



**The Abdus Salam  
International Centre for Theoretical Physics**



**2142-12**

**Advanced Conference on Seismic Risk Mitigation and Sustainable  
Development**

*10 - 14 May 2010*

**The geological evaluation of the seismic hazard in an area**

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ICTP Conference on Seismic Risk Mitigation, Trieste 10-14 May 2010



# The geological evaluation of the seismic hazard in an area

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Earthquakes produces effects on the ground/environment, and this is why the geologists can talk a lot about them

The goods geologist are able to recognize them

The good geologists are also able to estimate them and therefore to be very useful for the seismic hazard estimation



PRIMARY EFFECTS

		PRIMARY EFFECTS		
		SURFACE RUPTURES		TECTONIC UPLIFT/SUBSID
		ESI-2007	Offset	Length
OBSERVED	I-III			
	IV		ABSENT	ABSENT
DAMAGING	V			
	VI			
DESTRUCTIVE	VII	Rare and local		Permanent ground dislocations (< 10 cm)
	VIII	cm, hm		< 1 m
DESTRUCTIVE VERY DESTRUCTIVE	IX	dm, km		< 10 m
	X			
DEVASTATING	XI	metric, 10-100 km		> 10 m
	XII	> 100 km		

A

B

C



# SURFACE FAULTING



1915, January 13,  
Fucino earthquake,  
Italy



**MAXIMUM DISPLACEMENT**



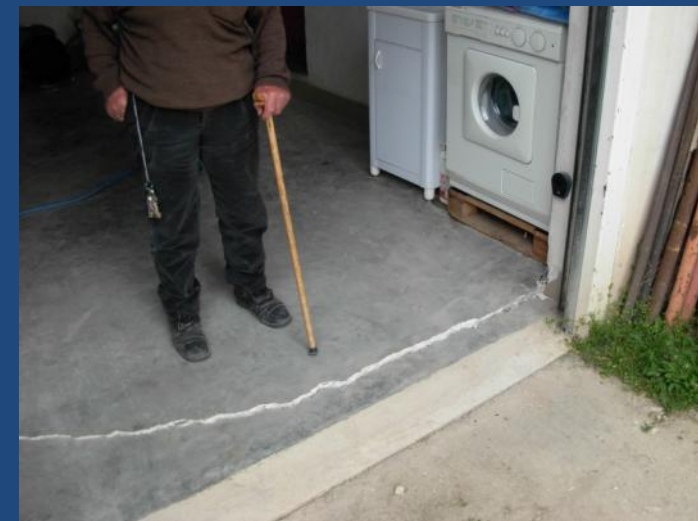
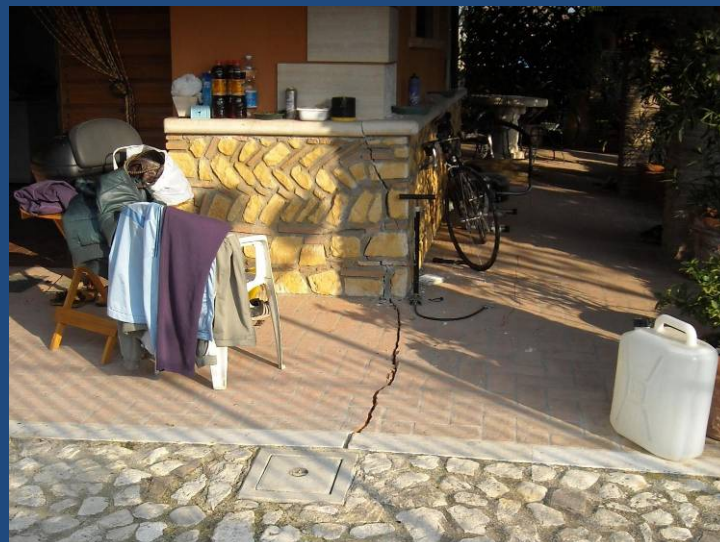
1980, November 23, Irpinia-Basilicata earthquake,  
Italy

# ICTP Conference on Seismic Risk Mitigation, Trieste 10-14 May 2010

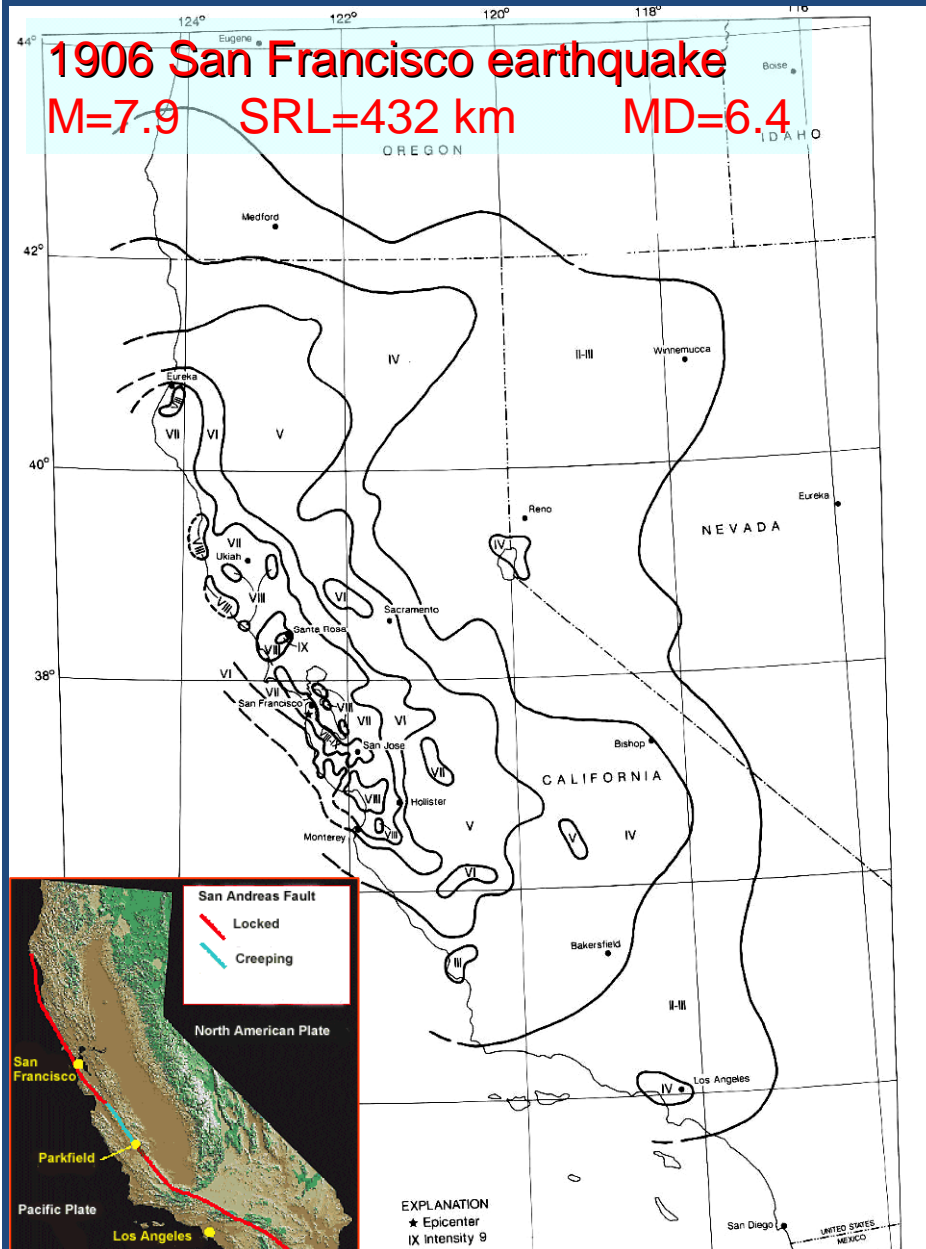


2009, April 6, L'Aquila earthquake, Italy





2009, April 6, L'Aquila earthquake, Italy

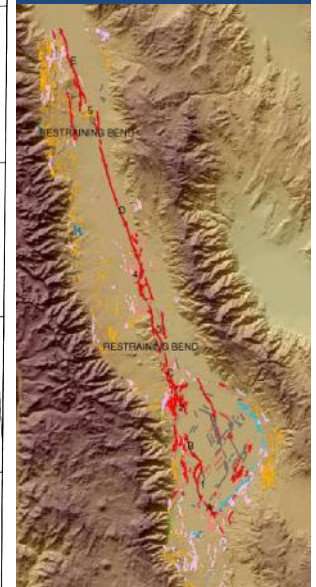


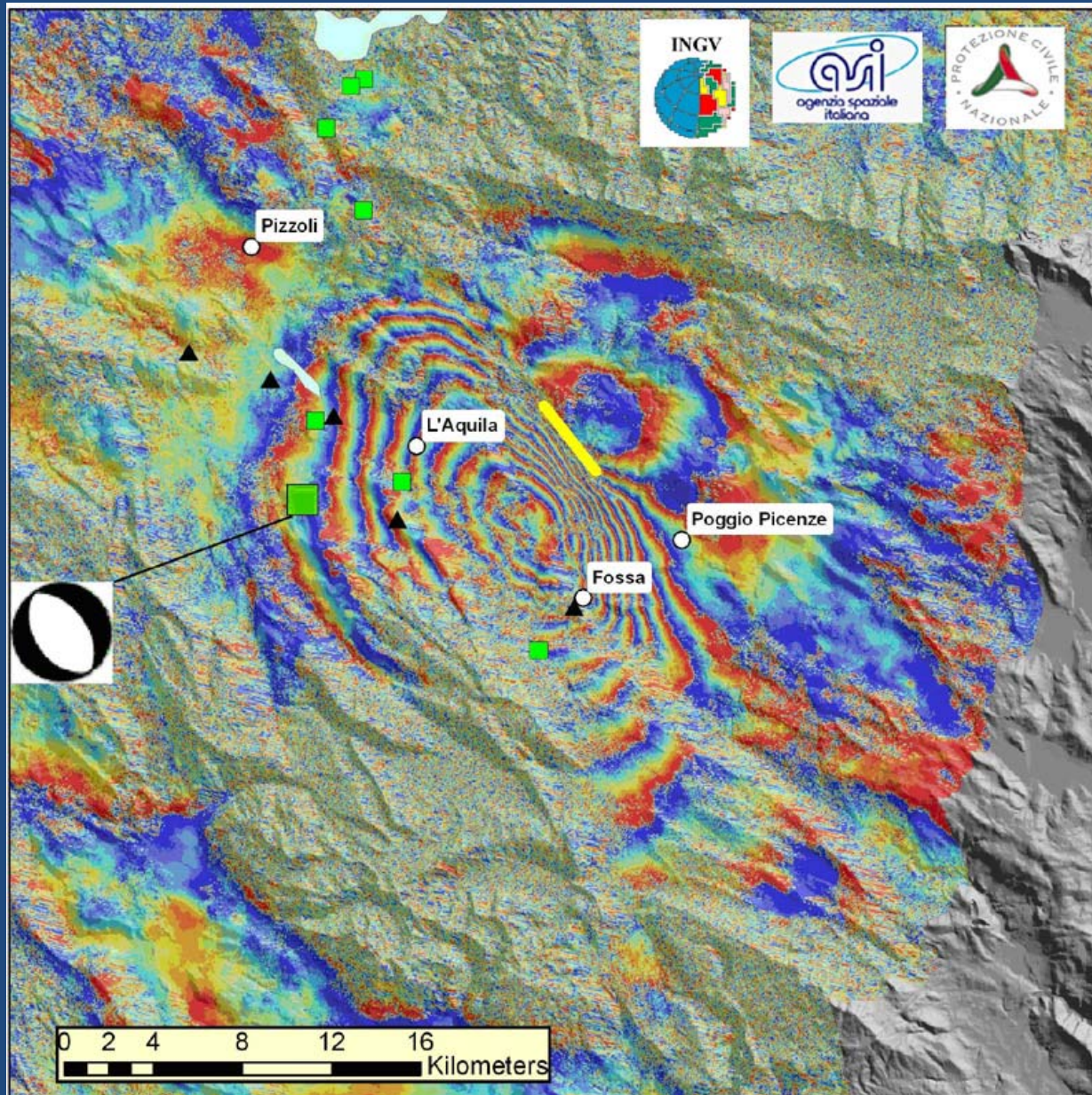
# 26.03.1872 Owens Valley (California, USA)

M=7.6

SRL>110 km

MD≥10m





*Interferogramma ENVISAT calcolato a partire da una coppia di immagini 1 Febbraio 2009 – 12 Aprile 2009. Il Massimo abbassamento è di circa 25 cm tra L'Aquila e Fossa (ogni frangia corrisponde a circa 2.5 cm). I quadratini verdi indicano il mainshock e gli aftershocks con  $M_w > 5$ ; la linea gialla indica la fagliazione superficiale a Paganica; i triangoli marcano la posizione dei caposaldi GPS utilizzati per il confronto con il SAR.*



## TECTONIC UPLIFT



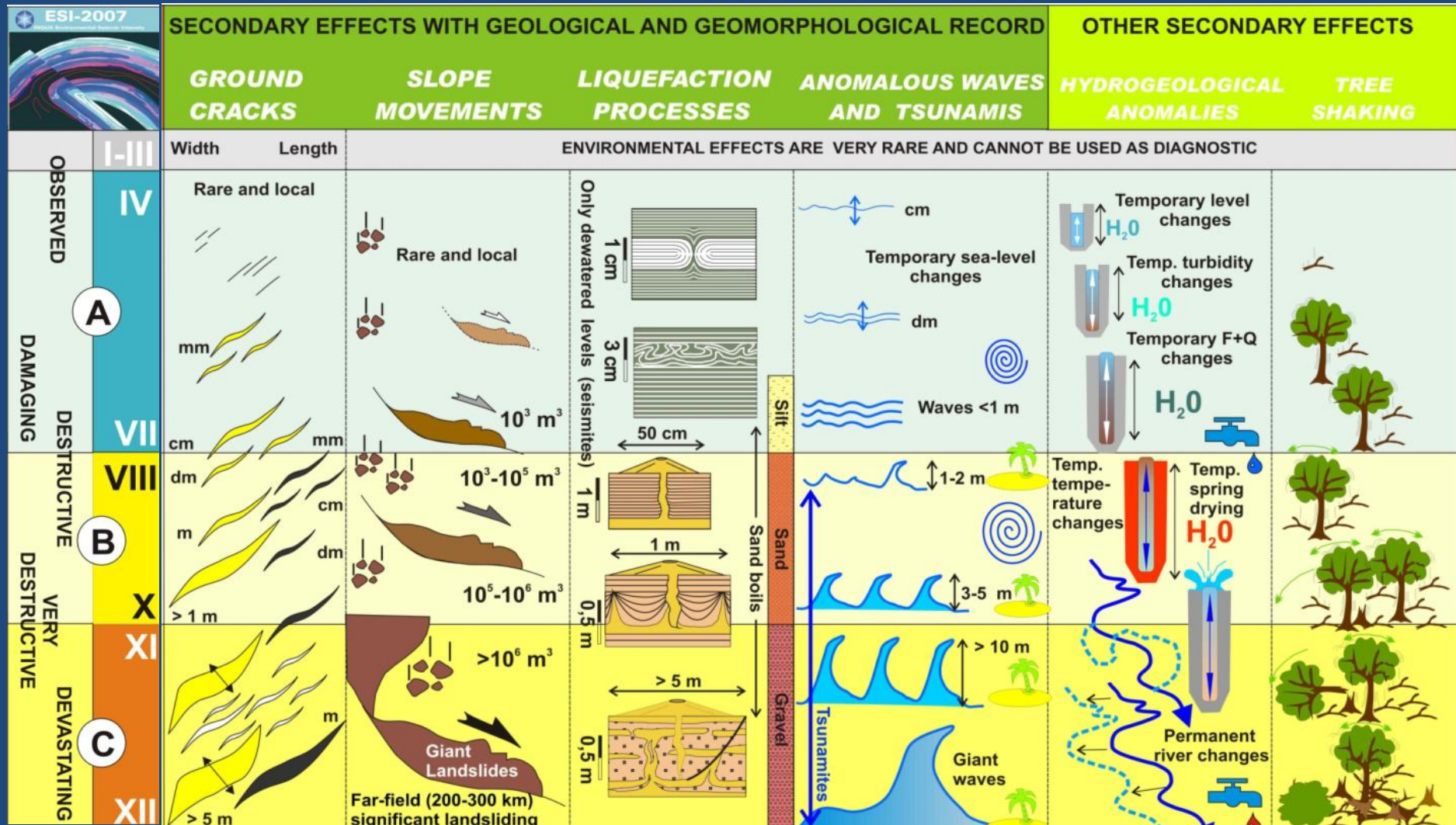
**1811-1812 New Madrid (USA) earthquakes ( $M_w$  between 7.2 and 8.3).**

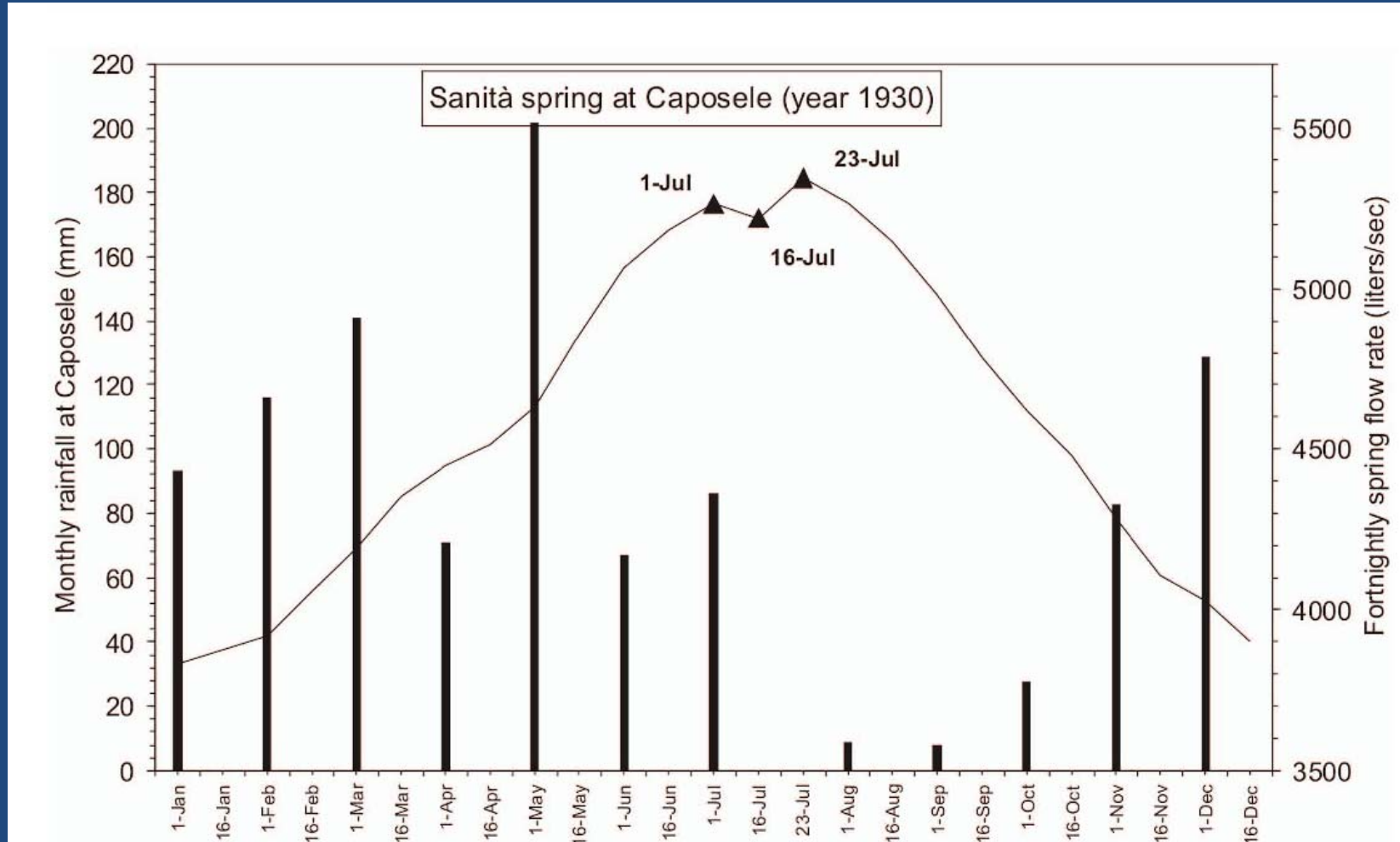
Reelfoot Lake, Tennessee, USA.

This lake was formed by coseismic uplift triggered by a blind thrust that caused the inundation of the forested area in foreground.



**SECONDARY EFFECTS**





1930 Irpinia earthquake: Hydrological anomaly recorded at the Sanità spring, Caposele.



## SLOPE MOVEMENTS



**January 25, 1999, Armenia,  
Colombia earthquake ( $M = 6.1$ ).**  
Seismically induced landslide at  
Cristales, Cajamarca.



**November 23, 1980 Irpinia-Basilicata,  
Italy earthquake ( $M_s = 6.9$ ).**  
S. Giorgio La Molara: coseismic  
reactivation of a landslide





**July 12, 2004 Kobarid, Slovenia earthquake ( $M_d = 5.1$ )**  
Two small landslides along the Kobarid – Bovec road.



## ROCK FALLS



**August 6, 2002 Bullas, Spain earthquake (VI MSK; 5.0 mb)**

**November 24, 2004, Salò, Italy earthquake (MI 5.2).**



2009 April 6<sup>th</sup> L'Aquila earthquake

Rock fall at Fossa



2009 April 6 ,  
L'Aquila earthquake



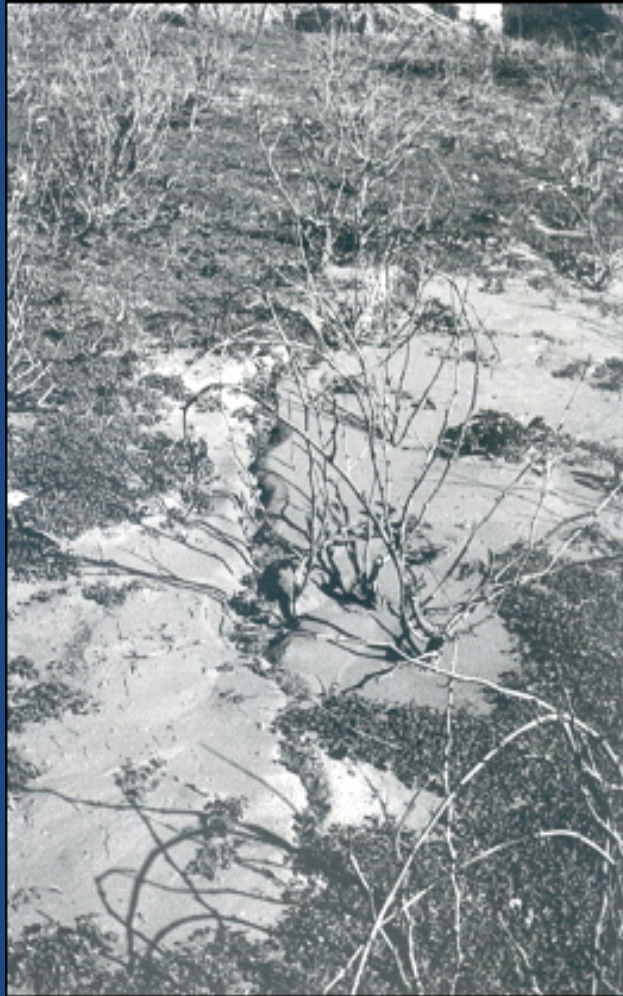
Rock fall at Stiffe



Rock fall at Bazzano



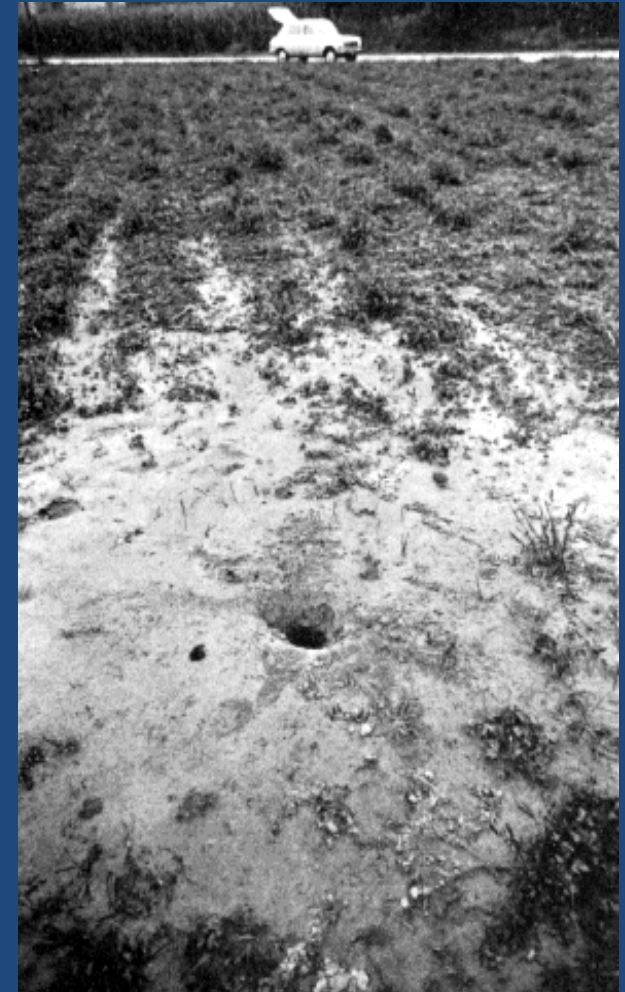
# LIQUEFACTIONS



15.01.1968  
Ms 5.9 Belice



06.05.1976, Ms 6.5 Friuli





**March 3, 1872 Owens Valley, California, USA earthquake ( $M_s$  7.6).**  
Owens Lake: aligned sand blows in the playa of the lake, dried in 1926.



**November 22, 1995 Nuweiba, Sinai, earthquake, ( $M_w$  = 7.2).**  
Gulf of Elat – Aqaba: An about one meter sand blow displaying coarse sand on its surface, suggesting that coarser material might have been ejected during a late liquefaction phase.



2009 April 6 ,  
L'Aquila earthquake



Liquefaction at Vittorito



## GROUND COLLAPSES



**March 27, 1964 Alaska earthquake (Mw = 9.2).**  
Collapse pits at Kasilof formed after eruptions of ground water and sand. The pit in the foreground is about one meter in diameter.



**August 14, 2003, Lefkada, Ionian Sea, Greece, earthquake (Mw 6.2).**  
Ground crater opened in the sandy beach of Agios Nikitos.





2009 April 6<sup>th</sup> ,  
L'Aquila earthquake

Ground failures ,  
Lake Sinizzo





Effects	Intensity	
	MSK	MCS
-Cracks in saturated soil and/or loose alluvium up to 1 cm,	VI	
- in saturated soil and/or loose alluvium a few cm,	VIII	VIII
- in saturated soil and/or loose alluvium up to 10 cm,	IX	
- in saturated soil and/or loose alluvium a few dm up to one m	X	X
- on road backfills and on natural terrigenous slopes over 10 cm	VII - IX	VIII
- on the dry ground or on asphalted roads	VII – XI	X – XI
-Faults in terrigenous terrains and in rocky terrains	XI - XII	XI
-Liquefaction and or mud volcanoes and/or susidence	IX – X	X – XI
-Landslides in sand or gravel dykes	VII – X	VII
- in terrigenous slopes	VI – XI	X - XI
-Rockfalls	IX – XII	X – XI
-Clouding in the closed water bodies and formation of waves	VII – IX	VII – VIII
-Water bodies new formation	VIII – XII	XII
-Flooding	X – XII	X
-Water level variation of the groundwater level and the flow rate of springs	V - X	VII - X



**CHART OF THE INQUA ENVIRONMENTAL SEISMIC INTENSITY SCALE 2007 - ESI 07** (Modified from Silva et al., 2008 and Reicherter et al., 2009)

ESI-2007	PRIMARY EFFECTS		SECONDARY EFFECTS WITH GEOLOGICAL AND GEOMORPHOLOGICAL RECORD				OTHER SECONDARY EFFECTS		AFFECTED AREA AND TYPE OF RECORD		
	SURFACE RUPTURES	TECTONIC UPLIFT/SUBSID	GROUND CRACKS	SLOPE MOVEMENTS	LIQUEFACTION PROCESSES	ANOMALOUS WAVES AND TSUNAMIS	HYDROGEOLOGICAL ANOMALIES	TREE SHAKING	Affected AREA	Type of RECORD	
I-III	Offset	Length	Width	Length	ENVIRONMENTAL EFFECTS ARE VERY RARE AND CANNOT BE USED AS DIAGNOSTIC						
OBSERVED DAMAGING DESTRUCTIVE	IV	ABSENT	ABSENT	Rare and local	Rare and local	Only dehydrated levels (seismites)	cm Temporary sea-level changes	Temporary level changes Temp. turbidity changes Temporary F+Q changes		Rare and local	Geological frequent and exceptionally geomorphological
	VII	Rare and local	Permanent ground dislocations (< 10 cm)	mm	10 <sup>3</sup> m <sup>3</sup>	1 cm 3 cm 50 cm	dm Waves < 1 m		● Local within epicentral zone ○ 1 km <sup>2</sup> ● 10 km <sup>2</sup>		
DAMAGING DESTRUCTIVE VERY DESTRUCTIVE	VIII	cm	< 1 m	dm	10 <sup>3</sup> -10 <sup>5</sup> m <sup>3</sup>	1 m	1-2 m	Temp. temperature changes Temp. spring drying		● 100 km <sup>2</sup> ● 1,000 km <sup>2</sup> ● 5,000 km <sup>2</sup> ● 10,000 km <sup>2</sup> ● 50,000 km <sup>2</sup>	Geological and geomorphological characteristic and frequently geomorphological
	X	dm	< 10 m	m	10 <sup>5</sup> -10 <sup>6</sup> m <sup>3</sup>	0.5 m	3-5 m				
DESTRUCTIVE VERY DESTRUCTIVE DEVASTATING	XI	metric	> 10 m	> 1 m	> 10 <sup>6</sup> m <sup>3</sup>	0.5 m	> 10 m	Permanent river changes			
	XII	> 100 km	> 10 m	m	Far-field (200-300 km) significant landsliding	> 5 m	Tsunamis Giant waves				
DESCRIPTION & ICONS	Dip and strike-slip offset of coseismic ruptures	Permanent ground dislocation	Width and length of cracks and fractures in soils and rocks	Bulk volume of mobilised material	Dimension of liquified levels and sand boils	Transitory sea-level changes, standing waves and Tsunamis	Base-level changes in springs, rivers, aquifers	Tree branches and tree-trunk falling, rupture, etc...			

**KEY REFERENCES**

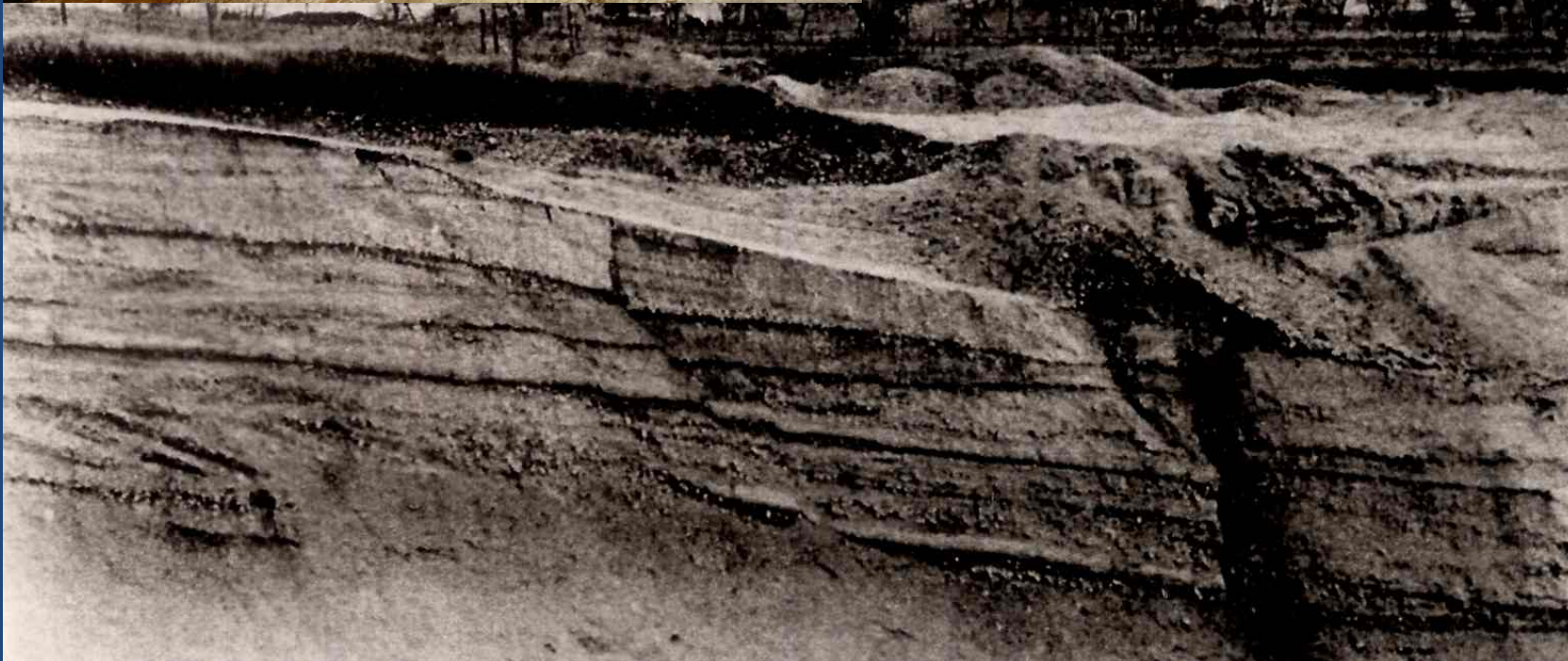
- Michetti et al., 2007. Environmental Seismic Intensity scale - ESI 2007. Memorie Descrittive della Carta Geologica d'Italia, 74. Servizio Geologico d'Italia, APAT, Rome, Italy
- Silva et al., 2008. Catalogue of the geological and environmental effects of earthquakes in Spain in the ESI-2007 Macroseismic scale. Cong. Geol. Esp. Gran Canaria, Spain
- Reicherter, K., Michetti, A.M., Silva, P.G., 2009. Paleoseismology: Historical and Prehistorical Record of Earthquake Ground Effects. Geol. Soc. London Spec. Publ. 316. 324 pp. GSL Publishing Hous, London, UK.







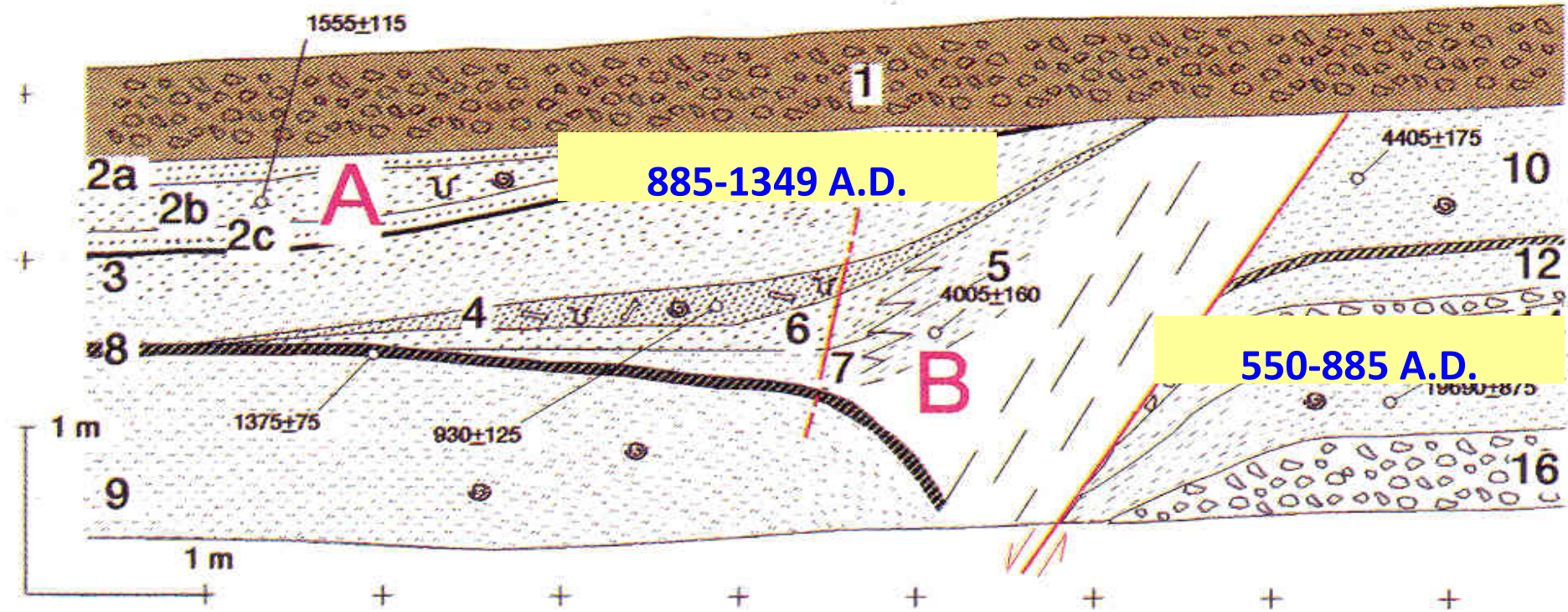
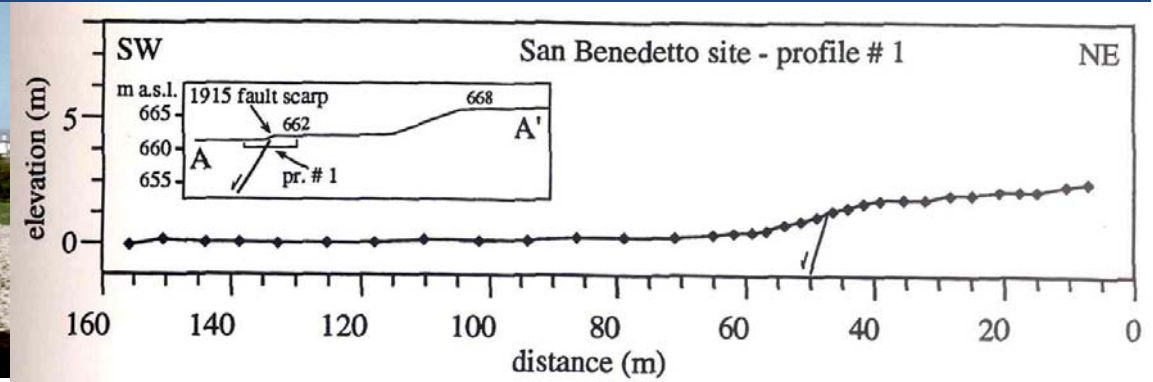
Paleoseismic record in the surroundings of the 1915 Fucino surface faulting

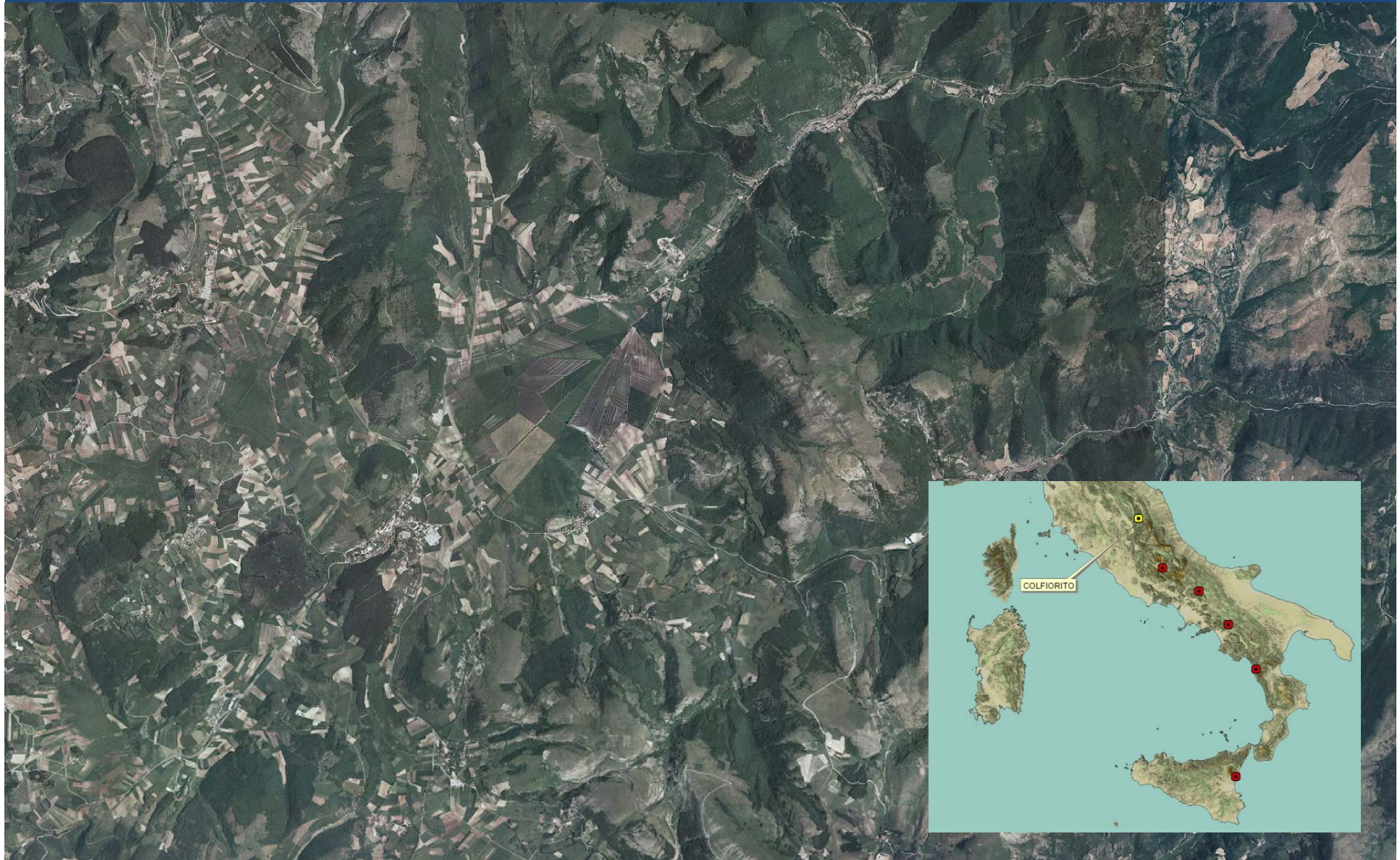




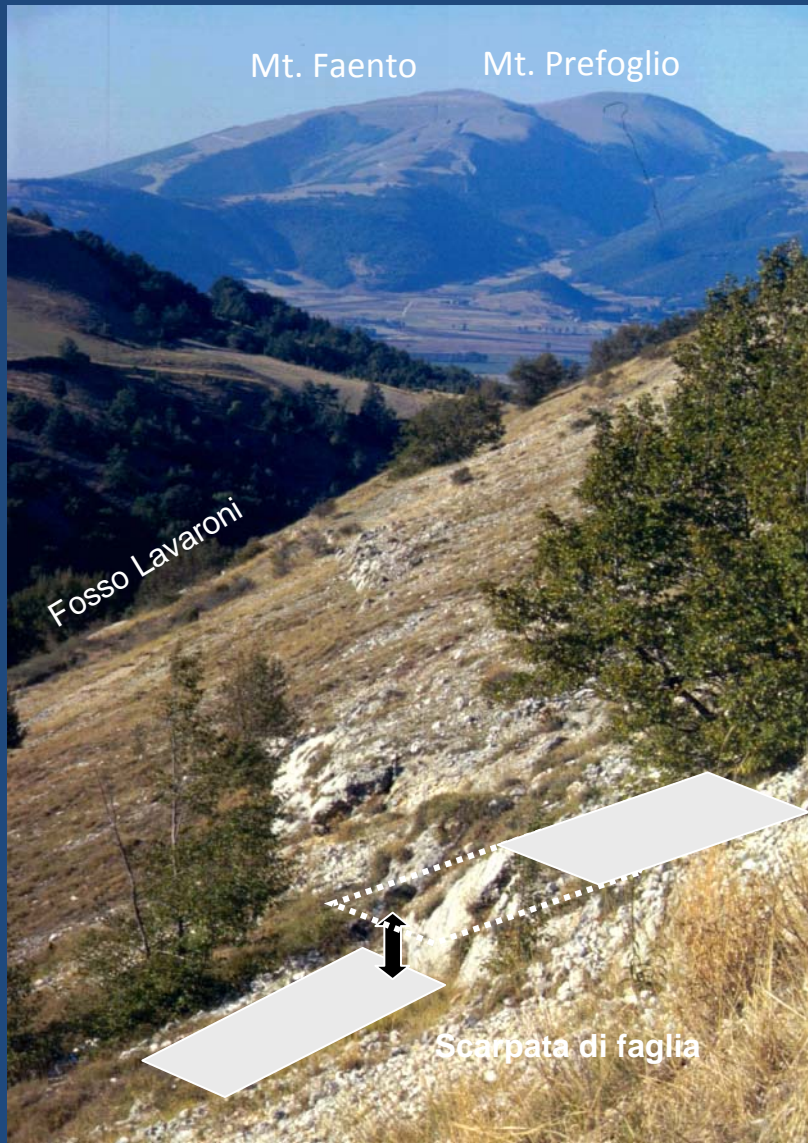


Trench investigations along the 1915 Fucino fault scarp

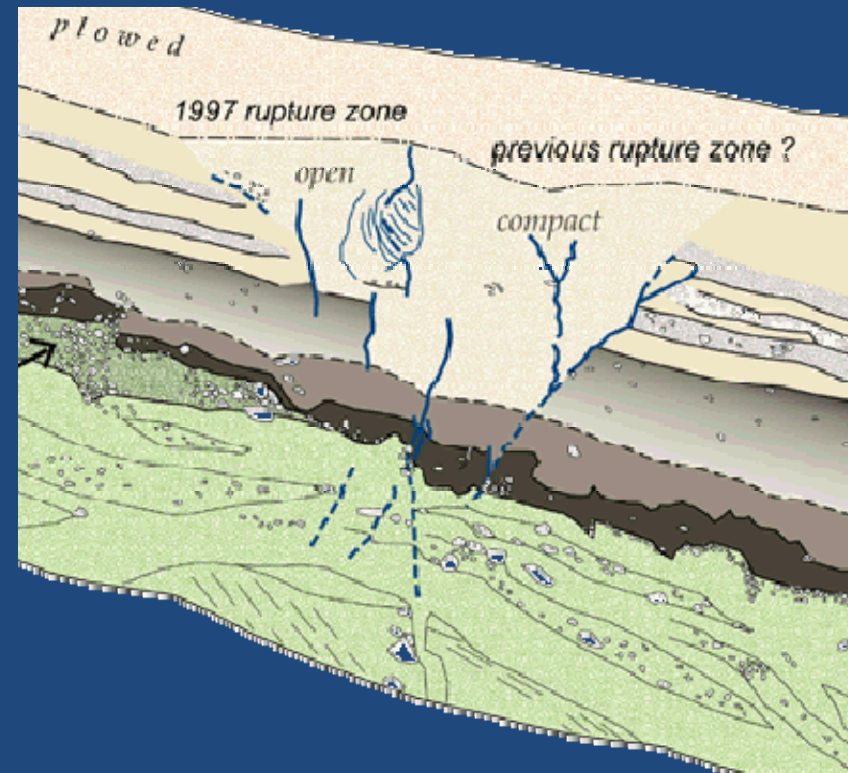
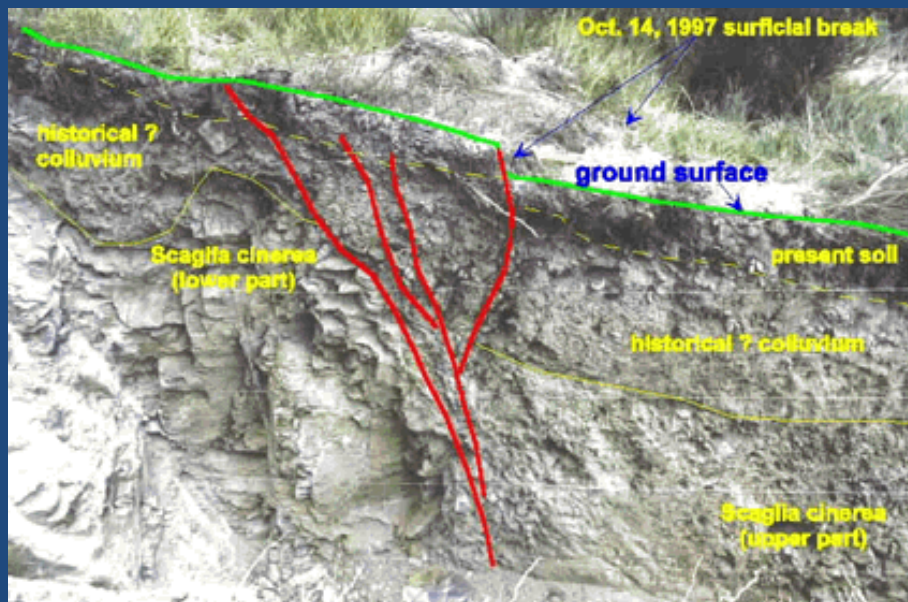




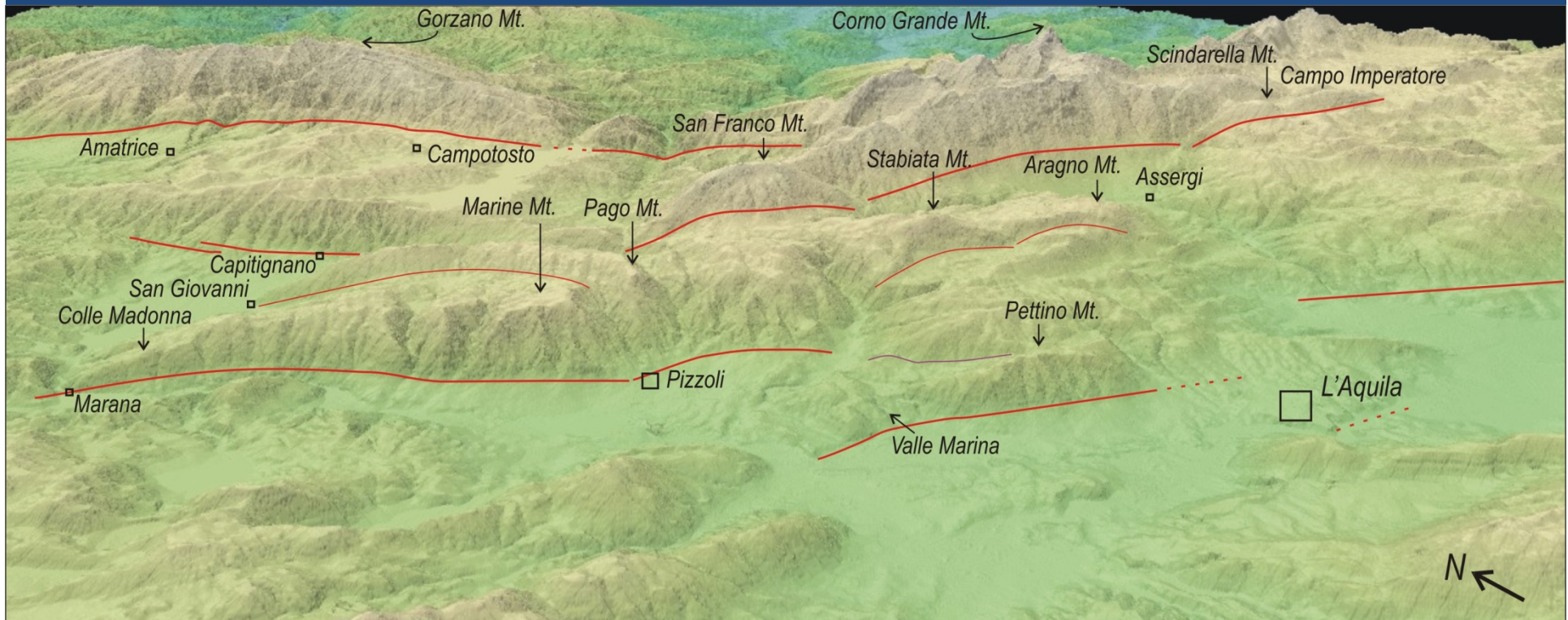




1997, September 26, Colfiorito earthquake, Italy

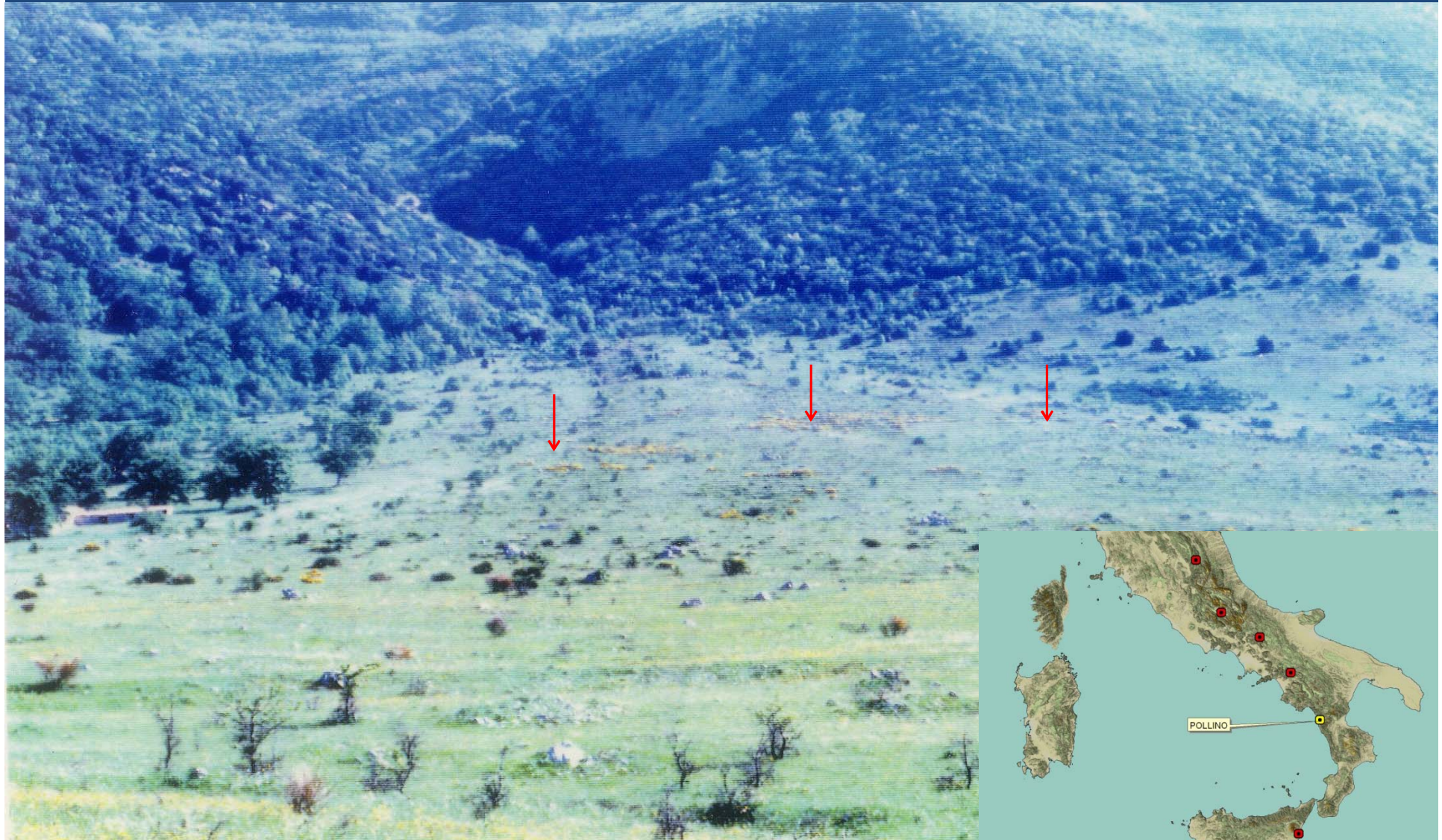


Trench investigations along the 1997 rupture zone



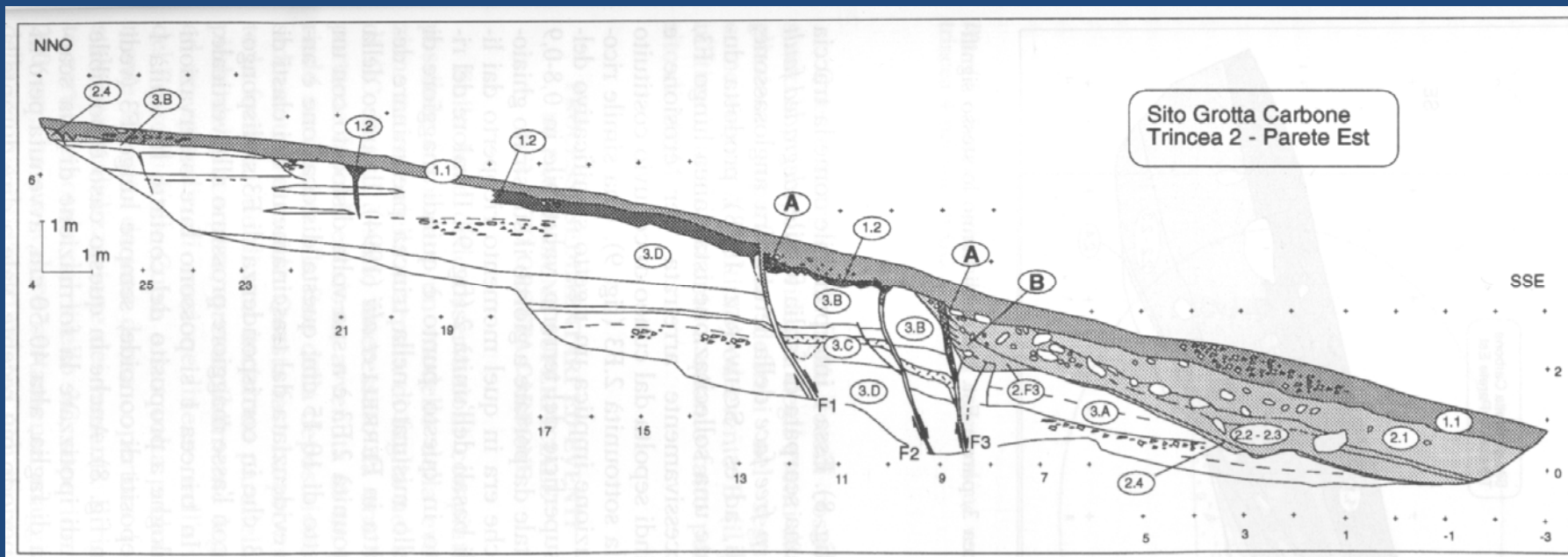


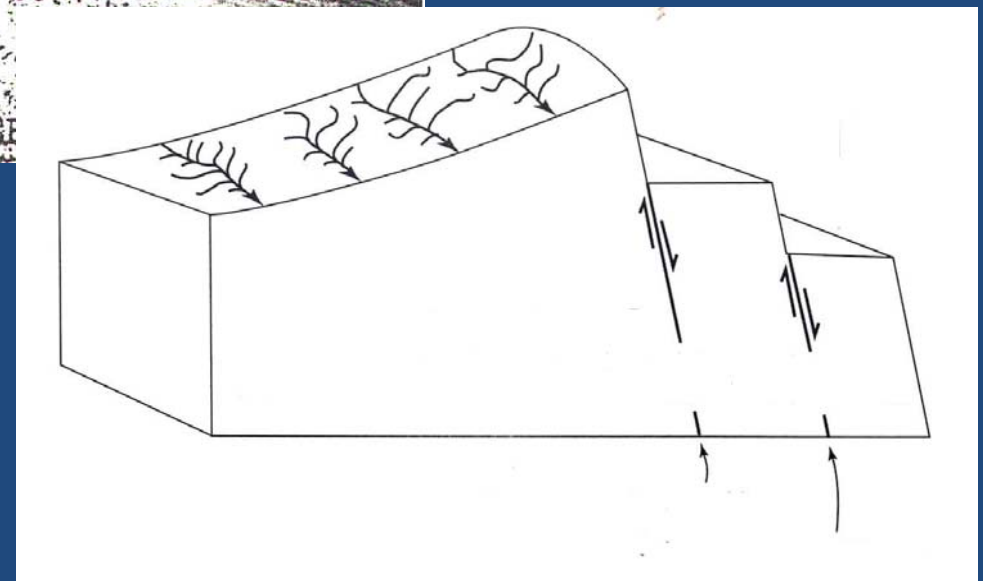
Paleoseismic record in the surroundings of the 2009 L'Aquila surface faulting





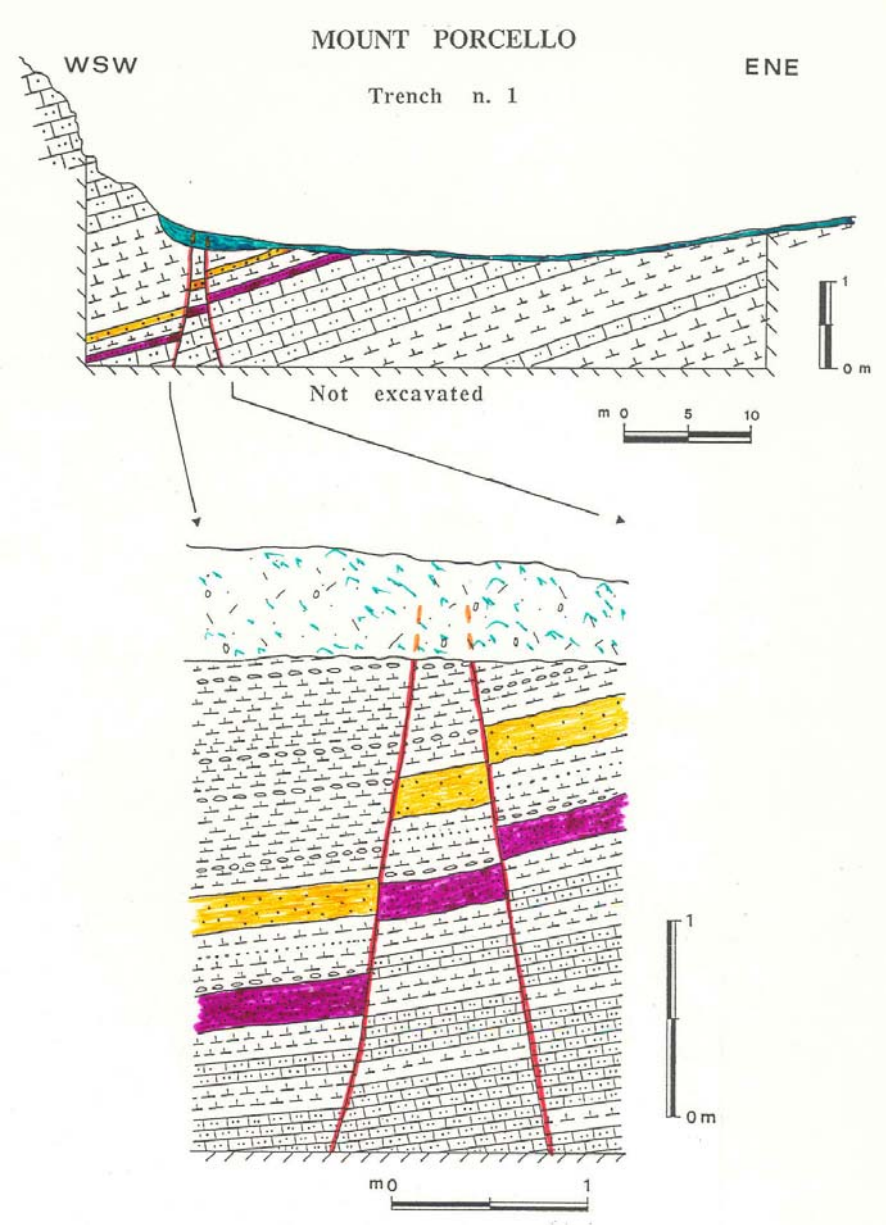
Trench investigations along the Pollino fault scarp





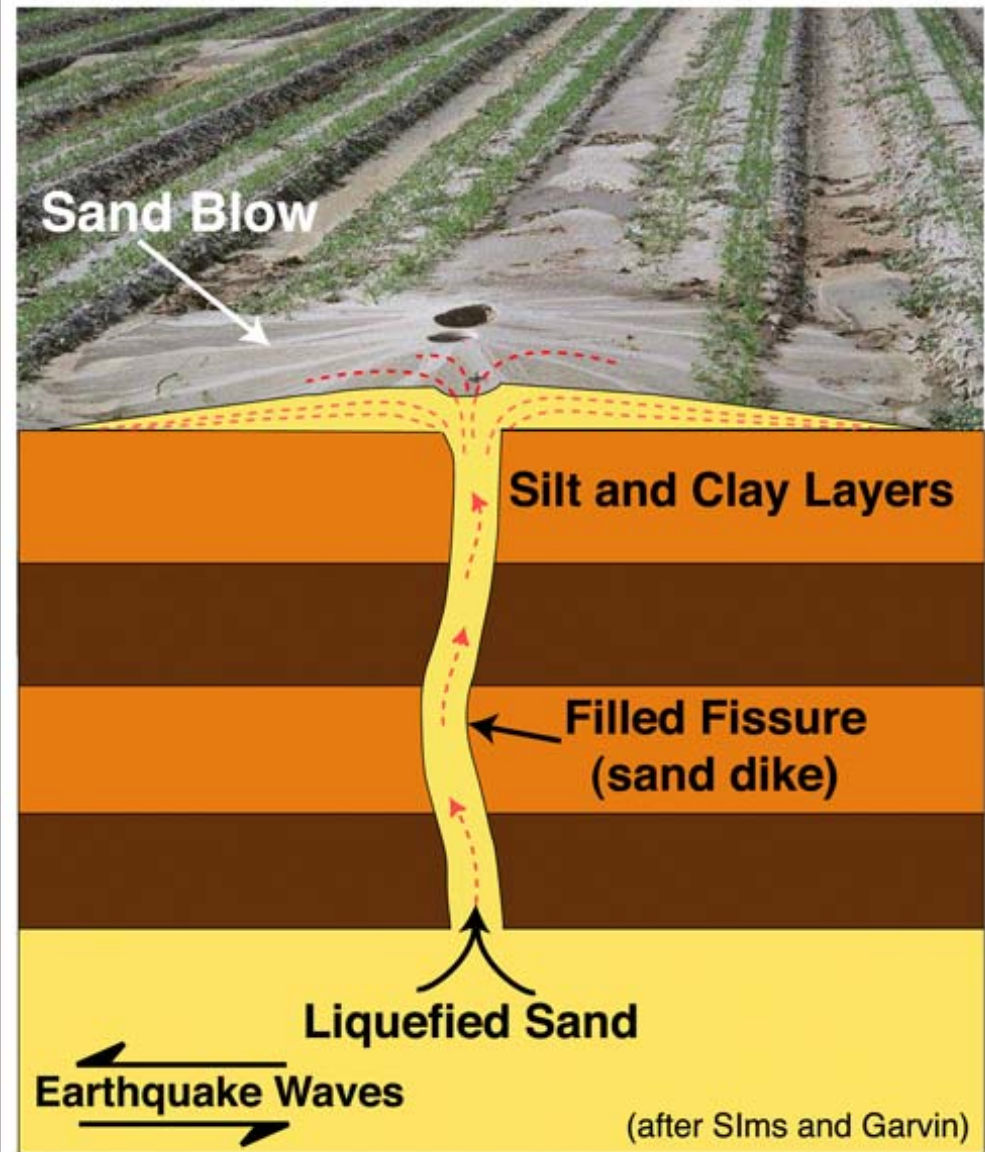
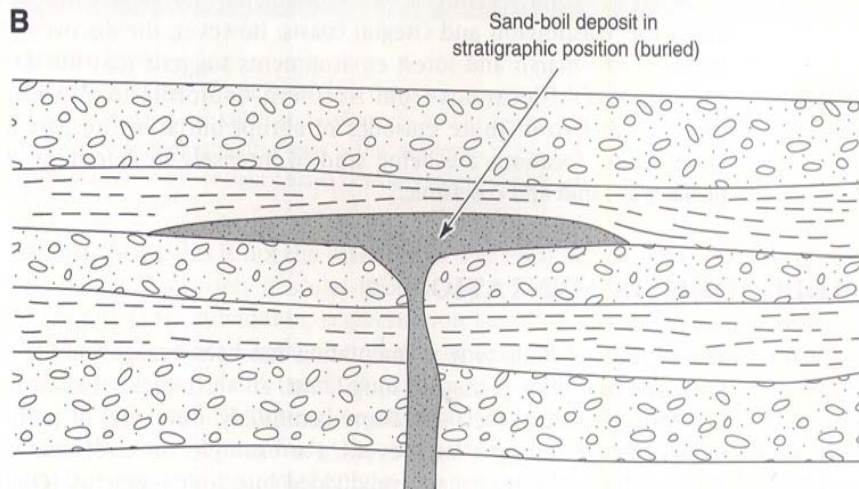








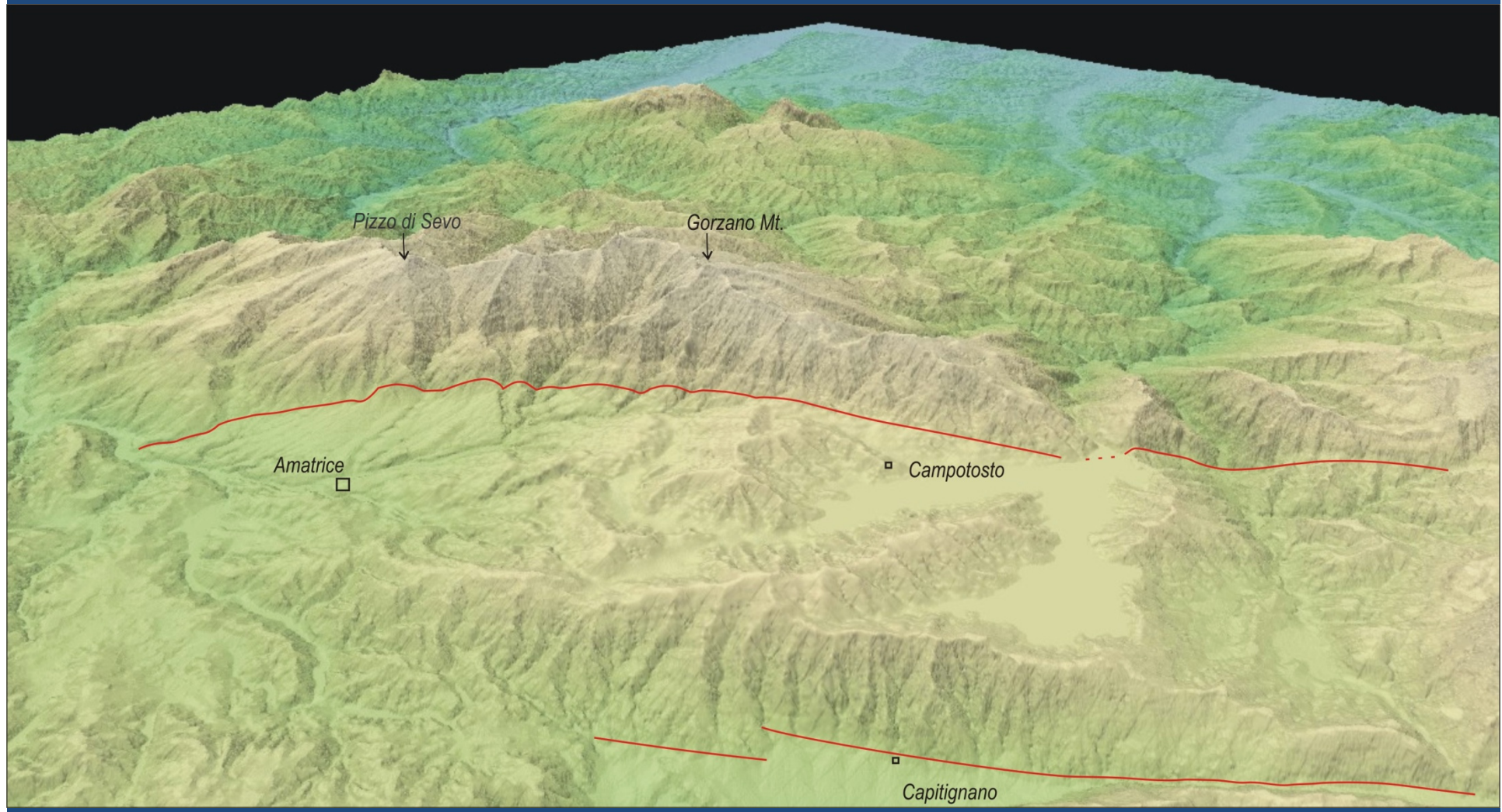
## Geological record of paleoliquefaction







Landforms resulting by repeated surface faulting events over a geological time interval





LANDSCAPE MODIFICATION

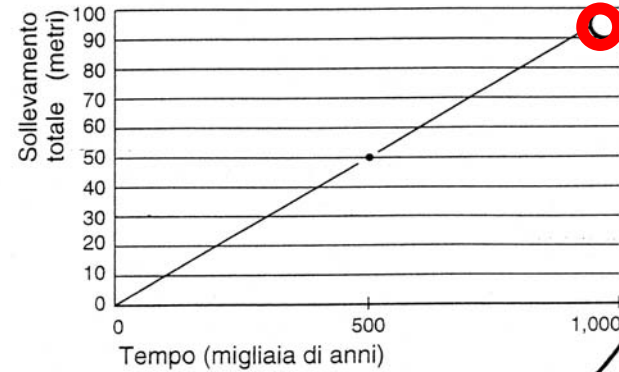


SEVERAL EARTHQUAKES

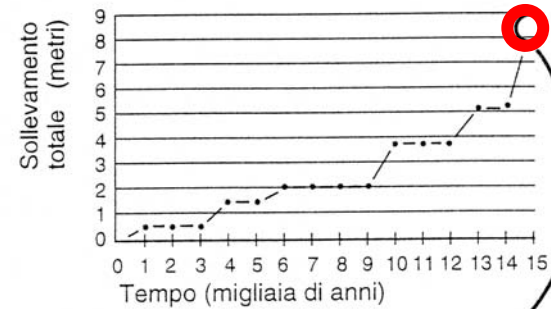


ONE EARTHQUAKE

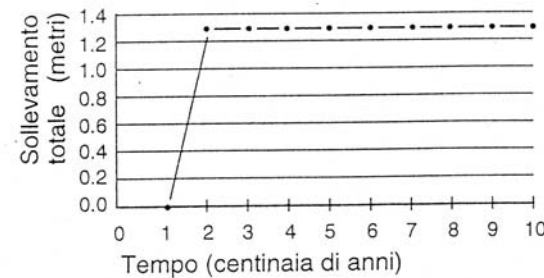
### VERSANTE MONTUOSO



### SCARPATE DI FAGLIA



### TERREMOTI STORICI



FROM THE SEISMIC  
LANDSCAPE



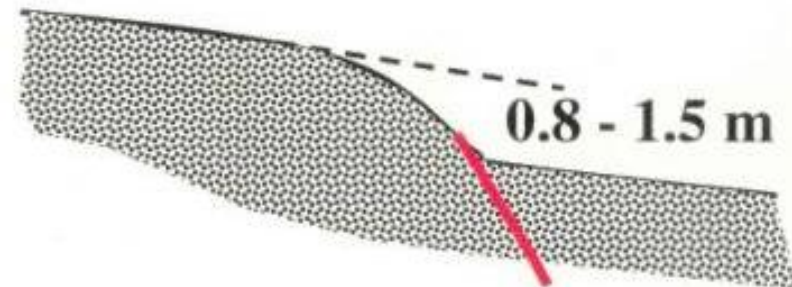
TO THE EARTHQUAKES



Historical slip – rates in the Bojano basin

Historical surface faulting (1 or 2 events)

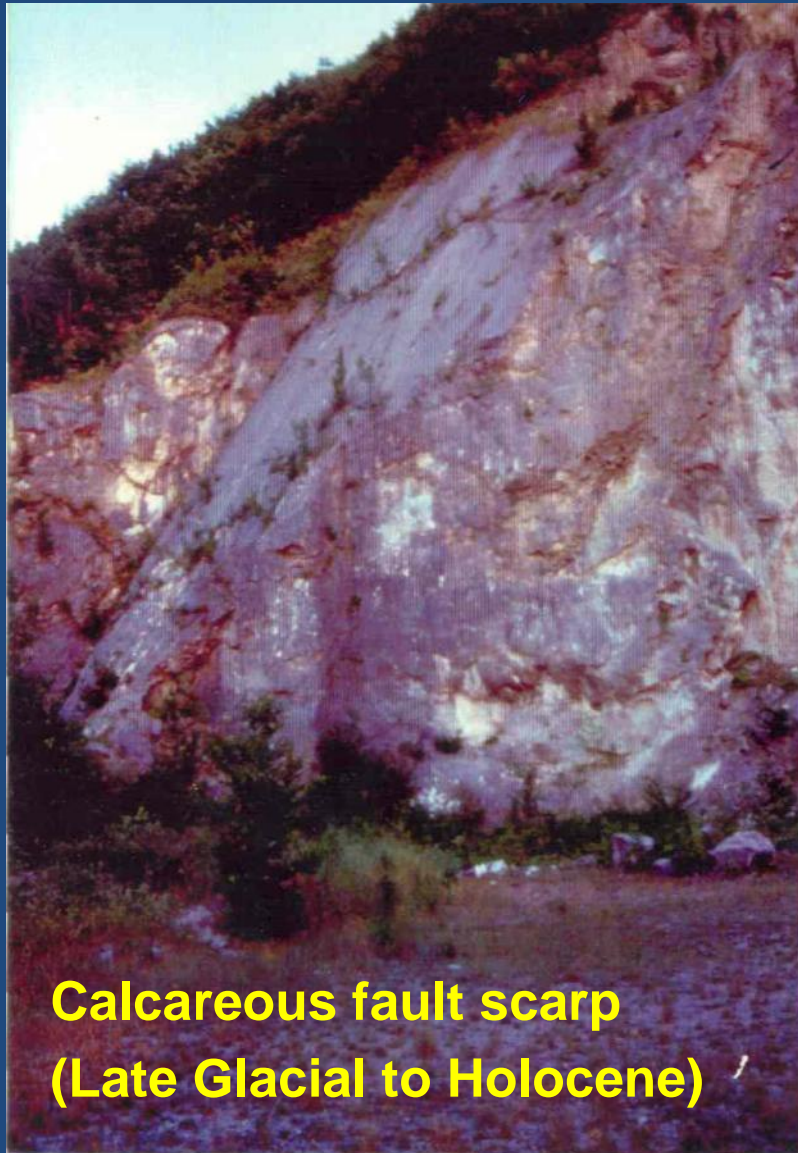
$10^2$  years



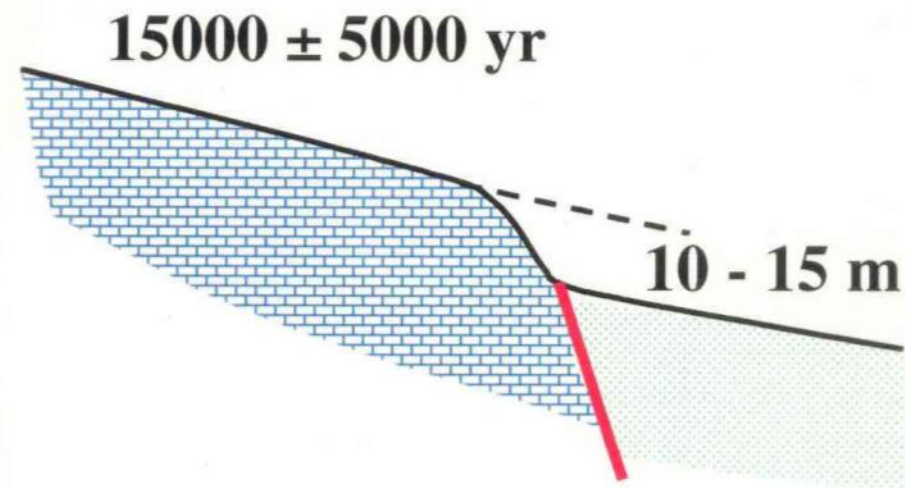
Uno o due terremoti storici  
(Guerrieri, 1999)



Late Glacial to Holocene slip – rates in the Bojano basin



**Calcareous fault scarp  
(Late Glacial to Holocene)**

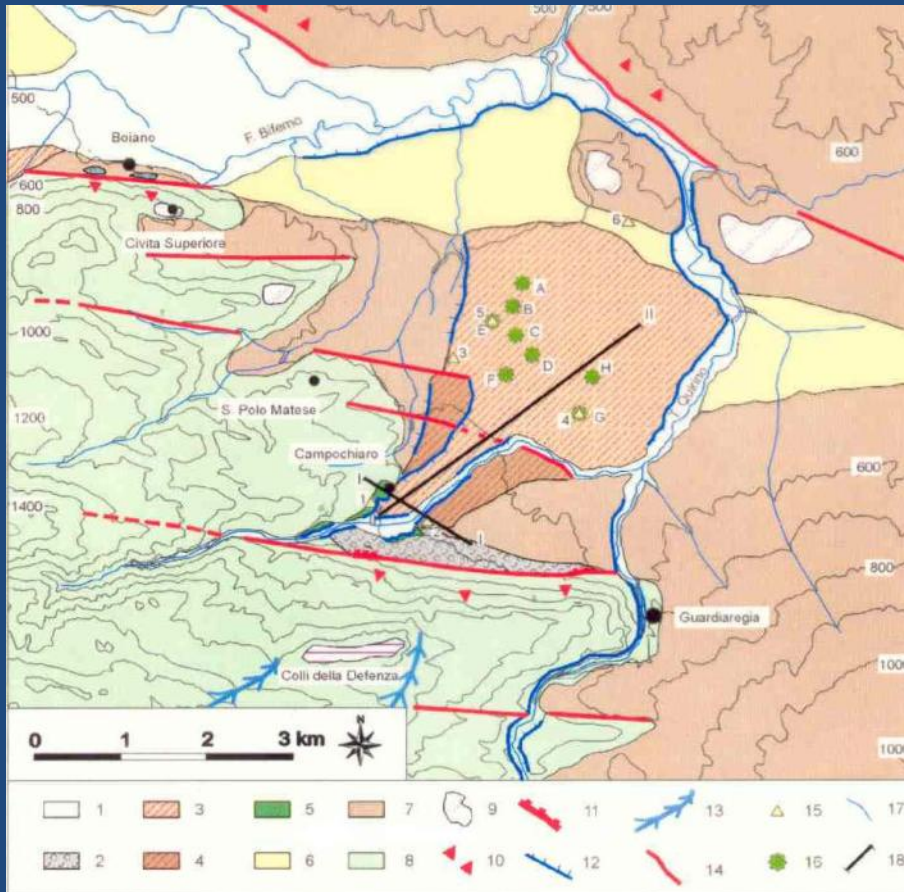


**0.5 - 1.5 mm/anno**  
(Guerrieri, 1999)

**10<sup>4</sup> yrs**

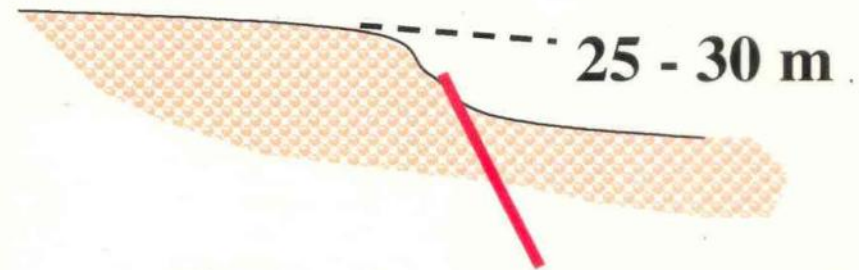


Upper Pleistocene - Holocene slip – rates in the Bojano basin



Offset along the Campochiaro alluvial fan (Upper Pleistocene)

$40000 \pm 15000$  yr



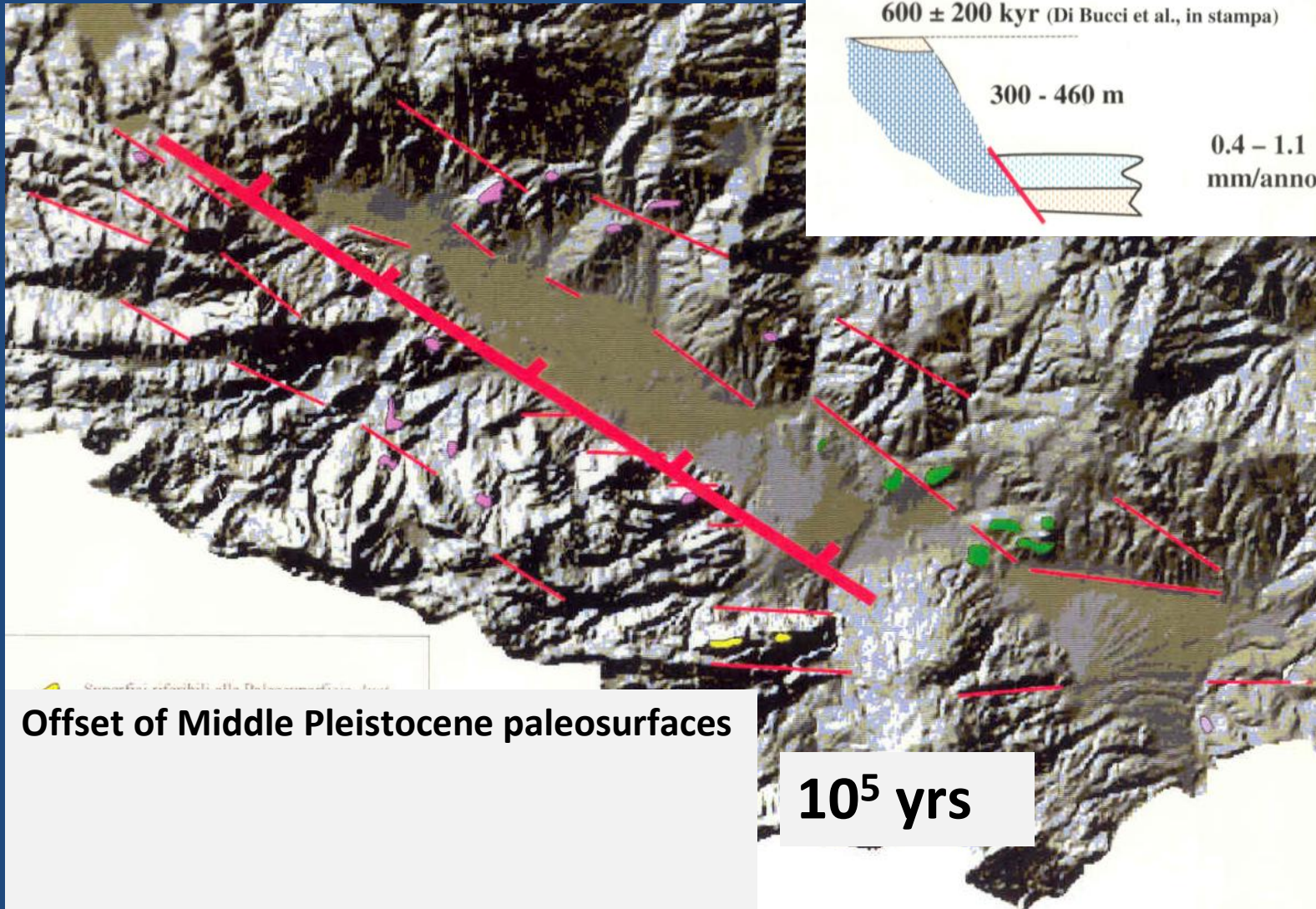
0.4 -1.2 mm/anno  
(Guerrieri, 1999)

$10^4$  yrs



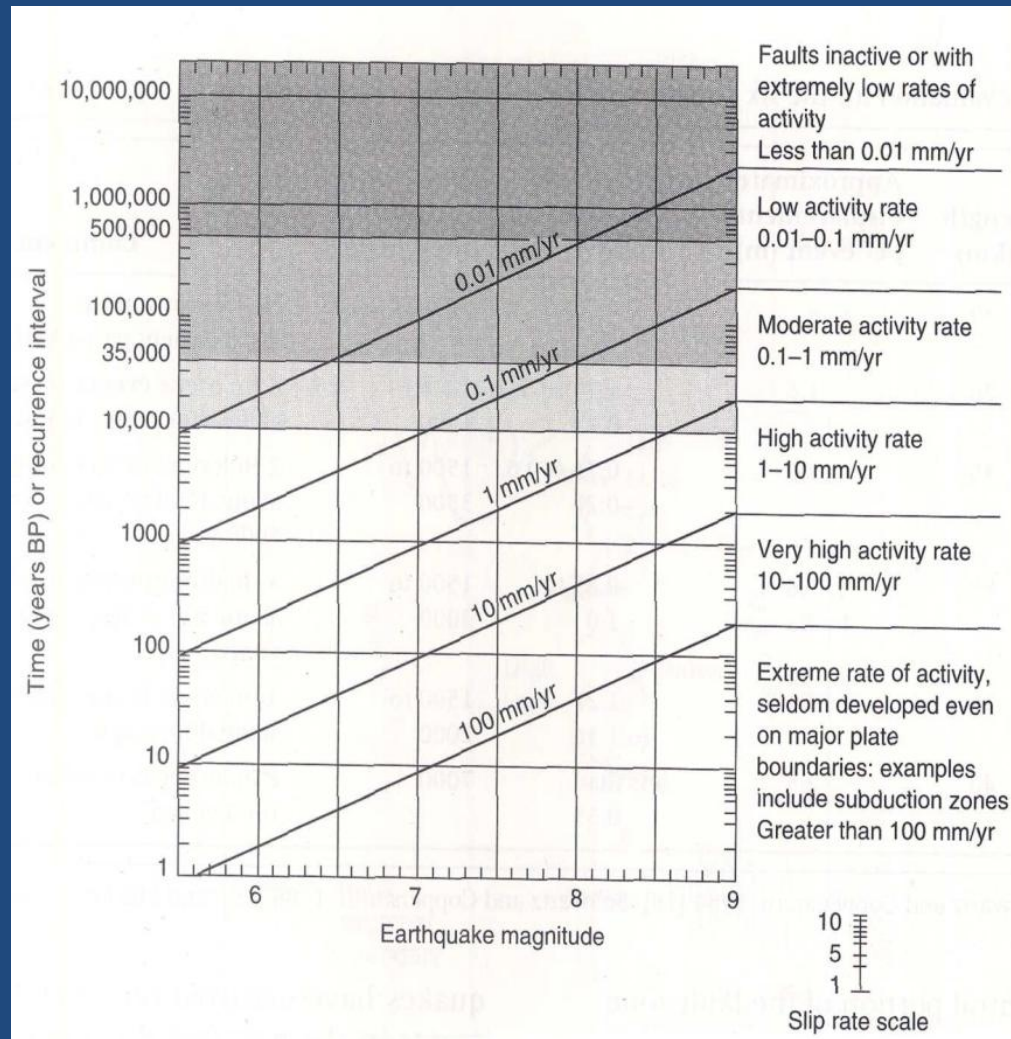


Middle Pleistocene - Holocene slip – rates in the Bojano basin





## Slip rates, recurrence interval and magnitude



Slemmons & de Polo (1986)



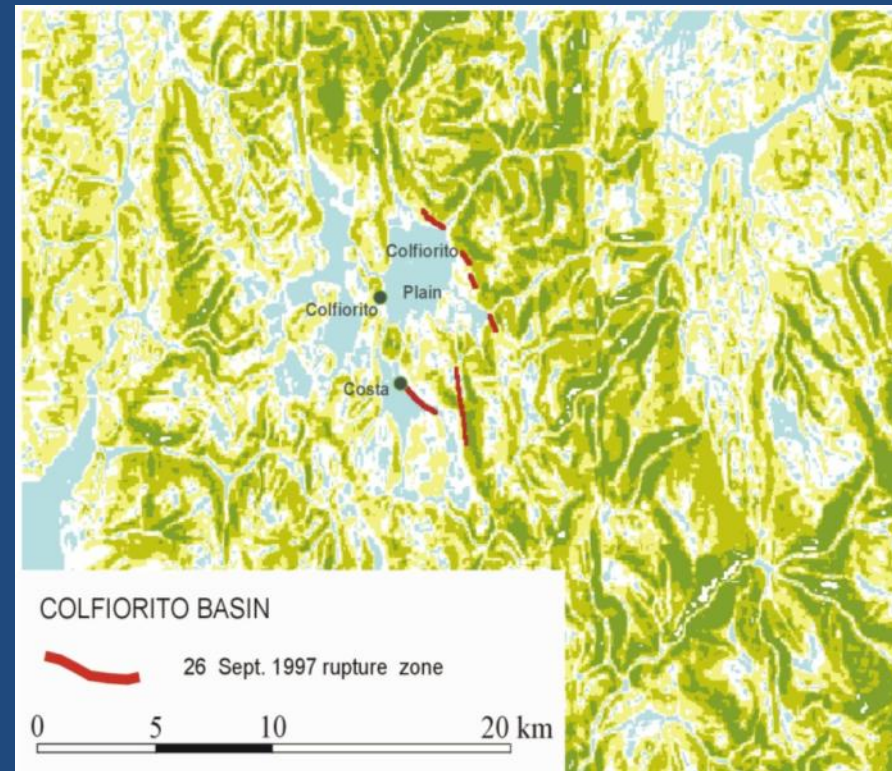
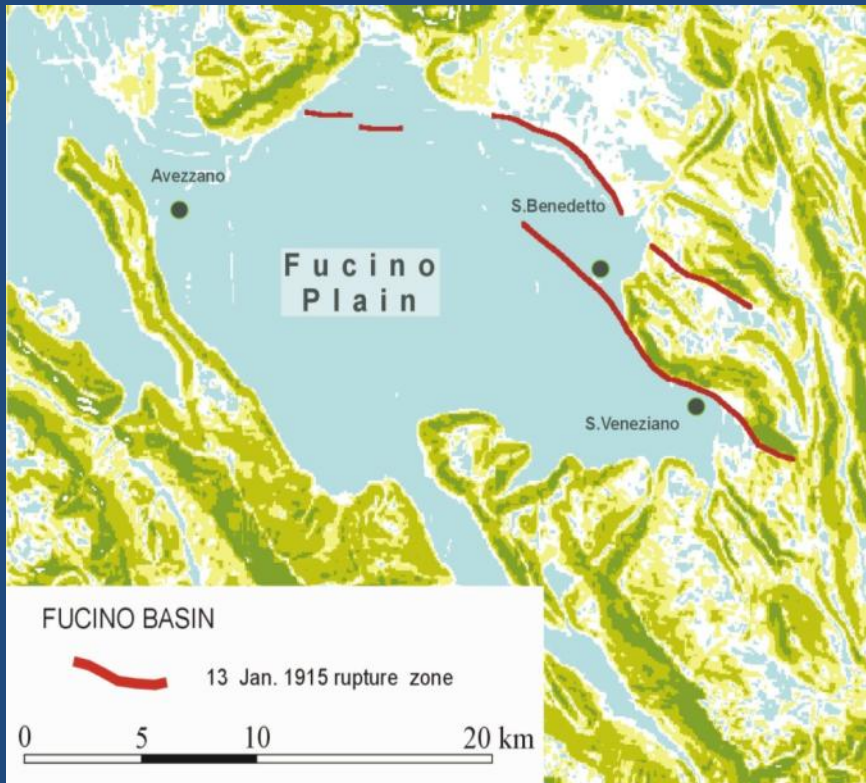
## Comparison between Fucino and Colfiorito basins



**MAXIMUM DISPLACEMENT**



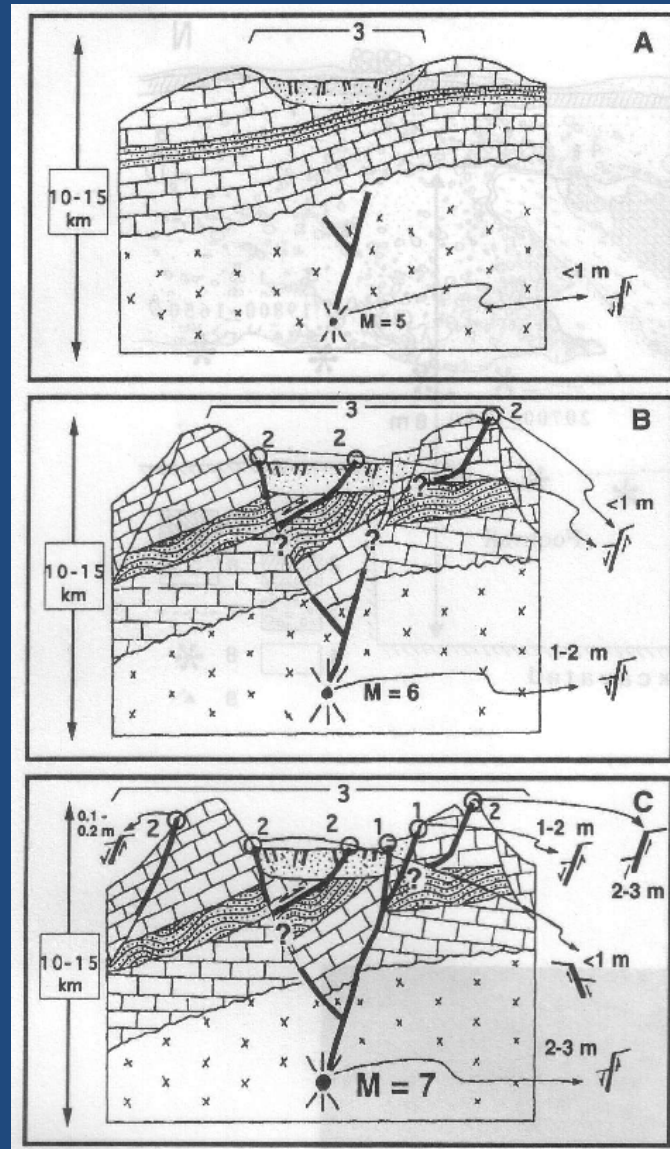
## Comparison between Fucino and Colfiorito basins



**RUPTURE ZONE – SIZE OF THE BASINS**



## Seismic landscapes in the Apennines

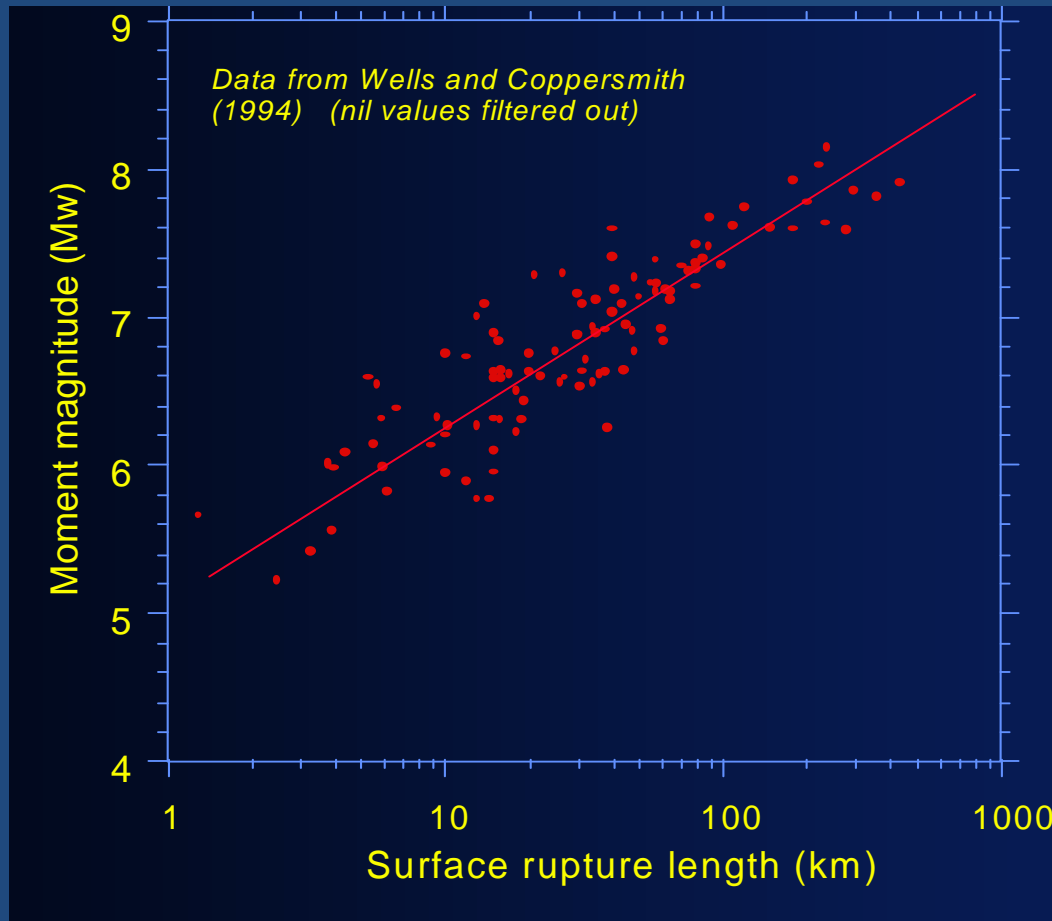


Type B - Colfiorito

Type C - Fucino



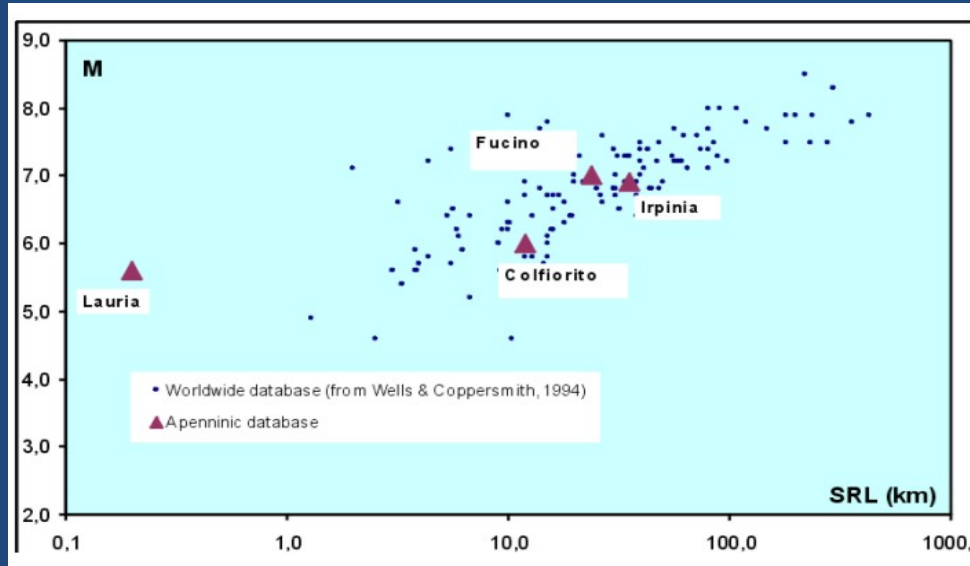
## Relationships between surface faulting and magnitude



Magnitude	Surface rupture (km)	Average deformation (cm)
9.00	800	800
8.00	250	500
7.00	50	100
6.00	10	20
5.00	3	5
4.00	1	2

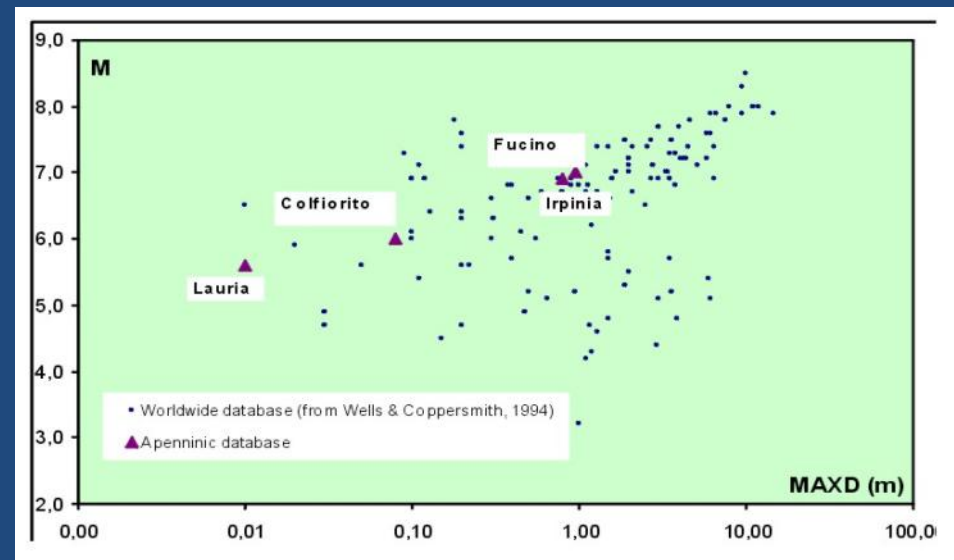


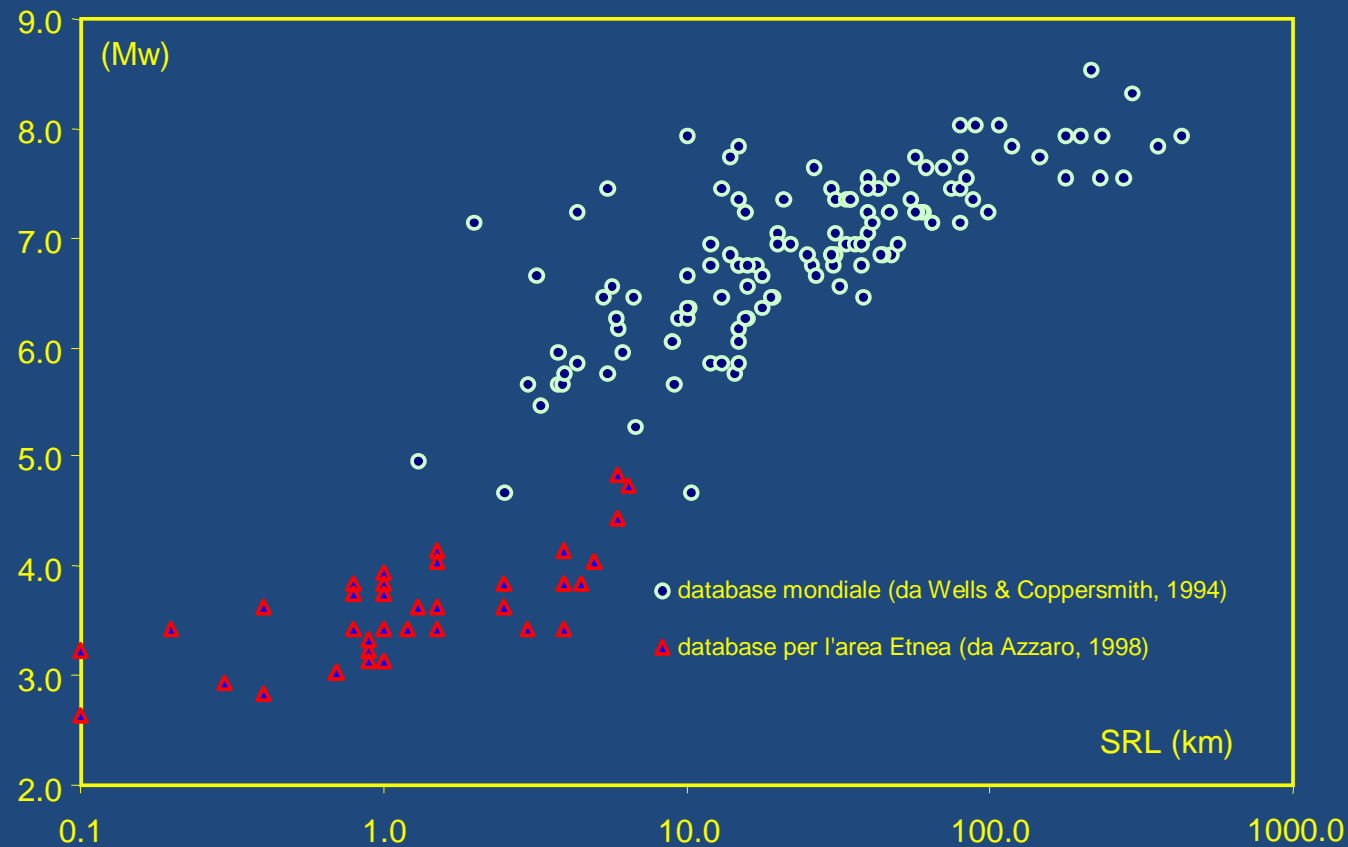
## Relationships between surface faulting and magnitude



Surface Rupture Length - Magnitude

Maximum Displacement - Magnitude





Earthquakes in a volcano-tectonic environment (Eastern Sicily)





## Relationships between surface faulting and magnitude

