

Micro Zonazione sismica: un approccio integrato tra geologia e geofisica

Dai cataloghi dei terremoti alla ricerca storica, dalle faglie capaci al database delle sorgenti sismogeniche, dall'analisi sul terreno agli studi geofisici

Approcci multidisciplinari per l'identificazione e caratterizzazione delle sorgenti sismogenetiche: esempi dal *database DISS*

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Fondazione Museo Civico Rovereto

Rovereto, Sala conferenze "Fortunato Zeni",

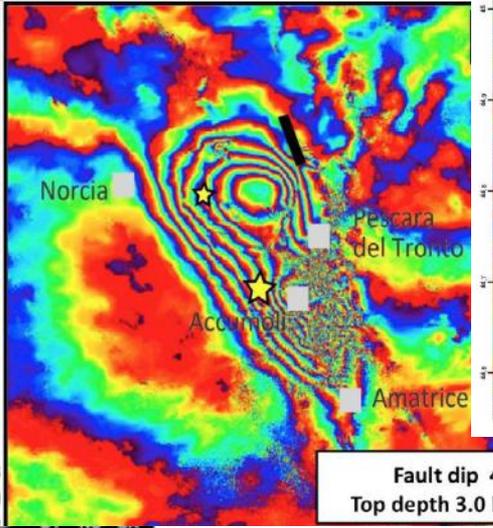
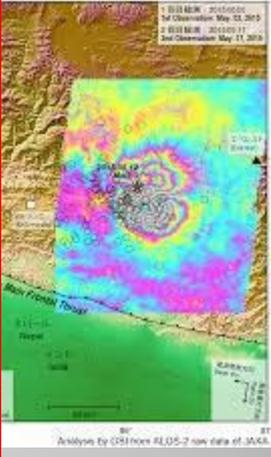
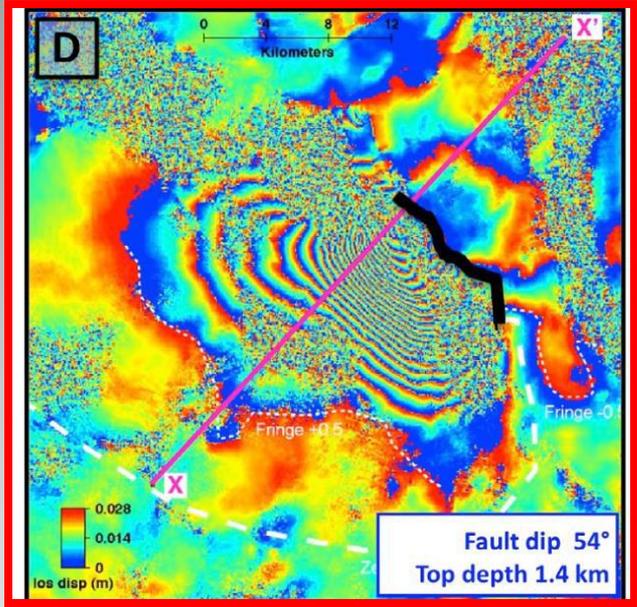
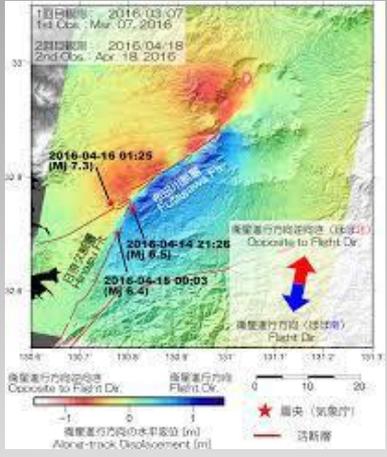
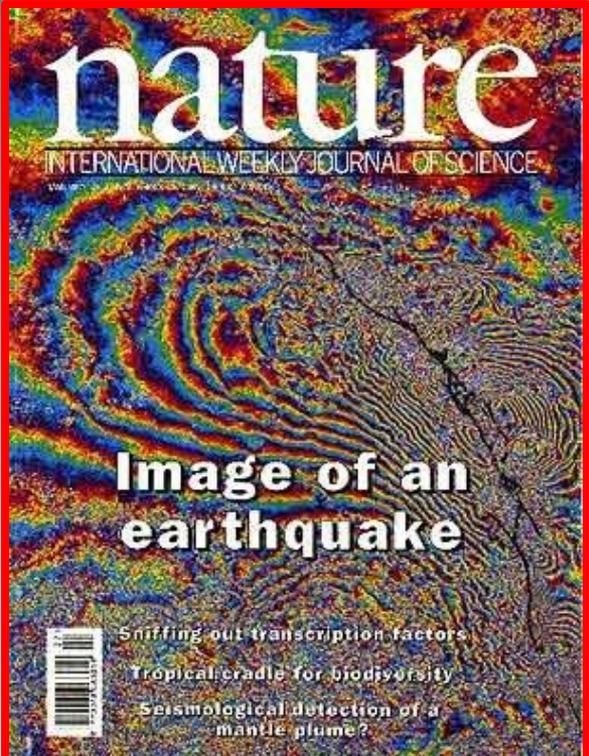
Giovedì 30 novembre e venerdì 1 dicembre 2017



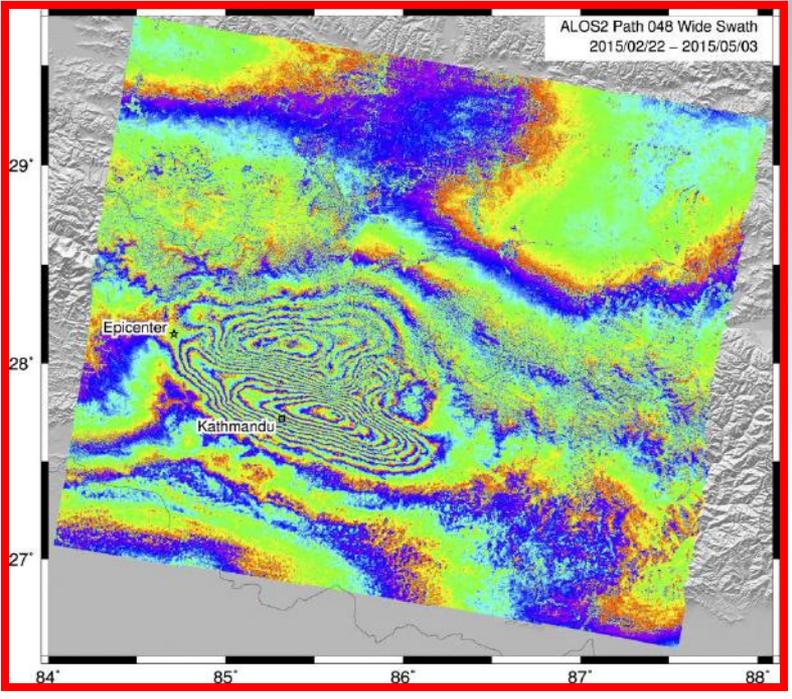
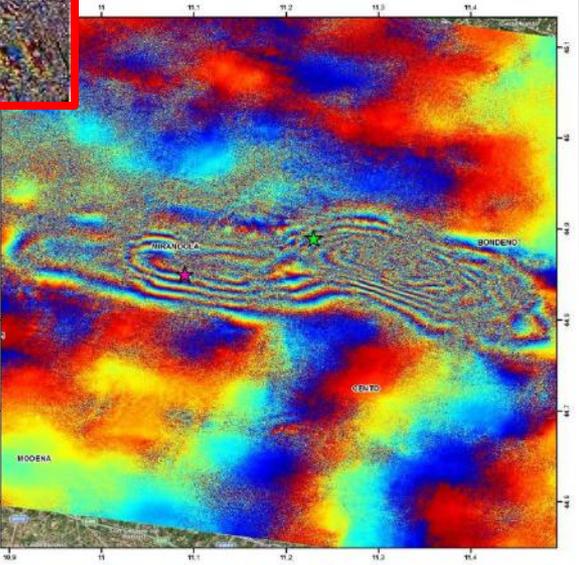
fondazione
museo civico
di rovereto



Leggere il paesaggio: l'impronta dei terremoti



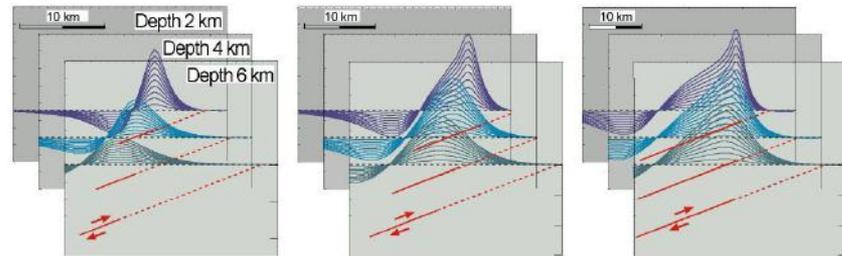
**Fault dip 46°
Top depth 3.0 km**



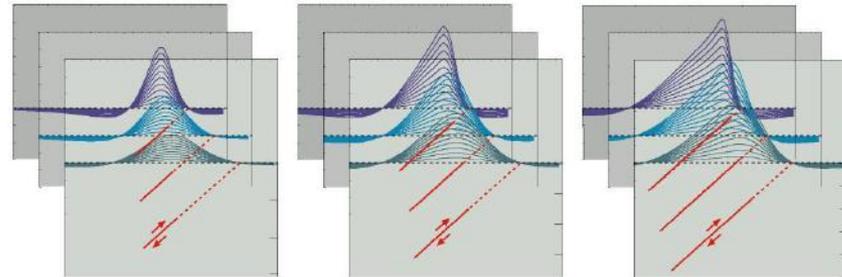
Relazioni tra geometria del piano di faglia e deformazione superficiale attesa

2D vertical displacement patterns

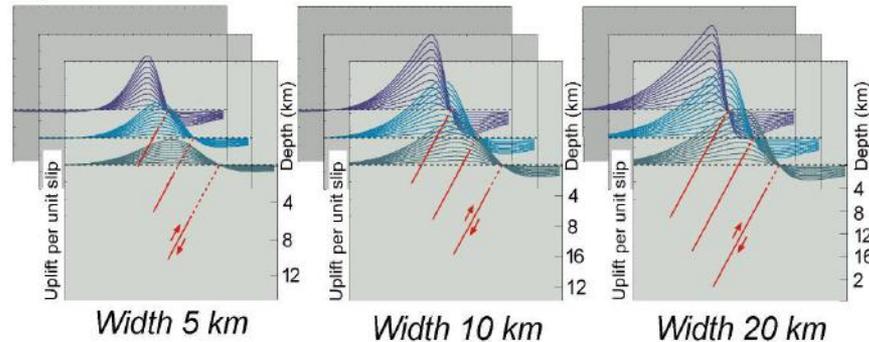
Dip 20° (totally relaxed halfspace)



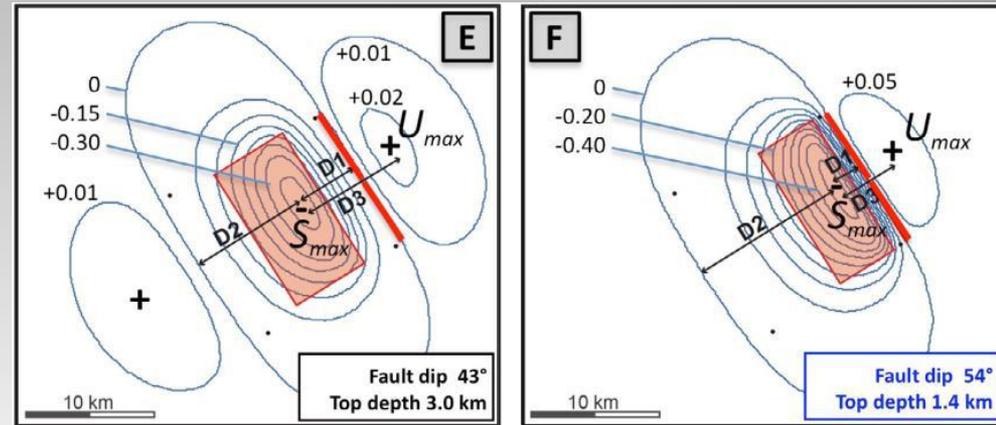
Dip 40°



Dip 60°



Faglia inversa

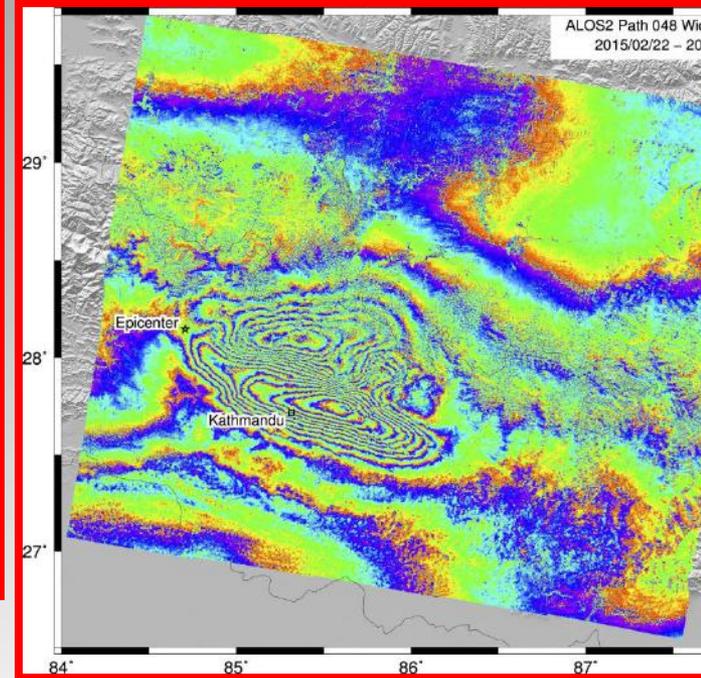
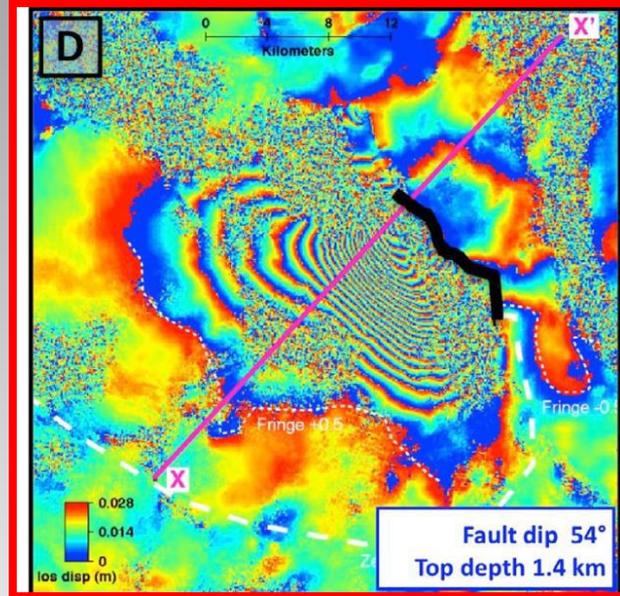
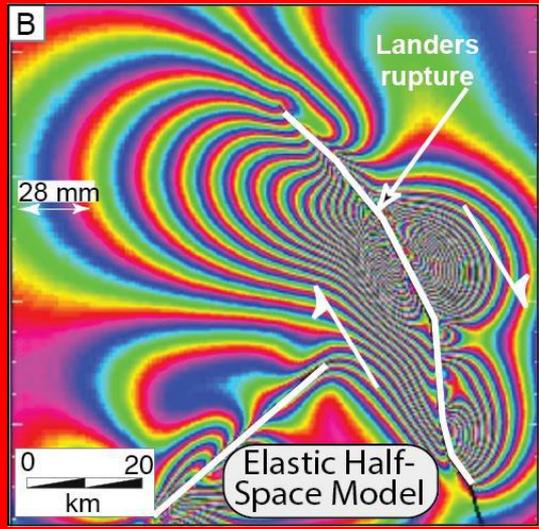
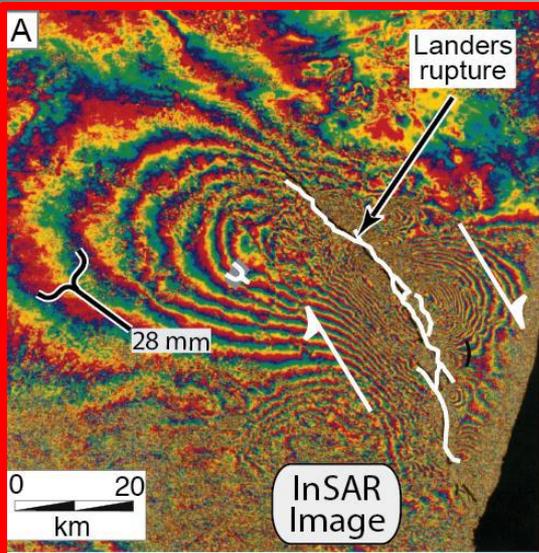


Faglia diretta

Valensise et al., 2016,
doi:10.4401/ag-7215

1. Immersione del piano di faglia
2. Profondità minima
3. Larghezza
4. Cinematica

Relazioni tra cinematica della faglia e deformazione superficiale attesa



Faglia diretta
1 Ottobre 1995, Mw 6.2
Dinar (Turchia)

Faglia inversa
25 Aprile 2015, Mw 7.8
Gorkha (Nepal)

Massonnet et al. (1993)
Nature, 264.

Faglia trascorrente
28 Giugno 1992, Mw 7.3 Landers (California)

1. Immersione del piano di faglia
2. Profondità minima
3. Larghezza
4. **Cinematica**

Effetti associati ad un terremoto

Scuotimento

Avviene sempre

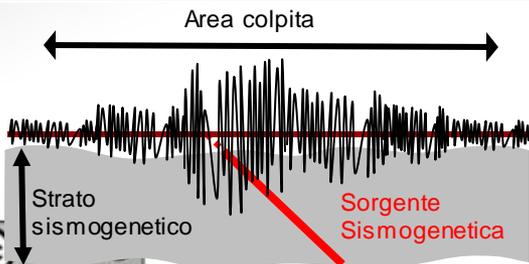
E' transitorio

Colpisce un'area vasta o molto vasta

E' responsabile della maggior parte dei danneggiamenti

Può innescare altri effetti geologici (e.g. *liquefazioni, frane, fratturazione del suolo*)

Per identificarne la sorgente bisogna effettuare studi alla scala 1:200k-1M



Deformazione superficiale

Avviene sempre

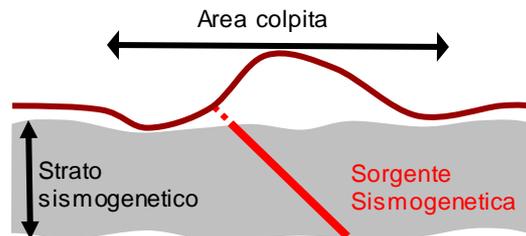
E' permanente

Colpisce un'area vasta (2 volte le dimensioni della faglia)

Produce danni limitati

Può innescare altri effetti geologici (*deviazioni fluviali, tsunami*) ed è responsabile dell'evoluzione di lungo termine del paesaggio

Richiede una mappatura alla scala 1:200k-1M



Fagliazione superficiale

Non avviene sempre

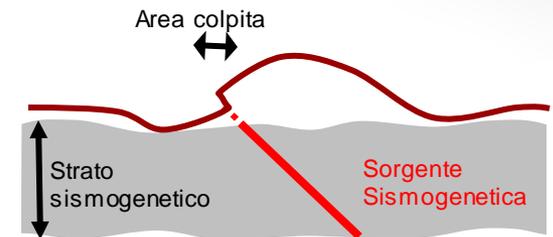
E' permanente

Colpisce un'area limitata

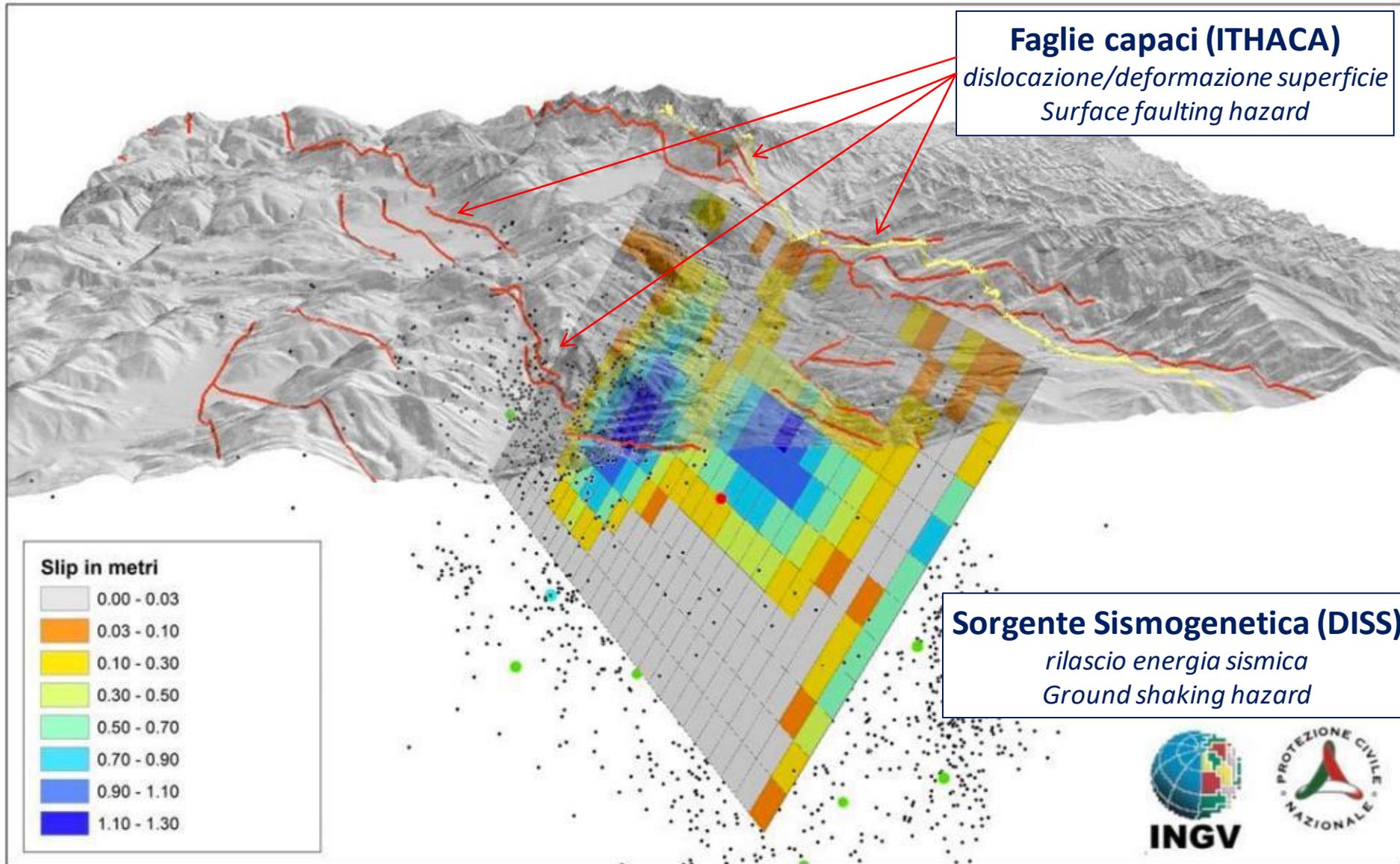
Può produrre danni ingenti

Può innescare altri effetti geologici (e.g. *blocco drenaggio, impaludamento*)

Richiede una mappatura alla scala > 1:10k



Faglie attive, faglie capaci e faglie sismogenetiche



<https://ingvterremoti.wordpress.com/2016/09/21/terremoto-in-italia-centrale-modellazione-della-sorgente-sismica-e-trasferimento-di-stress-sulle-faglie-limitrofe/>

Rappresentazione 3D del modello di slip a una faglia responsabile della deformazione cosimica registrata dal SAR - evento di M 6.0 del 24 agosto 2016



Faglie attive, faglie capaci e faglie sismogenetiche

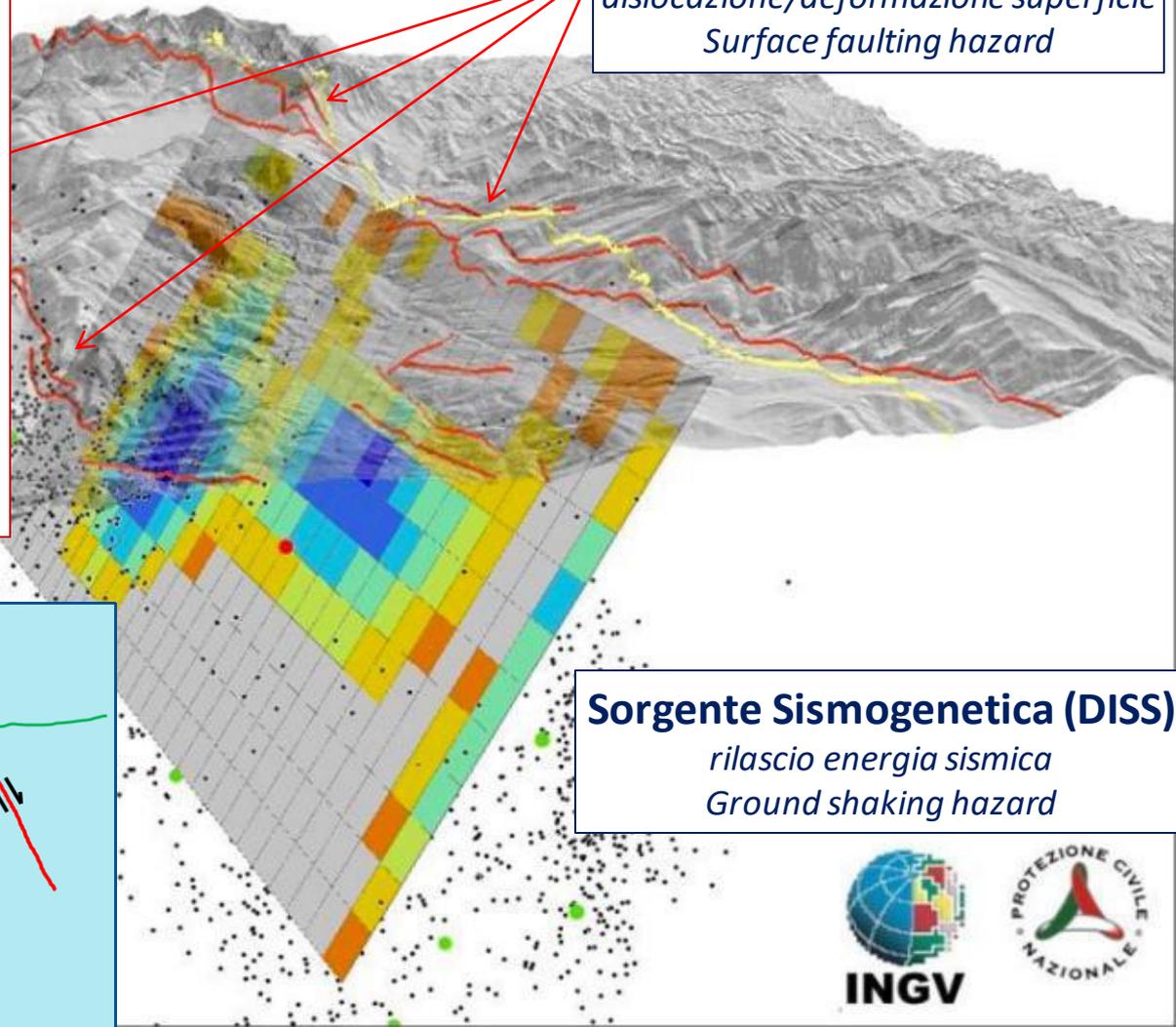
Classificazione

*relazione strutturale
meccanismo di attivazione*

- primaria
- secondaria sintetica
- secondaria antitetica
- Ereditata riattivata
- “propagazione diretta”
- “Bending moment”
- “Sympathetic” (trigger dinamico)
- “Stress loading”

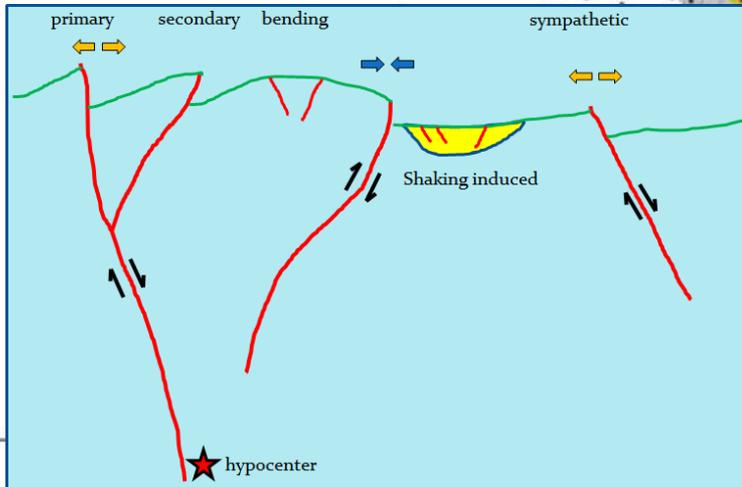
Faglie capaci (ITHACA)

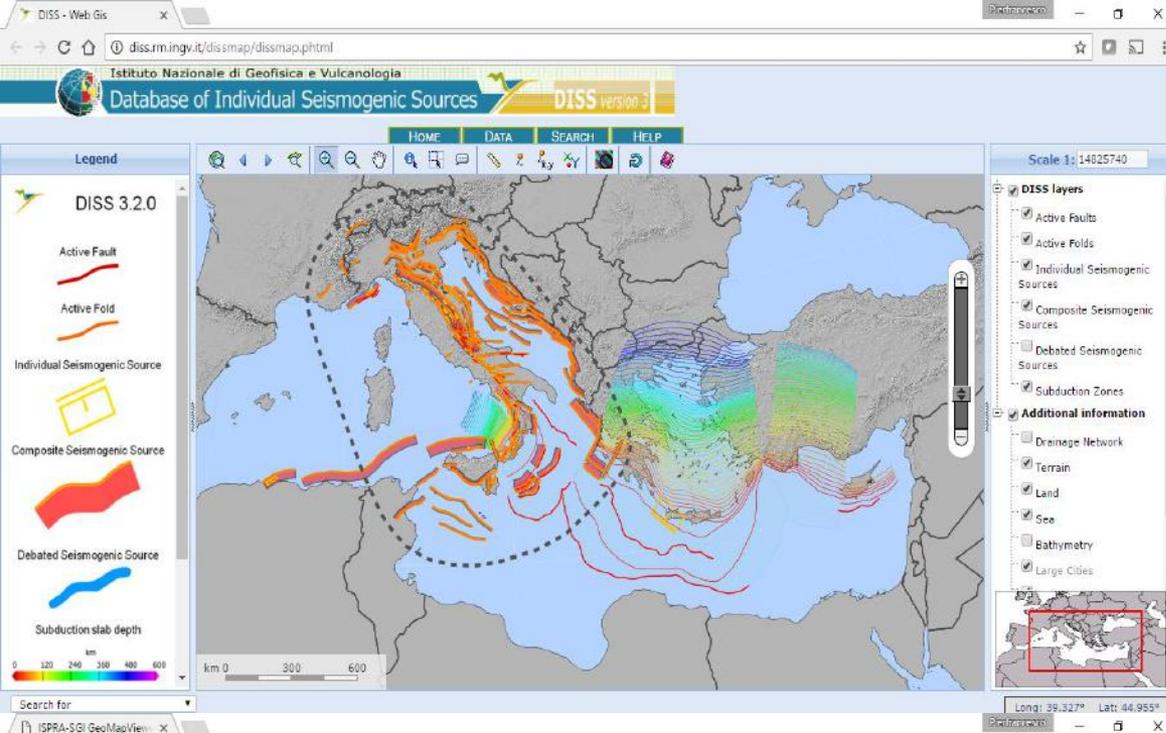
*dislocazione/deformazione superficie
Surface faulting hazard*



Sorgente Sismogenetica (DISS)

*rilascio energia sismica
Ground shaking hazard*

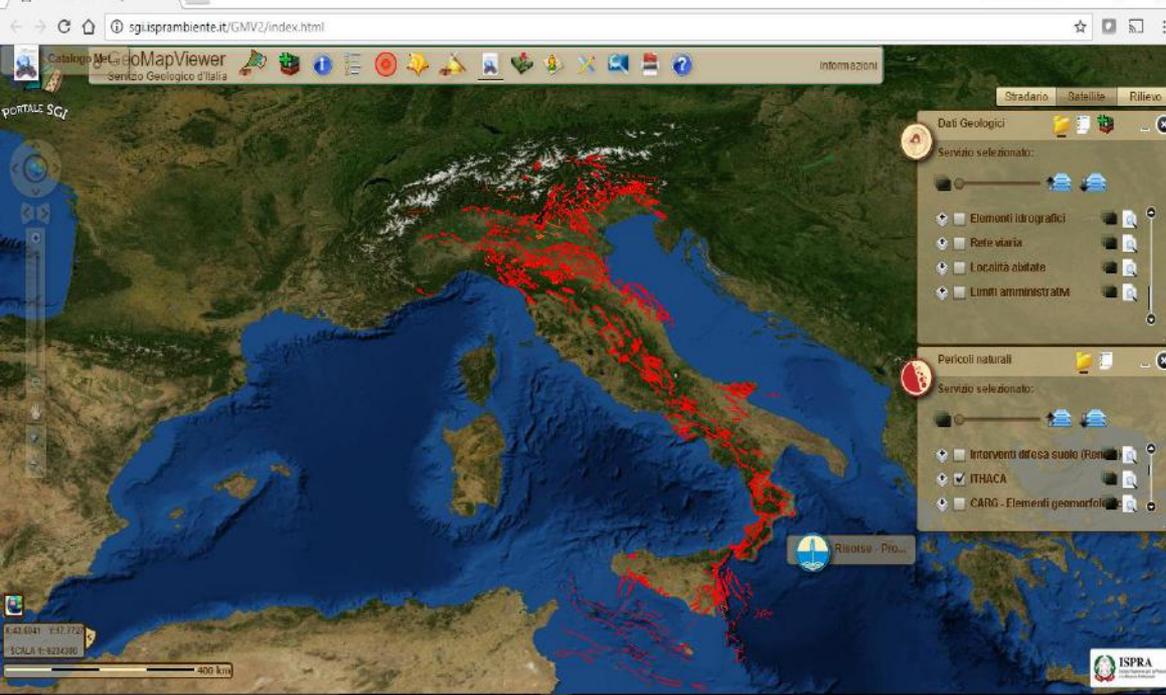




DISS

Database Sorgenti Sismogenetiche
<http://diss.rm.ingv.it/diss/>

Ground shaking hazard



ITHACA

Catalogo delle faglie Capaci
<http://www.isprambiente.gov.it/it/progetti/suolo-e-territorio-1/ithaca-catalogo-delle-faglie-capaci>

Surface faulting hazard

Due database a confronto: contenuto/struttura



<http://diss.rm.ingv.it/diss/>

- Sorgenti Sismogenetiche
- parametrizzazione geometrica 3D
- parametrizzazione cinematica
- **Pericolosità da scuotimento**
(*ground shaking hazard*)

Istituto Nazionale di Geofisica e Vulcanologia
 Database of Individual Seismogenic Sources **DISS** VERSION 2.0

User: Guest | Login | Home | Map | Search | Help

INDIVIDUAL SEISMOGENIC SOURCES

COMMENTARY | PICTURES | REFERENCES | USER COMMENTS

GENERAL INFORMATION

DISS-ID: ITIS130
 Name: Imperia Promontory
 Compiler(s): Vannoli P(1), Burrato P(1)
 Contributor(s): Vannoli P(1), Burrato P(1), Volensie G(1)
 Affiliation(s): 1) Istituto Nazionale di Geofisica e Vulcanologia; Simologia e Tettonofisica; Via di Vigna Murata, 695, 00143 Roma, Italy
 Created: 01-Jun-2001
 Updated: 06-Nov-2013

Display map ...

Related sources: ITC5022

PARAMETRIC INFORMATION

PARAMETER	QUALITY	EVIDENCE
Location [Lat, Lon]	43.88 / 8.28	EJ Inferred from geological and morphobathymetric data.
Length [km]	32.0	EJ Inferred from geological and morphobathymetric data.
Width [km]	15.0	ER Calculated using the relationships from Wells and Coppersmith (1994).
Min depth [km]	5.5	OD Based on geological and morphobathymetric data.
Max depth [km]	13.0	AR Derived from from dp, width and minimum depth.
Strike [deg]	240	OD Based on geological and morphobathymetric data.
Dip [deg]	30	OD Based on geological data.
Rake [deg]	90	EJ Inferred from active stress data.
Slip Per Event [m]	1.0	ER Calculated from M0 using the relationship from Hanks and Kanamori (1979).
Slip rate [mm/yr] min... max	0.15 - 0.2	EJ Inferred from topographic and geological data.
Recurrence [yr] min... max	5000 - 6667	EJ Inferred from slip rate and average displacement.
Magnitude [Mw]	6.6	LD Value adopted from the earthquake catalogue SHEEC.

LD=Literature Data, OD=Original Data, ER=Empirical Relationship, AR=Analytical Relationship, EJ=Expert Judgment

INFORMATION ABOUT THE ASSOCIATED EARTHQUAKES

Latest Earthquake: 23 Feb 1887 CPT111
 Penultimate Earthquake: Unknown See 'Commentary' for information.

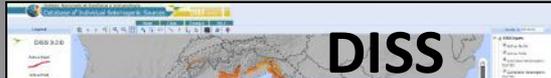


<http://geoportale.isprambiente.it/>

- Faglie Capaci
- parametrizzazione geometrica 2D
- parametrizzazione cinematica
- **Pericolosità da fagliazione superficiale**
(*surface faulting hazard*)

GEOLOGIC SETTING	The Provenzana-Pernicana-Fiumefreddo system, located in the north-eastern flank of Mt. Etna (the largest active strato volcano in Sicily), crosses the volcano edifice from the central crater to the sea. The Pernicana fault represents the central sector of this system.
SYNOPSIS	The Pernicana fault shows recent left strike-slip kinematics (with a large vertical component) and high activity as revealed by geomorphological and paleoseismological data. The fault is characterized by aseismic ruptures which damage human structures and lifelines. This very active system plays an important role in the geodynamic and morphologic evolution of the Etna volcano and it seems to be the northern boundary of an unstable sector.
FAULT NAME	Pernicana
FAULT CODE	12300
MACROZONE	7
REGION NAME	Sicilia
SYSTEM NAME	Provenzana-Pernicana-Fiumefreddo
RANK	PRIMARY
AVERAGE STRIKE	100
DIP	90
LENGTH (Km)	9.2
GEOMETRY	yes
SEGMENTATION	yes
DEPTH (Km)	5
LOCATION RELIABILITY (MAPPING SCALE)	1:25000
LAST ACTIVITY	Historical (<3,000)
ACTIVITY RELIABILITY	High reliability
RECURRENT INTERVAL (yr)	1
SLIP-RATE (mm/yr)	28
MAX CREDIBLE RUPTURE LENGTH	5
MAX CREDIBLE SLIP (m)	0.25
KNOWN SEISMIC EVENTS	Date I (MSK) 1981/01/08 VI 1982/07/07 VI 1984/10/18 VI 1985/12/25 VII 1986/10/29 VII 1988/10/28 VI
MAX CREDIBLE MAGNITUDE (Mw)	4.43
MAX CREDIBLE INTENSITY (INQUA scale)	IX
STUDY QUALITY	HIGH
NOTES	Mw by INGV - CATALOGO PARAMETRICO DEI TERREMOTI ITALIANI vers.2

Due database a confronto: rappresentazione



DISS



ITHACA

GEOLOGIC SETTING
SYNOPSIS
FAULT NAME
FAULT CODE
MACROZONE
REGION NAME
SYSTEM NAME
RANK
AVERAGE STRIKE
DIP
LENGTH (Km)

er.it/
erficiale

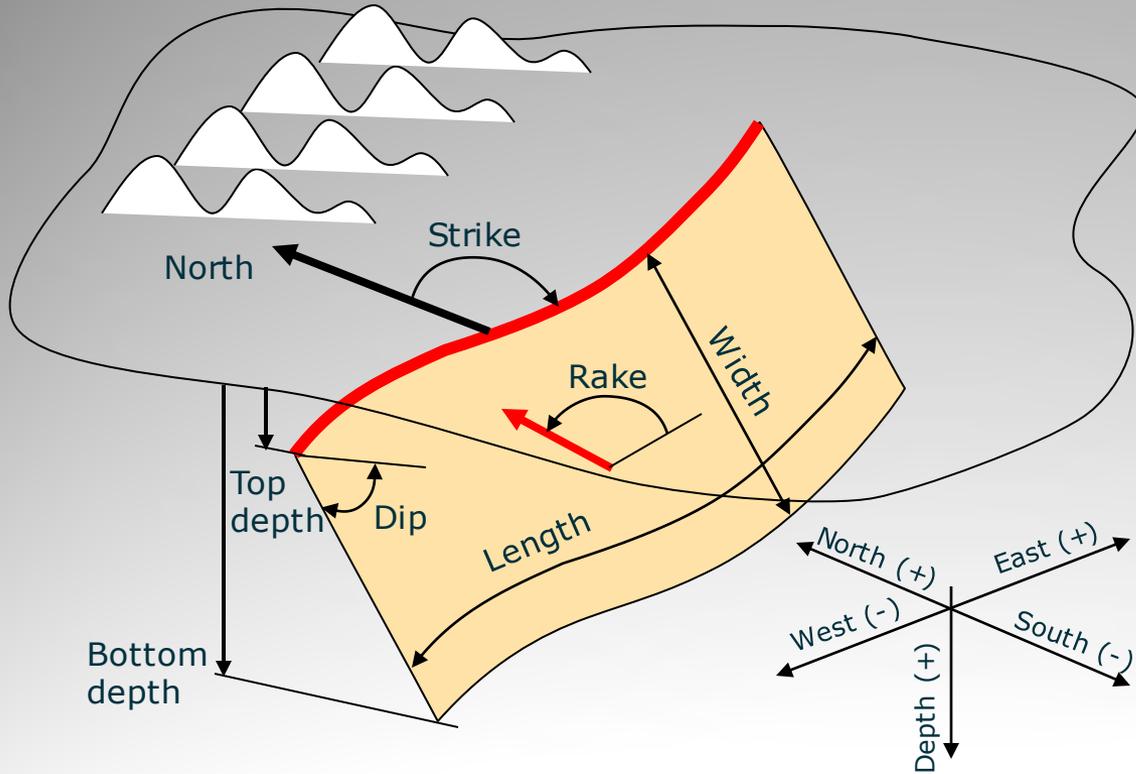
Length [km]	32.0	EJ	Inferred from geomorphobathymetry
Width [km]	15.0	ER	Calculated using Wells and Copp...
Min depth [km]	5.5	OD	Based on geomorphobathymetry
Max depth [km]	13.0	AR	Derived from minimum depth.
Strike [deg]	240	OD	Based on geomorphobathymetry
Dip [deg]	30	OD	Based on geomorphobathymetry
Rake [deg]	90	EJ	Inferred from act...
Slip Per Event [m]	1.0	ER	Calculated from relationship from (1979).
Slip rate [mm/y] min... max	0.15...0.2	EJ	Inferred from top data.
Recurrence [y] min... max	5000...6667	EJ	Inferred from slip displacement.
Magnitude [Mw]	6.6	LD	Value adopted from catalogue SHEE...

INFORMATION ABOUT THE ASSOCIATED EARTHQUAKES

Latest Earthquake	23 Feb 1887	CPT11.
Penultimate Earthquake	Unknown	See "Com...



Generalized seismogenic source model (used for ground-shaking hazard assessment)



Geometry

Location: Lat, Lon, Depth
Size: Length, Width
Orientation: Strike, Dip

Behavior

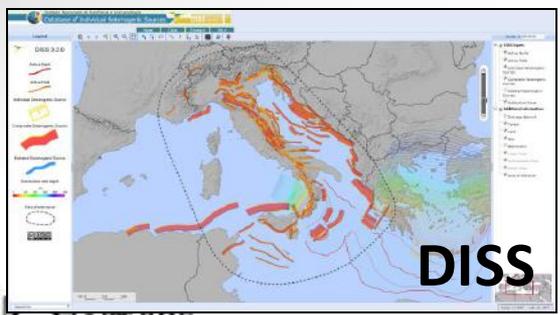
Rake
Slip Rate
Earthquake Magnitude
Activity Rate

Full 3D definition of the geometry of the fault

Sviluppo dell'interoperabilità tra i database DISS dell'INGV e ITHACA dell'ISPRA nell'ambito del Progetto DPC-INGV B2-Obiettivo 1

Per ottenere l'interoperabilità è sufficiente sovrapporre i due database?

DISS 3.2.0
Individual Seismogenic Source
Composite Seismogenic Source
Debated Seismogenic Source
Subduction slab depth
0 120 240 360 480 600 km
Google earth
Image IBCAO
Image Landsat / Copernicus
Data SIO, NOAA, U.S. Navy, NGA, GEBCO



Interoperabilità?

Sviluppo dei servizi web per il database DISS



EUROPEAN DATABASE OF SEISMOGENIC FAULTS 2013



The European Database of Seismogenic Faults (EDSF) was compiled in the framework of the EU Project SHARE. It includes only faults that are deemed to be capable of generating earthquakes of magnitude equal to or larger than 5.5 and aims at ensuring a homogeneous input for use in ground-shaking hazard assessment in the Euro-Mediterranean area.

[Go to the EDSF13 website](#)

[Go to the OGC services URLs](#)

DATABASE OF INDIVIDUAL SEISMOGENIC SOURCES



DISS is a georeferenced repository of tectonic, fault, and paleoseismological information expressly devoted, but not limited, to potential applications in the assessment of seismic hazard at regional and national scale in Italy. DISS represents faults in 3D and all its records are fully parameterized. It tends to completeness.

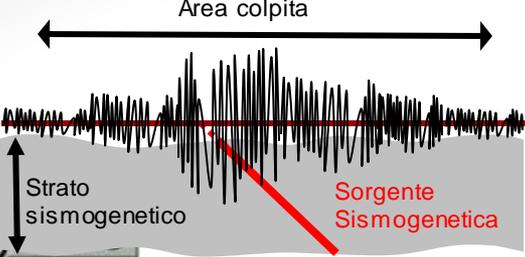
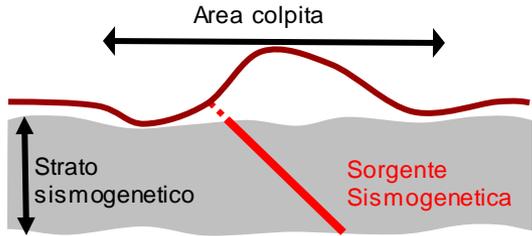
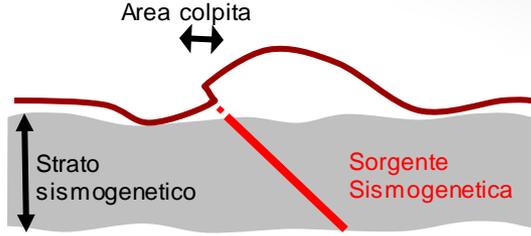
[Go to the DISS website](#)

[Go to the OGC services URLs](#)

Servizi web pubblicati @ www.seismofaults.eu

<http://diss.rm.ingv.it/diss/>

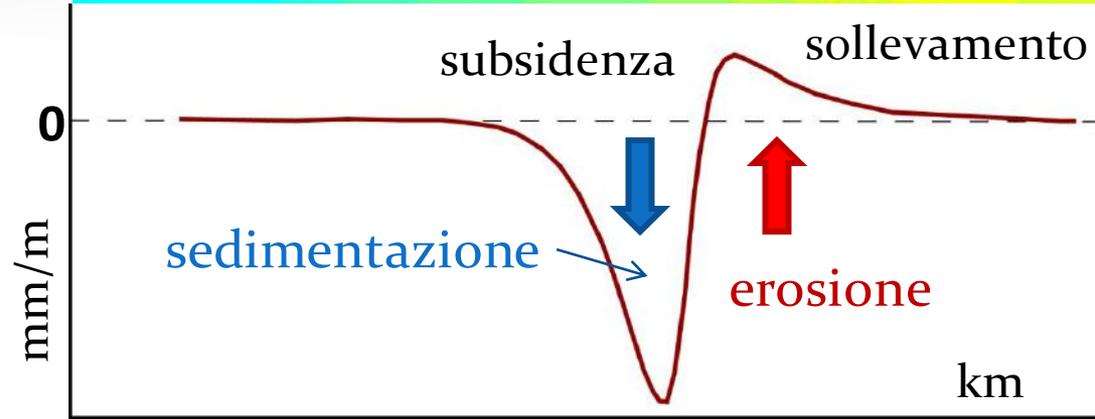
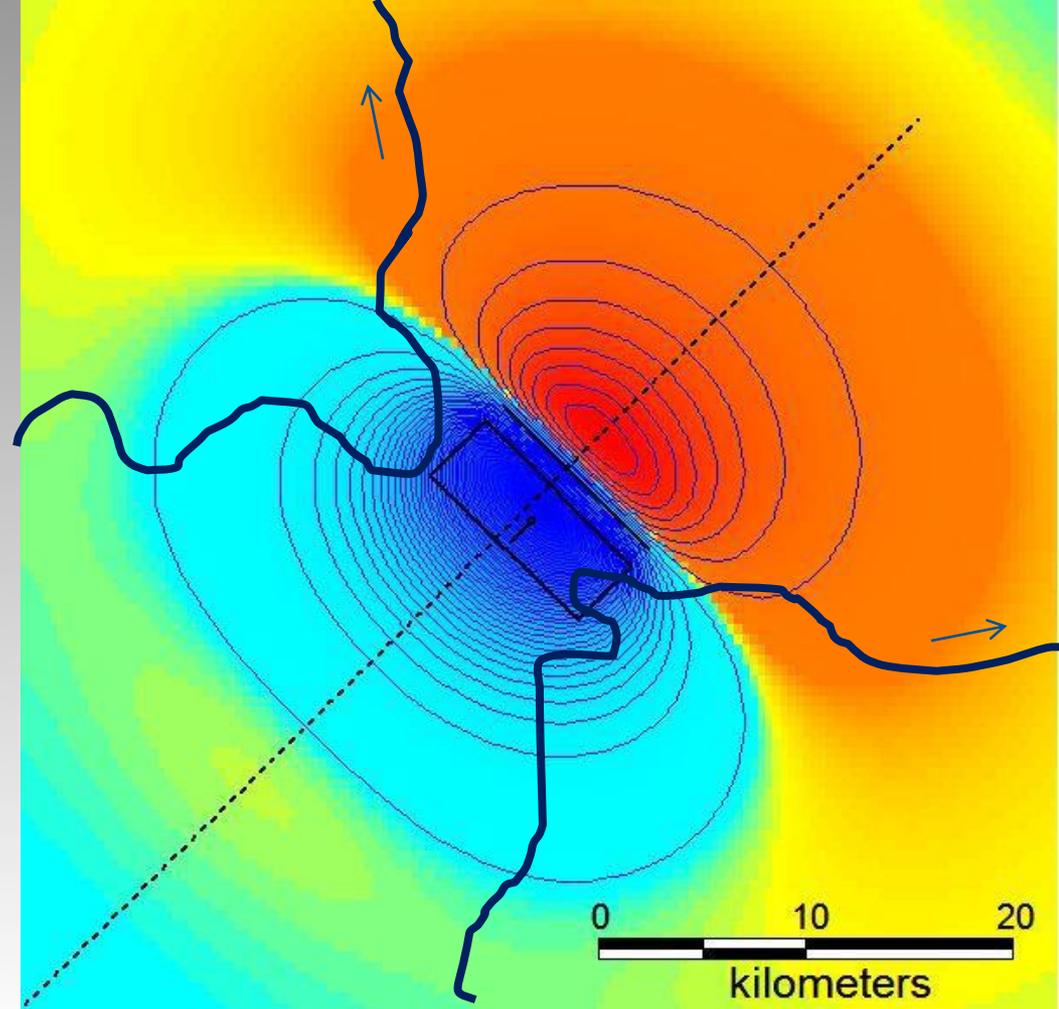
Effetti associati ad un terremoto

Scuotimento	Deformazione superficiale	Fagliazione superficiale
Avviene sempre	Avviene sempre	Non avviene sempre
E' transitorio	E' permanente	E' permanente
Colpisce un'area vasta o molto vasta	Colpisce un'area vasta (2 volte le dimensioni della faglia)	Colpisce un'area limitata
E' responsabile della maggior parte dei danneggiamenti	Produce danni limitati	Può produrre danni ingenti
Può innescare altri effetti geologici (e.g. <i>liquefazioni, frane, fratturazione del suolo</i>)	Può innescare altri effetti geologici (<i>deviazioni fluviali, tsunami</i>) ed è responsabile dell'evoluzione di lungo termine del paesaggio	Può innescare altri effetti geologici (e.g. <i>blocco drenaggio, impaludamento</i>)
Per identificarne la sorgente bisogna effettuare studi alla scala 1:200k-1M	Richiede una mappatura alla scala 1:200k-1M	Richiede una mappatura alla scala > 1:10k
		

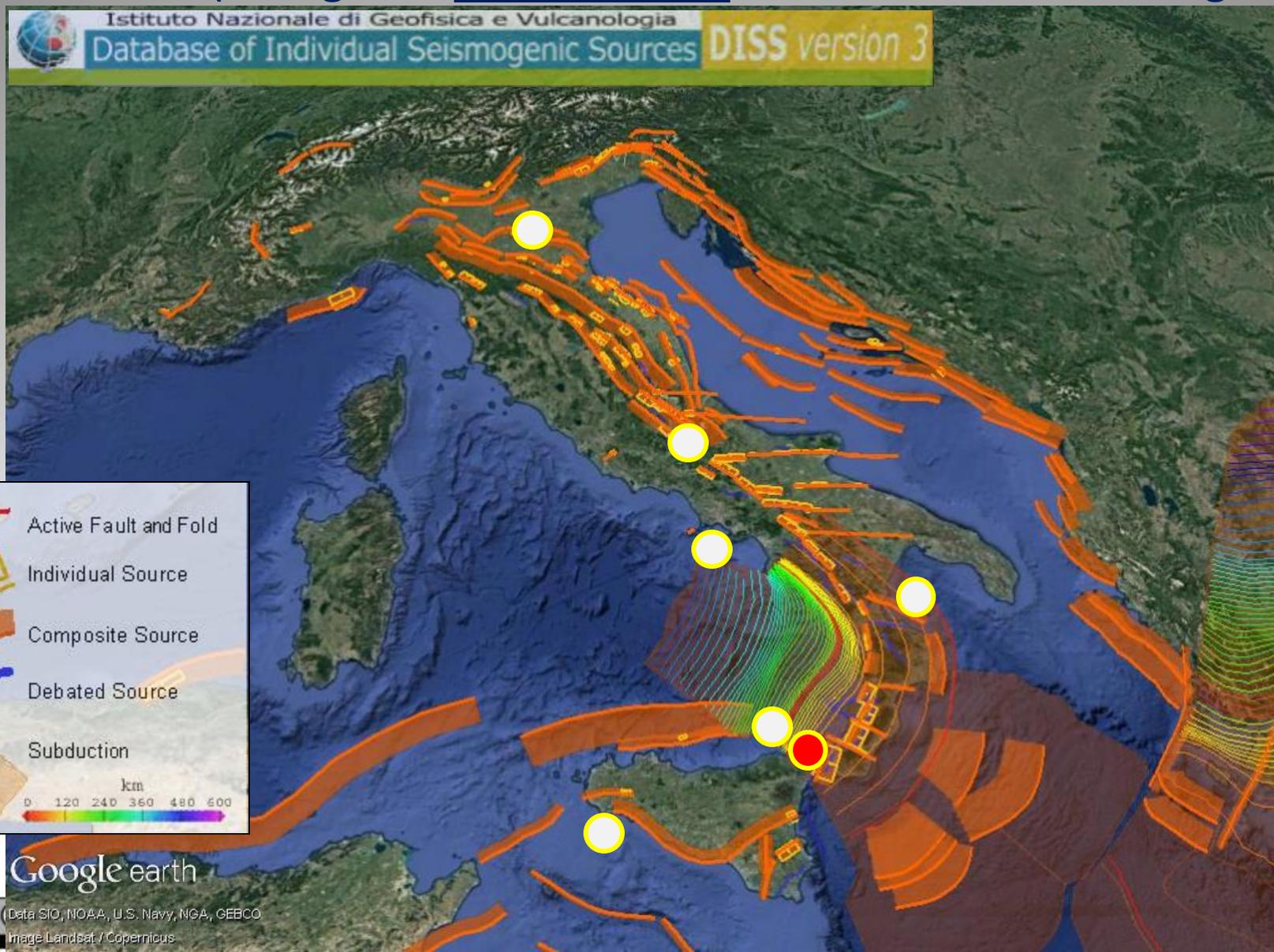
Attività tettonica

Controllo su (strumenti)

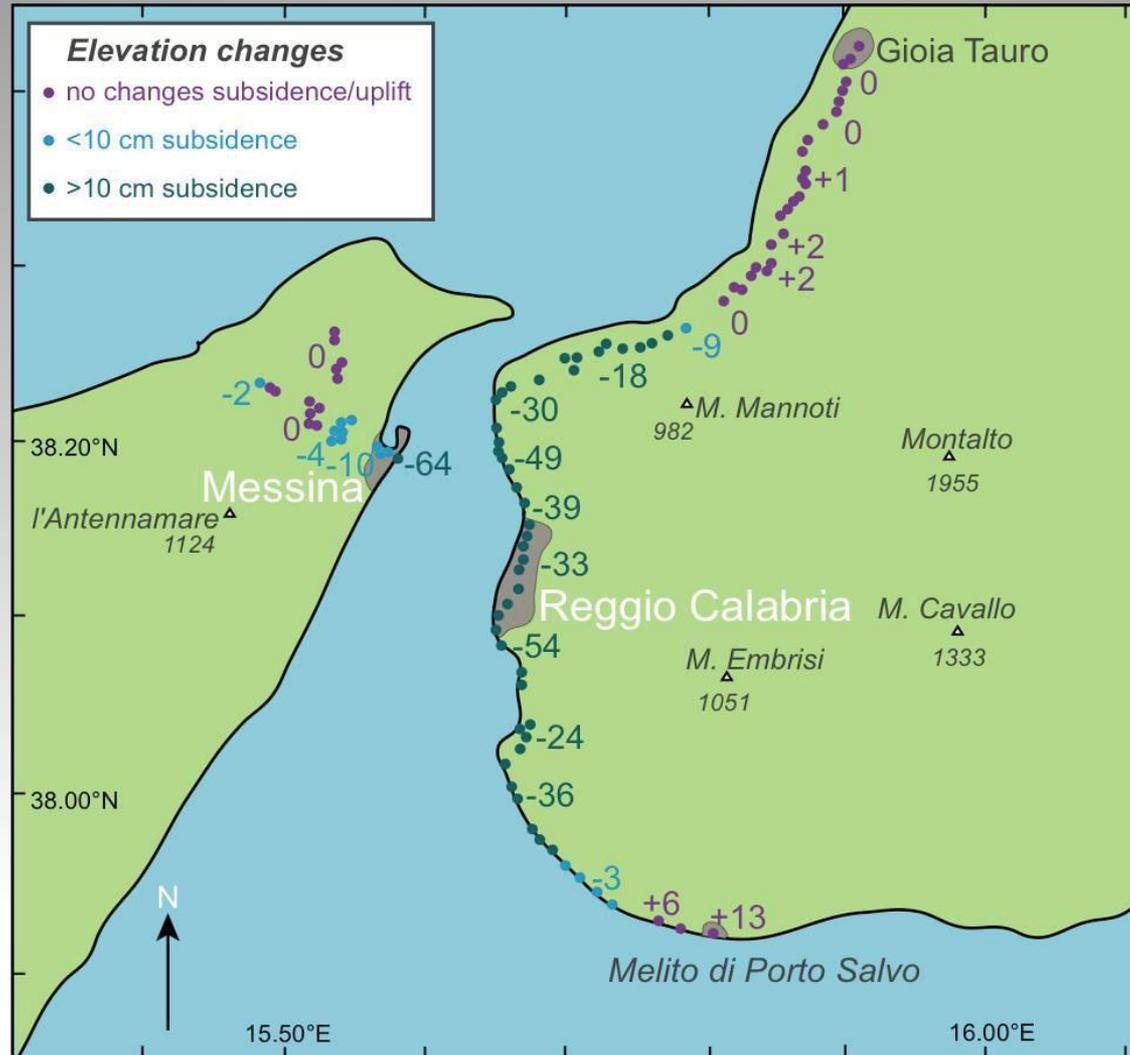
- topografia
- processi erosivi e deposizionali
- andamento drenaggio
- comportamento drenaggio
- geometria corpi sedimentari
- geometria e andamento altimetrico terrazzi (marini e fluviali)
- analisi alla scala dell'intera faglia
- identificazione: geometria
- caratterizzazione: cinematica/tassi di attività



Approcci che utilizzano una quantificazione degli effetti della **deformazione superficiale cosismica** (collegata ad un terremoto) o **cumulata** (collegata a più terremoti - storia sismica della faglia)



Non solo geodesia spaziale: il terremoto di Messina del 1908, M_w 7.1

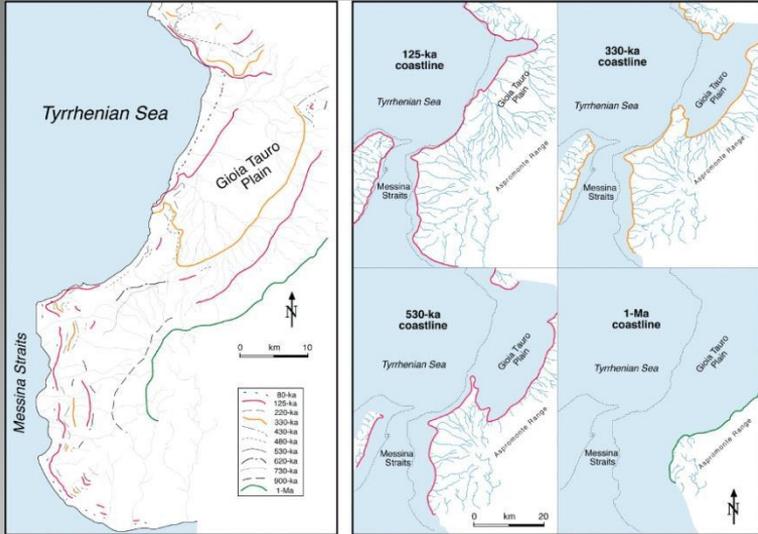


Pino et al., 2009

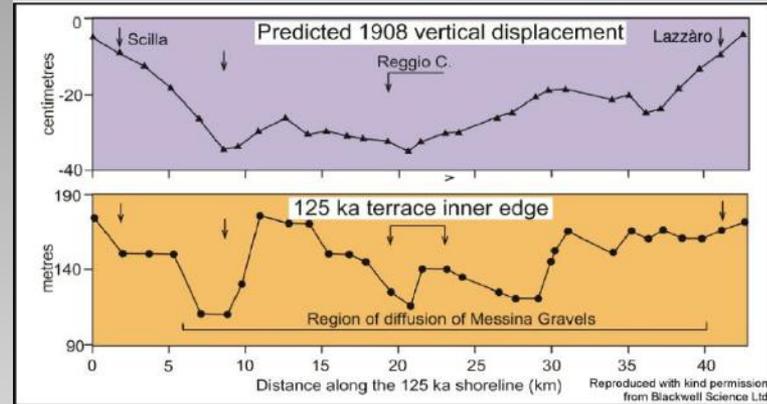
Le misure di livellazione eseguite prima e dopo il terremoto lungo la linea ferroviaria da Loperfido (1909) mostrano un settore principale in subsidenza sul lato calabrese.

Terremoto di Messina del 1908, M_w 7.1

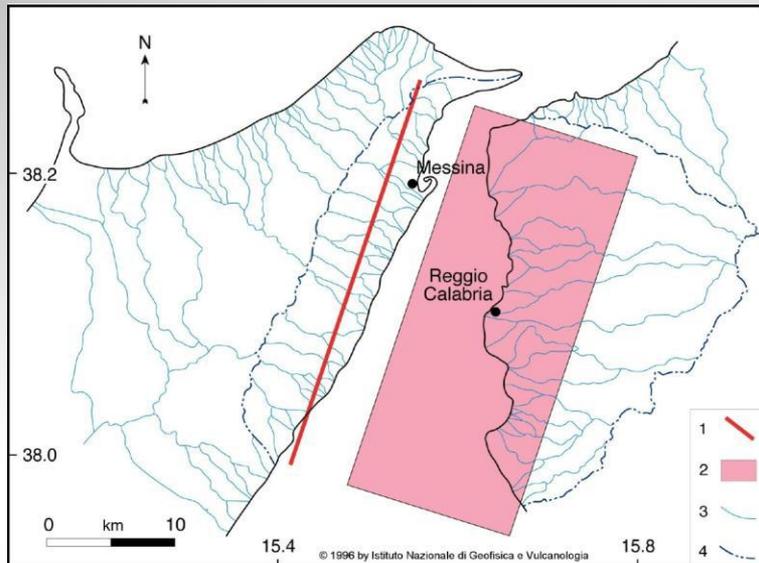
identificazione e caratterizzazione della Sorgente Sismogenetica



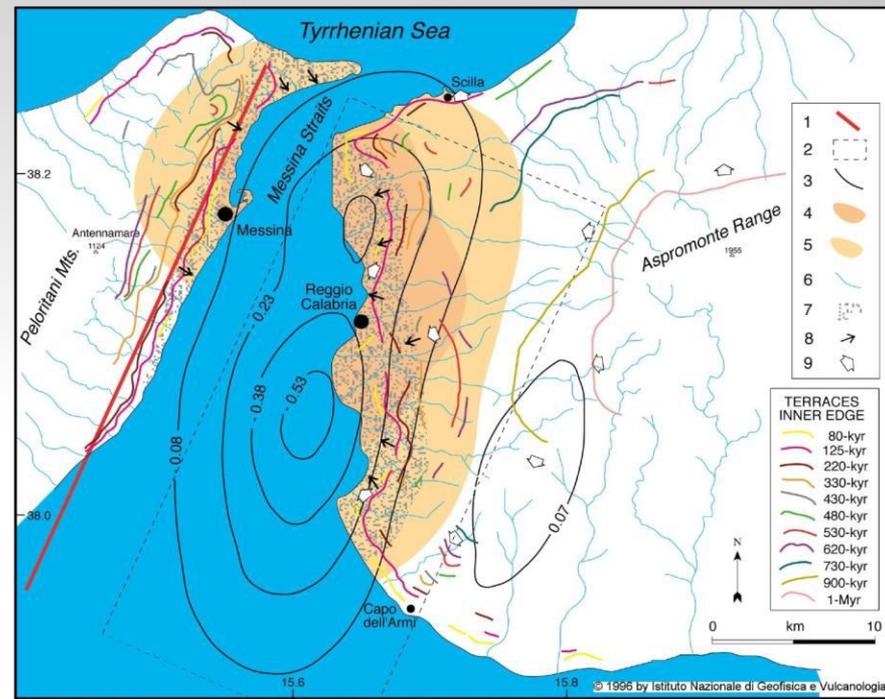
1- Evoluzione di lungo termine del paesaggio



3- Modellazione deformazione cosismica da dati di livellazione geodetica



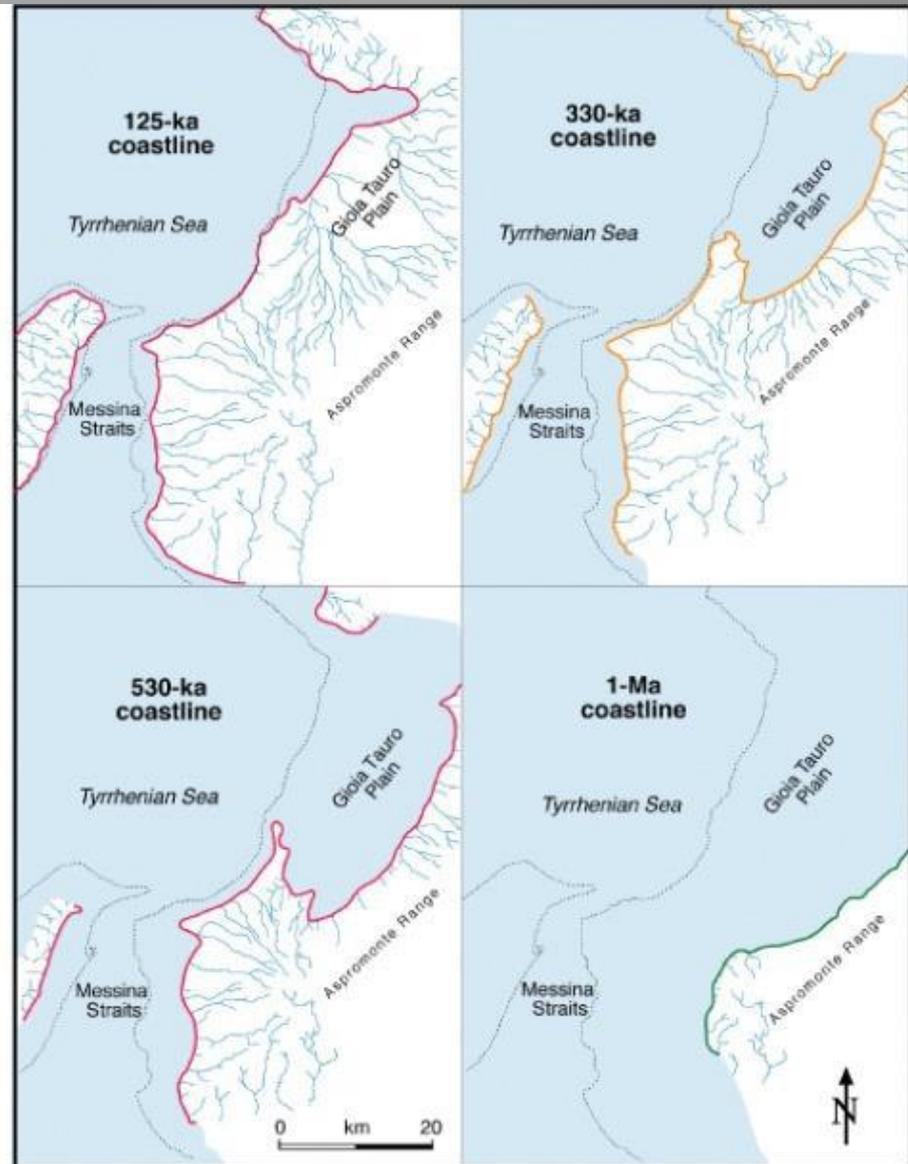
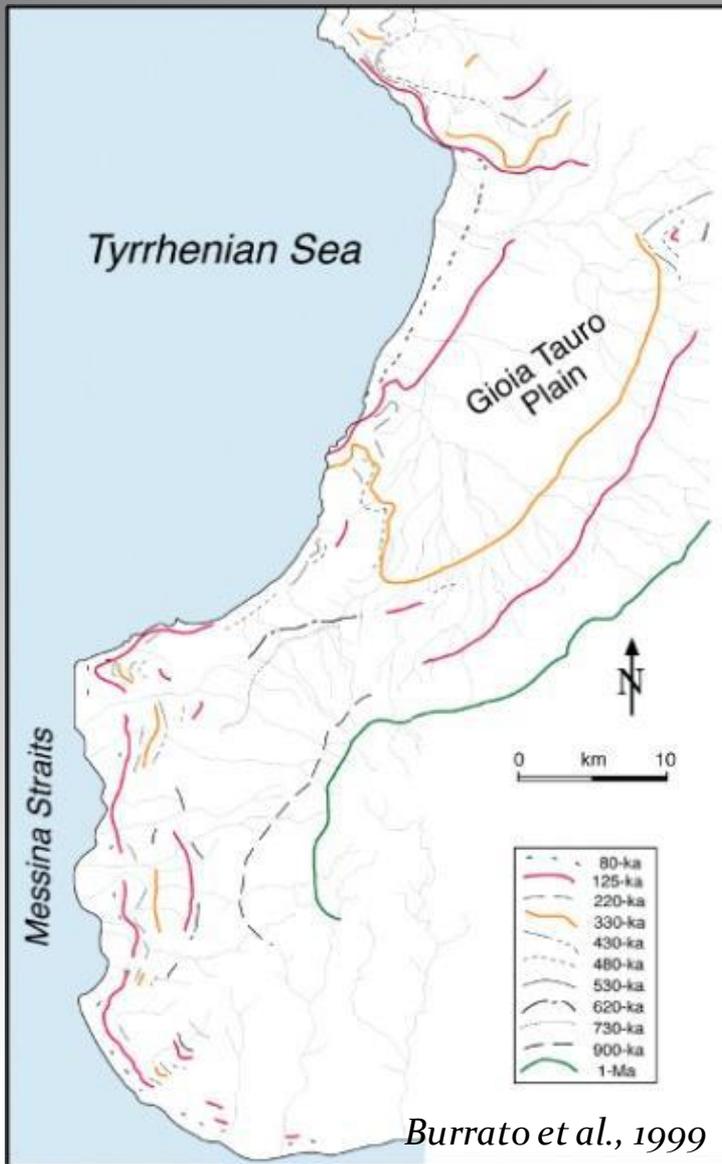
2- Controllo tettonico sul drenaggio



4- Deformazione verticale attesa vs geologia e geomorfologia

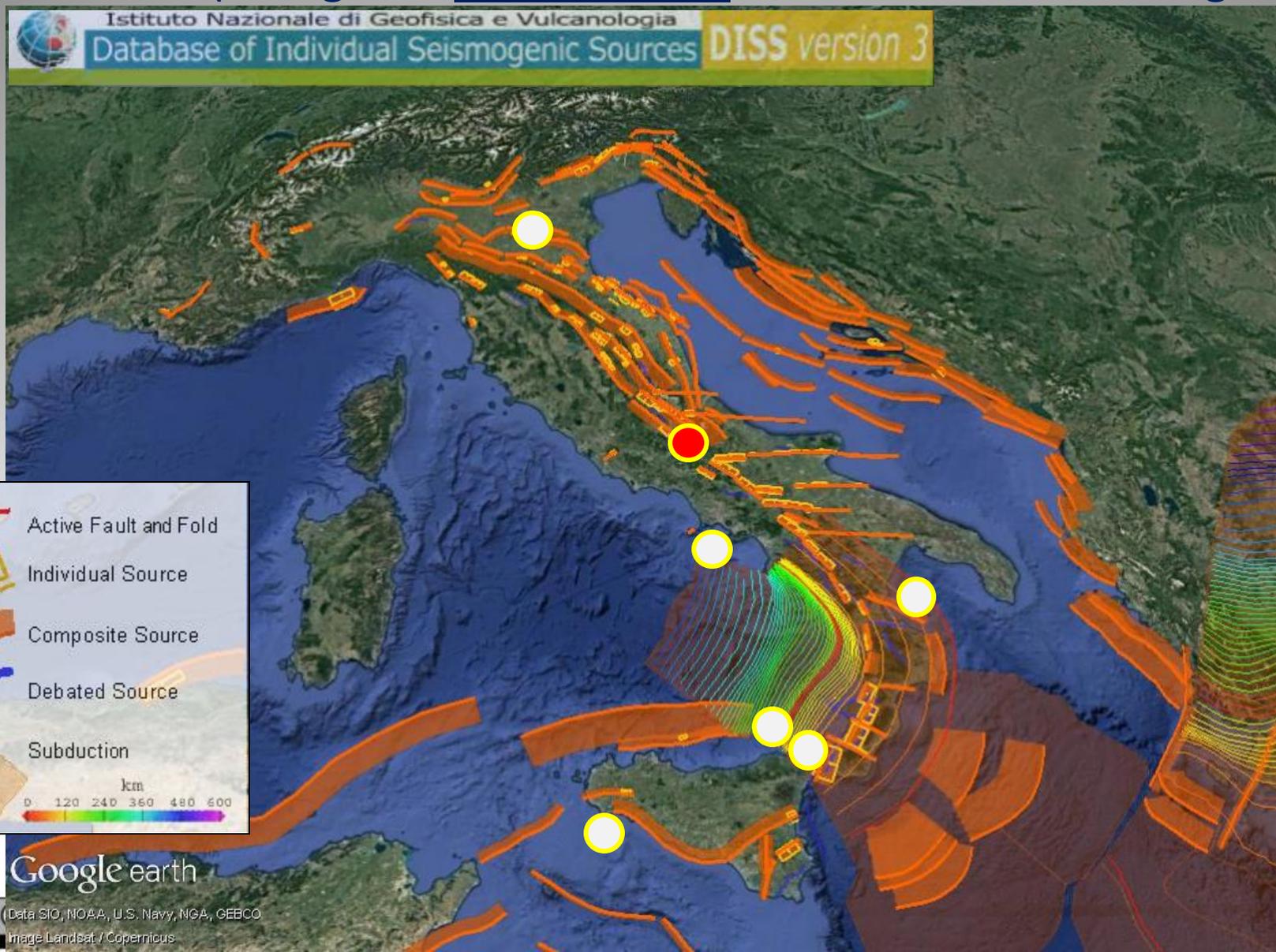
(1) Burrato et al., 1999; (2, 4) Cucci et al., 1996; (3) Valensise & Pantosti, 1992

Terrazzi marini

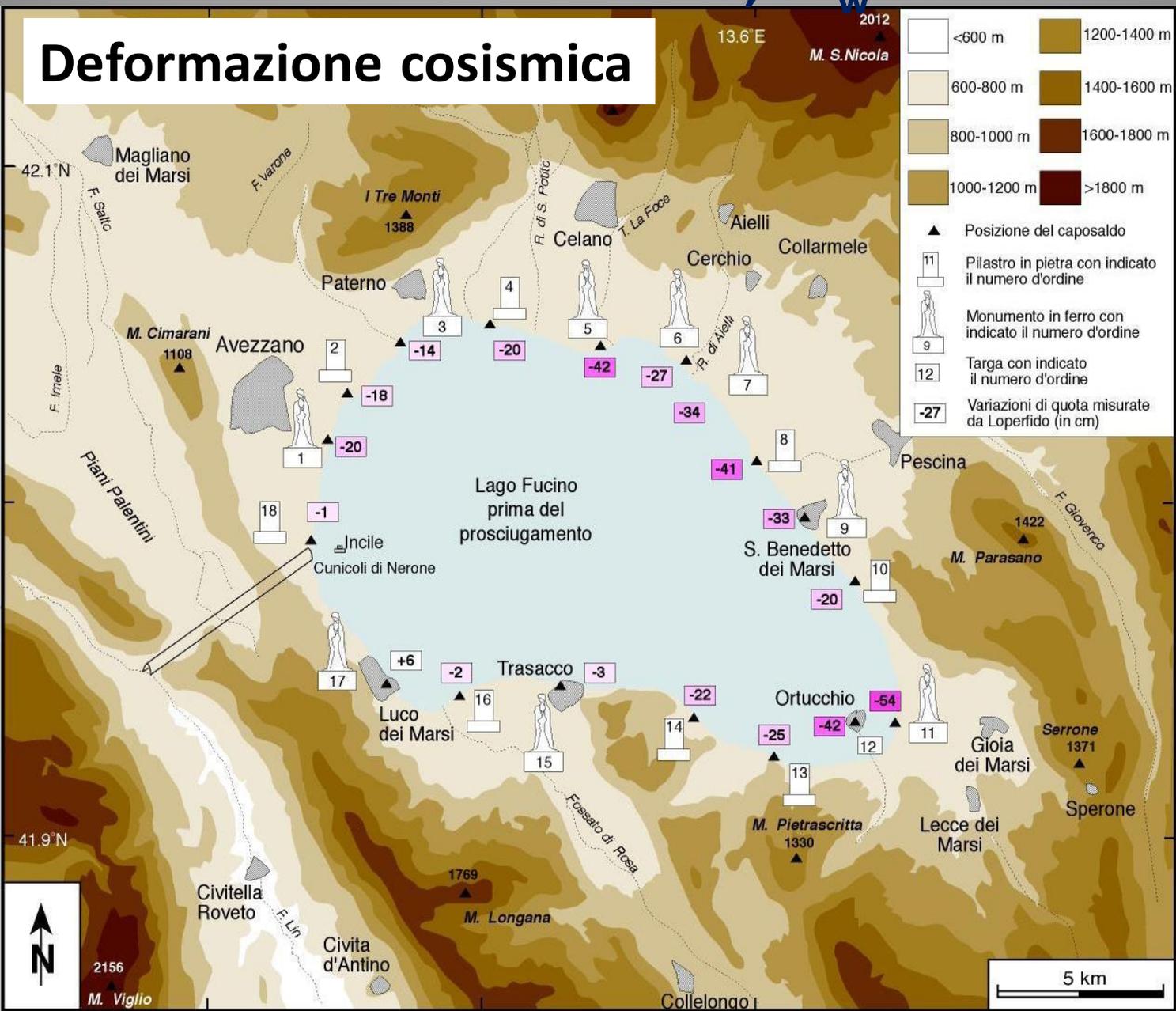


Andamento e quota controllati da fenomeni tettonici a scala regionale (subduzione) e locale (fagliazione)

Approcci che utilizzano una quantificazione degli effetti della **deformazione superficiale cosismica** (collegata ad un terremoto) o **cumulata** (collegata a più terremoti - storia sismica della faglia)



Le "Madonnine" – Marsica 1915, M_w 7.1



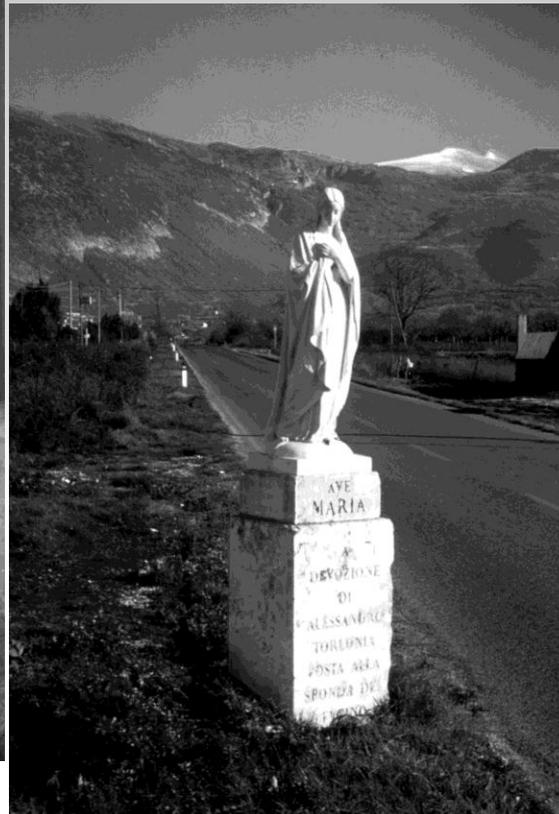
D'Addezio e Valensise, 1998



Le “Madonnine” – Marsica 1915, M_w 7.1



San Benedetto dei Marsi



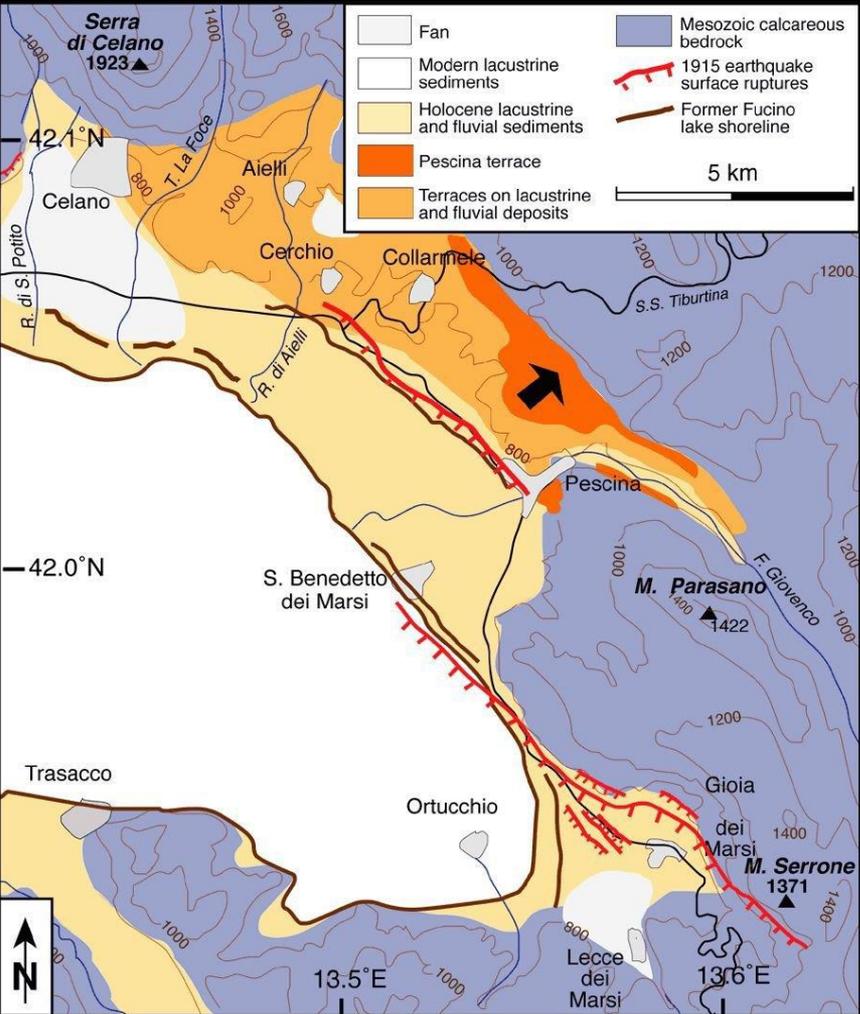
Strada Ortucchio - Gioia



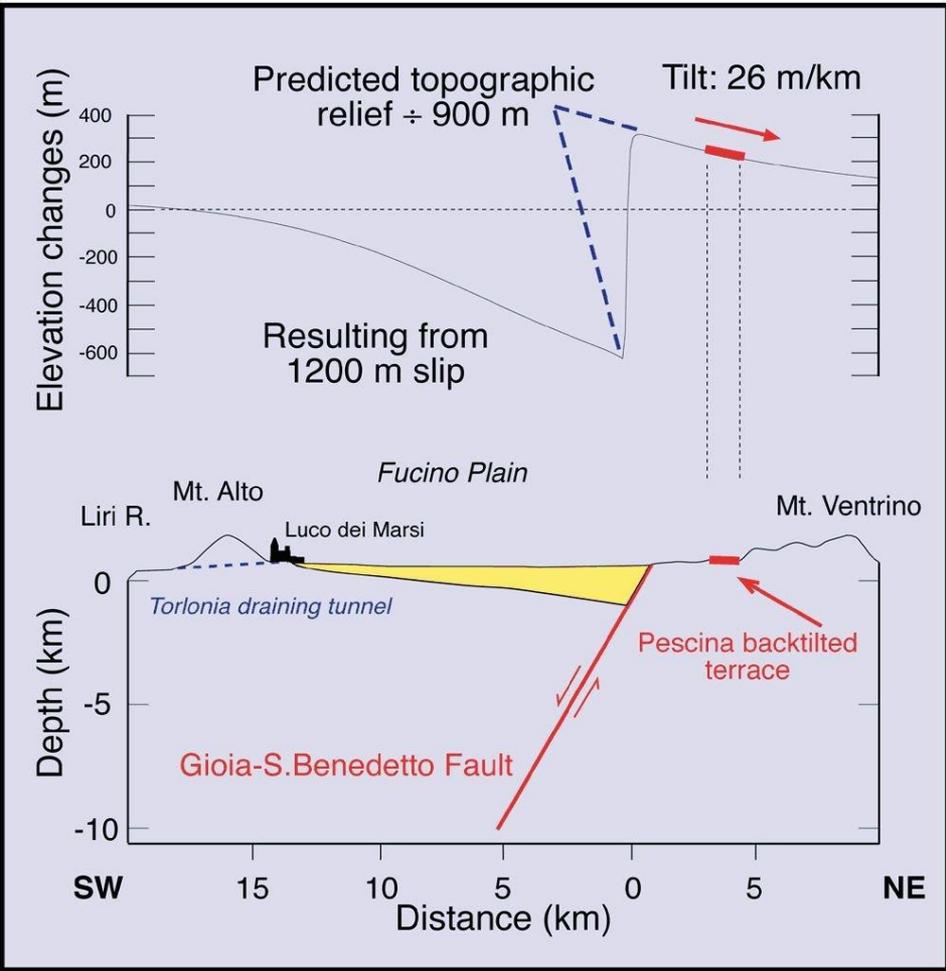
Ortucchio

La deformazione di lungo termine

Effetti cumulati di più terremoti - intera storia sismica della faglia



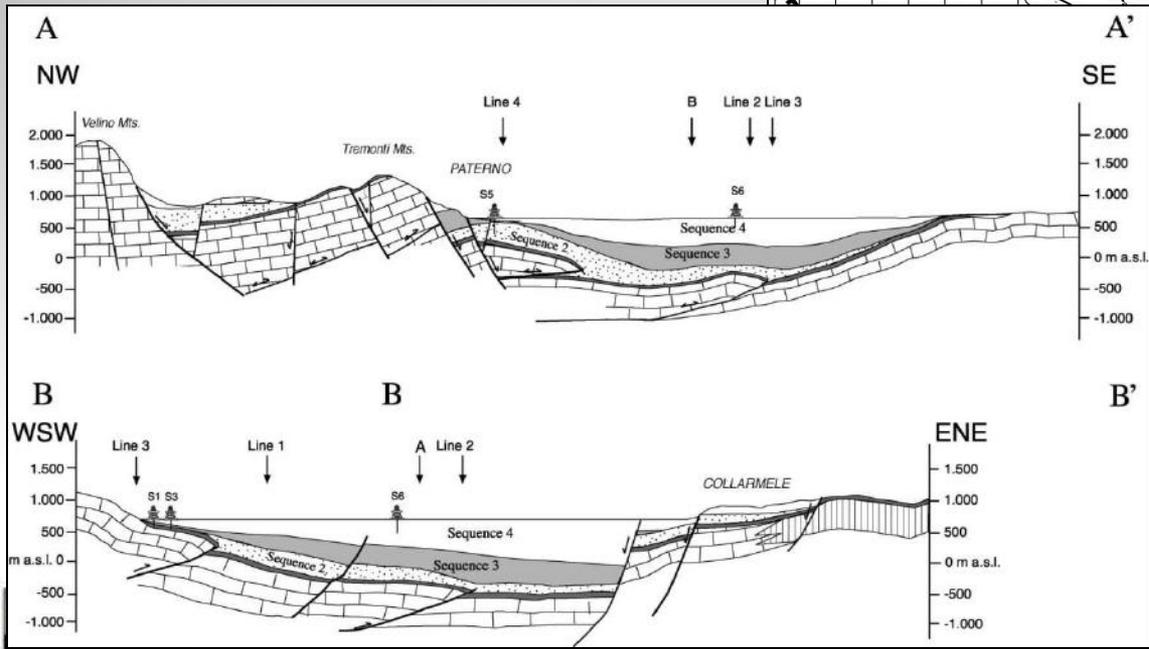
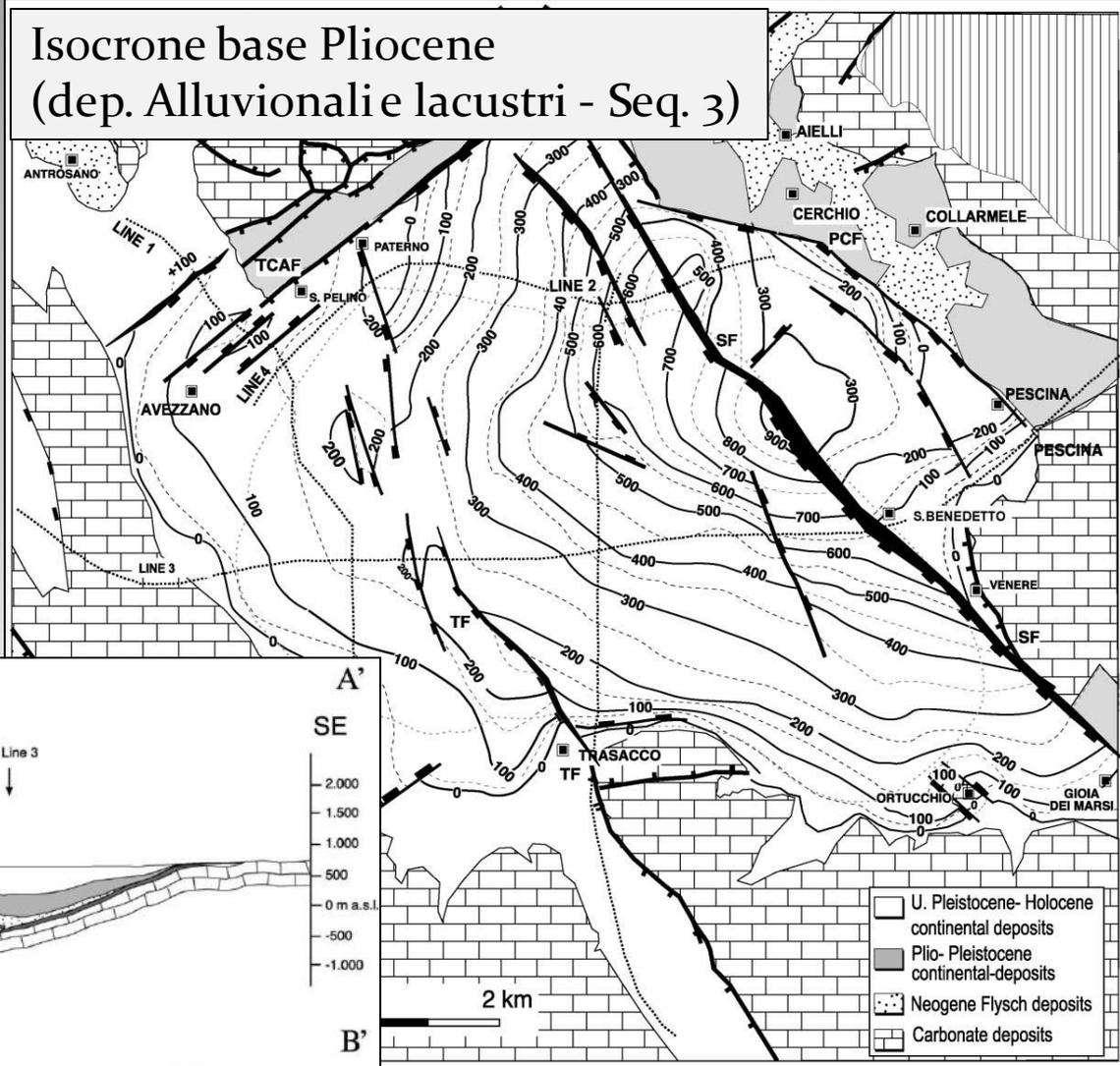
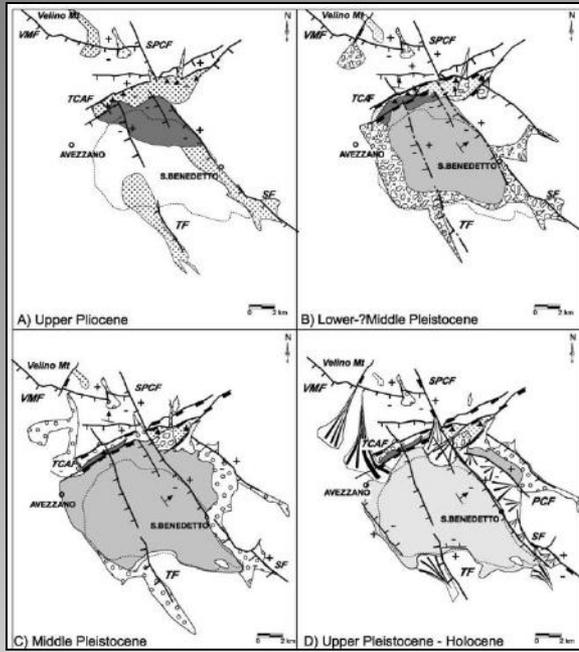
Cumulative elevation changes produced by repeated 1915-type earthquakes and topographic profile of the Fucino plain



D'Addezio e Valensise, 1998



Il segnale di lungo termine nel sottosuolo



Cavinato et al., 2002

Il modello di faglia a *slip* variabile

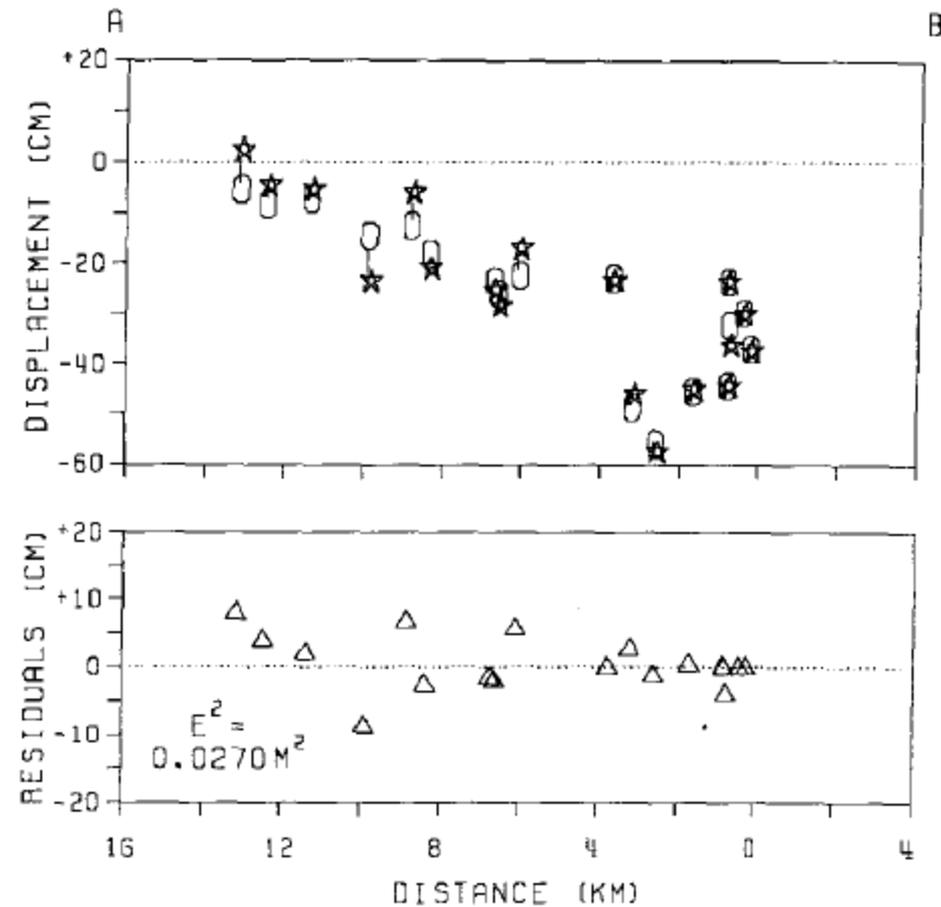
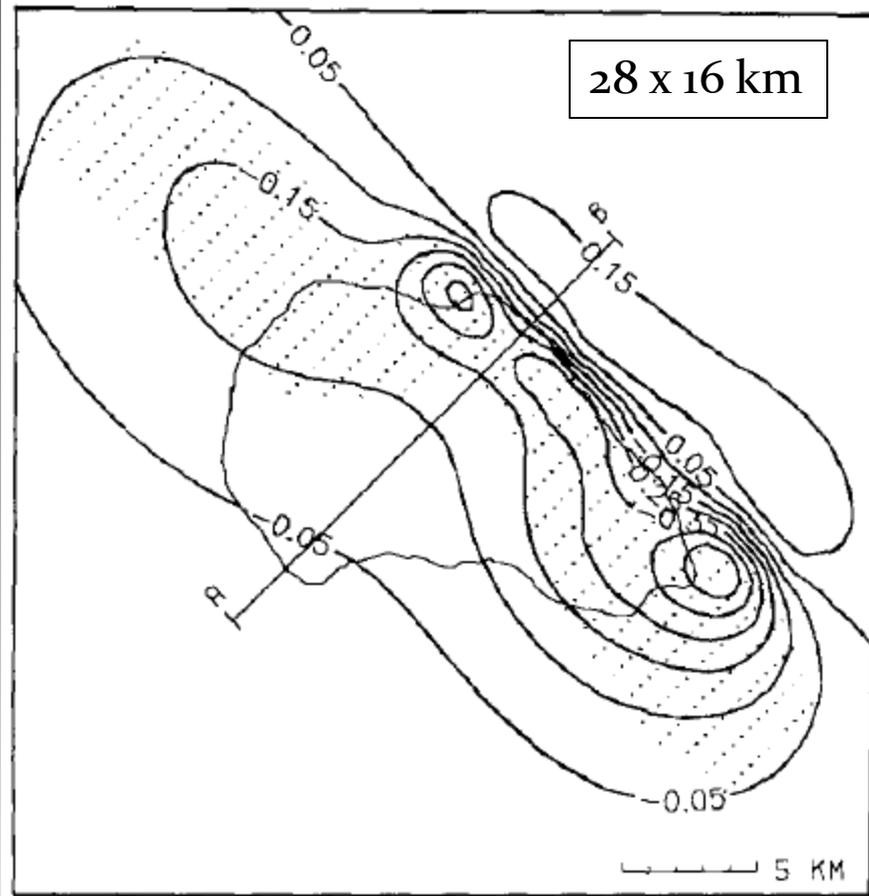
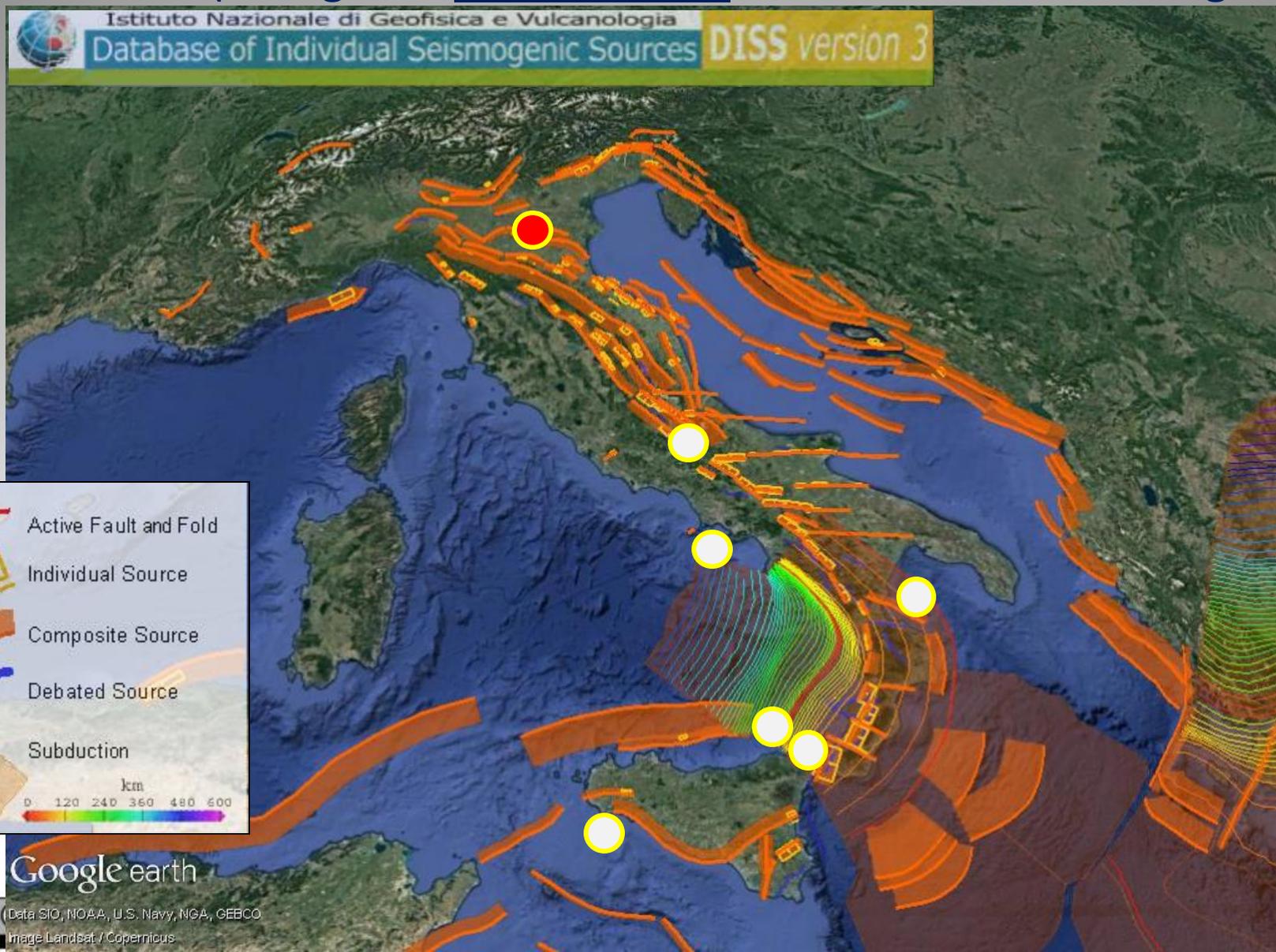
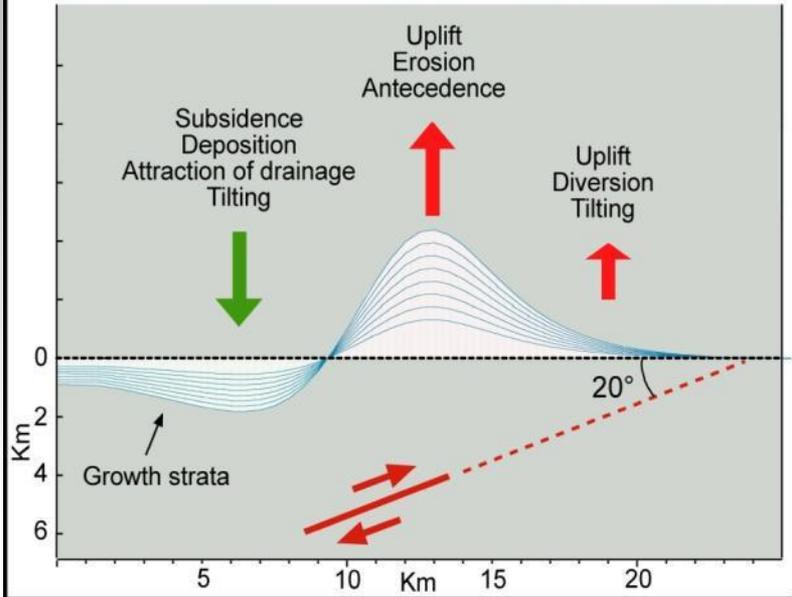
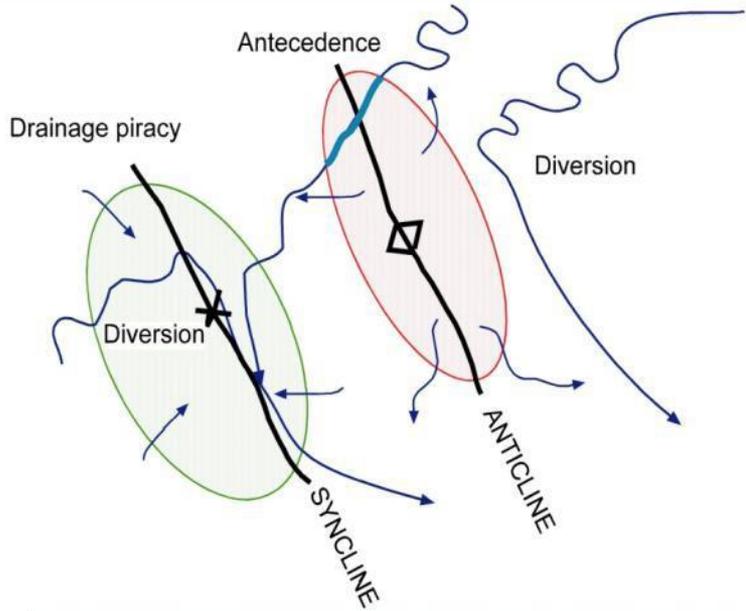


FIG. 8. (Left) Contour map of vertical surface deformation at 0.1 m intervals for the VSP model of Figure 7. Light dots represent the surface projection of locations of non-zero slip. (Right) Observed and theoretical vertical displacements (*top*) and VSP residuals (*bottom*) projected along A-B. Summed square error (0.027 m^2) is six times less than the best USP fit and about 4 per cent more than the expected survey error.

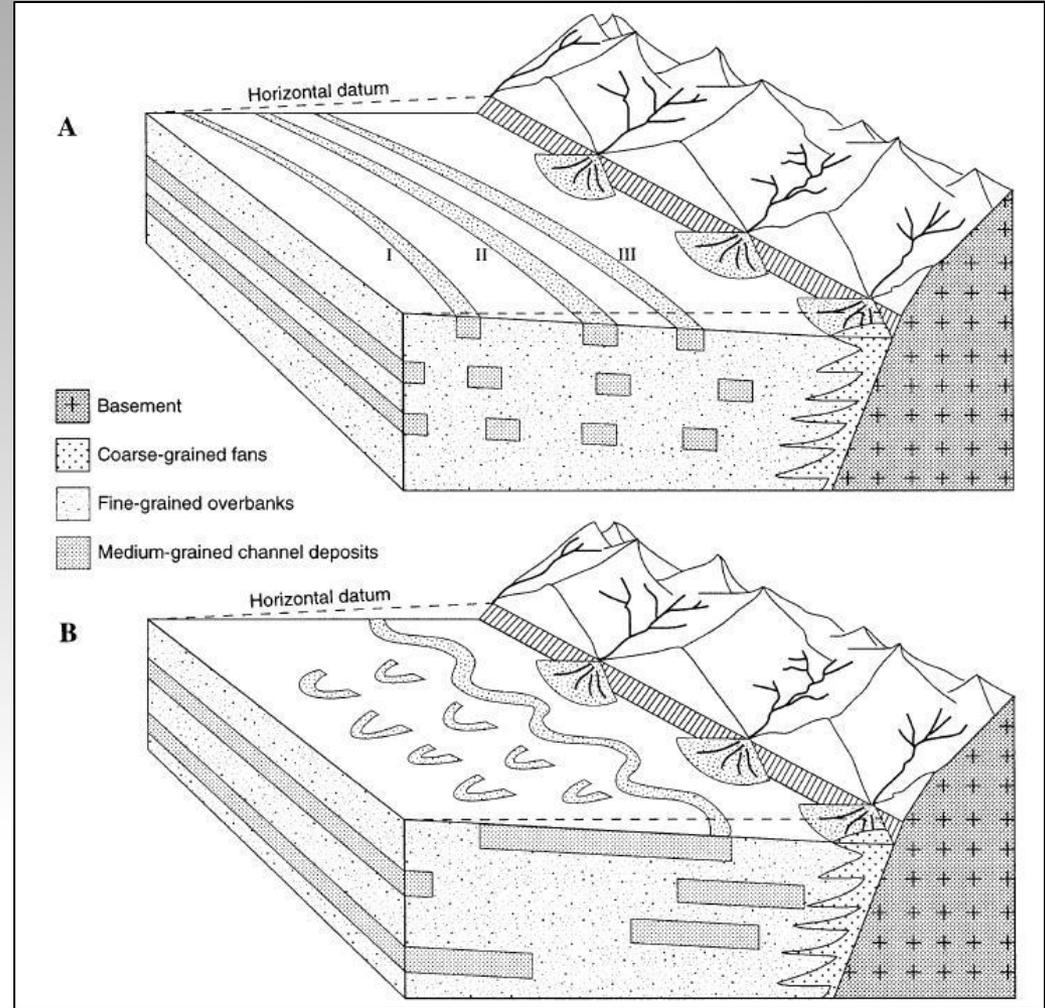
Approcci che utilizzano una quantificazione degli effetti della **deformazione superficiale cosismica** (collegata ad un terremoto) o **cumulata** (collegata a più terremoti - storia sismica della faglia)



Deformazioni verticali del suolo e anomalie del drenaggio

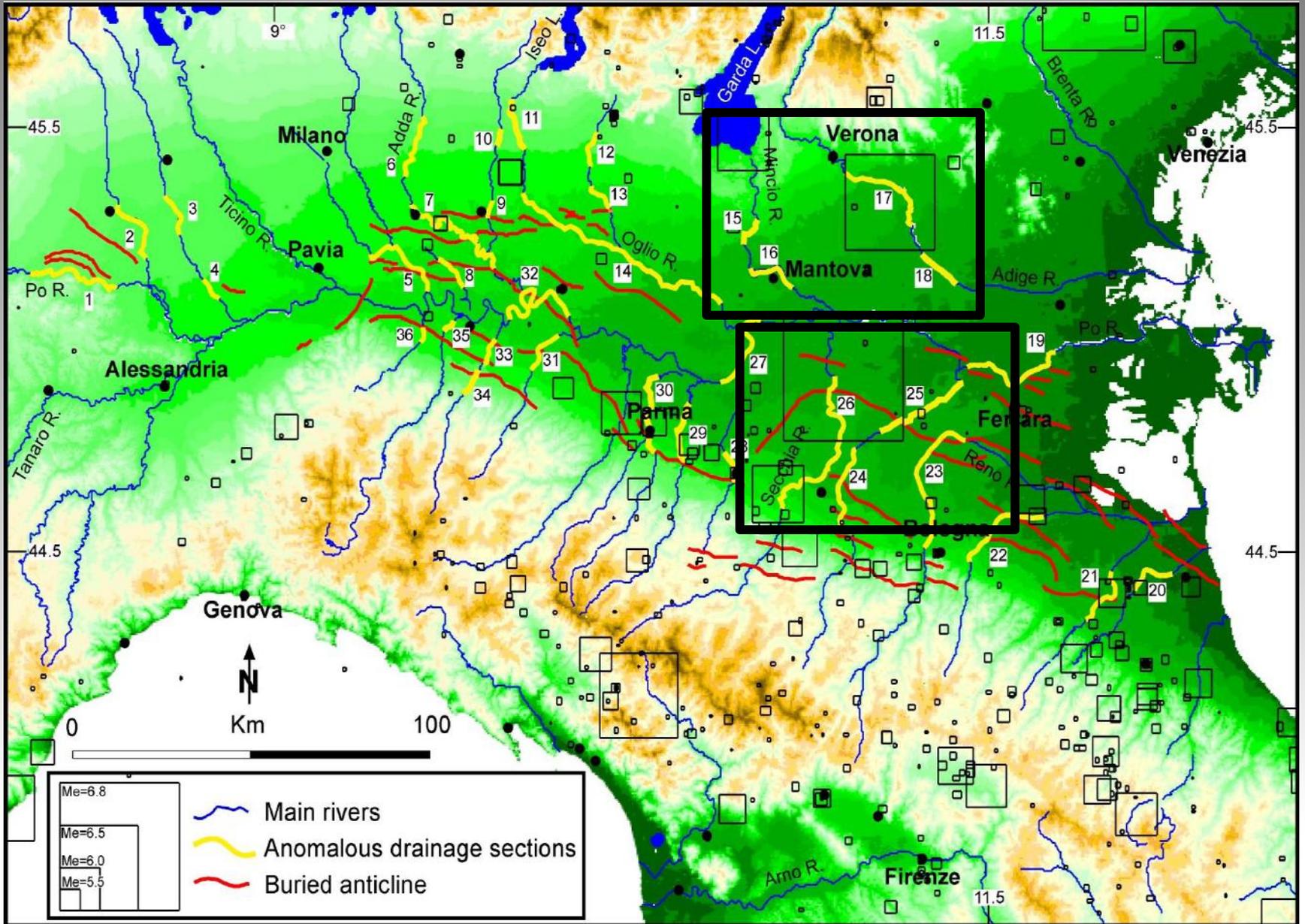


Burrato et al., 2003

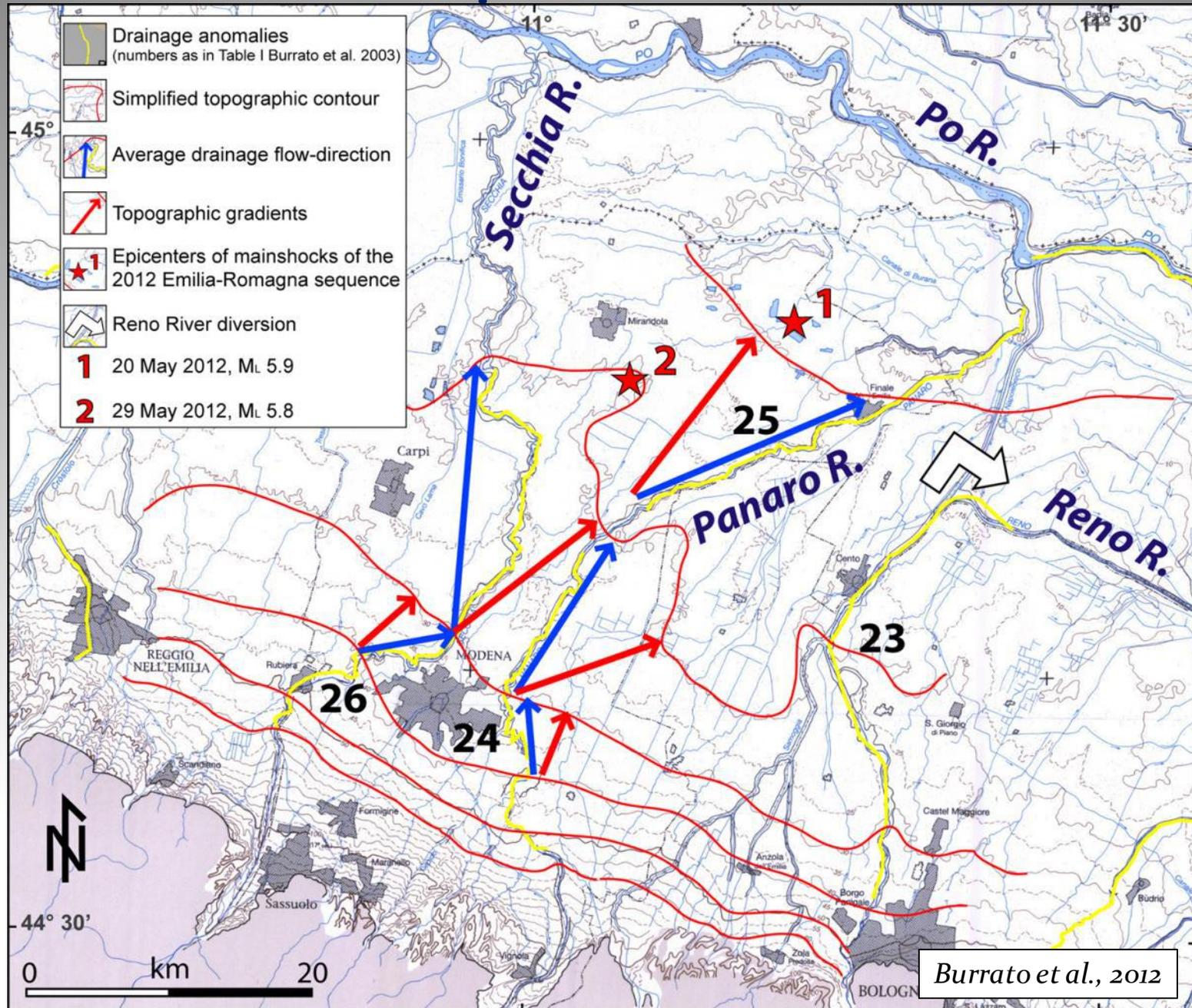


Peakall et al., 2000

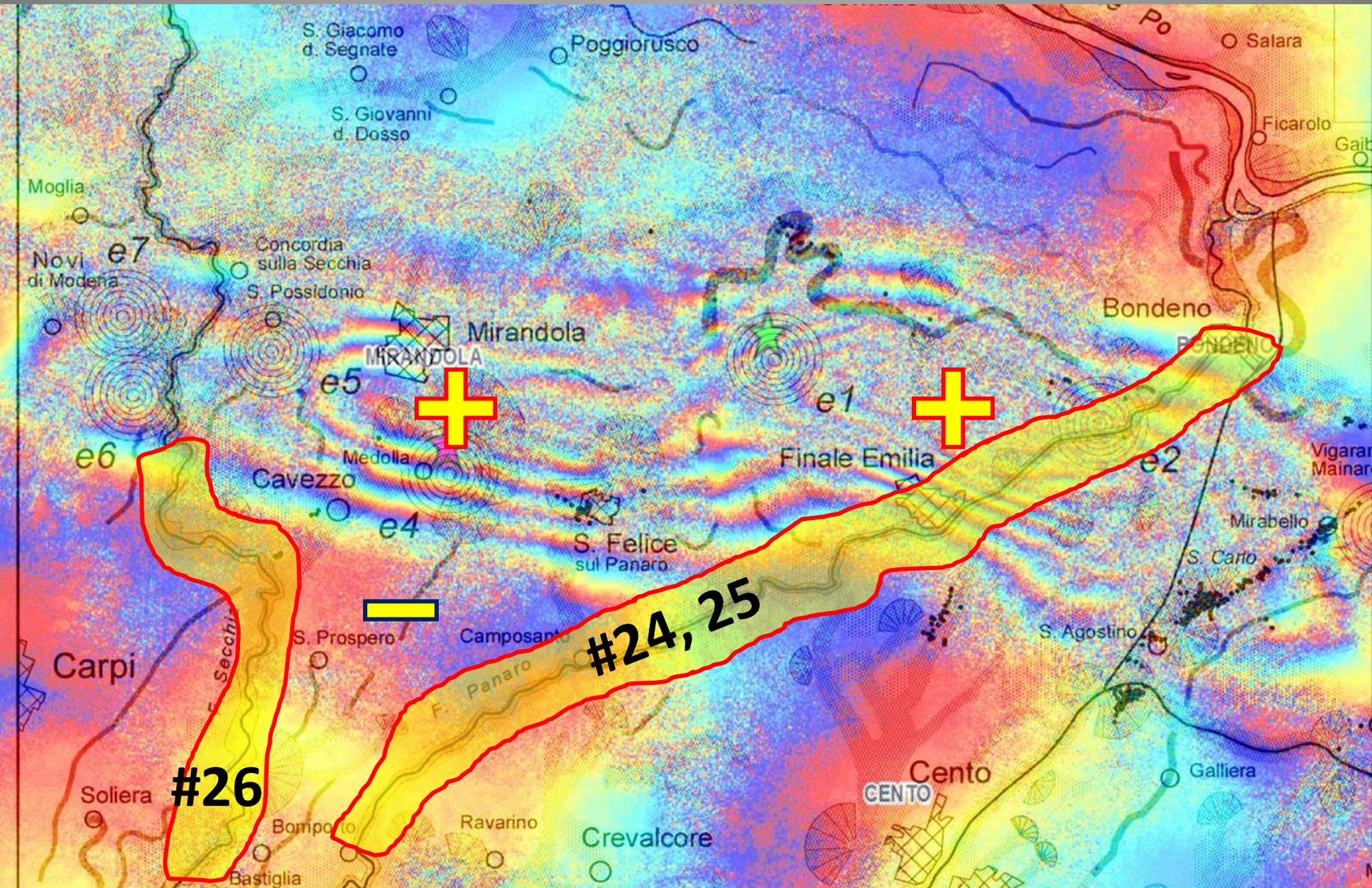
Un database di anomalie del drenaggio per la Pianura Padana



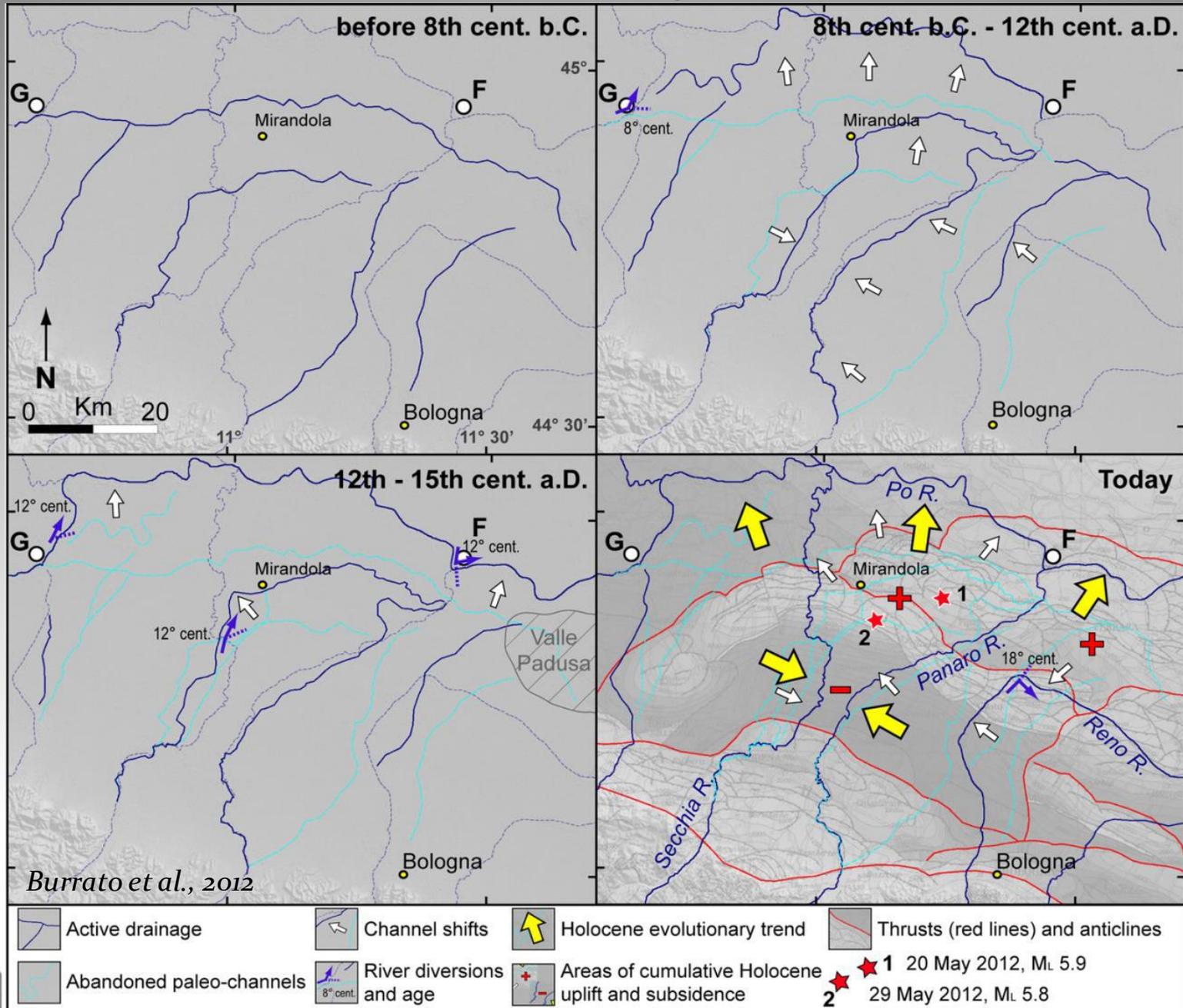
Come dichiarare la presenza di una anomalia?



Sollelevamenti cosismici dei terremoti dell'Emilia del 2012



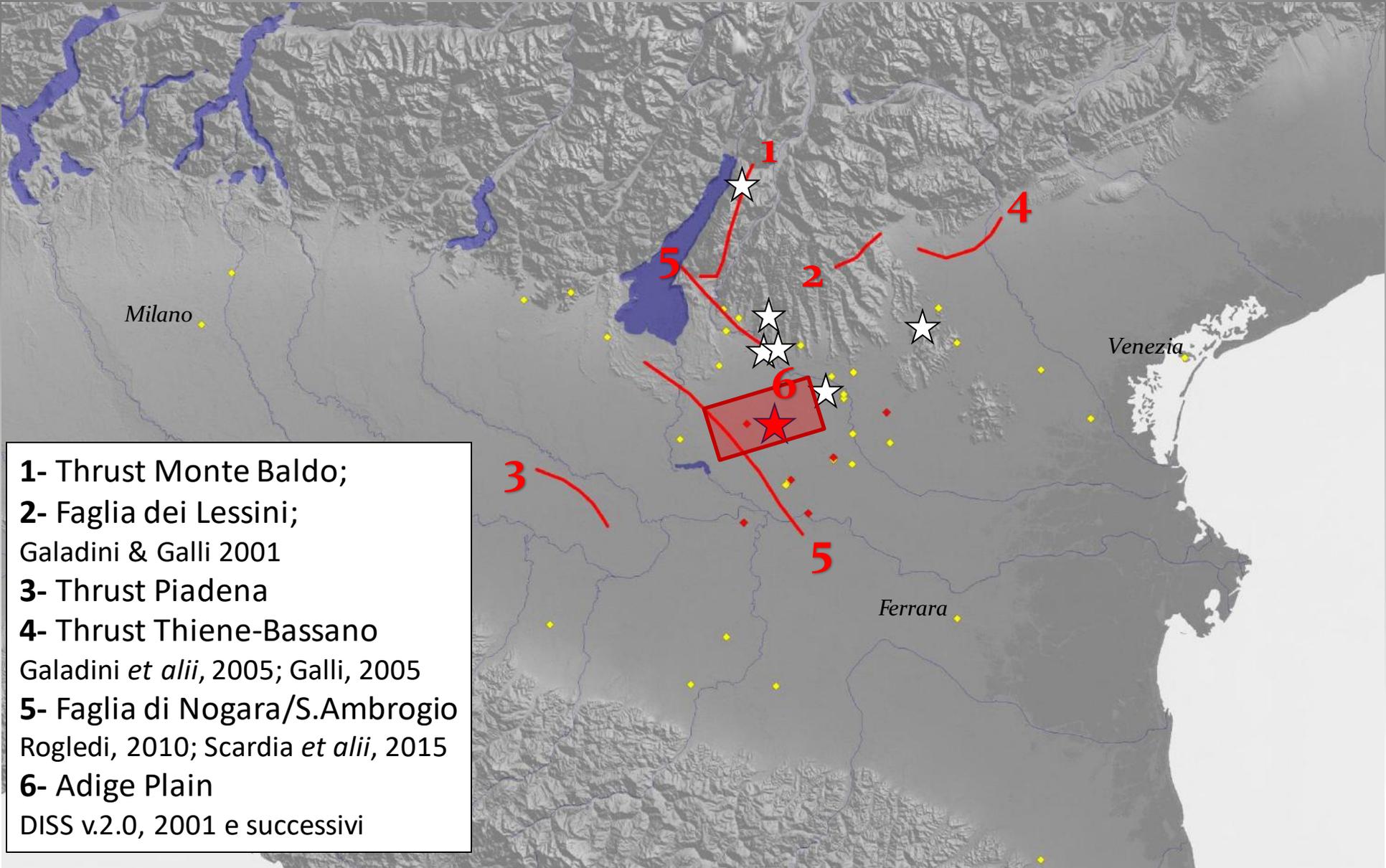
Evoluzione dei Fiumi Po, Secchia e Panaro



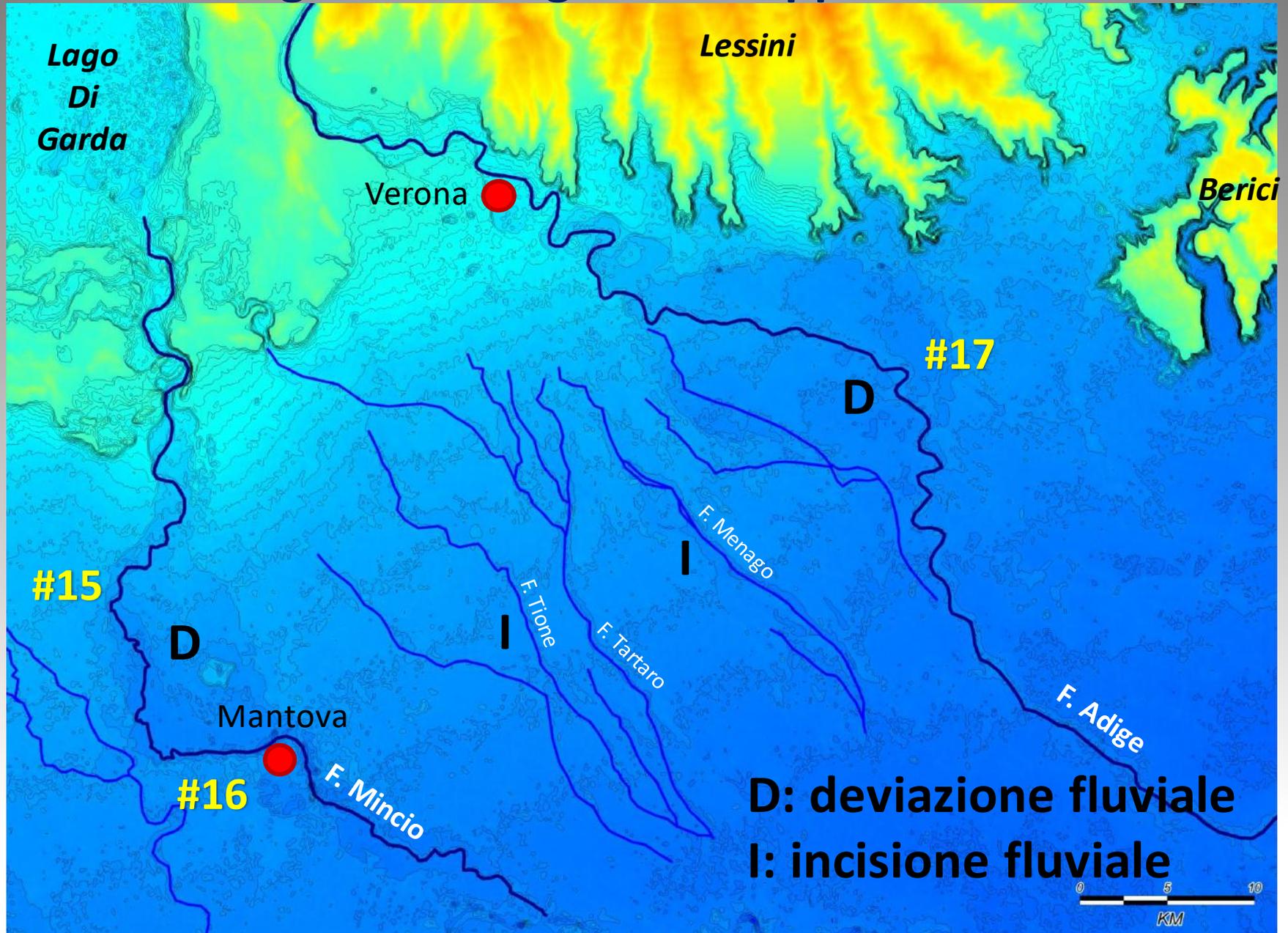
Burrato et al., 2012



Sintesi delle ipotesi sulla Sorgente del 1117 - M_w 6.5



Osservazioni geomorfologiche di supporto al modello DISS

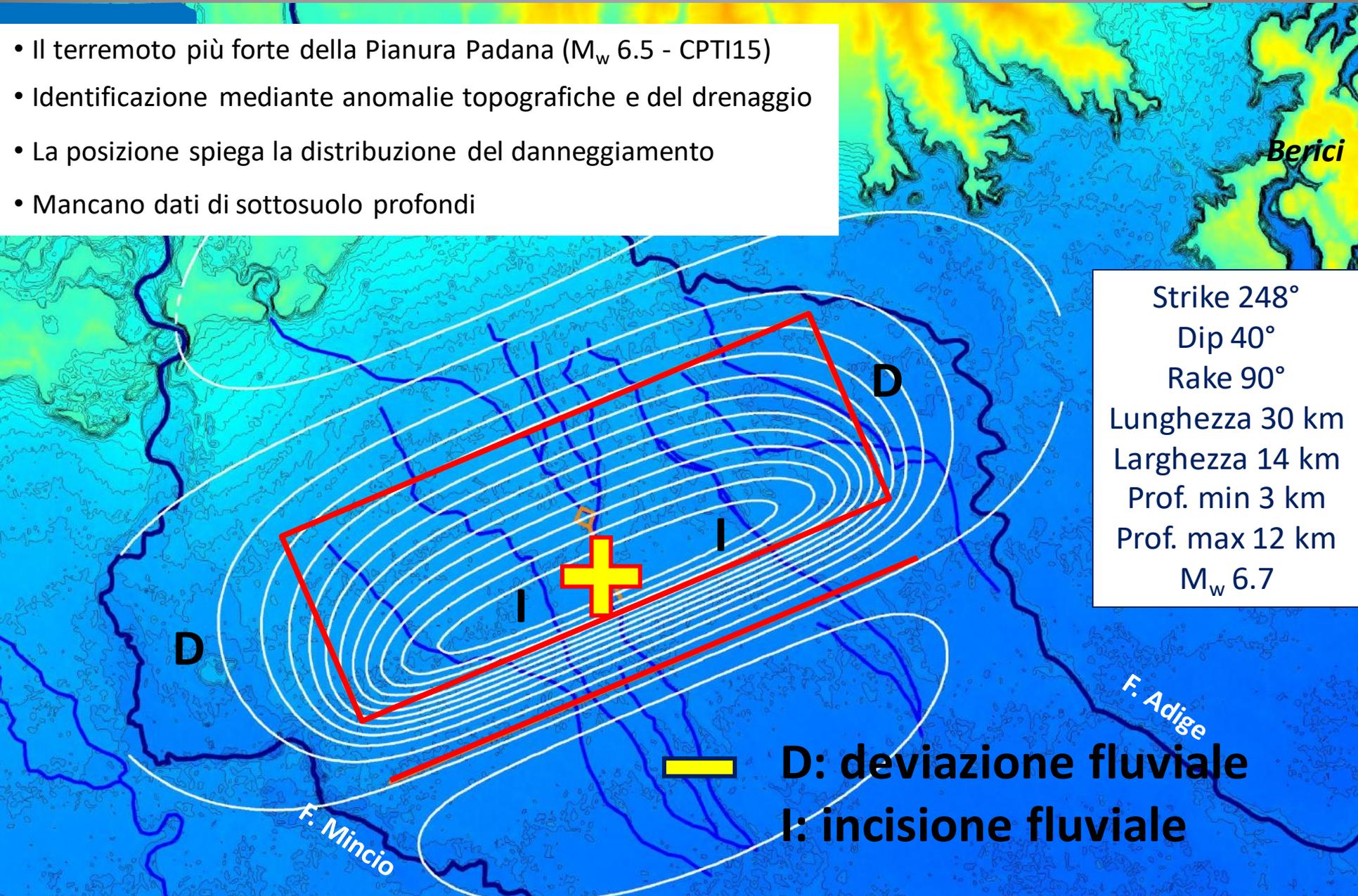


D: deviazione fluviale
I: incisione fluviale

isoipse ogni 5 m tra 0-100 slm

Modellizzazione analitica e geomorfologia

- Il terremoto più forte della Pianura Padana (M_w 6.5 - CPTI15)
- Identificazione mediante anomalie topografiche e del drenaggio
- La posizione spiega la distribuzione del danneggiamento
- Mancano dati di sottosuolo profondi

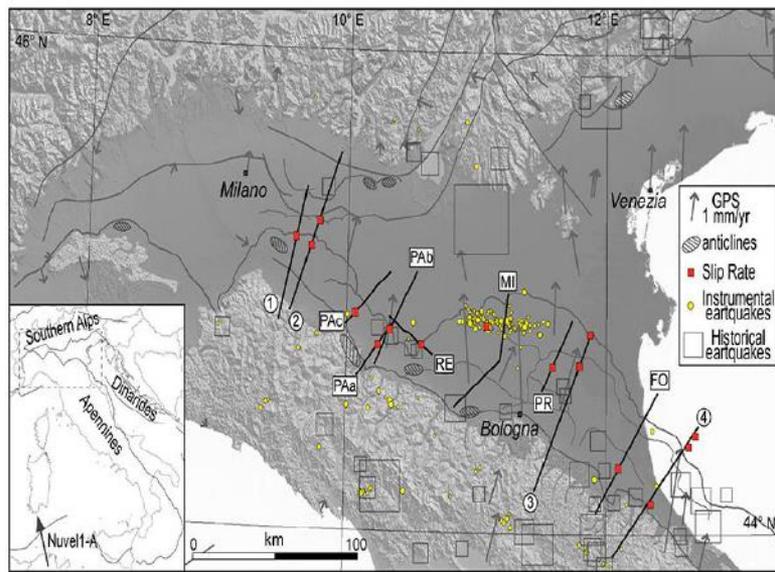


Slip rates in Pianura Padana

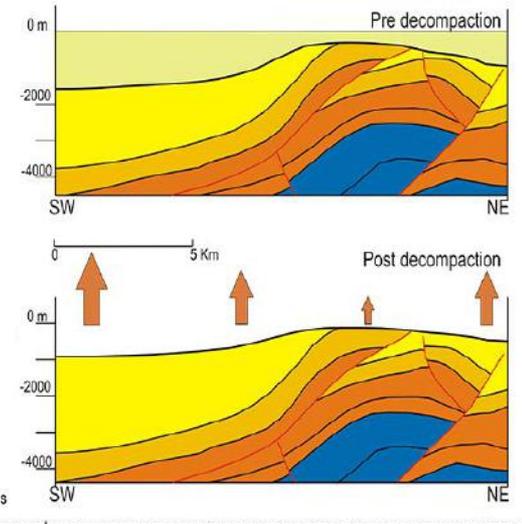
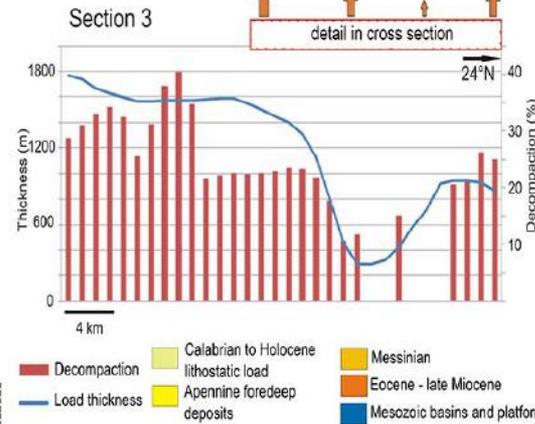
- decompattazione delle unità sedimentarie clastiche recenti;

La decompattazione è necessaria per rimuovere gli effetti dei cambi di volume dovuti alla diminuzione della porosità nel tempo indotta dal peso stesso dei sedimenti

- retrodeformazione con algoritmi differenti (*trishear/fault parallel flow/dislocation modeling*).



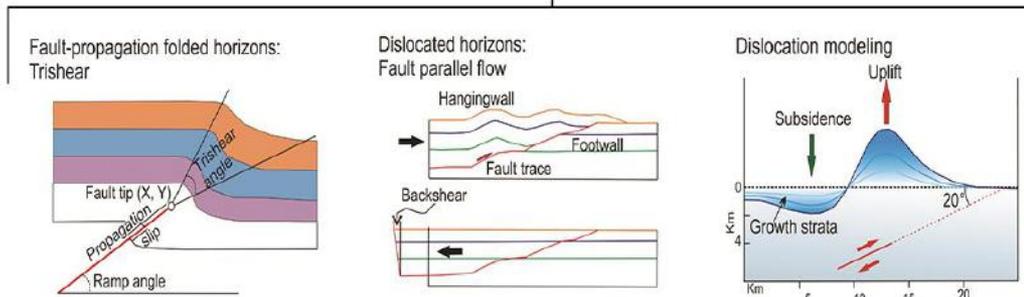
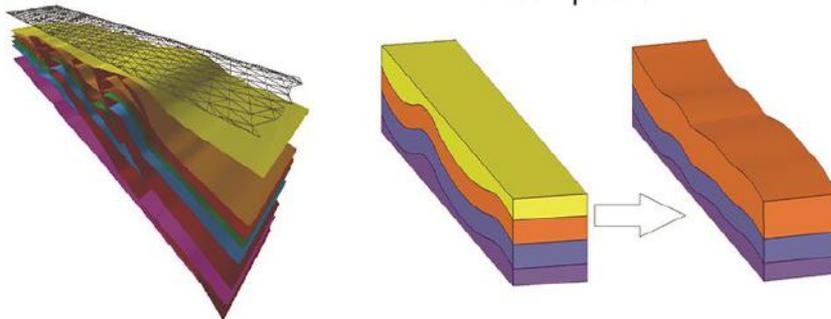
Effects of differential compaction on syntectonic deposits



3D models

→ Decompaction

→ Restoration algorithms



Approcci che utilizzano una quantificazione degli effetti della
deformazione superficiale cosismica o cumulata

Studi in aree marine e costiere

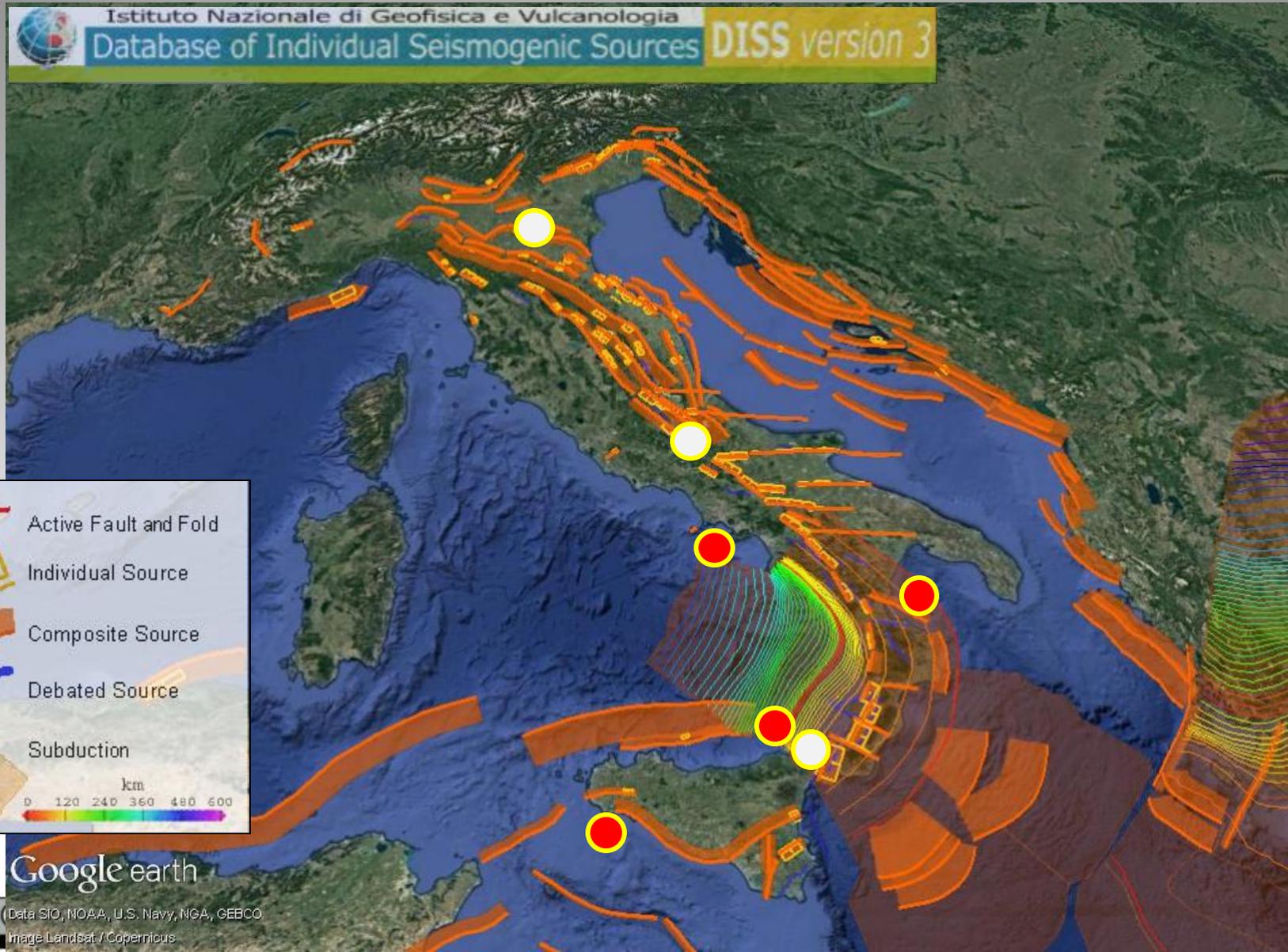




foto di P. Burrato



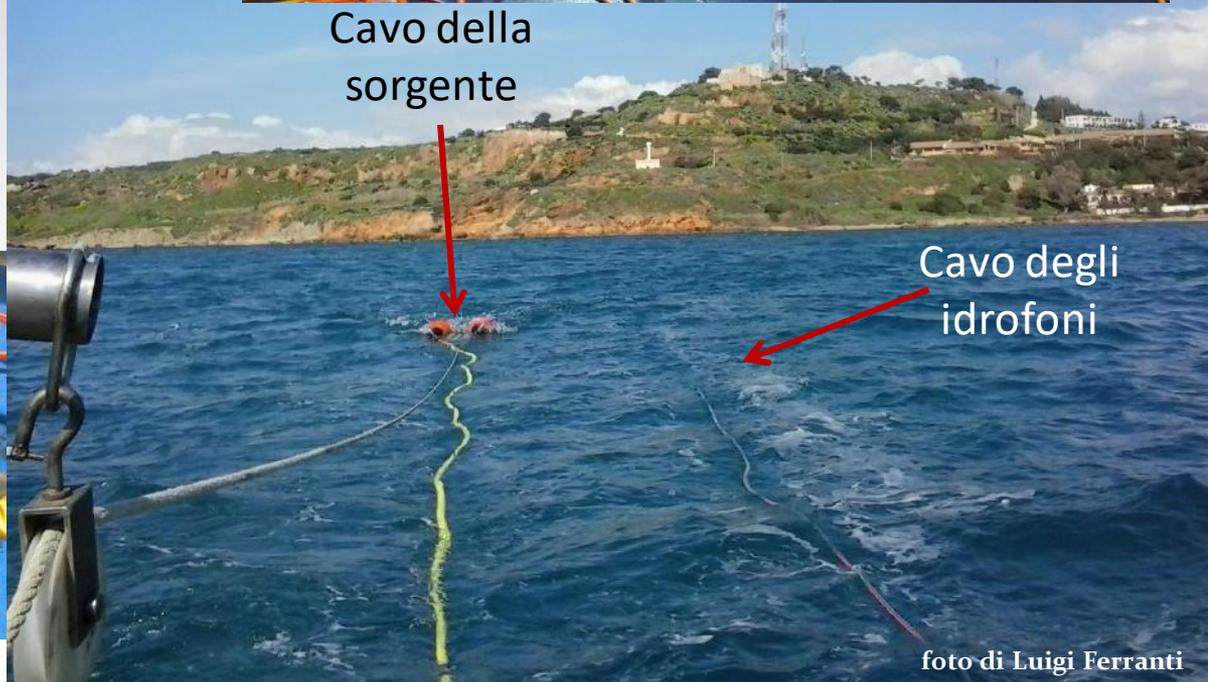
Sismica multicanale Sparker

Lo Sparker si basa sul principio della scarica in mare di una batteria di condensatori ad alta tensione mediante elettrodi montati su un dispositivo trainato dalla nave ad una certa profondità

Sorgente (scintillatore multitip)



Cavo della sorgente



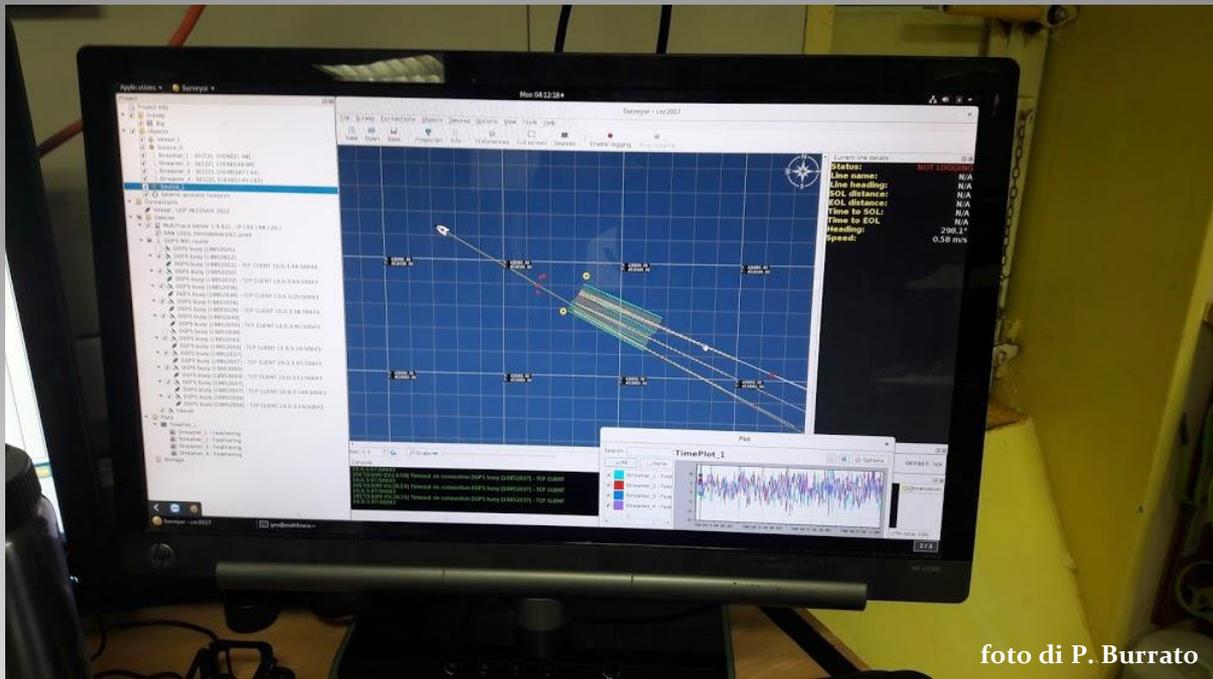


foto di P. Burrato

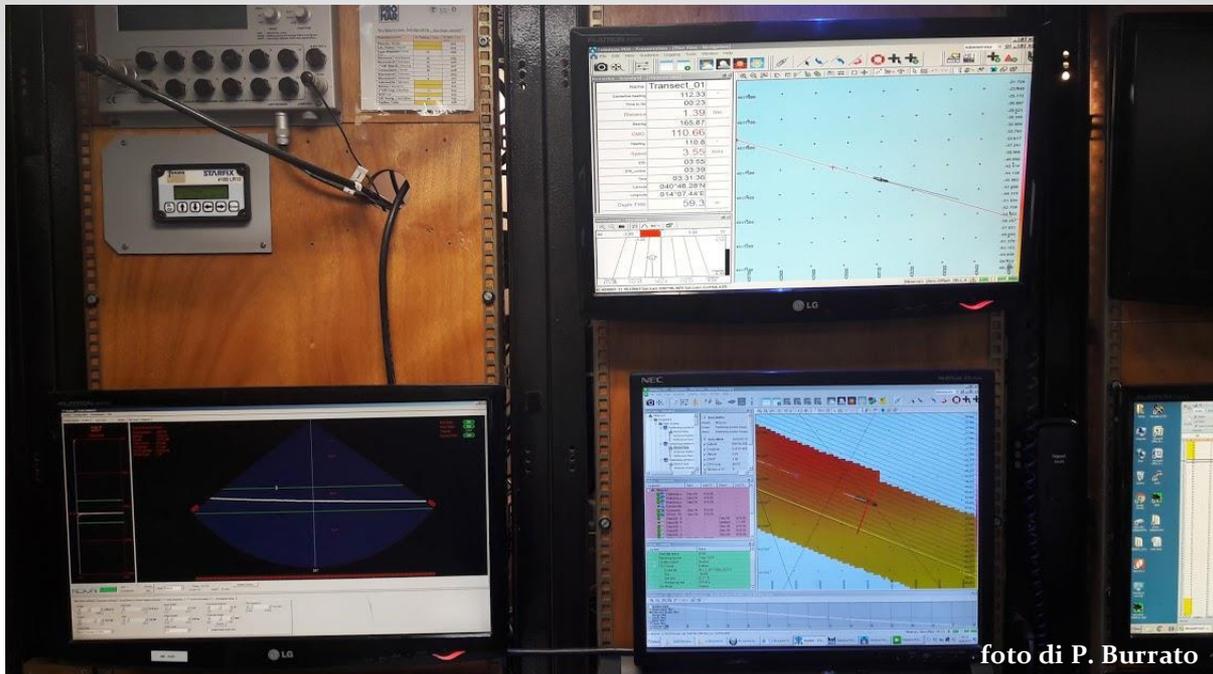
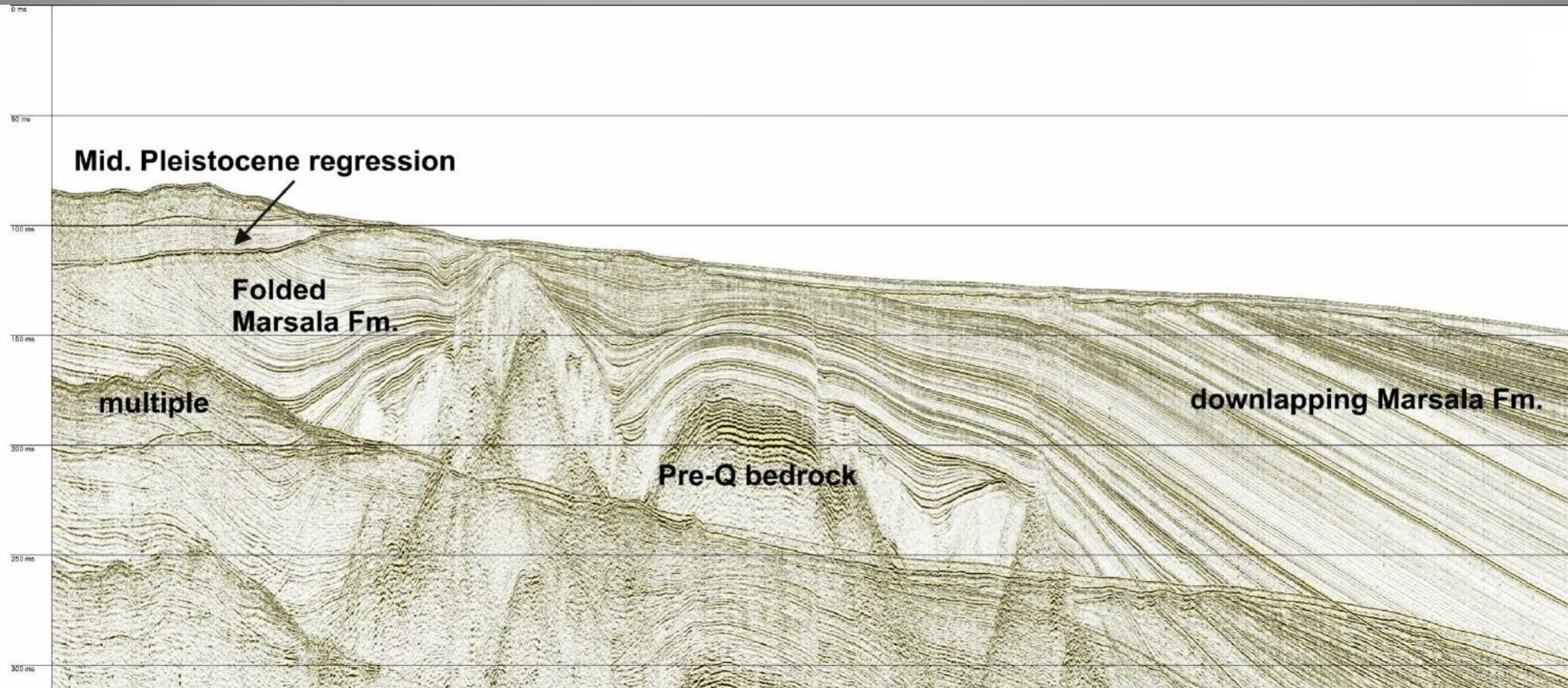
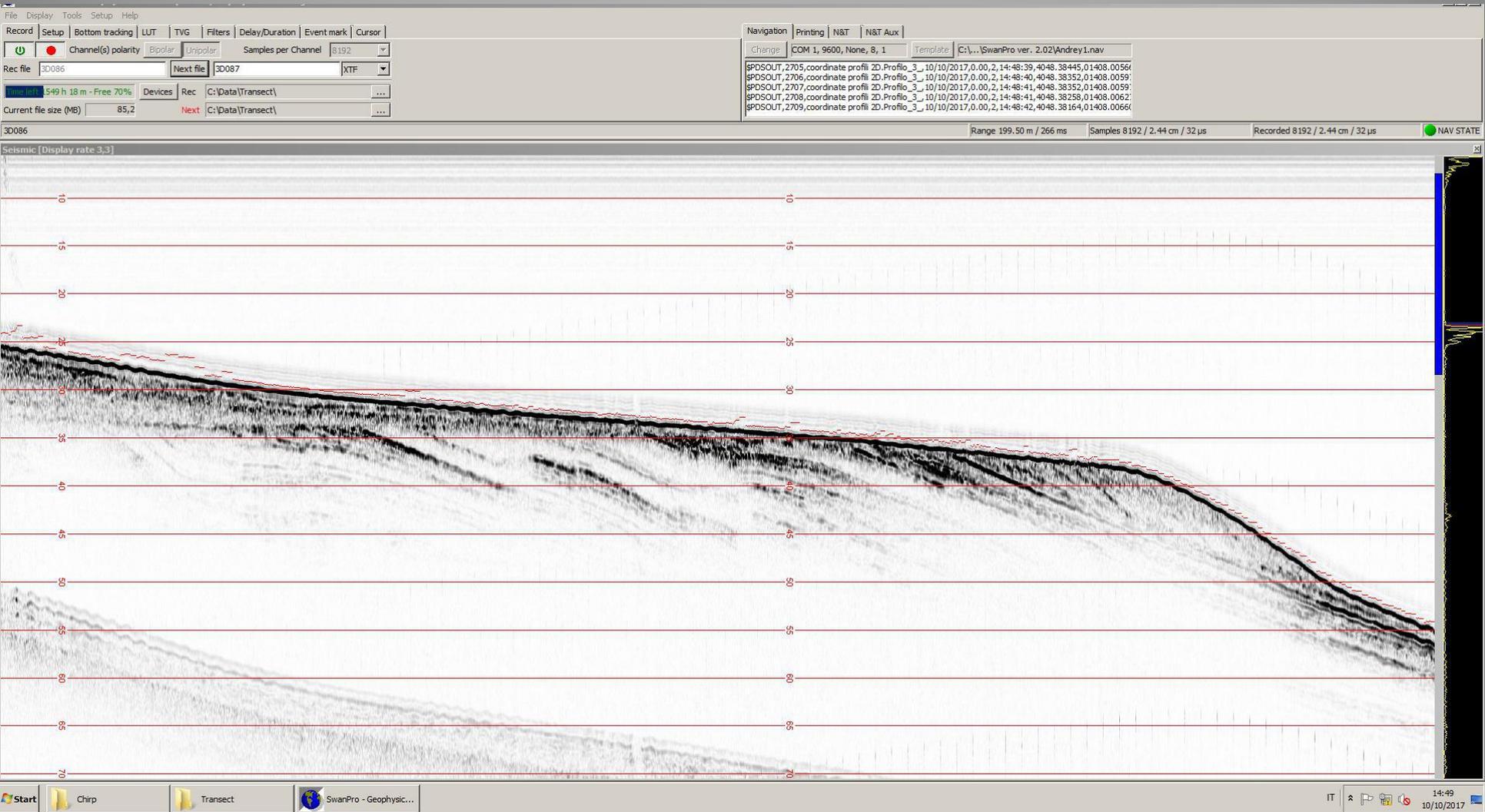


foto di P. Burrato



La Formazione di Marsala è caratterizzata da una progradazione sopra un substrato deformato, con deformazioni che si propagano fino al fondo mare (la parte emersa è definita *Calcareniti di Marsala*).

Sismica multicanale CHIRP



Sismica multicanale CHIRP

File Display Tools Setup Help

Record Setup Bottom tracking LUT TVG Filters Delay/Duration Event mark Cursor

Channel(s) polarity Bipolar Unipolar Samples per Channel 8192

Rec file 3D086 Next file 3D087 XTF

Time left: 549 h 18 m - Free 70% Devices Rec C:\Data\Transect\

Current file size (MB) 85,2 Next C:\Data\Transect\

Navigation Printing N&T N&T Aux

Change COM 1, 9600, None, 8, 1 Template C:\...\SwanPro ver. 2.02\Andrey1.nav

SPDSOUT, 2705, coordinate profili 2D.Profilo_3_10/10/2017,0.00,2,14:48:39,4048,38445,01408.0056
SPDSOUT, 2706, coordinate profili 2D.Profilo_3_10/10/2017,0.00,2,14:48:40,4048,38352,01408.0059
SPDSOUT, 2707, coordinate profili 2D.Profilo_3_10/10/2017,0.00,2,14:48:41,4048,38352,01408.0059
SPDSOUT, 2708, coordinate profili 2D.Profilo_3_10/10/2017,0.00,2,14:48:41,4048,38258,01408.0062
SPDSOUT, 2709, coordinate profili 2D.Profilo_3_10/10/2017,0.00,2,14:48:42,4048,38164,01408.0066

3D086 Range 199.50 m / 266 ms Samples 8192 / 2.44 cm / 32 μ s Recorded 8192 / 2.44 cm / 32 μ s NAV STATE

Seismic [Display rate 3.3]

Record Setup Bottom tracking LUT TVG Filters Delay/Duration Event mark Cursor

Channel(s) polarity Bipolar Unipolar Samples per Channel 8192

Rec file 3D_062 Next file 3D_063 XTF

Time left: 561 h 47 m - Free 70% Devices Rec C:\Data\Transect\

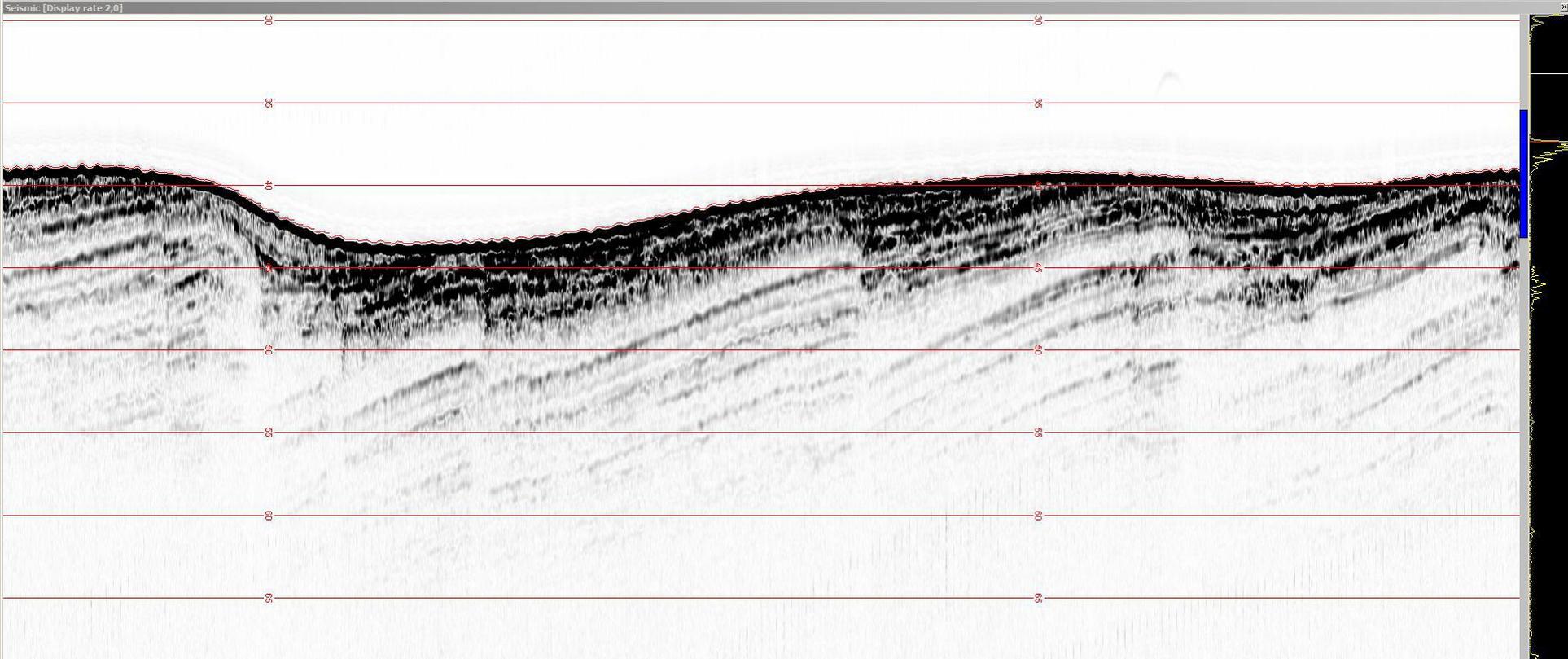
Current file size (MB) 105,6 Next C:\Data\Transect\

Navigation Printing N&T N&T Aux

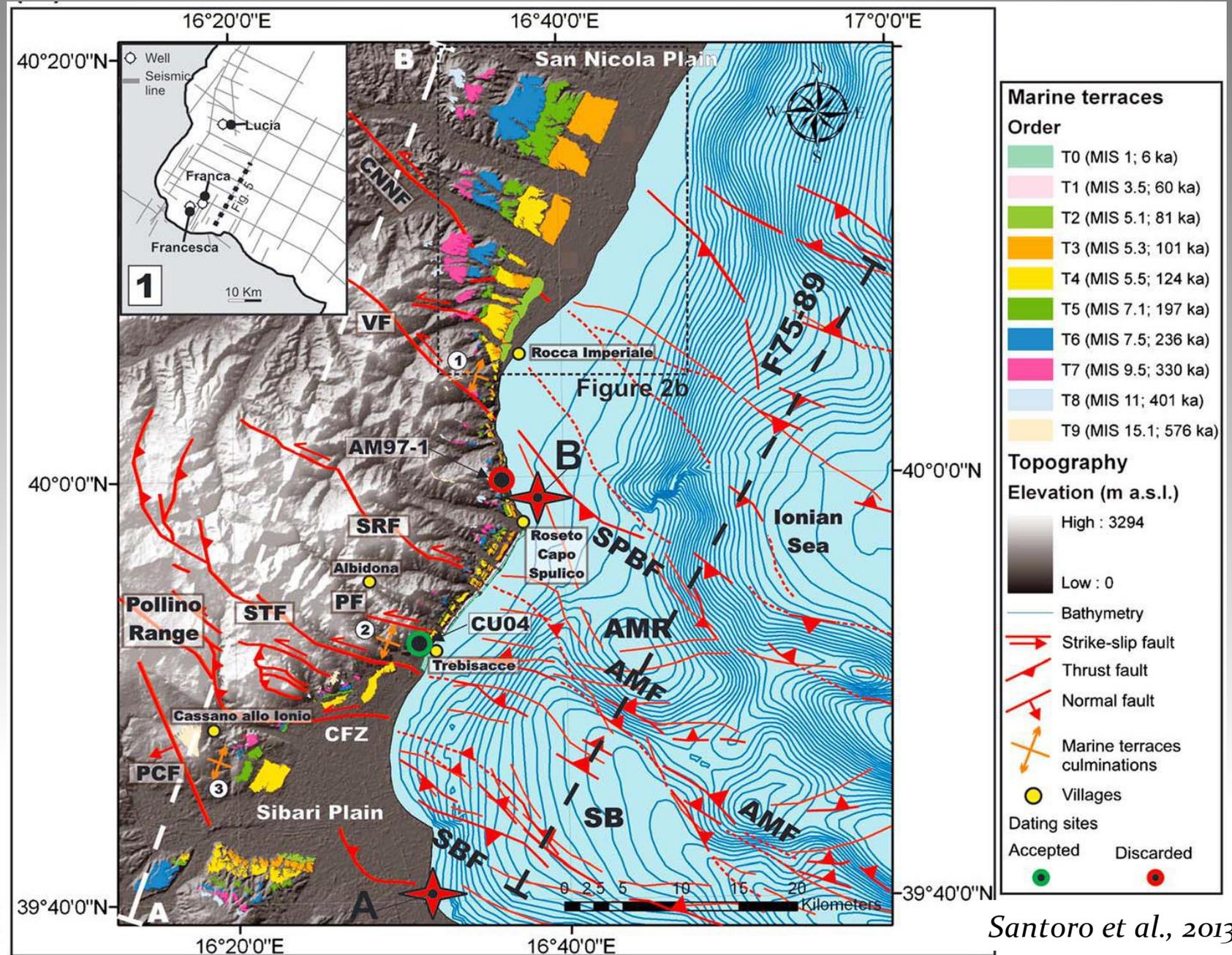
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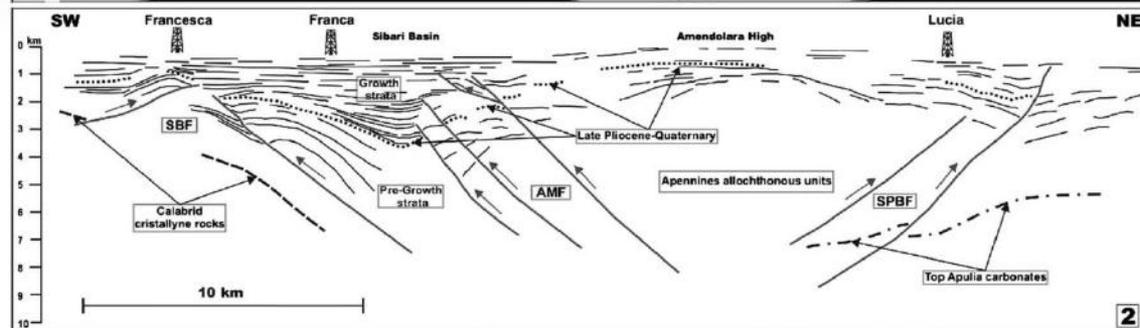
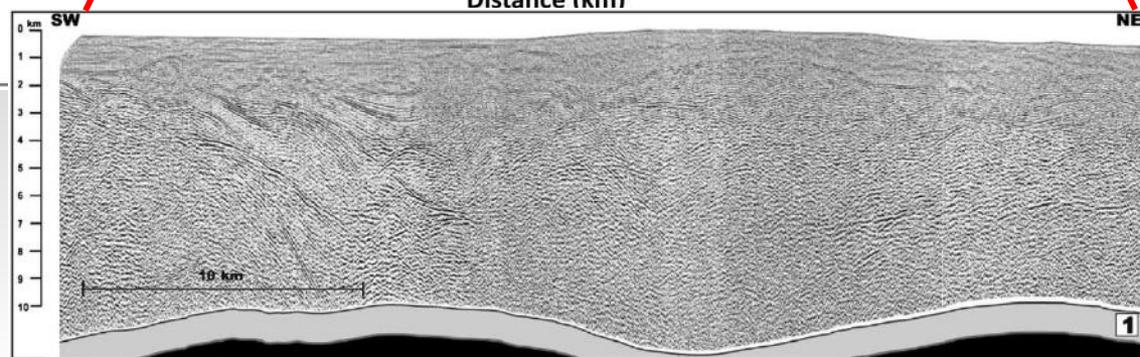
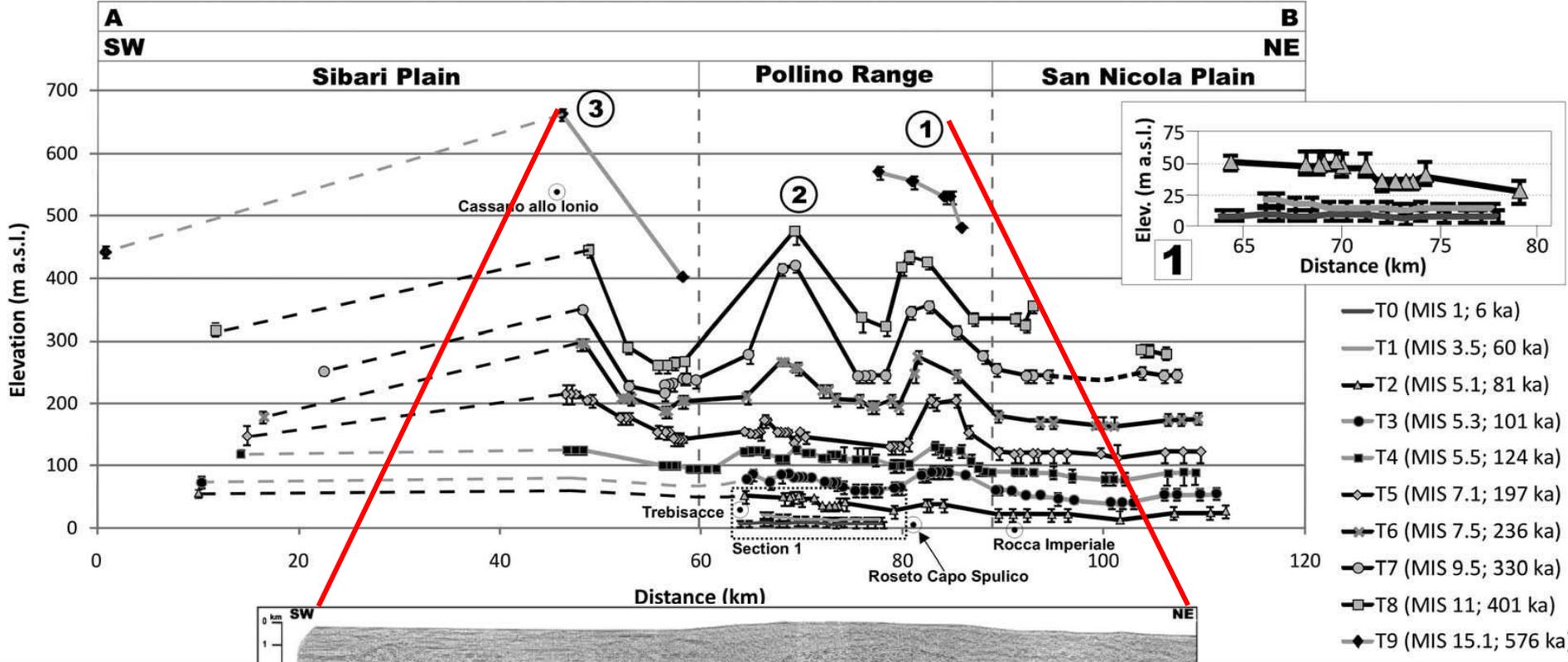
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3D_062 Range 203.49 m / 266 ms Samples 8192 / 2.48 cm / 32 μ s Recorded 8192 / 2.48 cm / 32 μ s NAV STATE



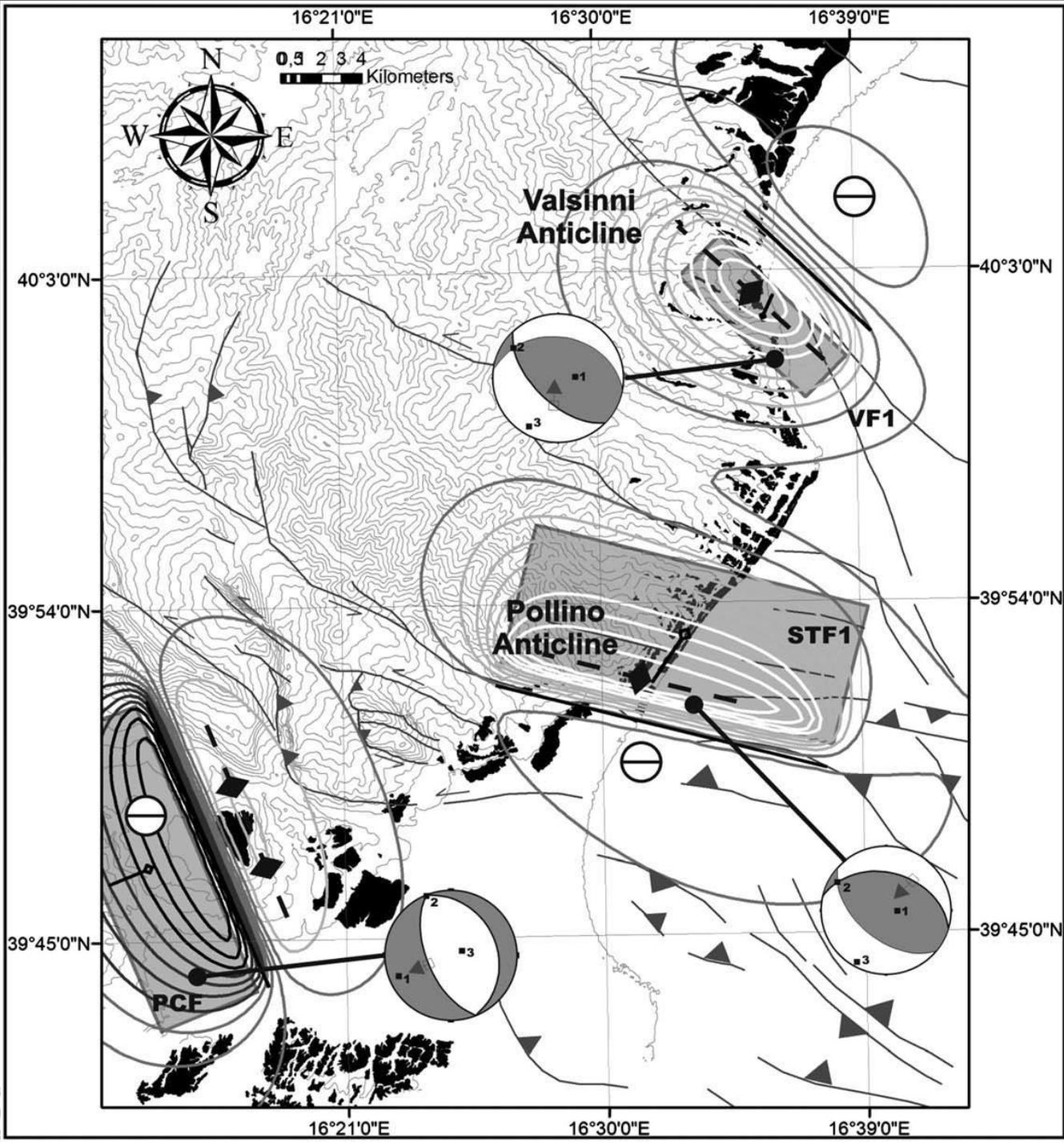
Strutture costiere che deformano terrazzi marini





Santoro et al., 2013





Legend

Vertical cumulative fold-related displacement

Values (m) in the last 124 ka

— -33.6_-26.3

— -26.3_-11.8

— -11.8_2.8

— 2.8_17.3

— 17.3_31.9

■ Marine terraces

▭ Fault model

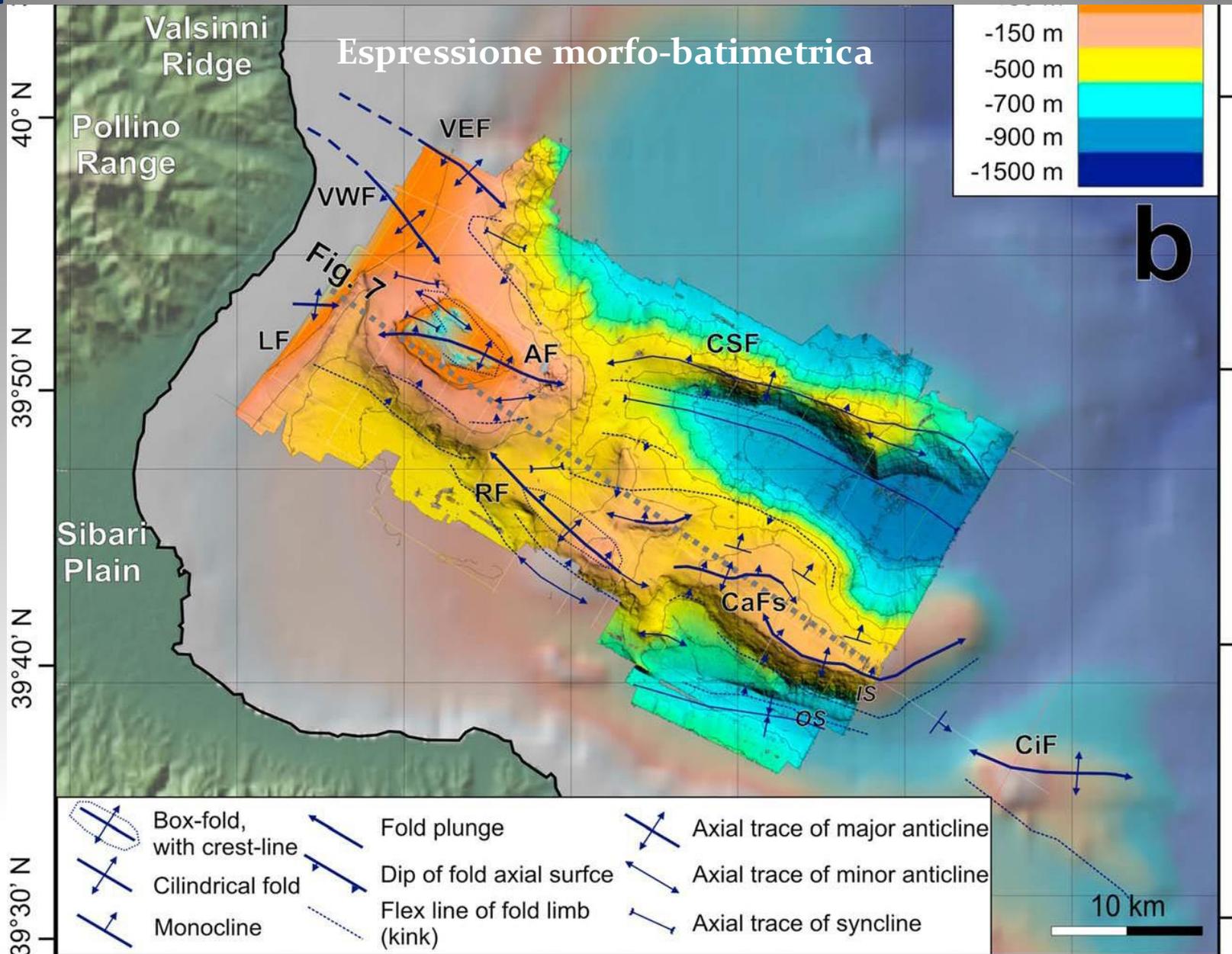
▲ Thrust fault

↔ Strike-slip fault

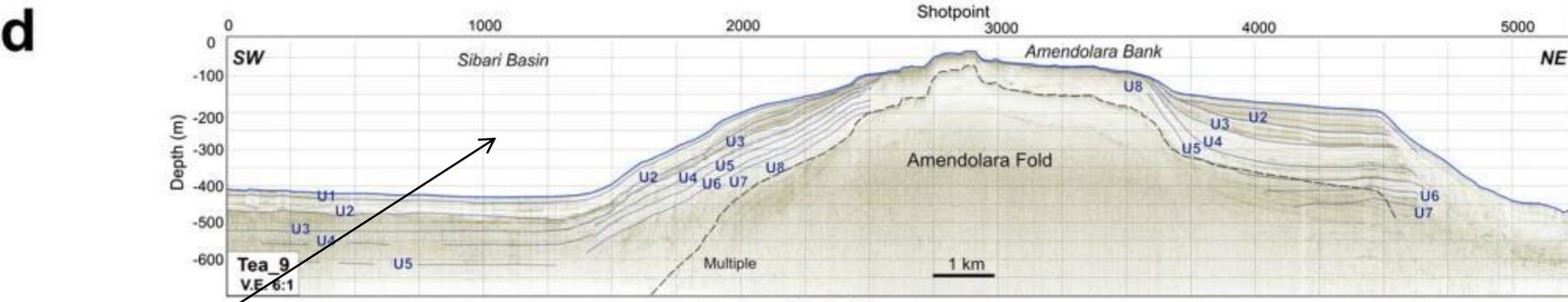
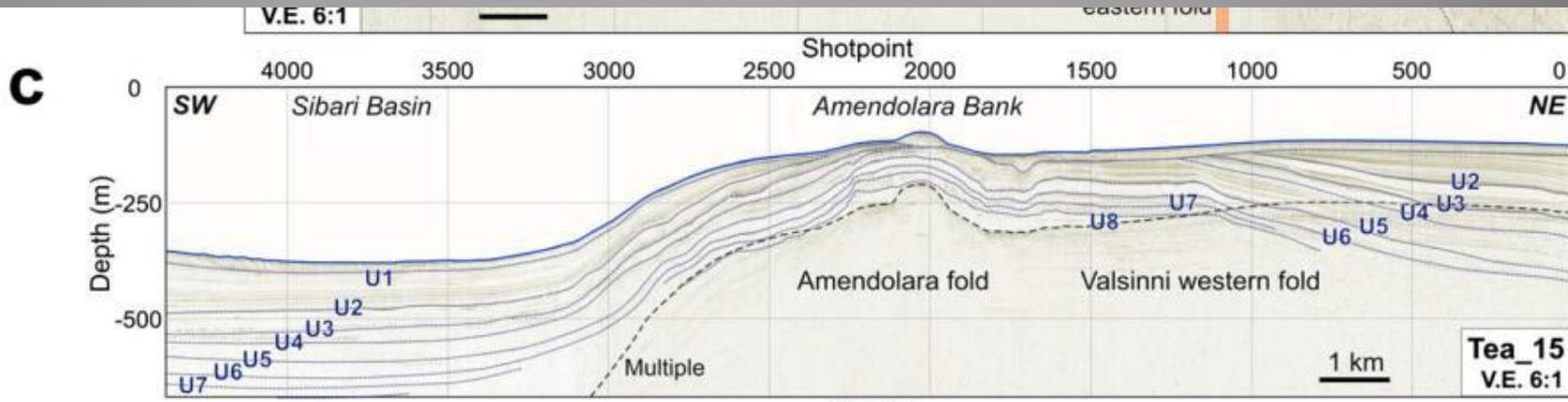
⊖ Fault-induced subsidence

◆ Fault-induced anticline

La prosecuzione offshore - “Dorsale di Amendolara”

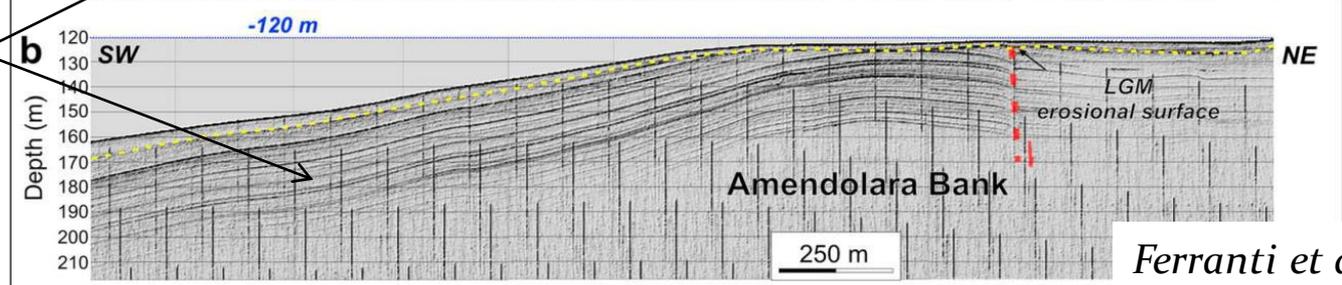
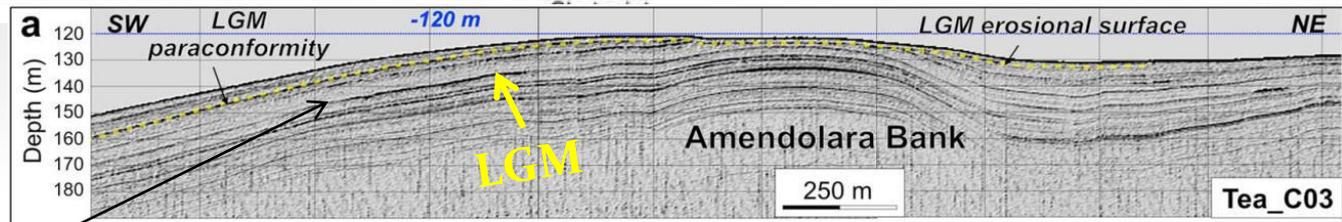


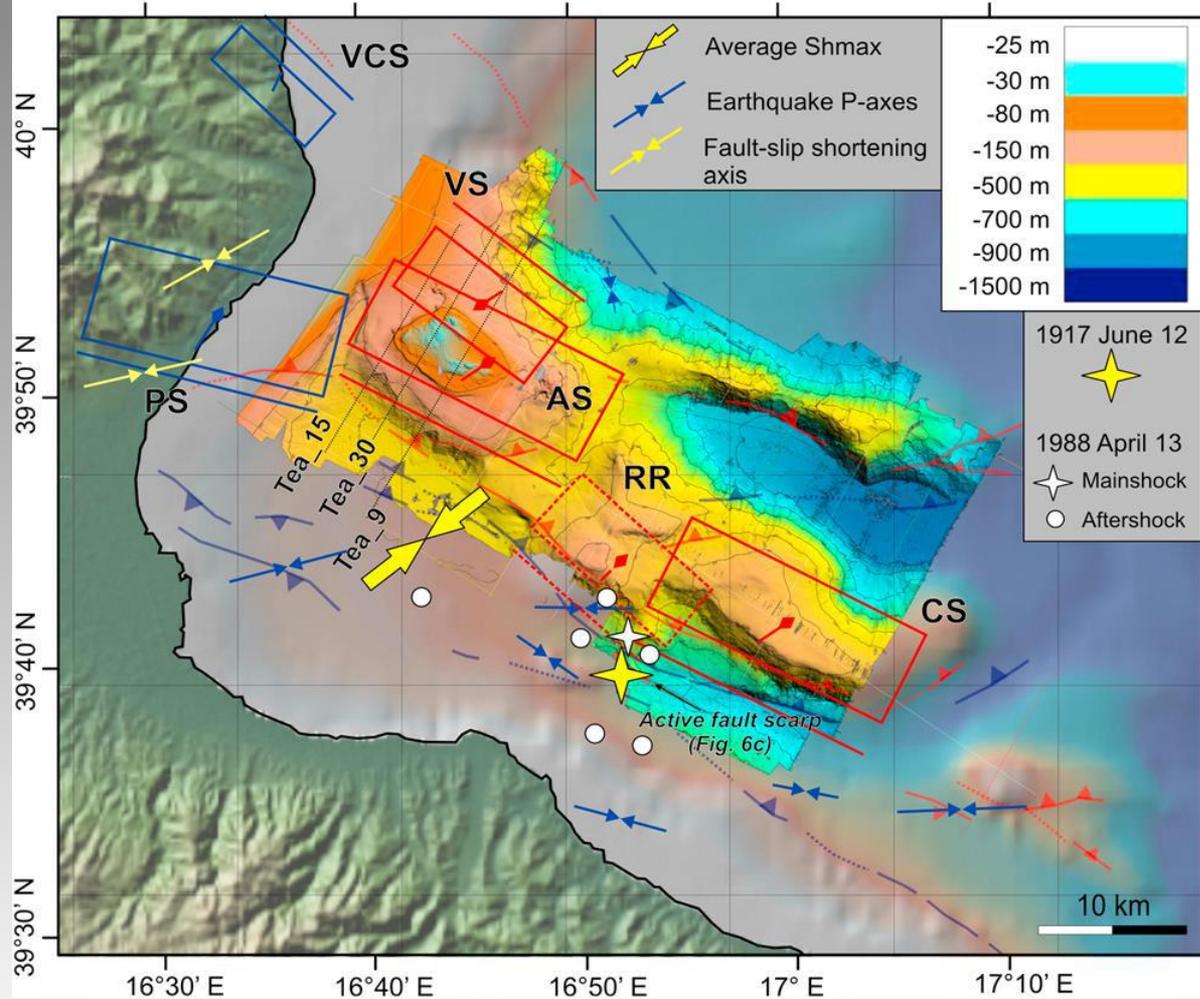
Sismica ad alta e altissima risoluzione (CHIRP) monocanale



Unconformity
Growth strata

Pleistocene sup.
Olocene





Ferranti et al., 2014

Table 2. Geometrical Parameters of Individual Thrusts From Dislocation Modeling^a

Name	Strike	Dip	Rake	Length	Width	Minimum Depth (km)	Maximum Depth (km)	Expected Magnitude
Amendolaria Segment	298	45	64	17.5	9.5	2.0	8.7	6.3
Cariati Segment	298	45	65	18	9.7	1.5	8.4	6.3
Valsinni Segment	128	45	70	11.3	7.0	2.0	6.9	6.1

^aGeometric and kinematic parameters of the fault segments underlying the Amendolaria Ridge modeled in this study. The expected magnitude of each segment was derived from the empirical relationships of *Wells and Coppersmith* [1994].

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Rovereto



Grazie dell'attenzione!

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