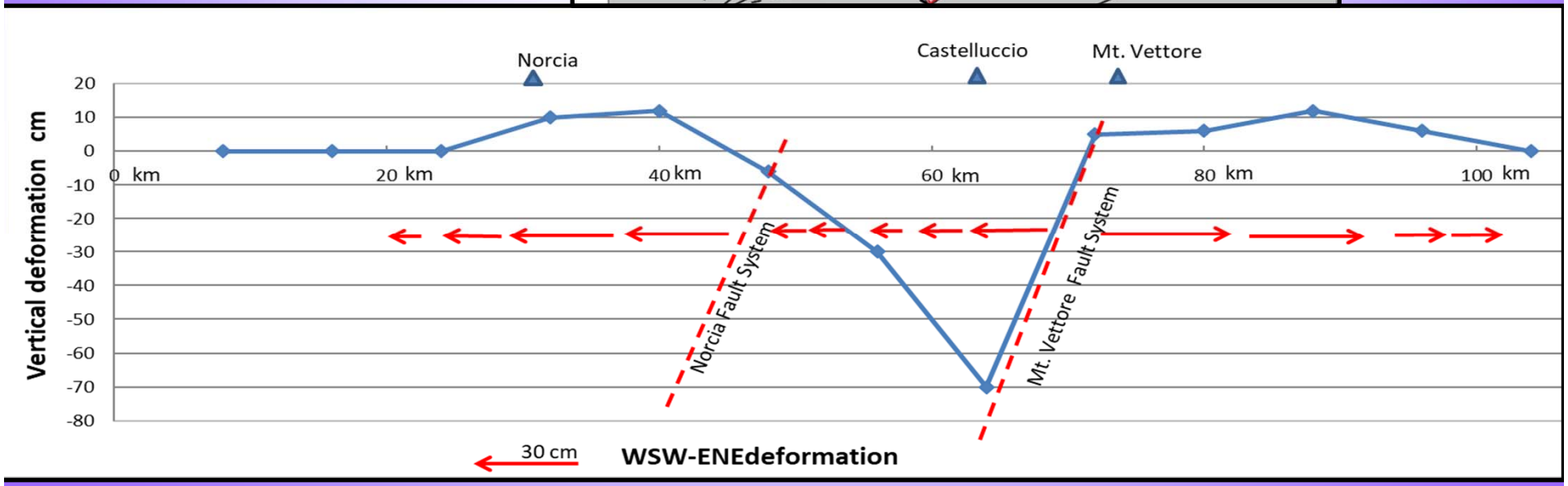
3D view - colour-coded maps showing the vertical displacement distribution obtained by the DInSAR technique recorded on 26 October 2016 (pre-event images) and on 1 November 2016 (post-event images) (http://www.irea.cnr.it/index.php?option=com)

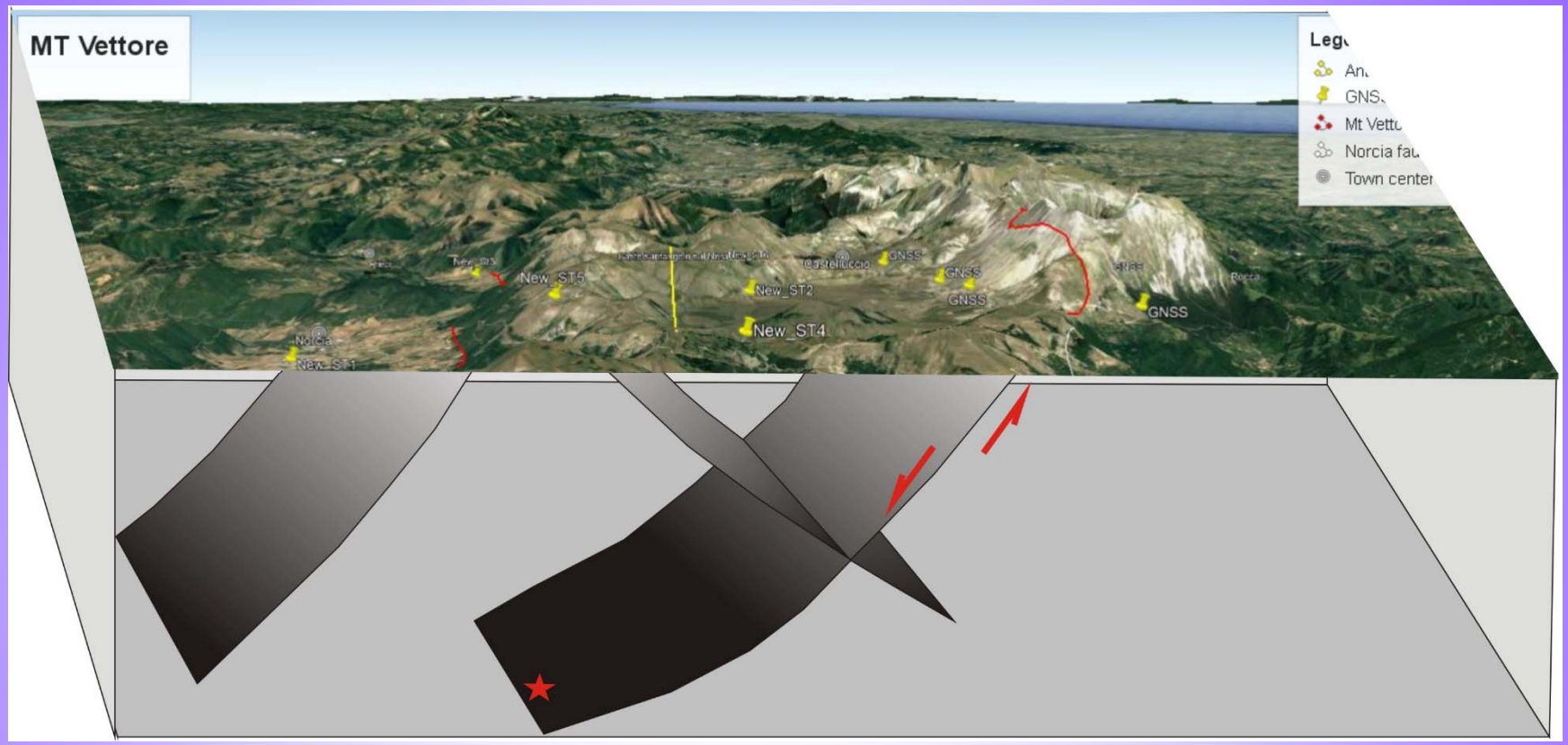


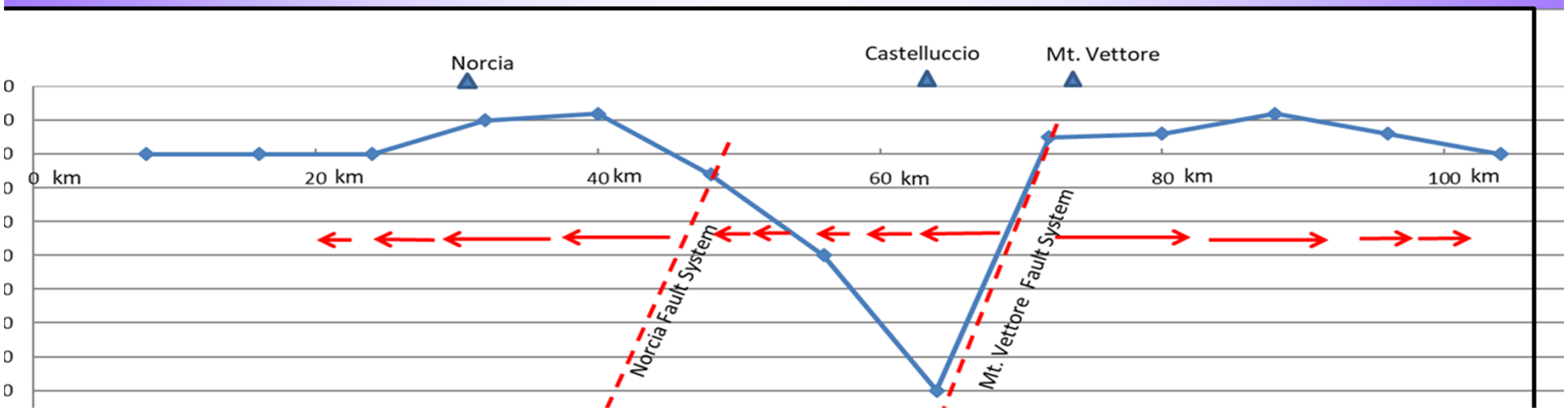
Blind antithetic fault segment

The semi quantitative deformation analysis along a schematic west-east transect, indicates on the footwall of the blind antithetic fault segment both horizontal and vertical differential deformation with maximum values of about 400 and 120 mm, respectively

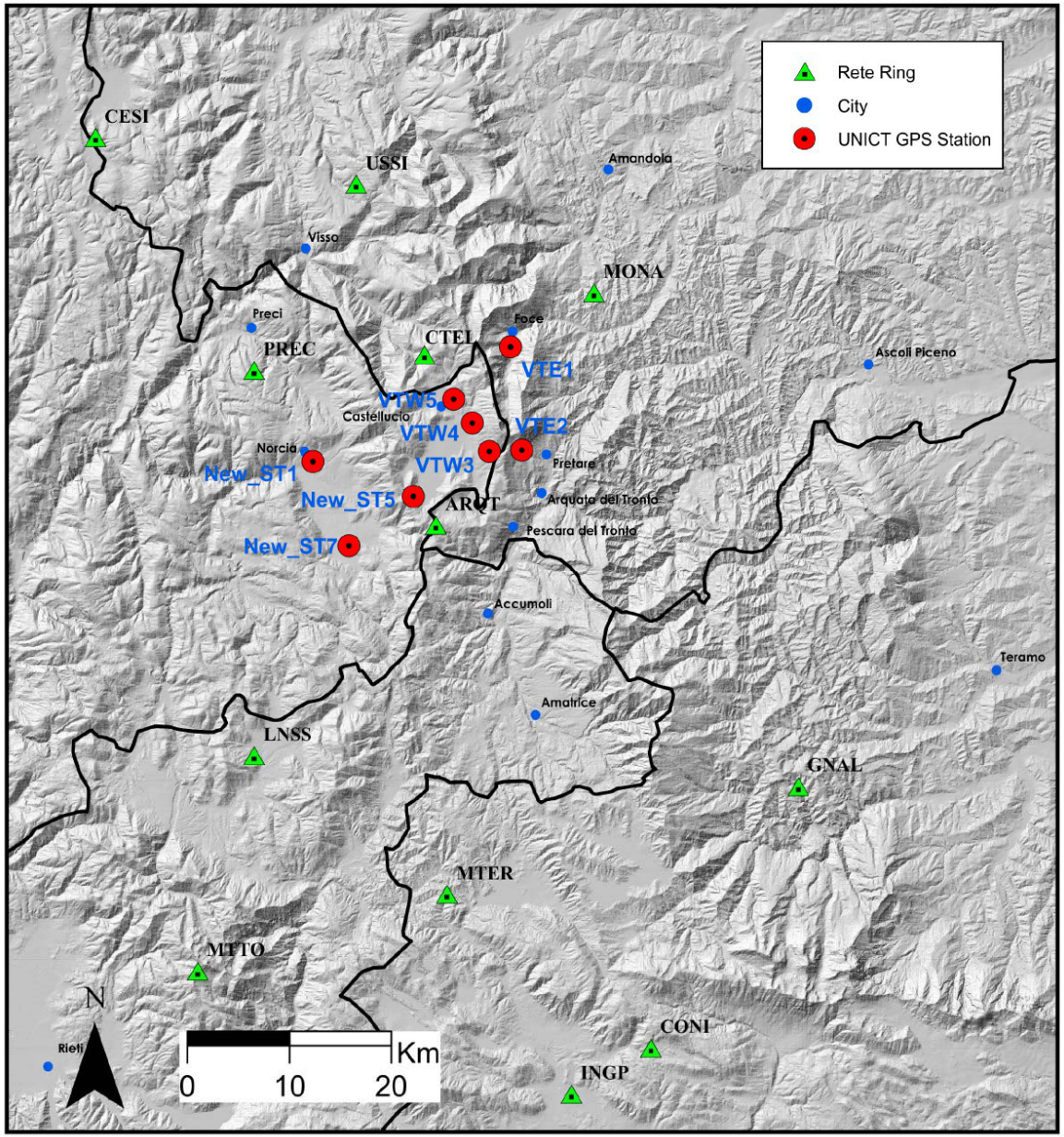





MT Vettore
Mt Vettu
Norcia fau
Town center
New_ST5
New_ST2
New_ST4
New_ST1
GNSS
GNSS
GNSS
GNSS


Norcia
Castelluccio
Mt. Vettore
0 km
20 km
40 km
60 km
80 km
100 km
Norcia Fault System
Mt. Vettore Fault System

Third campaign of measurements (25–30 October 2017)



Conclusion

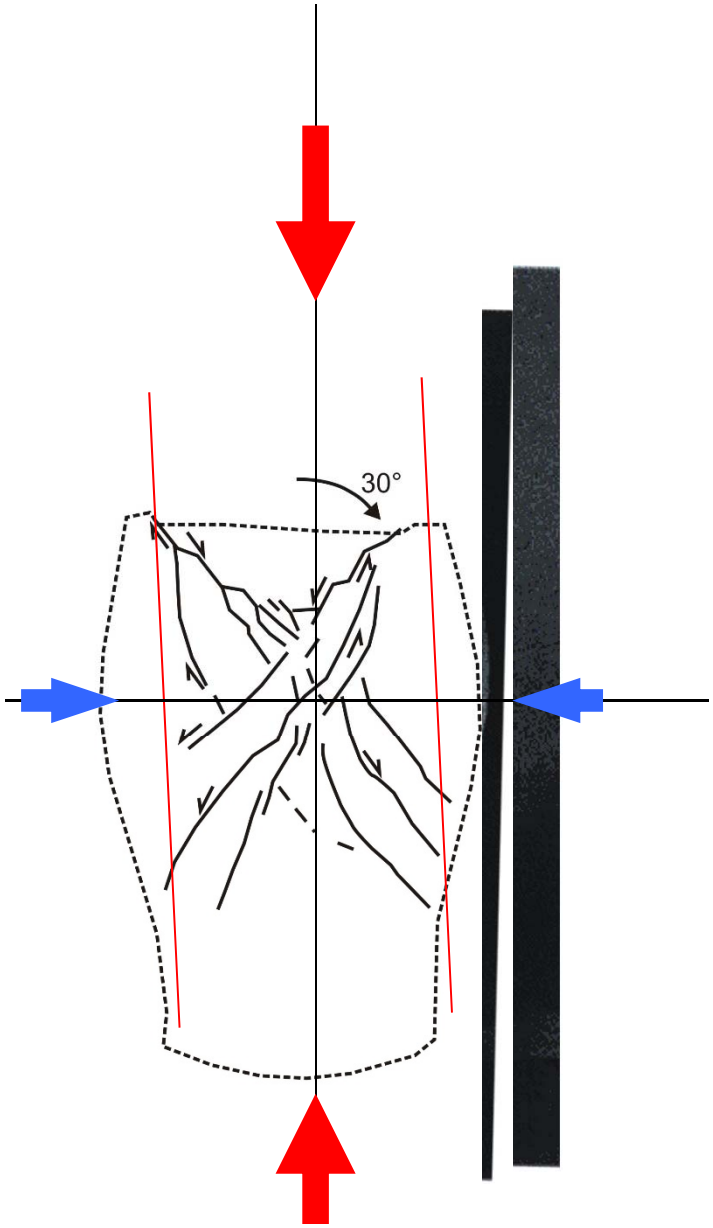
Using the GNSS technique, we investigated the ground deformation that occurred in the surroundings of the Mt Vettore fault system during the 2016 central Italy seismic sequence

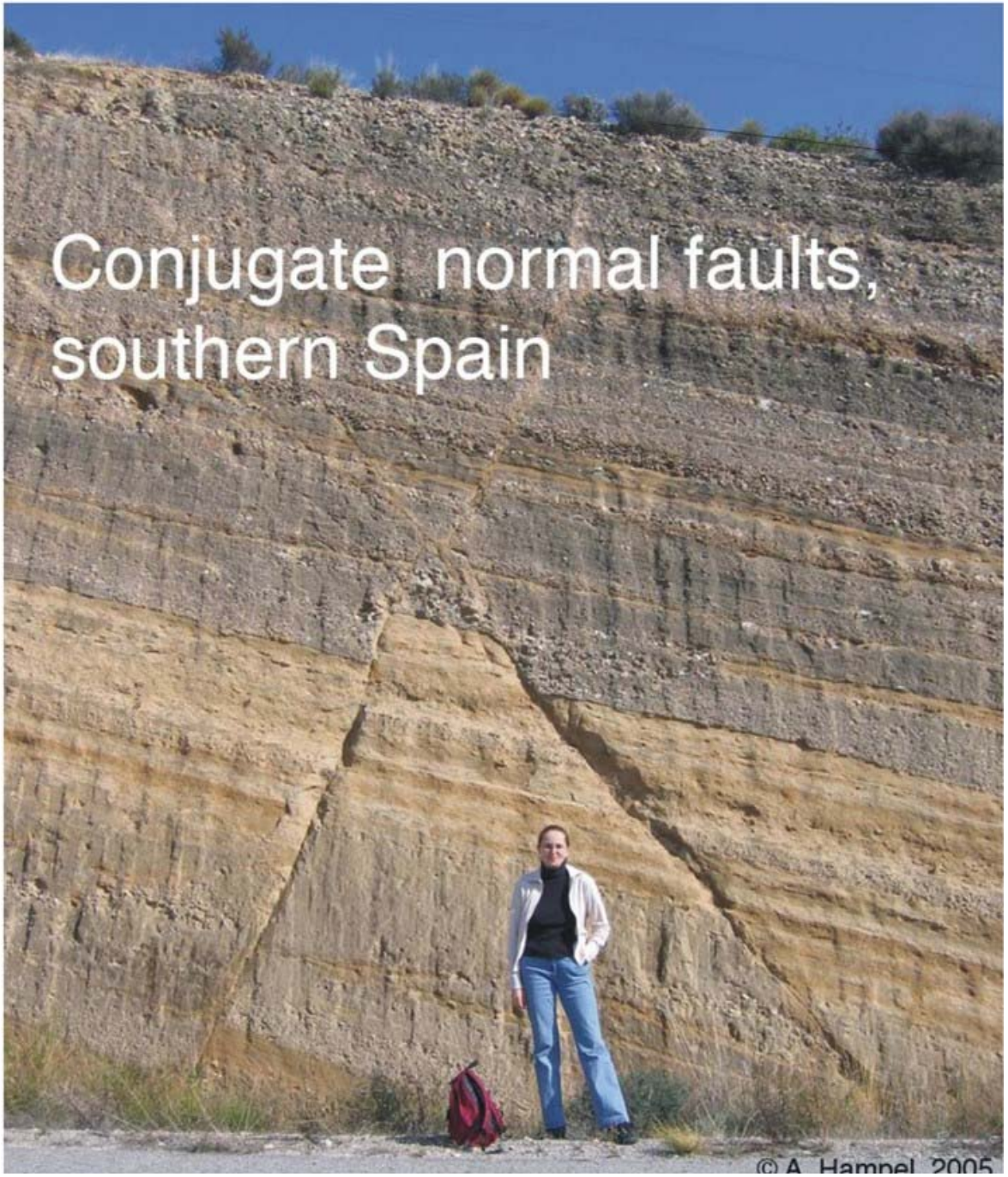
This foresight allowed us to record the co-seismic deformation and part of the post-seismic deformation of the second and third (strongest) events (Mw D 5.9 and Mw D 6.5) on 26 and 30 October 2016, respectively

We think that the blind antithetic sliding that occurred in correspondence of the Castelluccio plain released only partially the upper crustal stress, whereas in the upper part of the antithetic fault (from 2 km to the ground surface) regional stress could have been accommodated by aseismic ductile deformation along an incipient detachment within the surficial sedimentary succession.

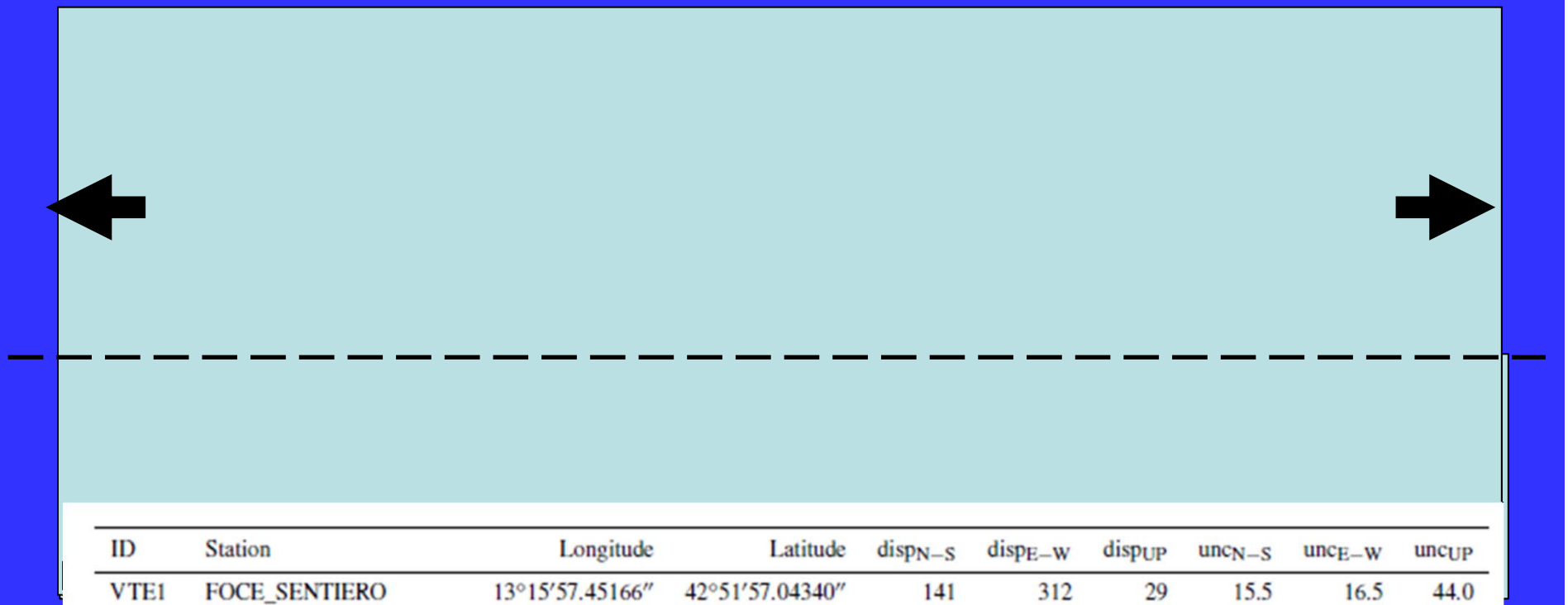
Alternatively, the deformation recorded at the surface across the antithetic fault could be still elastic and therefore it could be released by a future event

Based on these evidence and following the stress-triggering concept. In the attempt to verify this hypothesis we installed new benchmarks in strategic positions for monitoring possible pre-seismic deformation associated with the antithetic Castelluccio Fault


30°


Conjugate normal faults,
southern Spain
© A. Hampel, 2005

E-W max displacement 0,70 m



ID	Station	Longitude	Latitude	$disp_{N-S}$	$disp_{E-W}$	$disp_{UP}$	unc_{N-S}	unc_{E-W}	unc_{UP}
VTE1	FOCE_SENTIERO	13°15′57.45166″	42°51′57.04340″	141	312	29	15.5	16.5	44.0
VTE2	PRETARE	13°16′33.20959″	42°47′56.56780″	60	282	67	19.0	16.5	46.0
VTW3	QUARTUCCIOLO	13°14′46.41153″	42°47′56.57032″	198	26	−349	15.5	14.5	36.0
VTW4	COLLE_CURINA	13°13′55.01245″	42°48′59.62491″	102	288	−769	15.5	15.0	36.0
VTW5	CASTELLUCCIO_VALLE	13°12′56.20423″	42°49′54.89014″	353	418	−707	15.0	13.5	37.5

Geological and paleoseismological studies conducted by Galadini and Galli (2003) along the Mt. Vettore – Mt. Bove fault system anticipated that this active tectonicstructure was one of the main seismic gaps of the central Apennines, potentially responsible for up to M 6.5 seismic event.

Historical seismicity of study area The area hit by the 2016-2017 seismic sequence has been repeatedly struck by 5.2 < M < 6.2 earthquakes in the last 400 years, with the largest local earthquake occurring in 1639 (Io 9–10 MCS, M 6.2; Rovida et al., 2016).

Historical seismicity in central Italy Apart from the 1703 earthquake sequence (with M up to 6.9), the broader region was the locus of other damaging moderate-sized earthquakes that struck central Italy in recent times: the Mw 5.8 1979 Norcia to the west (Deschamps et al., 1984; Brozzetti & Lavecchia, 1994), the Mw 6.0 1997 Umbria-Marche (Colfiorito) earthquake sequence to the northwest (Amato et al., 1998; Boncio & Lavecchia, 2000; Ferrarini et al., 2014), and the Mw 6.1 2009 L'Aquila sequence to the southeast (Chiarabba et al., 2009; Scognamiglio et al., 2011; Chiaraluce et al., 2011; Lavecchia et al., 2012; Valoroso et al., 2013).

Surface faulting in Apennine Chain

Within the Apennine chain, evidence of surface faulting was documented after the catastrophic Ms 6.9–7.0, 1915 Avezzano earthquake (Oddone, 1915; Serva et al., 1988; Michetti et al., 1996; Galadini and Galli, 1999) as well as after the Ms 6.9, 1980 Irpinia earthquake (Westaway and Jackson, 1984; Pantosti and Valensise, 1990).

More recently, for the Mw 6.1, 2009 L'Aquila earthquake, geologic data (EMERGEO Working Group, 2010; Boncio et al., 2010; Vittori et al., 2011) documented the occurrence of surface faulting. Conversely, the occurrence of primary seismogenic surface rupture remains controversial for the Mw 6.0 1997 Colfiorito earthquake (e.g., Cinti et al., 1999; Cello et al., 2000; Basili et al., 1998; Mildon et al., 2016)

Coseismic surface ruptures in the study area were observed following the Mw 6.0 24 August 2016 normal-faulting Amatrice earthquake (Figure 1). Ruptures trending ~N155° with prevalent dip-slip kinematics, SW side down (average dip-slip displacement of about 0.15 m) were mapped for more than 5 kilometers along the southern portion of the VBFS (EMERGEO Working Group, 2016; Lavecchia et al., 2016). These coseismic features were interpreted as the result of primary surface faulting by Livio et al., 2016, Aringoli et al., 2016 and Pucci et al., 2017, while much less clear (1-2 cm of surface displacement) and discontinuous coseismic features were recorded along the Laga Mts. fault system by most of the research groups working in the area

Geological Map of Umbria-Marche central Apenines

Umbria-Marche Sabine Apenines including calcareous, marly-calcareous and marly basin succession (Upper Trias-Miocene p.p.)

Lazio-Abruzzi Apenines including carbonate plataform/slope succession (Upper Trias-Miocene p.p.)

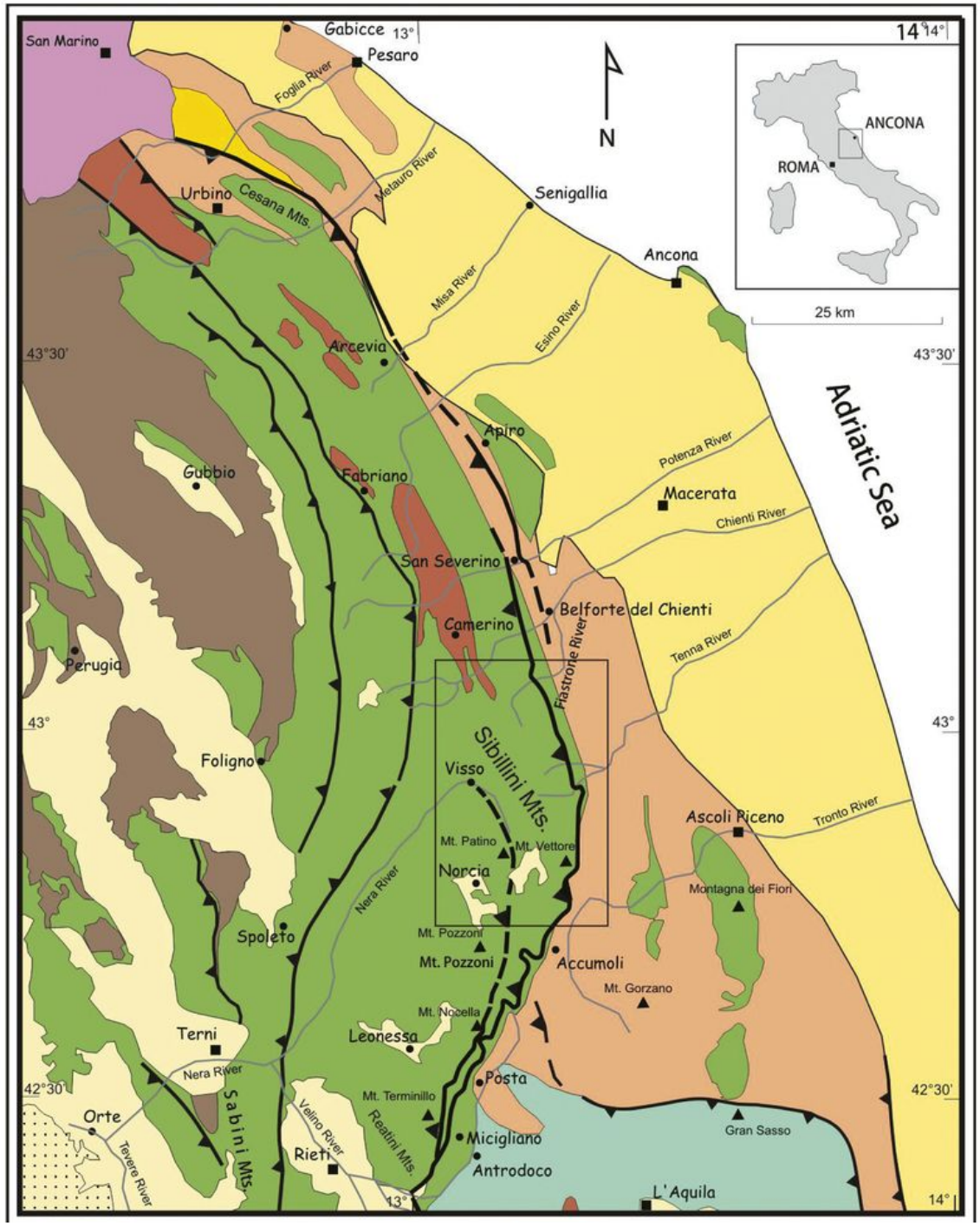
Miocene siliciclastic turbiditic deposits of the pre-Appennine area (Burdigaglianp.p. – Tortonian p.p.)

Miocene siliciclastic turbiditic deposits of the intra-Appennine area (Serravalian p.p. – Messinian p.p.)

Miocene siliciclastic turbiditic deposits of the foothils (Messinian p.p.)

Plio-Pleistocene peri-Adriatic succession

Post-orogenic marine and continental Plio-Quaternary deposits (a), and volcanic deposits of the Latium domain (b)



Following the 26 October 2016, Mw 5.9 Visso earthquake (Figure 1), only sparse and discontinuous (each up to few hundred of meters long) ground ruptures were observed for more than 10 km along the northern portion of the VBFS (approximately between the villages of Cupi and Macchie, Figure 1), with average vertical displacement of about 0.15 m. Similar to the preceding event, the Visso earthquake surface ruptures show an average N145° strike and prevalent dip-slip kinematics, with the SW side down. Noteworthy, the field survey of the coseismic effects of the Visso event was not fully achieved having been
overprinted by the occurrence of the 30 October Mw 6.5 mainshock.

The 30 October mainshock occurred with an epicenter close to the town of Norcia (Figure 1), and produced surface coseismic effects on the natural environment over a ~450 km2 wide area. The coseismic effects mainly consist of primary surface ruptures (those directly related to the earthquake fault - Figures 2 and 3), together with other coseismic effects related to ground shaking (e.g. landslides, hydrological variations, liquefactions, etc.)

Primary surface ruptures An almost continuous NW-SE pattern of primary surface ruptures was observed for an overall extent of about 28 km along the VBFS, clearly reactivating all the 24 August and, partially, the 26 October 2016 ground breaks

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Surface rupture displacement exhibits predominantly normal dip-slip kinematics, with an average 0.3 m vertical offset. In general, the ruptures are organized in a systematic pattern of dominantly synthetic (west side down) and subordinately antithetic (east side down) strands. Notably, the ~N155° striking alignment of ground ruptures typically follows the trace of mapped faults (Pierantoni et al., 2013 and references therein), although in some cases, the coseismic ruptures occurred along fault splays that were not previously recognized

Dettagli TDMT

Campo	Valore
Magnitudo	6
Momento Scalare	1.06622E+25 dyne-cm
Profondità calcolata	5 km
Qualità	Aa
Variance Reduction	55.02%
Doppia Coppia	98%
CLVD	2%
ISO	0%
Modello utilizzato	CIA
Mode	manual
Status	reviewed

Componenti Momento Tensore

Componente	Valore
Mrr	-1.06092883E+25
Mtt	2.2822264E+24
Mpp	8.3270619E+24
Mrt	-3.104816E+23
Mrp	1.4210326E+24
Mtp	-4.2453358E+24

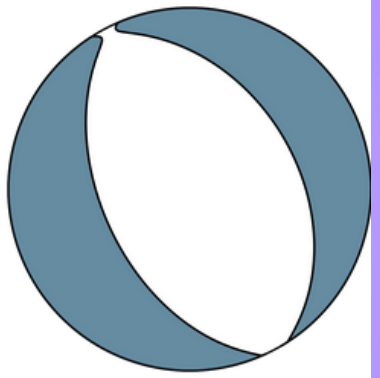
Piani Nodali

Nome	Strike	Dip	Rake
PN1	155	49	-87
PN2	331	41	-93

psmeca (Documentazione GMT)

13.2232 42.7063 5 155 49 -87 331 41 -93 1.06622 25 13.7232 43.2063

Meccanismo Focale



Riferimenti TDMT

Maggiori informazioni e riferimenti