May 20, 2012 and May 29, 2012

Earthquakes in Emilia Romagna Northern Italy

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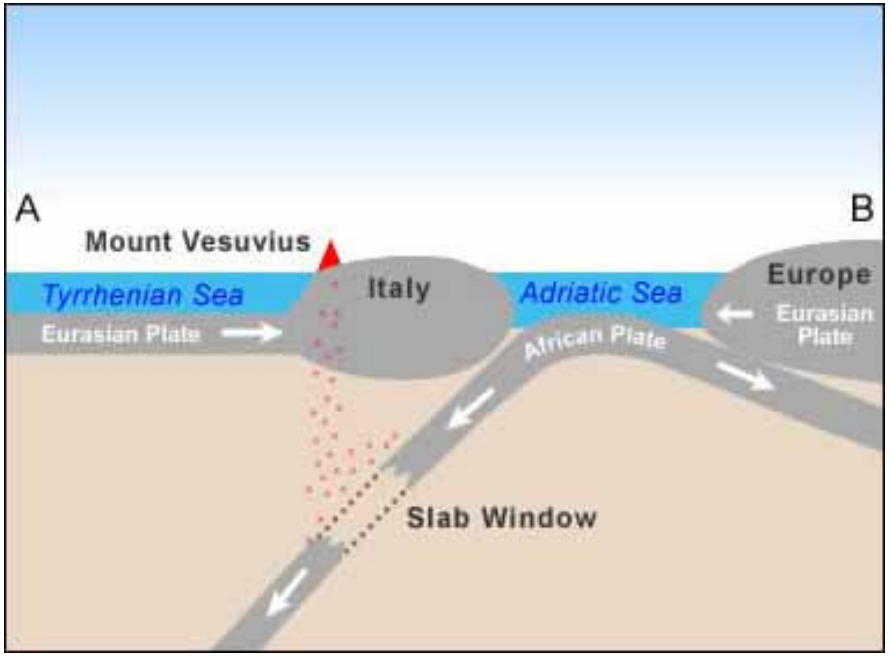
and Earthquake Geotechnical Engineering

Aristotle University

Thessaloniki, Greece.

General

Tectonics



Italy is one of the countries in the Mediterranean with the highest seismic risk, due to its particular geographic position at the convergence of the African and Eurasian plates.

source: www.protezionecivile.gov.it

Tectonics

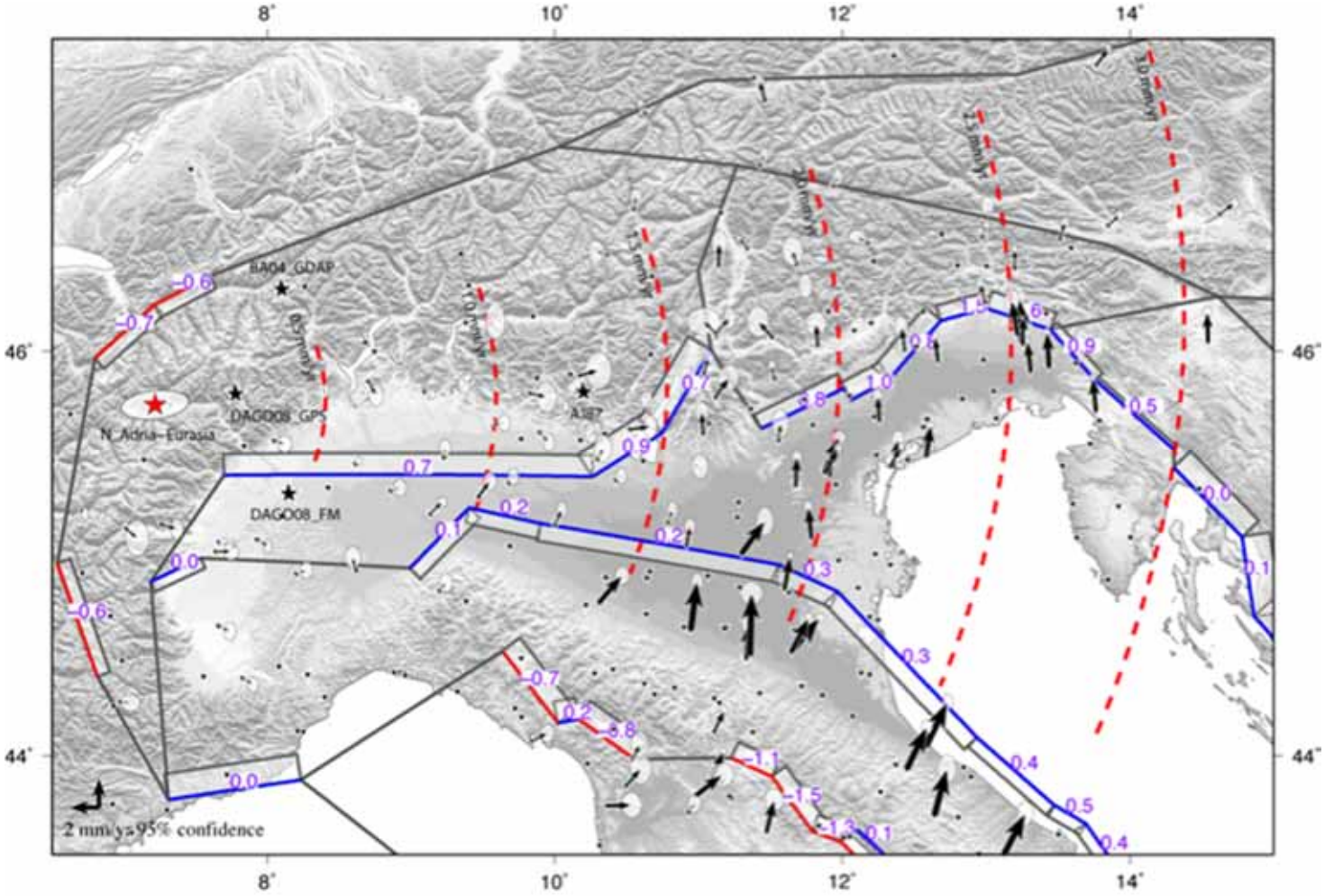
An earthquake of magnitude 6.0 hit Northern Italy, on **May 20th, 2012**, in the region of Emilia Romagna.

This event was largely felt in Northern Italy. Important damages are reported in the cities of Finale Emilia, Ferrara and Modena, where significant cultural heritage buildings and industrial facilities have been affected.

9 days later, on **May 29th, 2012**, a magnitude 5.8 occurred 15 km west from the May 20th event.

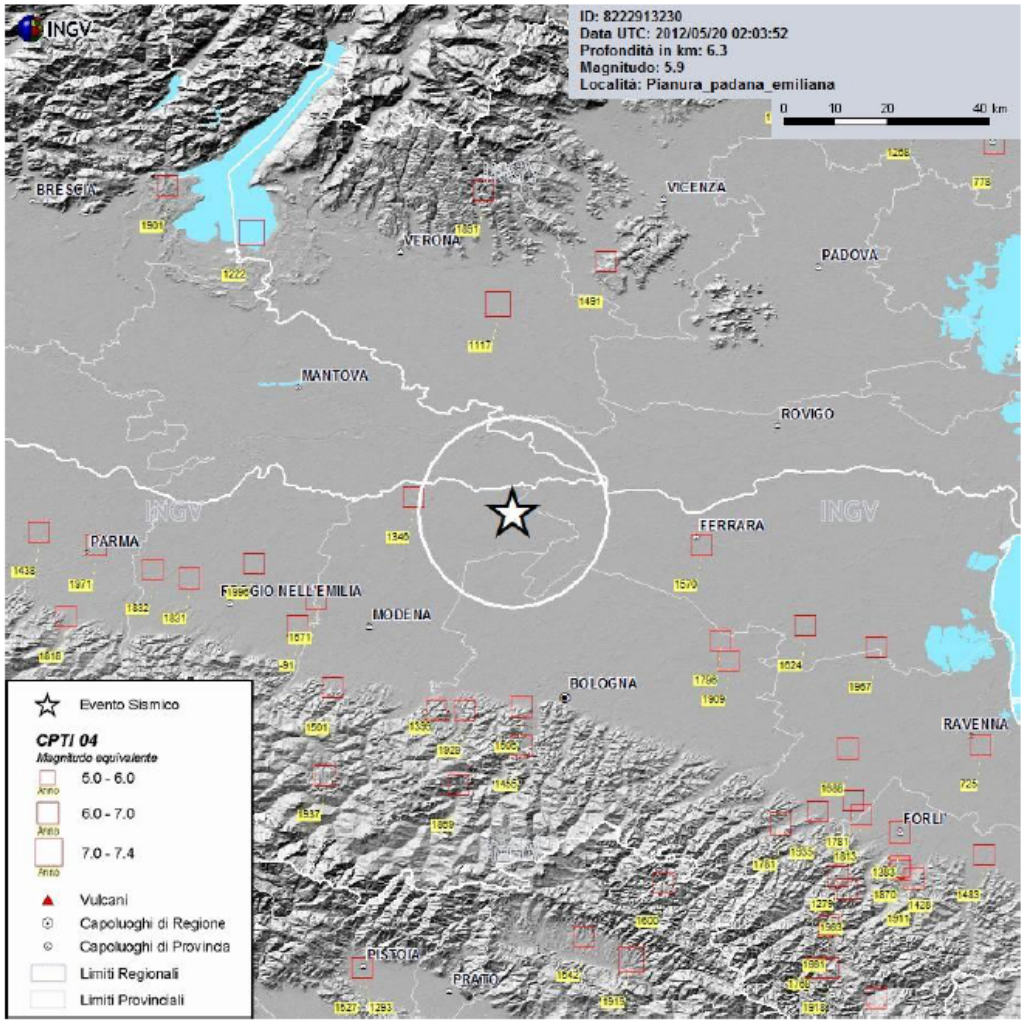
The mechanisms involved in both events are similar.

Tectonics



Crustal deformation

Historic Seismicity of the region

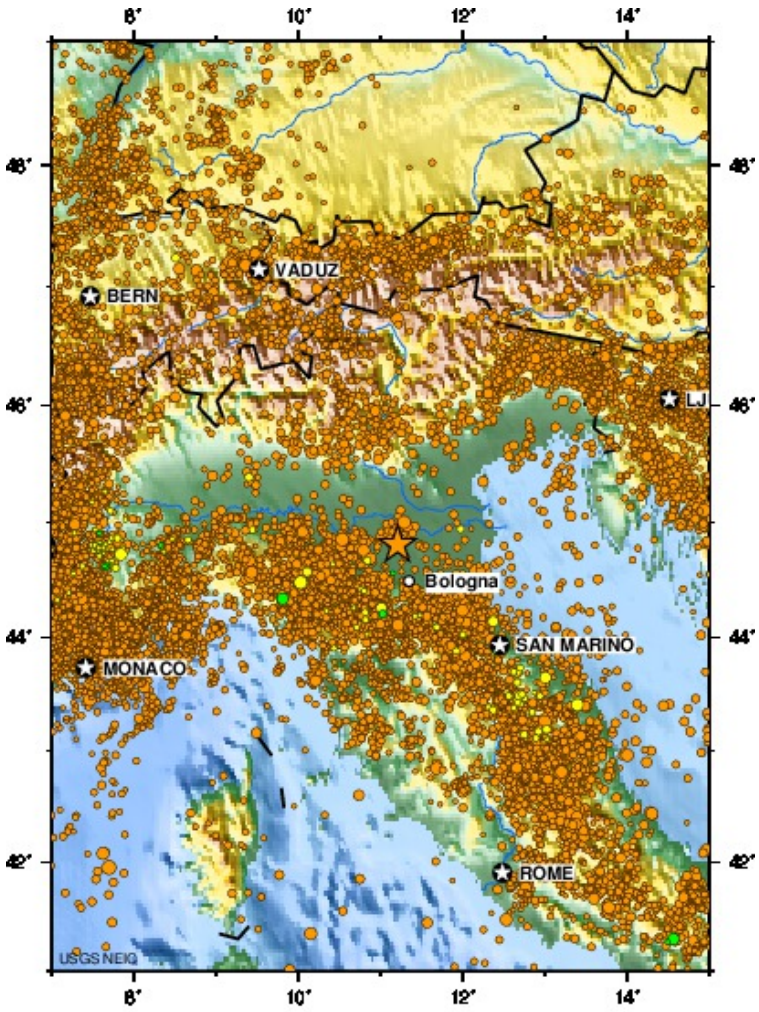


No significant events in a region of 30-40km from the May 20 event epicenter

source: www.ingv.it

Historic Seismicity of the region

Since 1990



NORTHERN ITALY

2012 05 20 02:03:53 UTC 44.81N 11.21E Depth: 10.1 km

Seismicity 1990 to Present

M>7 since 1900

NORTHERN ITALY

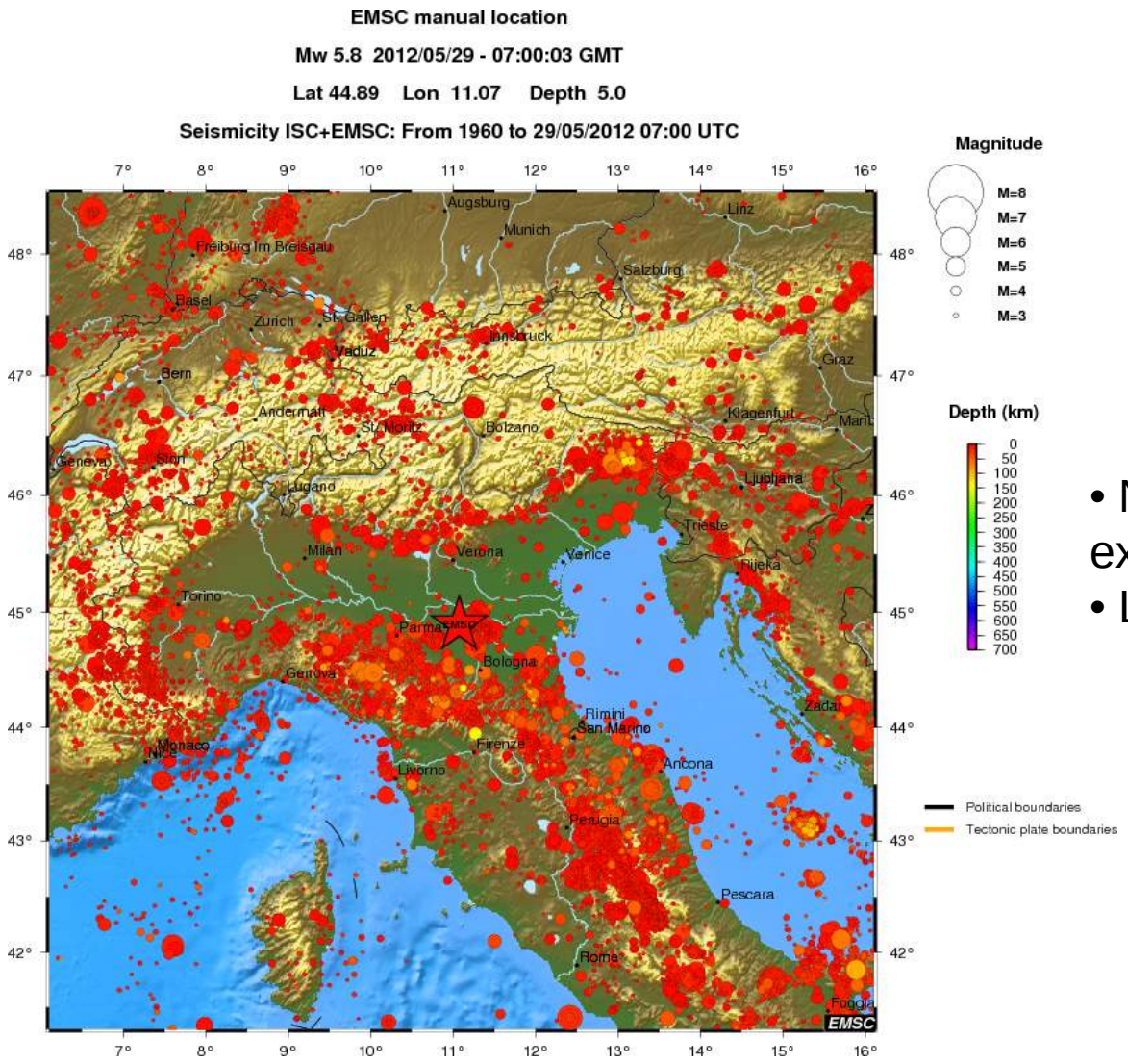
2012 05 20 02:03:53 UTC 44.81N 11.21E Depth: 10.1 km

Magnitude 7 and Greater Earthquakes Since 1900

source: http://www.usgs.gov/

Historic Seismicity of the region

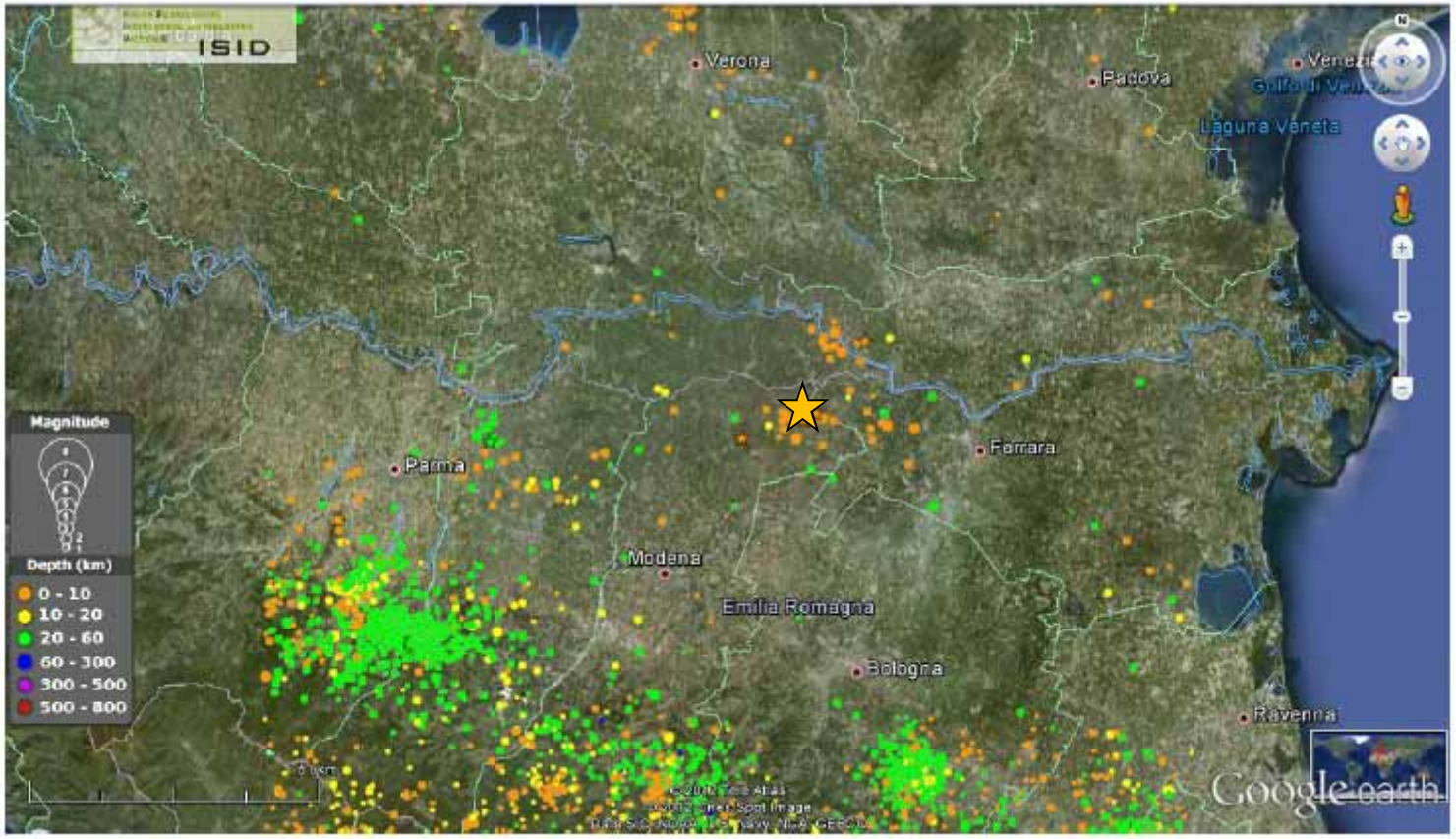
Since 1960



- No significant events in the region except from the May 2012 sequence
- Low depth events

source: www.emsc-csem.org

2005-2012 seismicity of the region



- No seismic activity in the last three months
- Sporadic and scarce seismicity since 2005

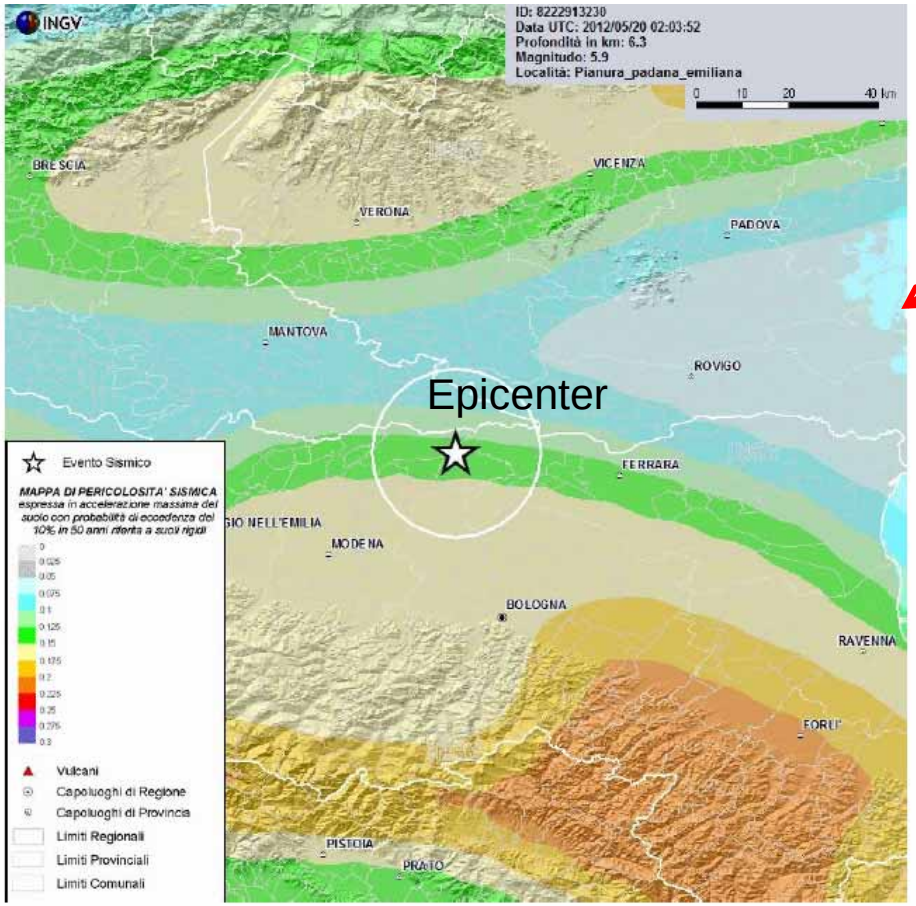
source: www.ingv.it

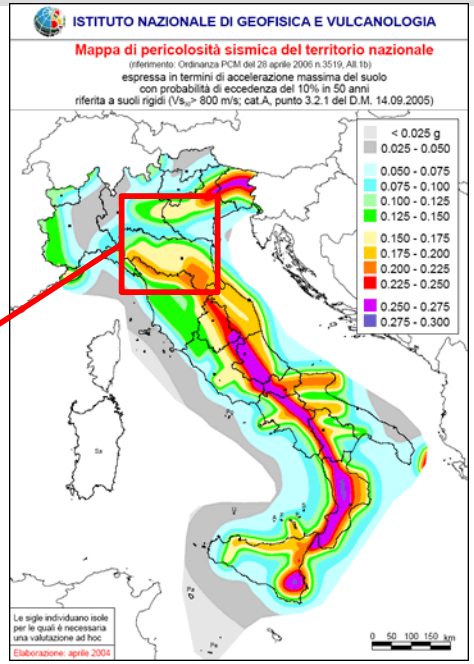
2012 seismicity of the region

source: http://www.usgs.gov/

Seismicity hazard map of the region

PGA on rock (Vs,30>800m/s)
for 10% probability of exceedance in 50 years





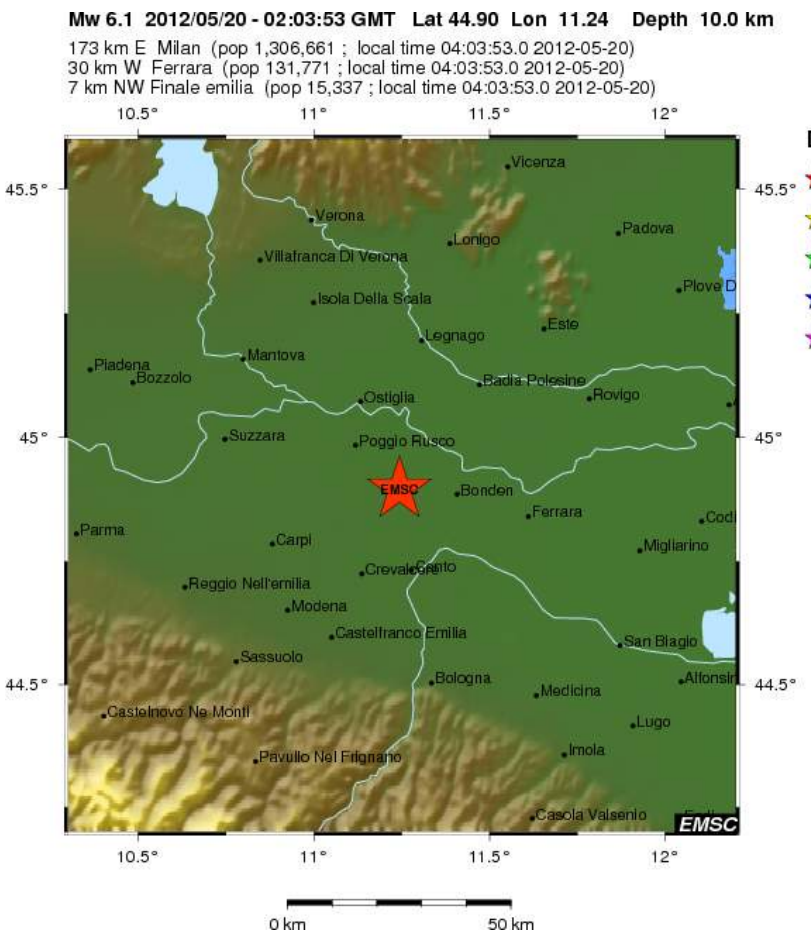
- Relatively low seismic hazard in the region
- Design PGA ranging from 0.12-0.15g
- Compulsory seismic design only for structures built after 2003!

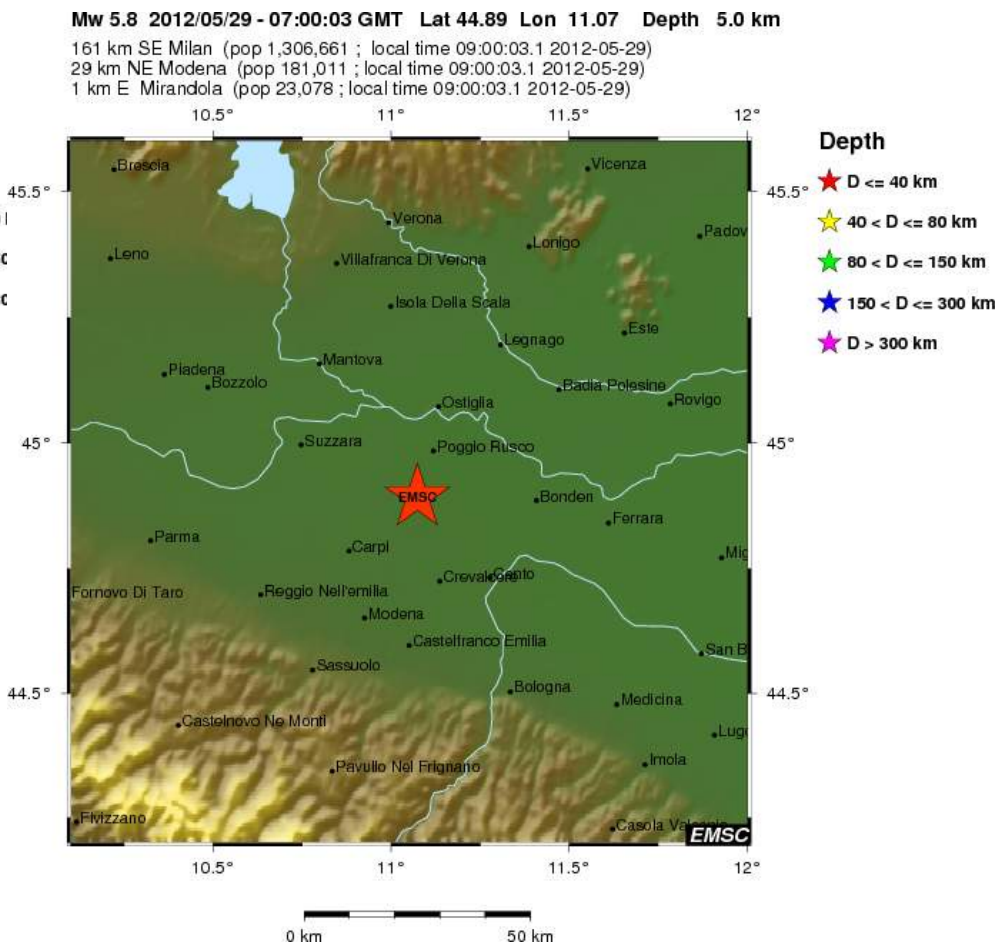
DdL MPS 2004

source: www.ingv.it

Seismological aspects

May 2012 Earthquakes





May 20th, 2012, Mw 6.1

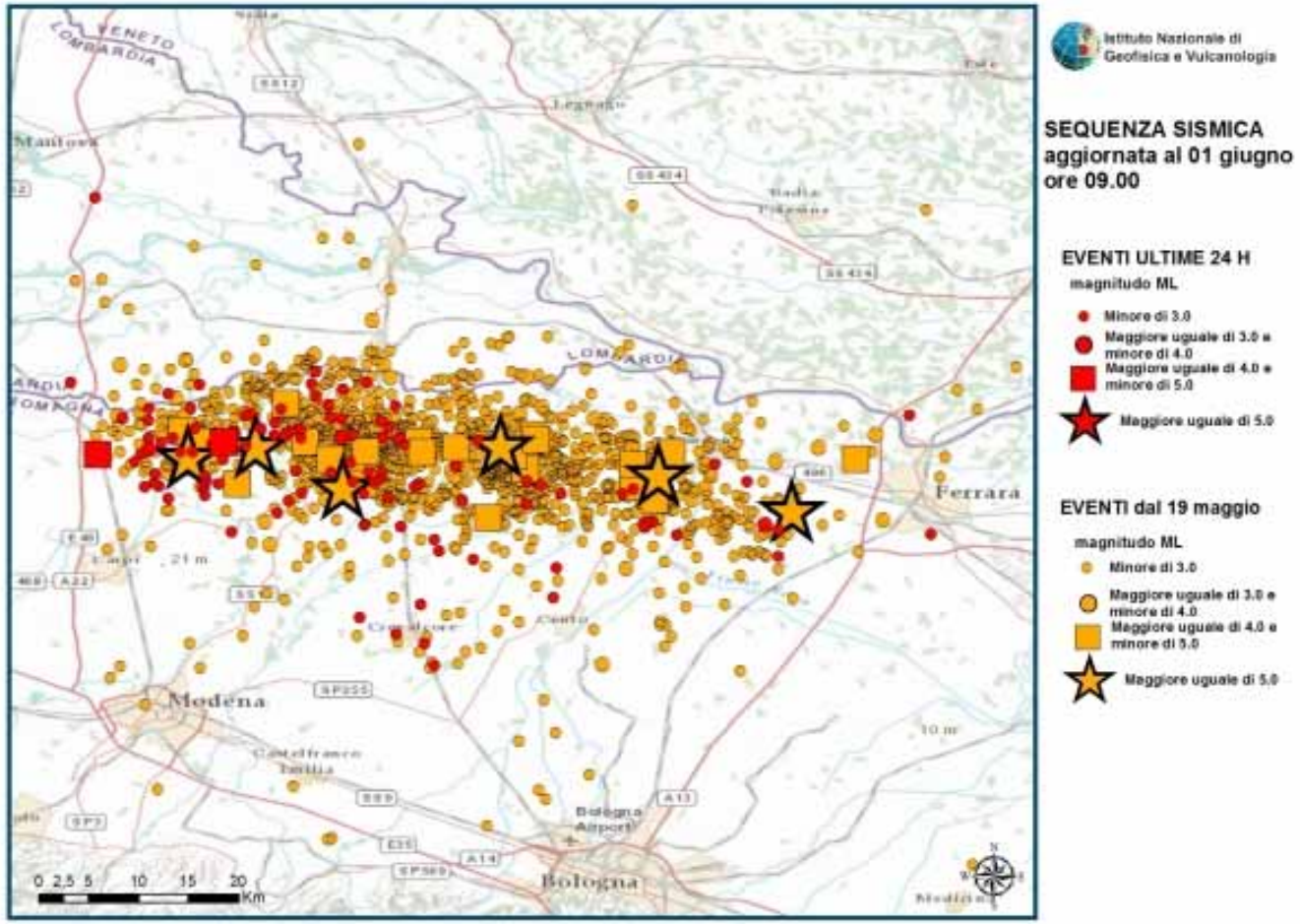
May 29th, 2012, Mw 5.8

source: www.emsc-csem.org

May 2012 Earthquakes

May 20th, 2012, Mw 6.1 & May 29th, 2012, Mw 5.8

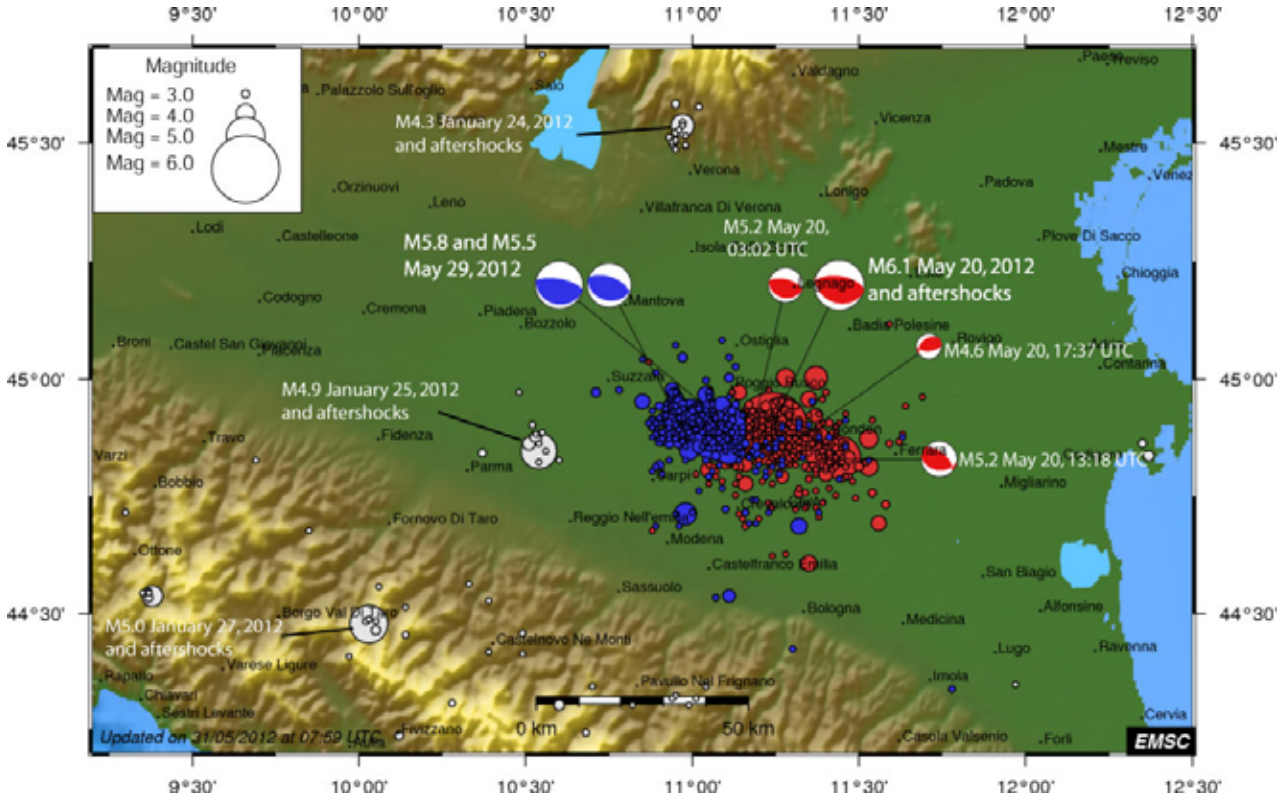
May 2012 Earthquake Sequence



source: www.ingv.it

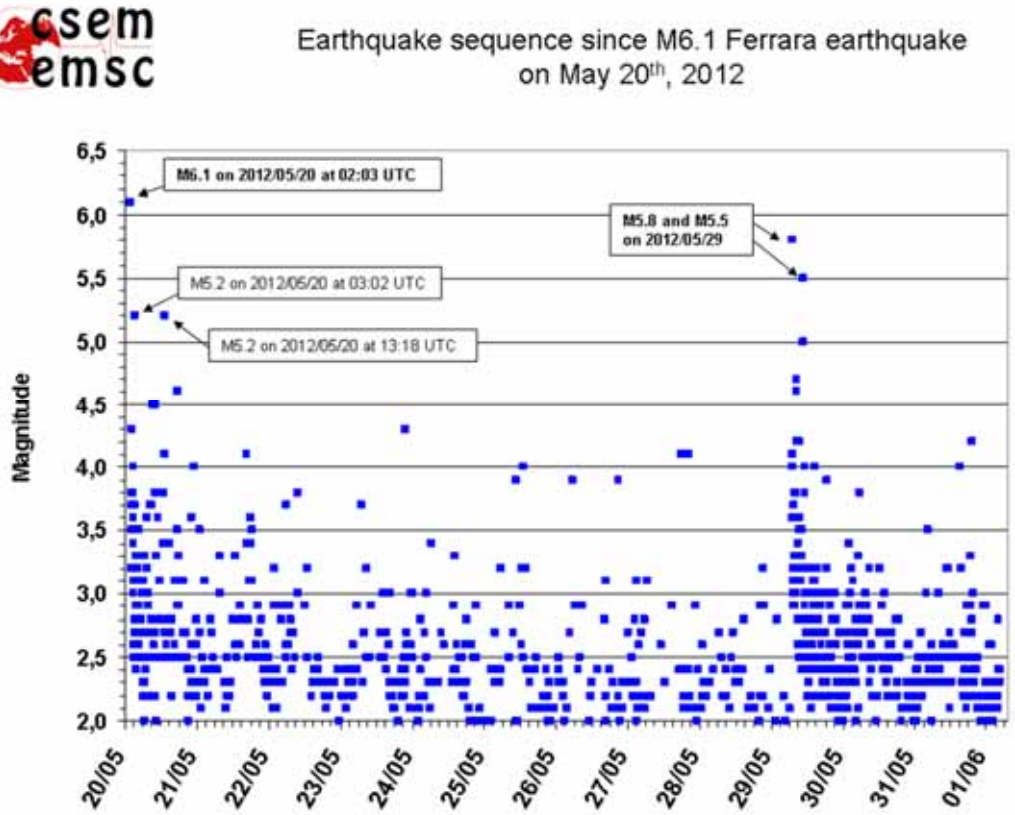
Earthquake sequence

- The sequence follows a series of moderate to strong earthquakes that occurred in Northern Italy in January 2012 in the vicinity of Ferrara.



source: www.emsc-csem.org

May 2012 Earthquake Sequence



Magnitude	Number of events from May 20th to June 1st within 50 km
M > 3	179
M > 4	31
M > 5	6

source: www.emsc-csem.org

M6.0 20 May 2012 earthquake

Mw 6.0, Emilia Romagna Region, Northern Italy
20.05.2012, 02:03:52 UTC

- 7 victims
- 50 injured
- 4500 homeless
- Evacuation of several buildings
- Important damages in the cities of Finale Emilia, Ferrara and Modena
- Damages in significant cultural heritage and industrial buildings

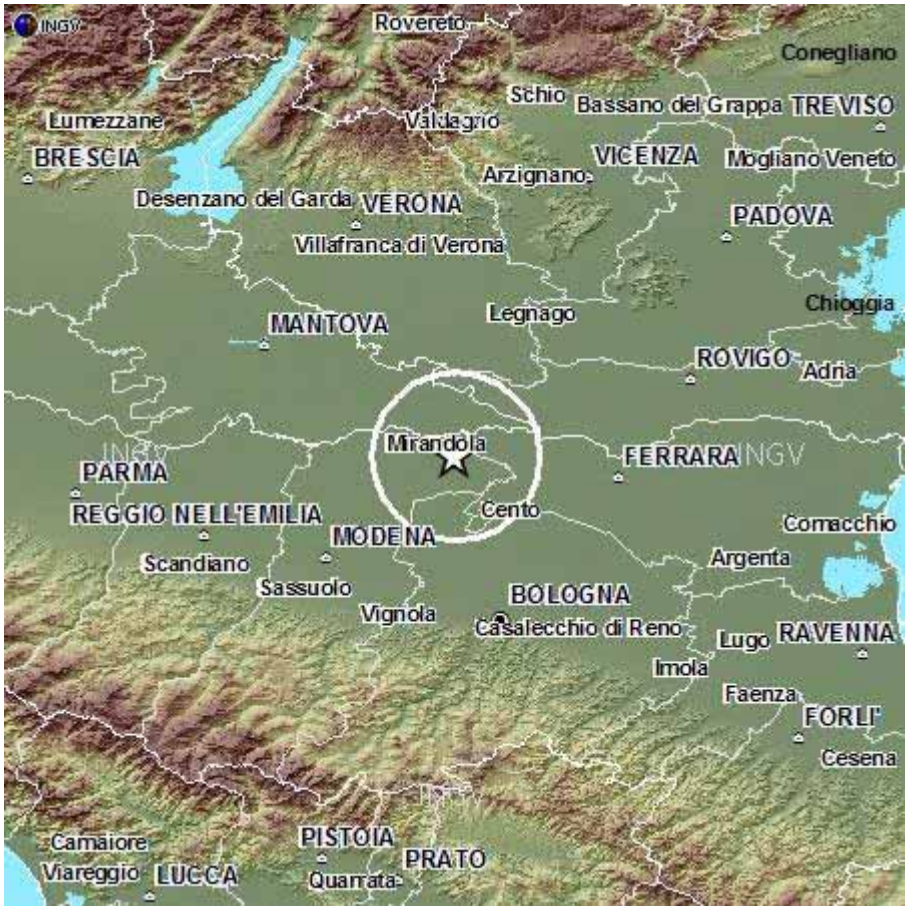
Earthquake Details

- Magnitude Mw: **6.0**
- Date-Time: **Sunday, May 21, 2012 at 02:03:52 UTC**
- Location: 44.777°N, 11.227°E
- Depth: 9 km
- Region: 6km E of Camposanto, Italy
- Distances :
  6km E of Camposanto, Italy
  7km NW of Cento, Italy
  8km SW of Finale Emilia, Italy
  8km NE of Crevalcore, Italy
  135km NW of San Marino, San Marin

  Location Uncertainty : horizontal +/- 12.2 km (7.6 miles); depth +/- 0.6 km (0.4 miles)
- Parameters: Nph= 0, Dmin=0 km, Rmss=0.98 sec, Gp= 0,
  M-type="moment" magnitude from initial P wave (tsuboi method) (Mi/Mwp),
  Version=D
- Source : USGS National Earthquake Information Center

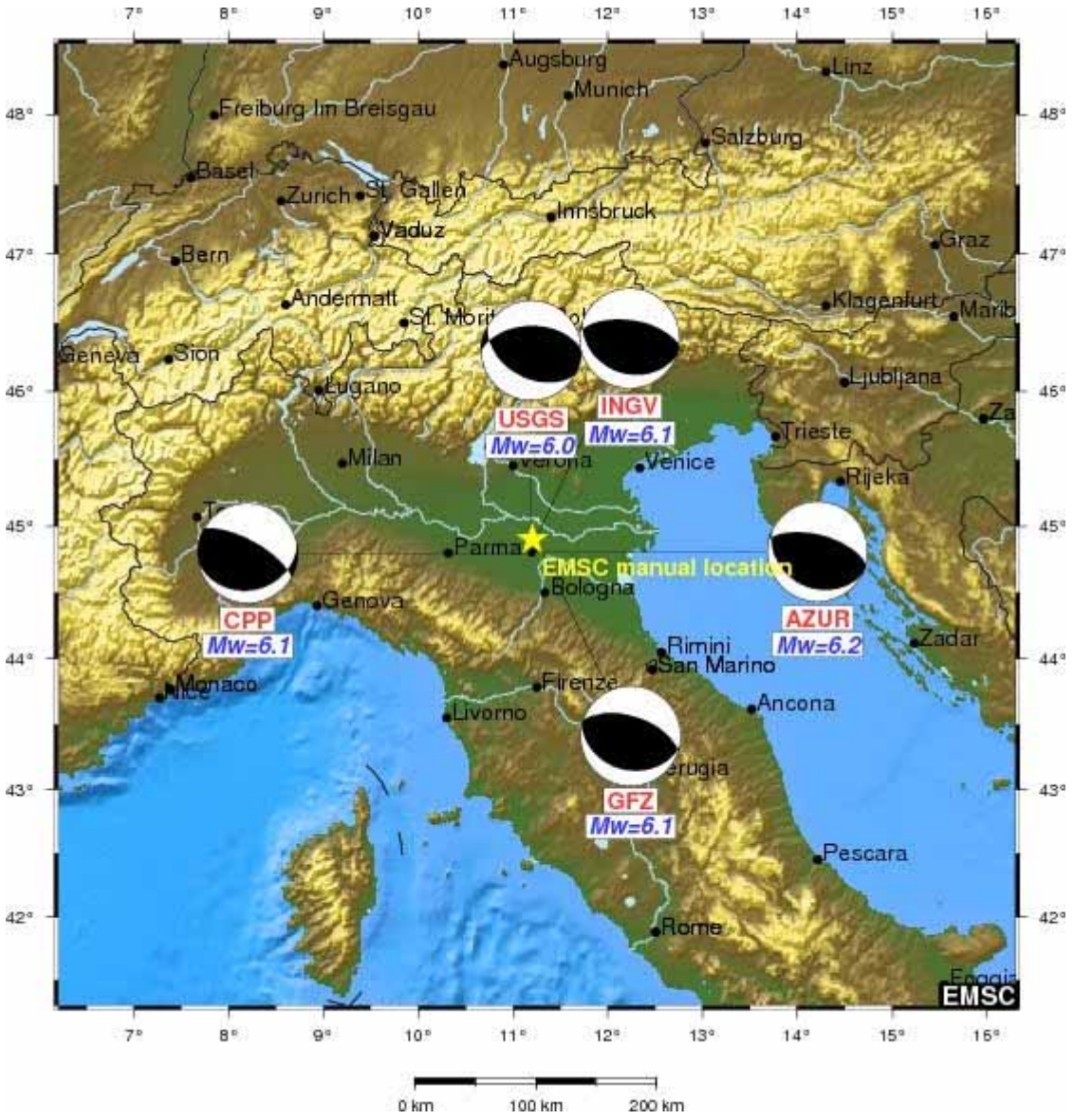
source: http://www.usgs.gov/

Epicenter location



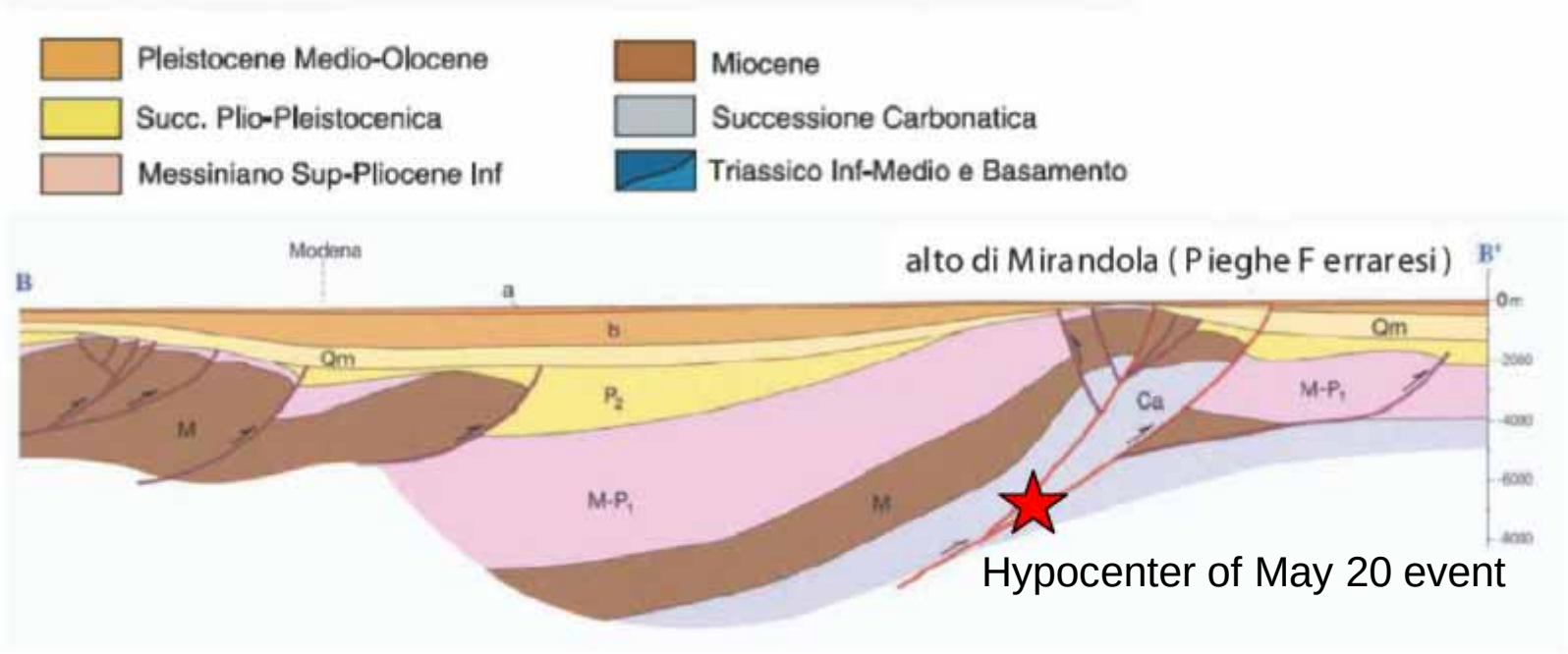
source: www.ingv.it

Magnitude estimation



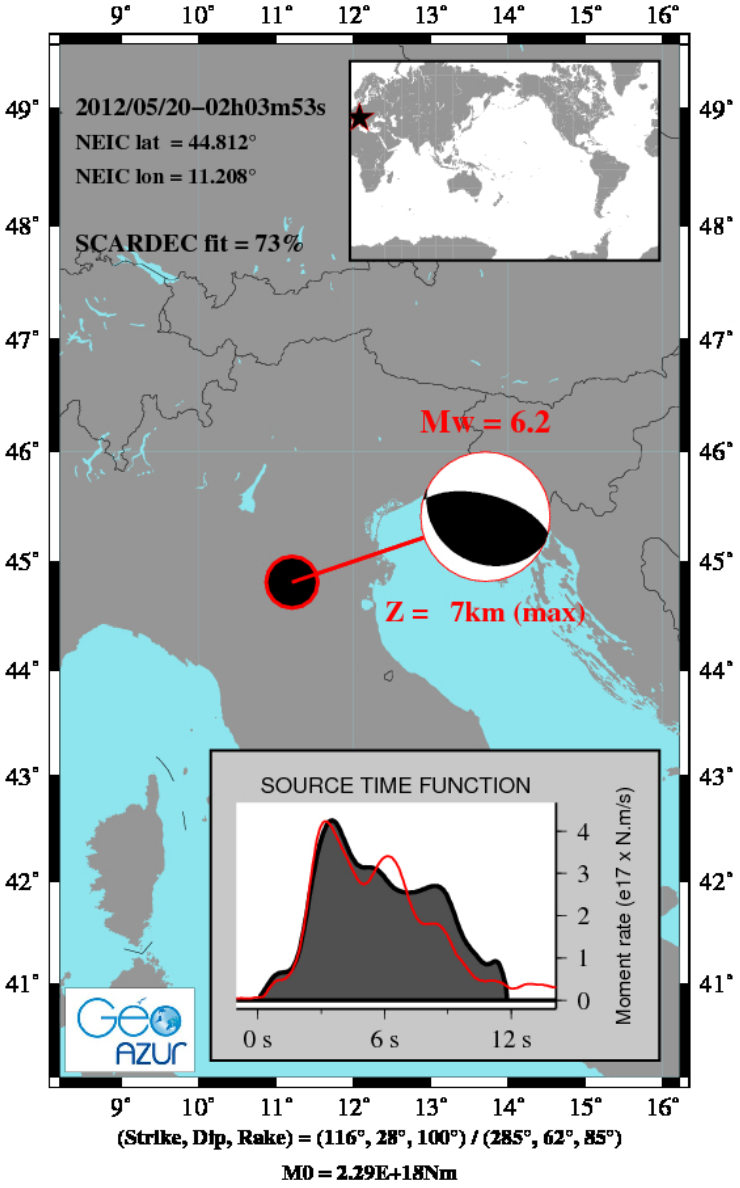
source: https://sites.google.com/site/**cellulepostsismique**/

Seismotectonic context



source: www.ingv.it

Fault rupture mechanism

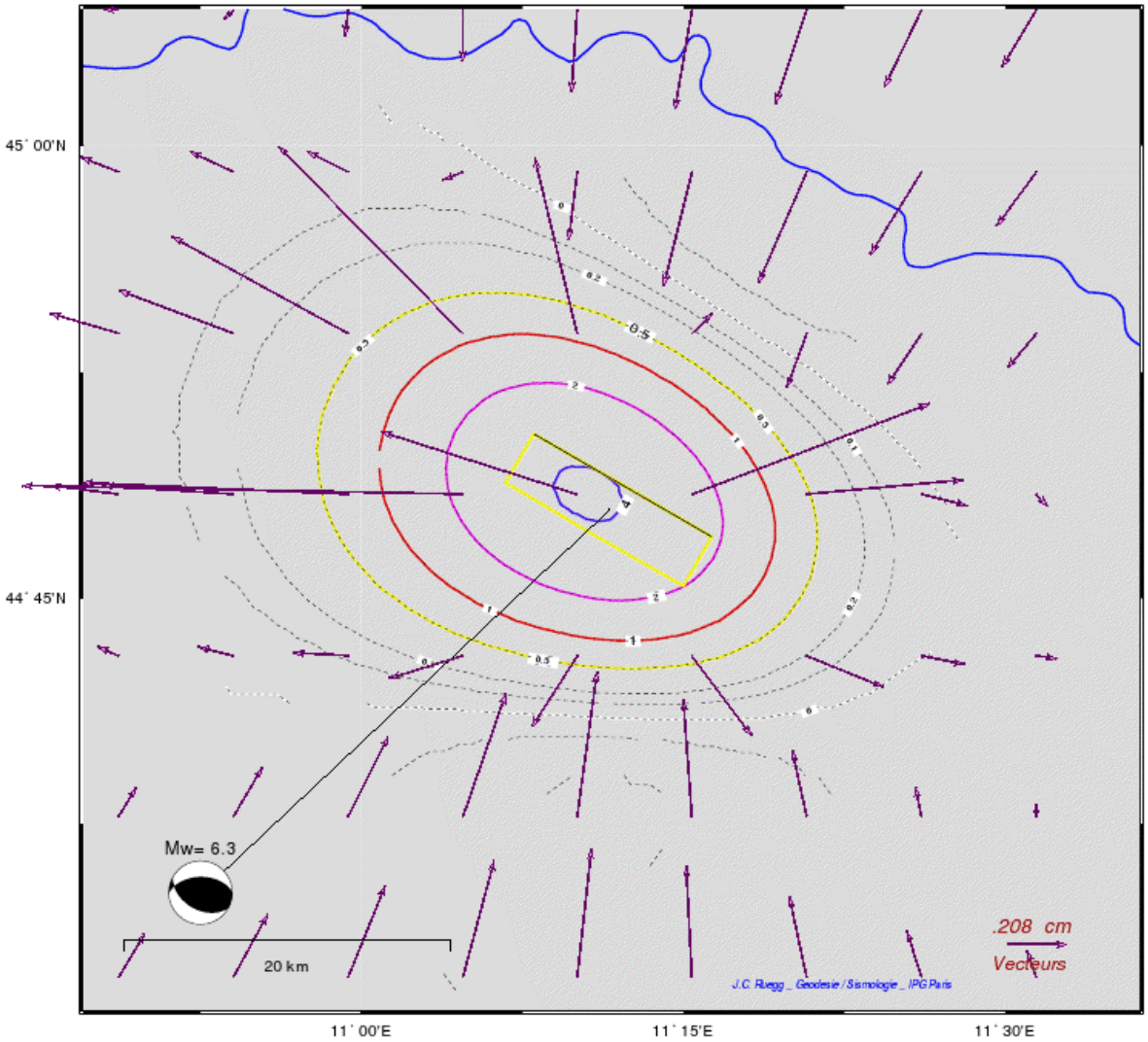


Solution with SCARDEC method performed by GEOAZUR

SCARDEC: a new technique for the rapid determination of seismic moment magnitude, focal mechanism and source time functions for large earthquakes using body-wave deconvolution.

source: https://sites.google.com/site/**cellulepostsismique**/

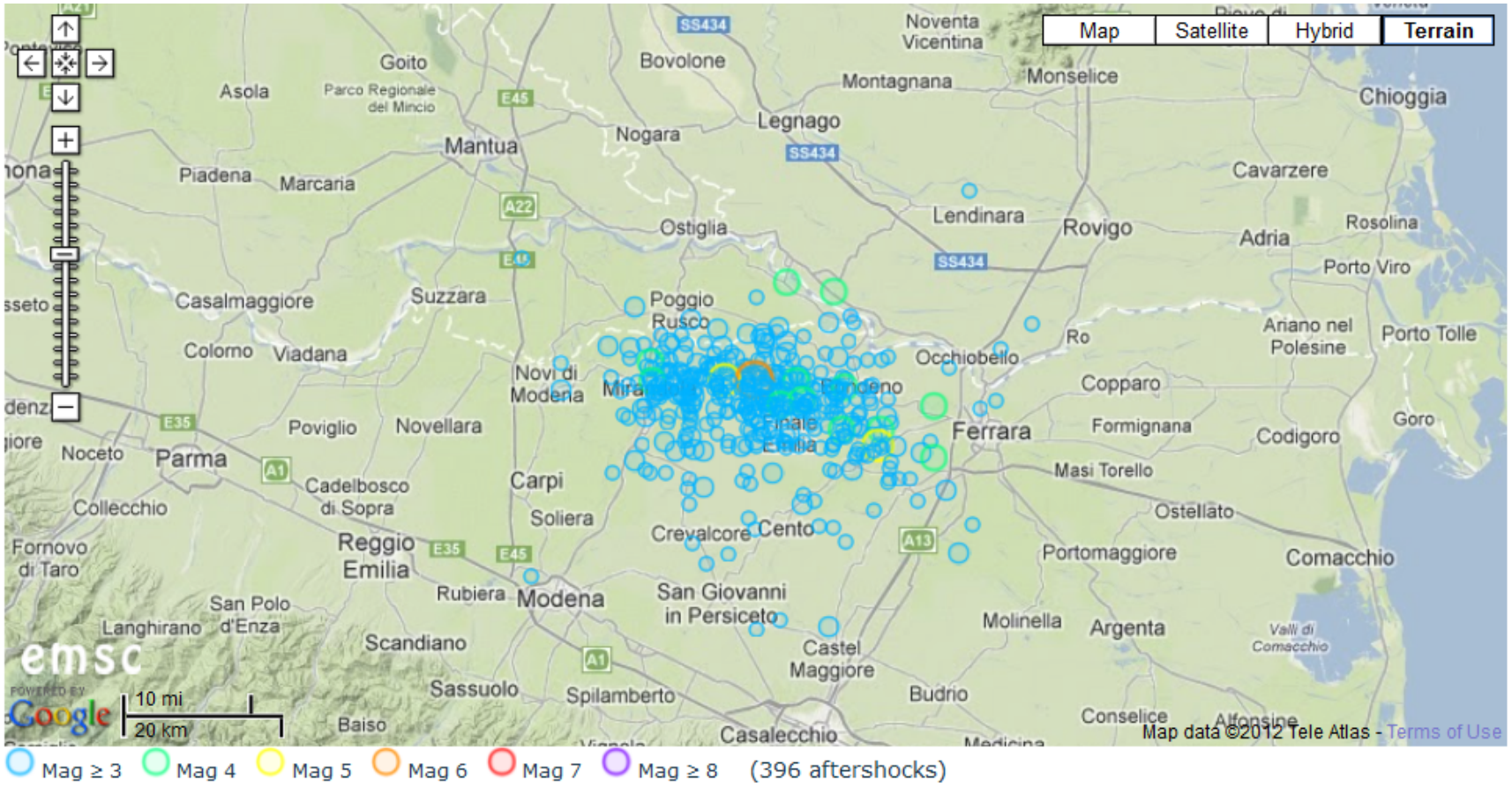
Simulation of ground movement



performed byJean-Claude Ruegg

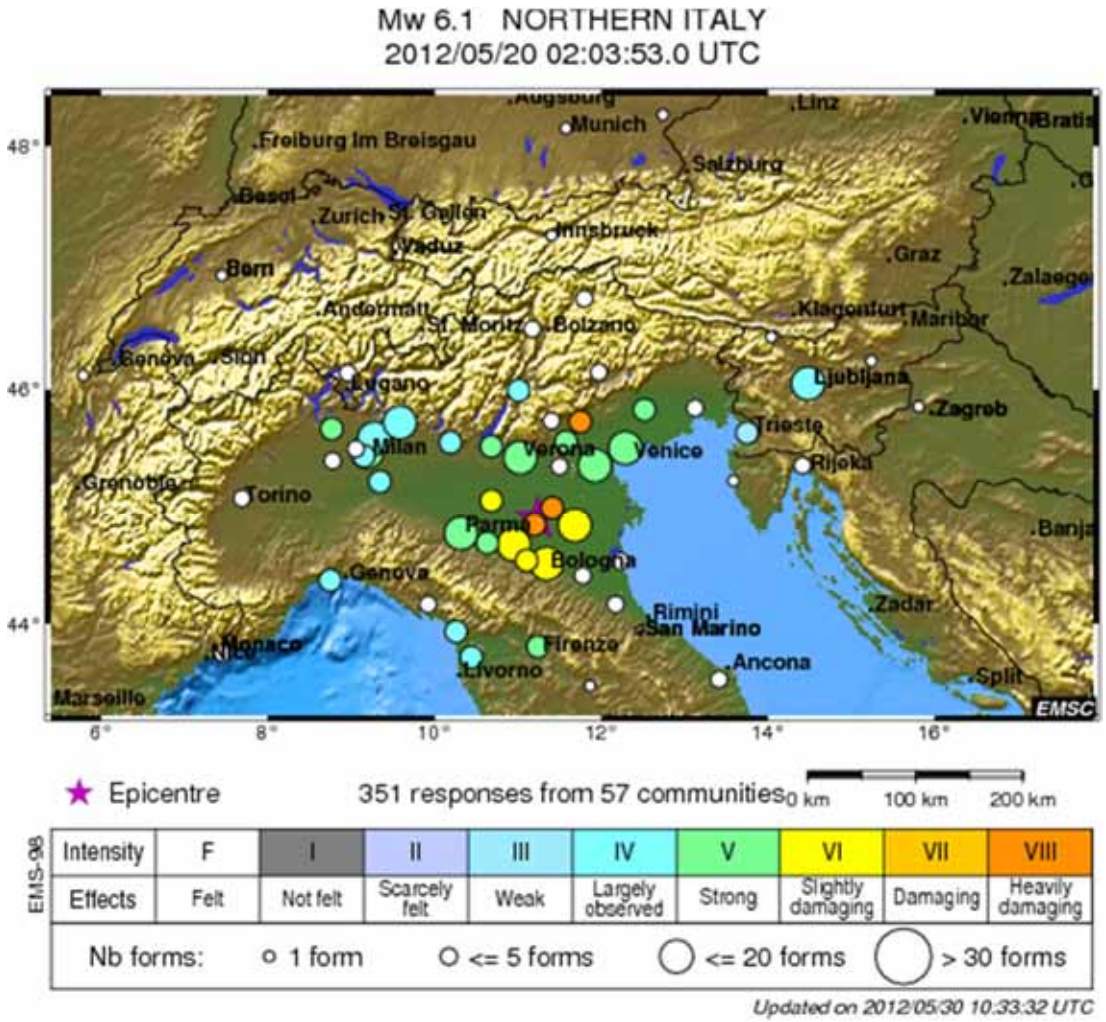
source: https://sites.google.com/site/**cellulepostsismique/**

Aftershocks location



source: www.emsc-csem.org

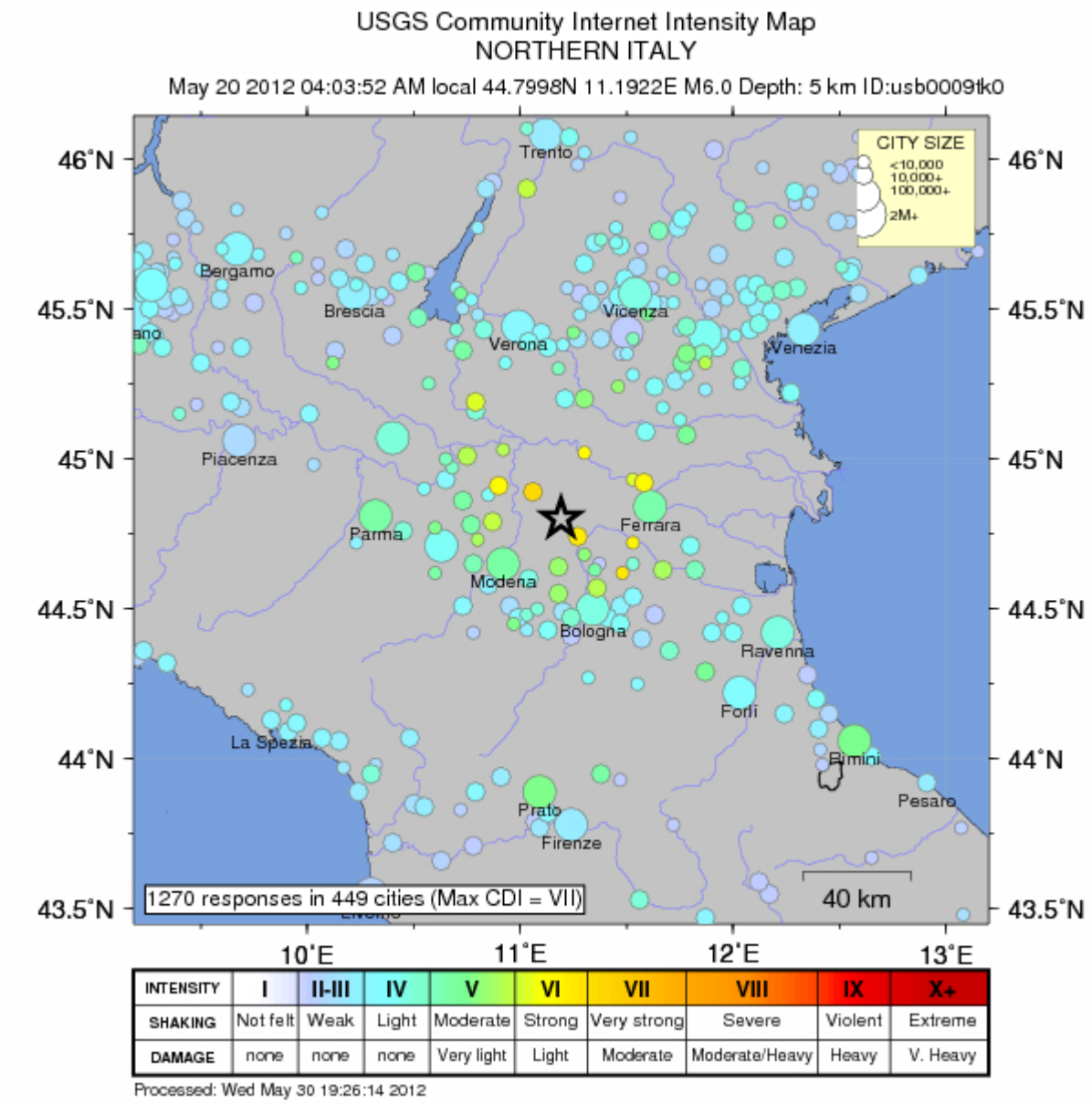
Intensity map



(generated with the results of the online questionnaire)

source: www.emsc-csem.org

Intensity map



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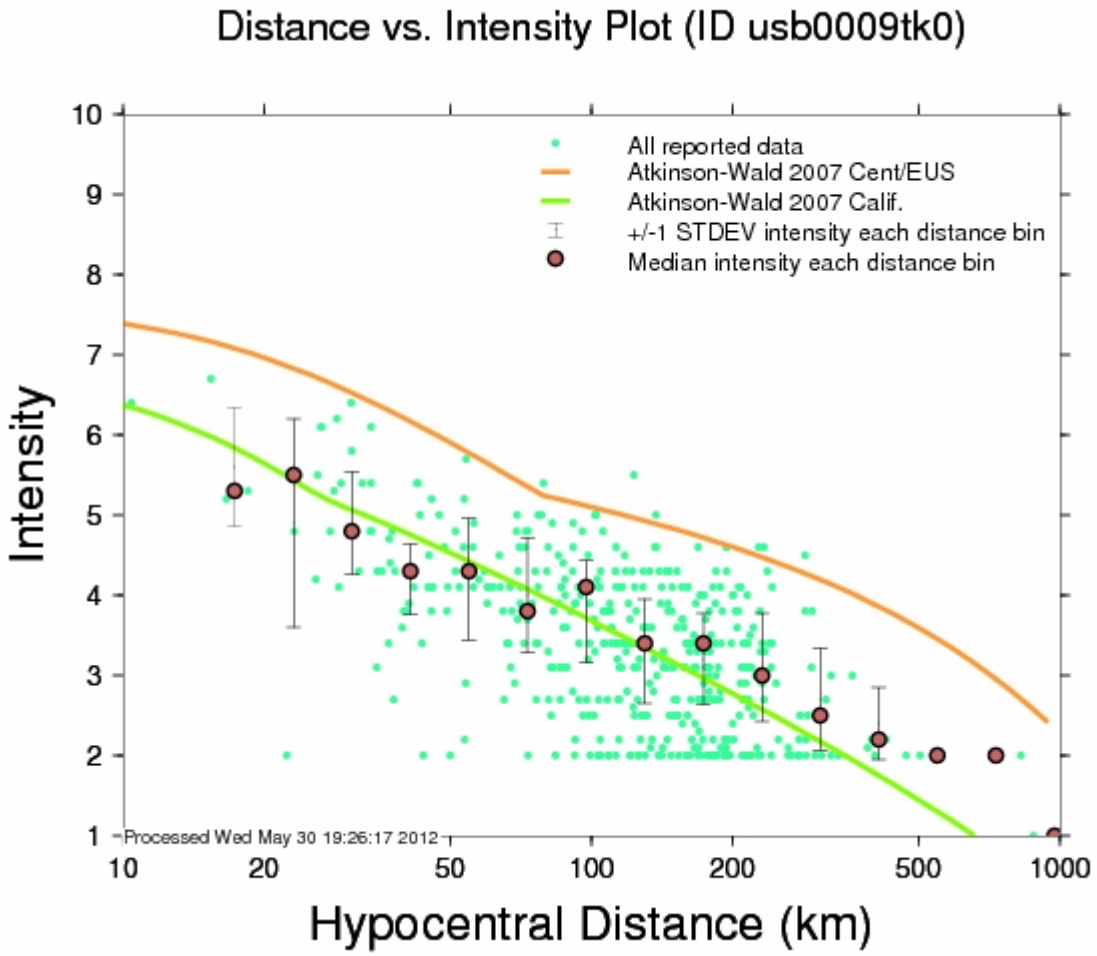
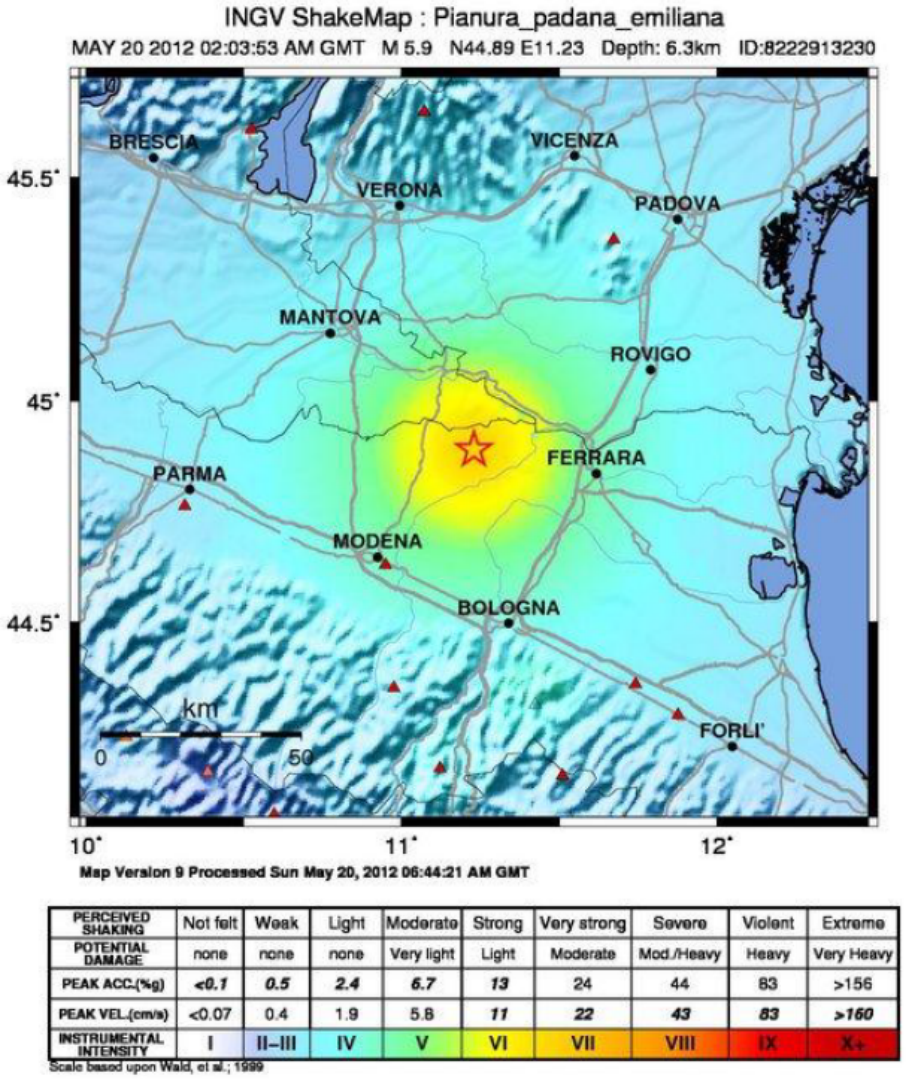
Intensity map



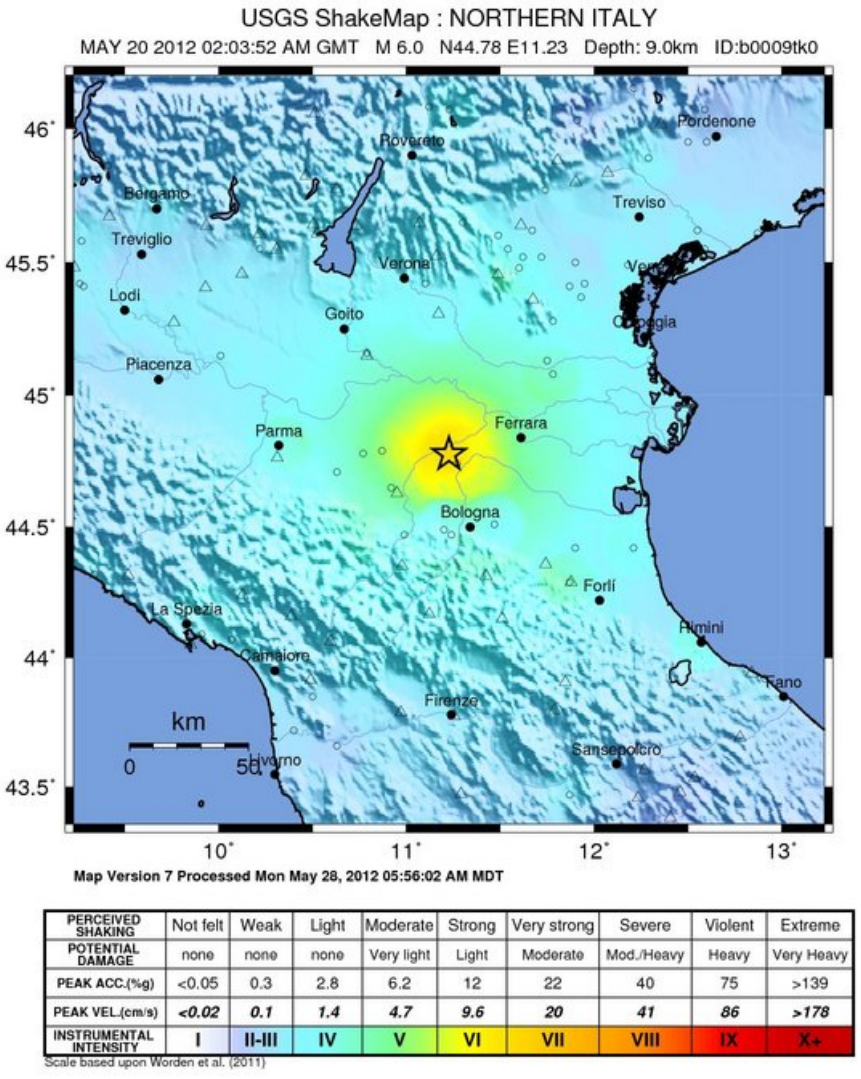
source: http://www.usgs.gov/

Shake maps - Intensity



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	*<0.1*	*0.5*	*2.4*	*6.7*	*13*	24	44	83	>156
PEAK VEL.(cm/s)	<0.07	0.4	1.9	5.8	*11*	*22*	*43*	*83*	*>160*
INSTRUMENTAL INTENSITY	I	II–III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Wald, et al.; 1999



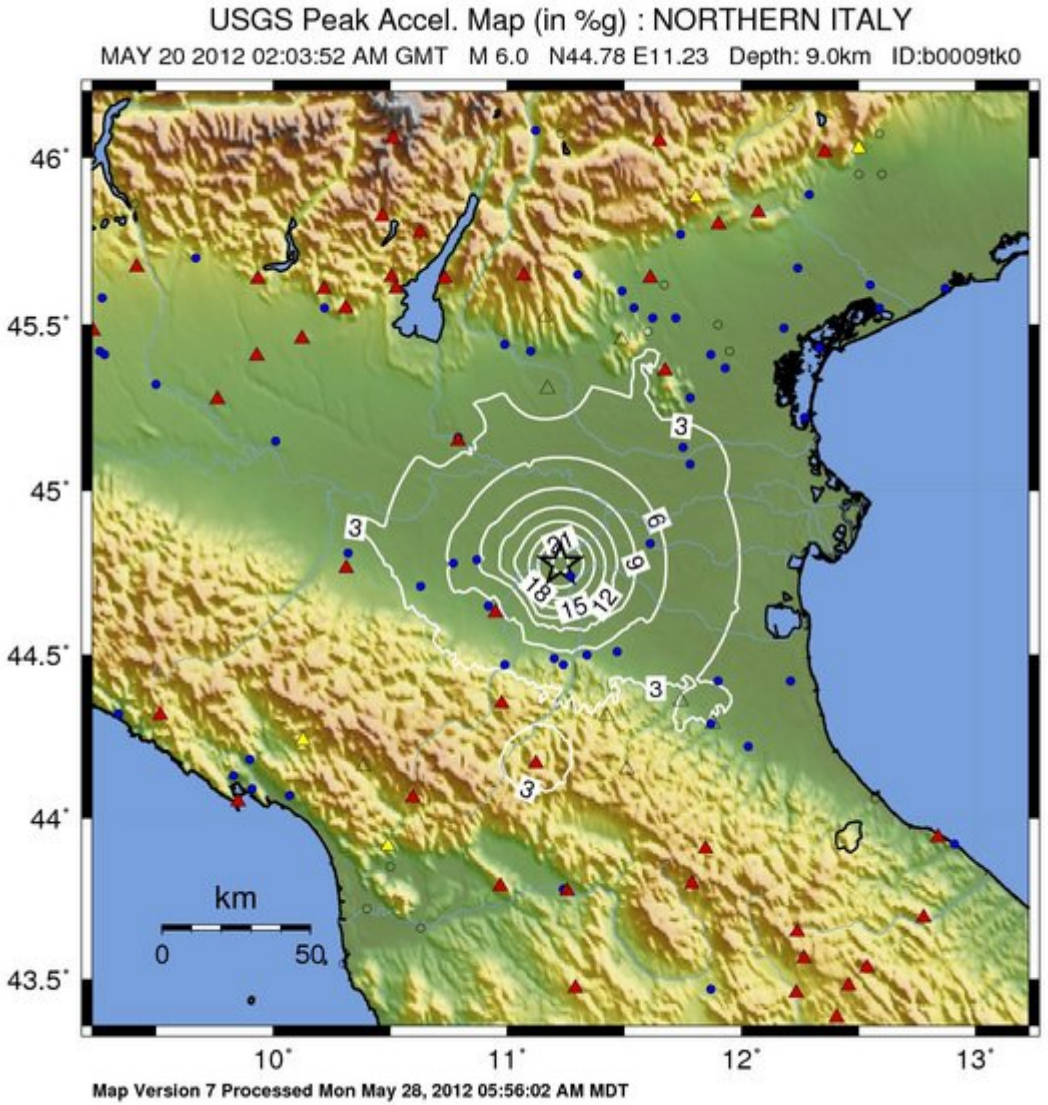
PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<0.05	0.3	2.8	6.2	12	22	40	75	>139
PEAK VEL.(cm/s)	*<0.02*	*0.1*	*1.4*	*4.7*	*9.6*	*20*	*41*	*86*	*>178*
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Worden et al. (2011)

source: www.ingv.it

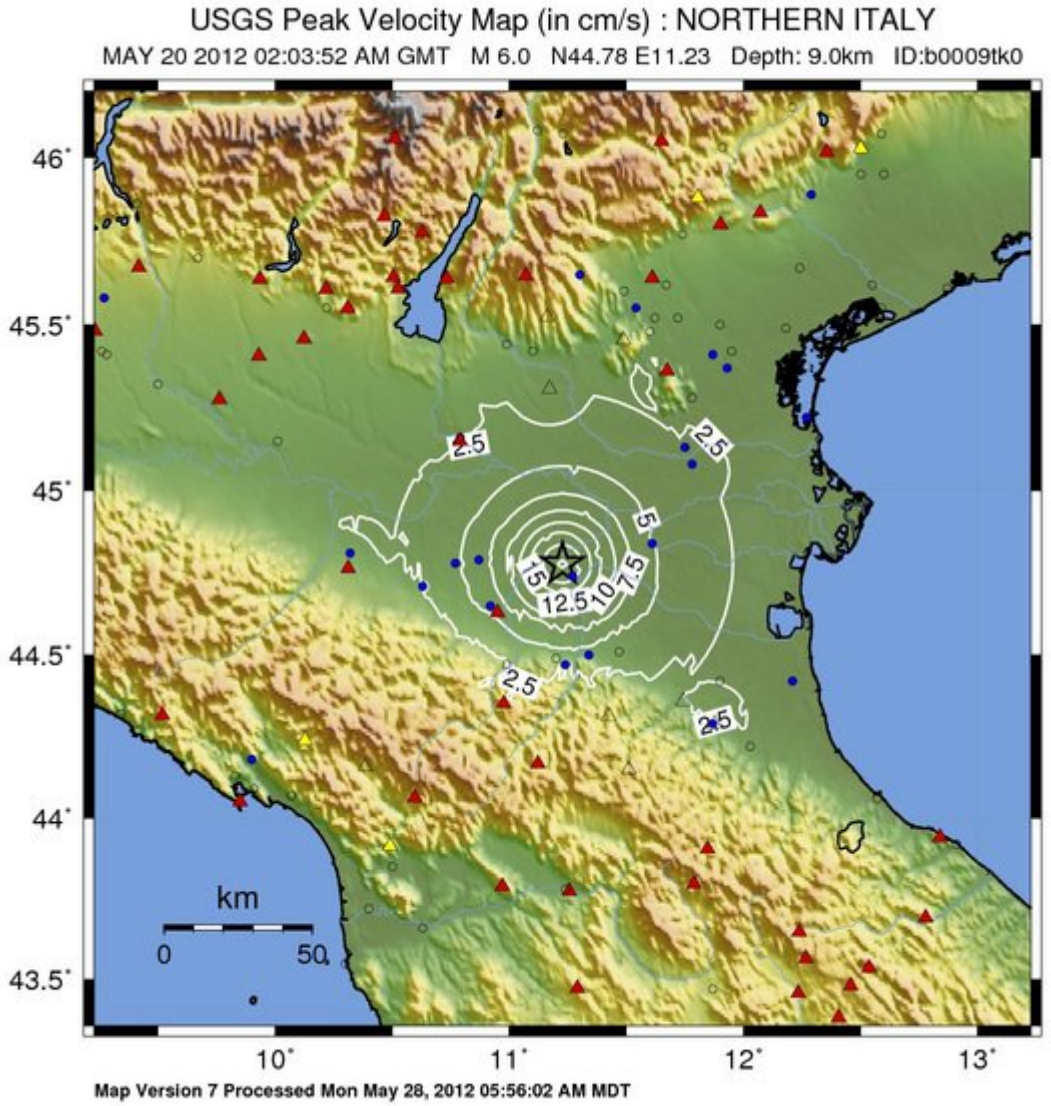
source: http://www.usgs.gov/

Shake maps - PGA



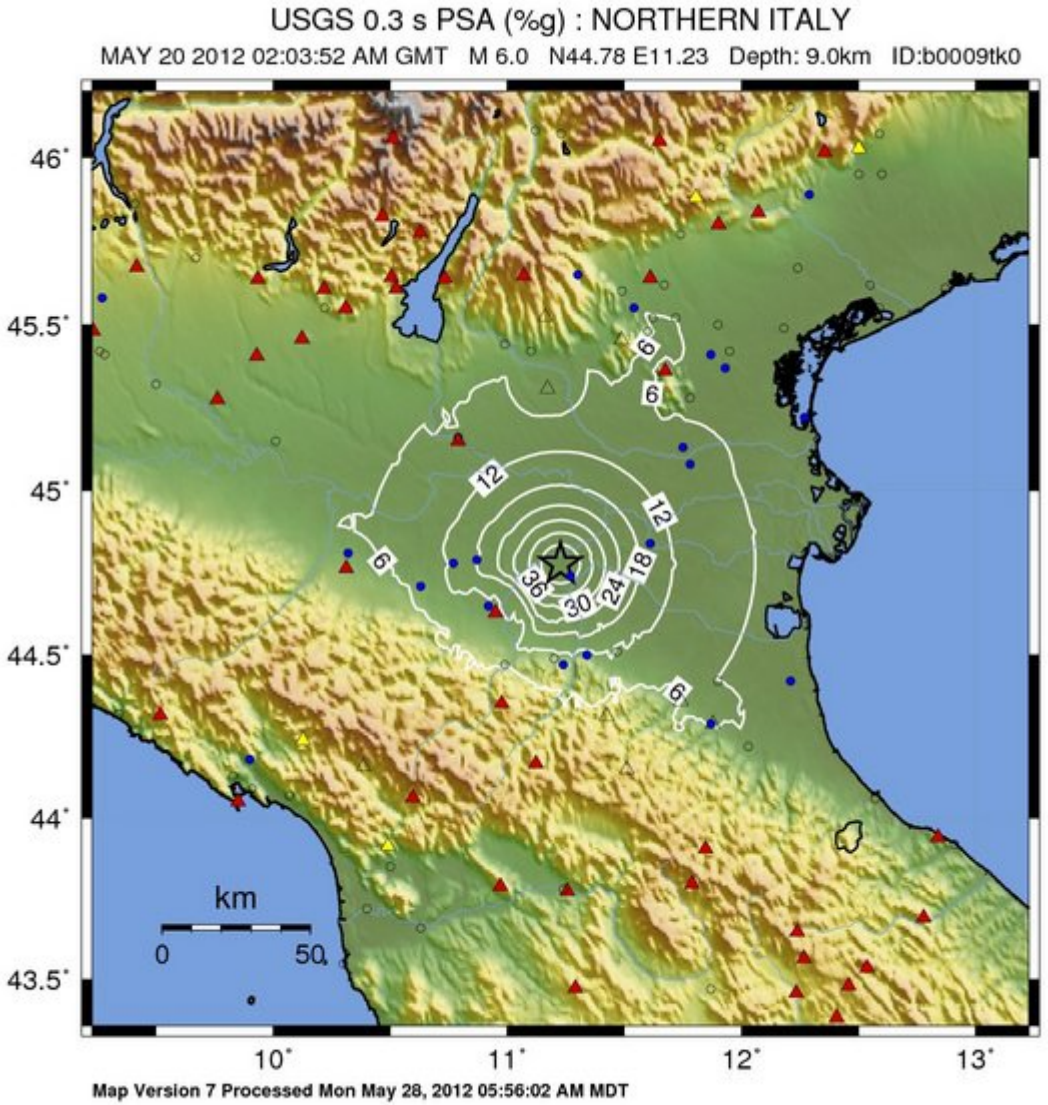
source: http://www.usgs.gov/

Shake maps - PGV



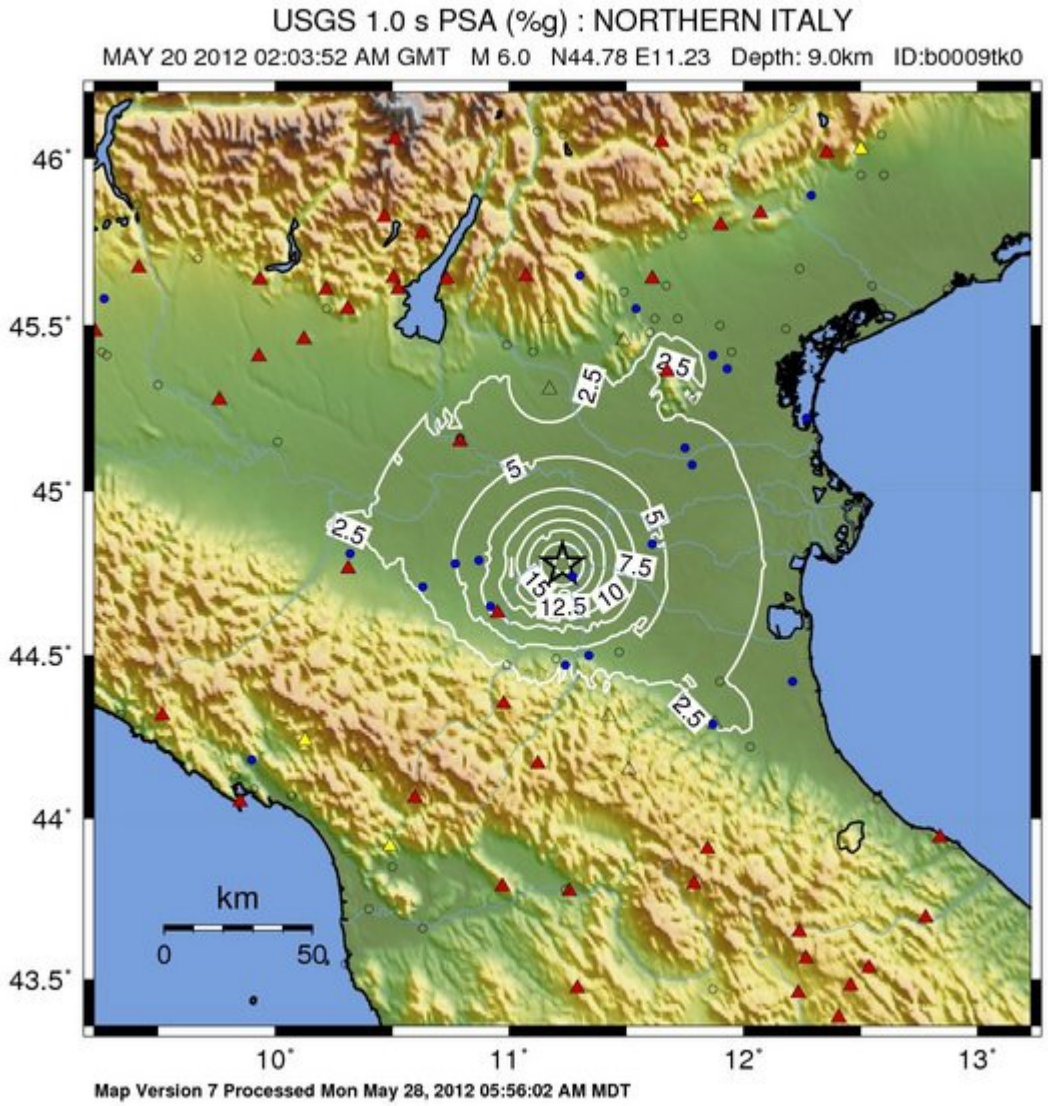
source: http://www.usgs.gov/

Shake maps – PSA T=0.3s



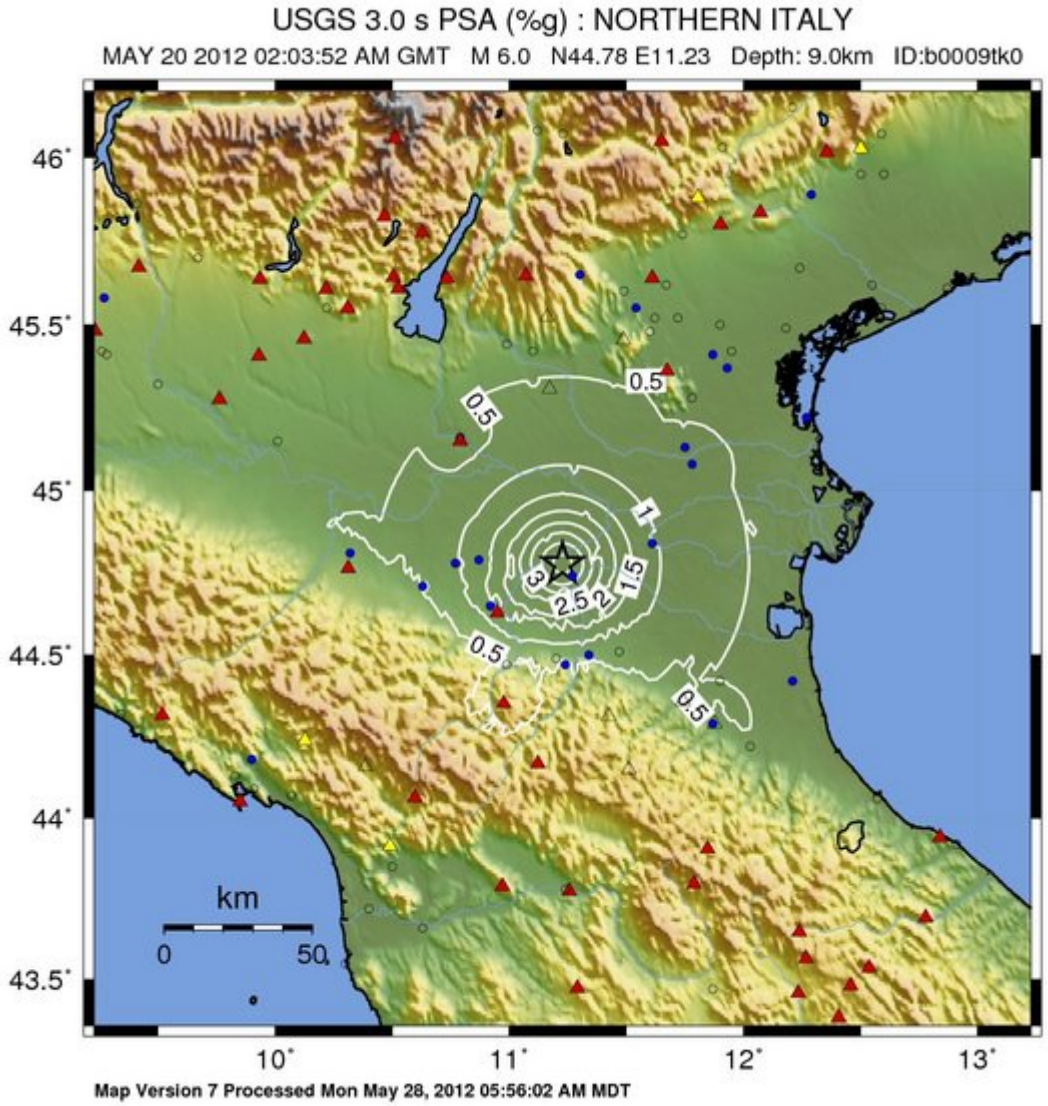
source: http://www.usgs.gov/

Shake maps – PSA T=1.0s



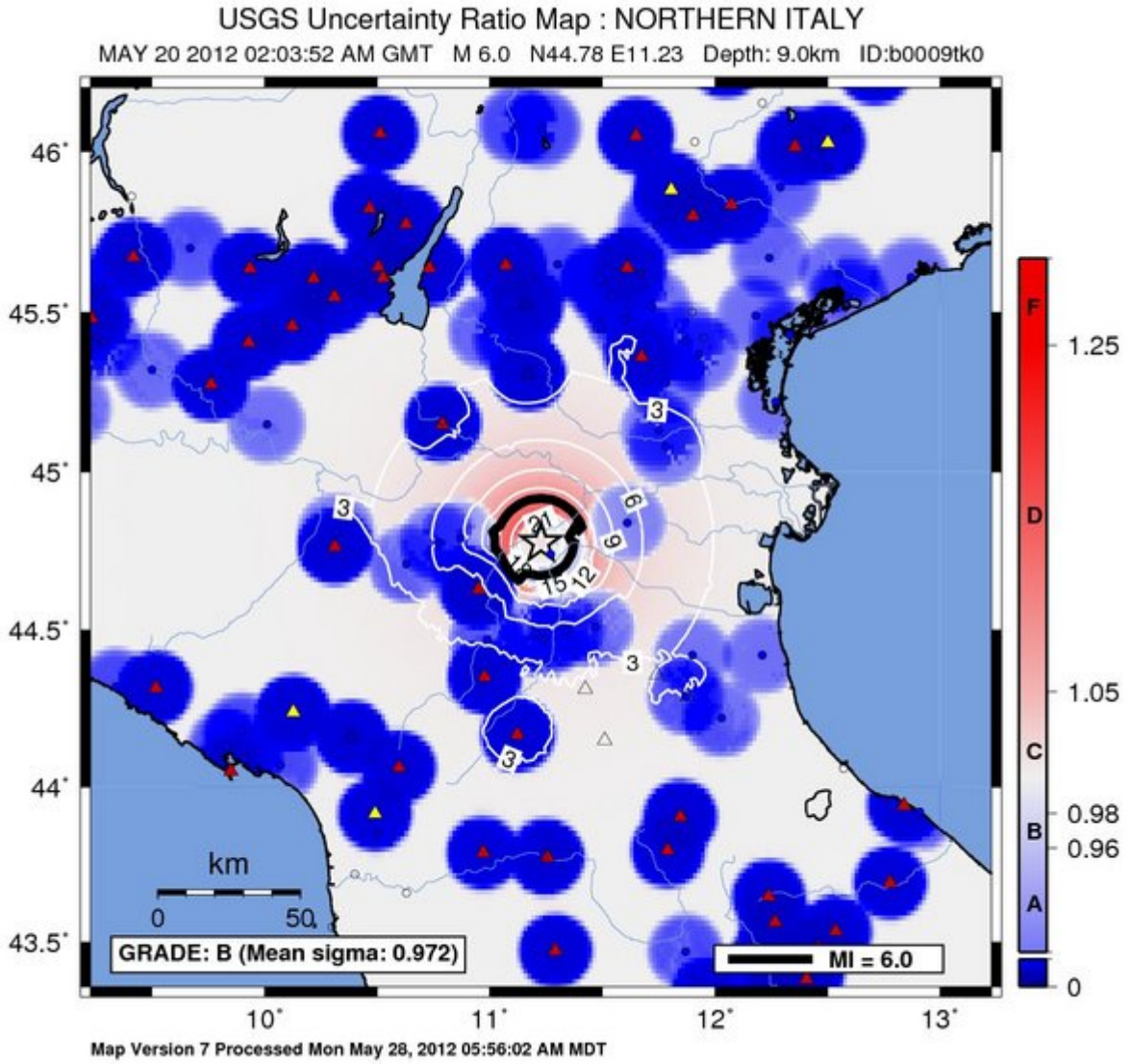
source: http://www.usgs.gov/

Shake maps – PSA T=3.0s



source: http://www.usgs.gov/

Shake maps – Uncertainty



source: http://www.usgs.gov/

M5.8 29 May 2012 earthquake

Mw 5.8, Medolla, Northern Italy
29.05.2012, 07:00:03 UTC

- 16 victims
- 350 injured
- 14000 homeless
- Evacuation of several buildings
- The region, already affected by the 20th May event, is experiencing important damages and casualties

Earthquake Details

- Magnitude Mw: **5.8**
- Date-Time: **Tuesday, May 29, 2012 at 07:00:03 UTC**
- Location: 44.89 N ; 11.07 E
- Depth: 5 km
- Region: 1km E of Mirandola, Italy
- Distances :

  3km SSE of Medolla, Italy

  5km WSW of San Felice sul Panaro, Italy

  8km S of Mirandola, Italy

  11km NNW of Crevalcore, Italy

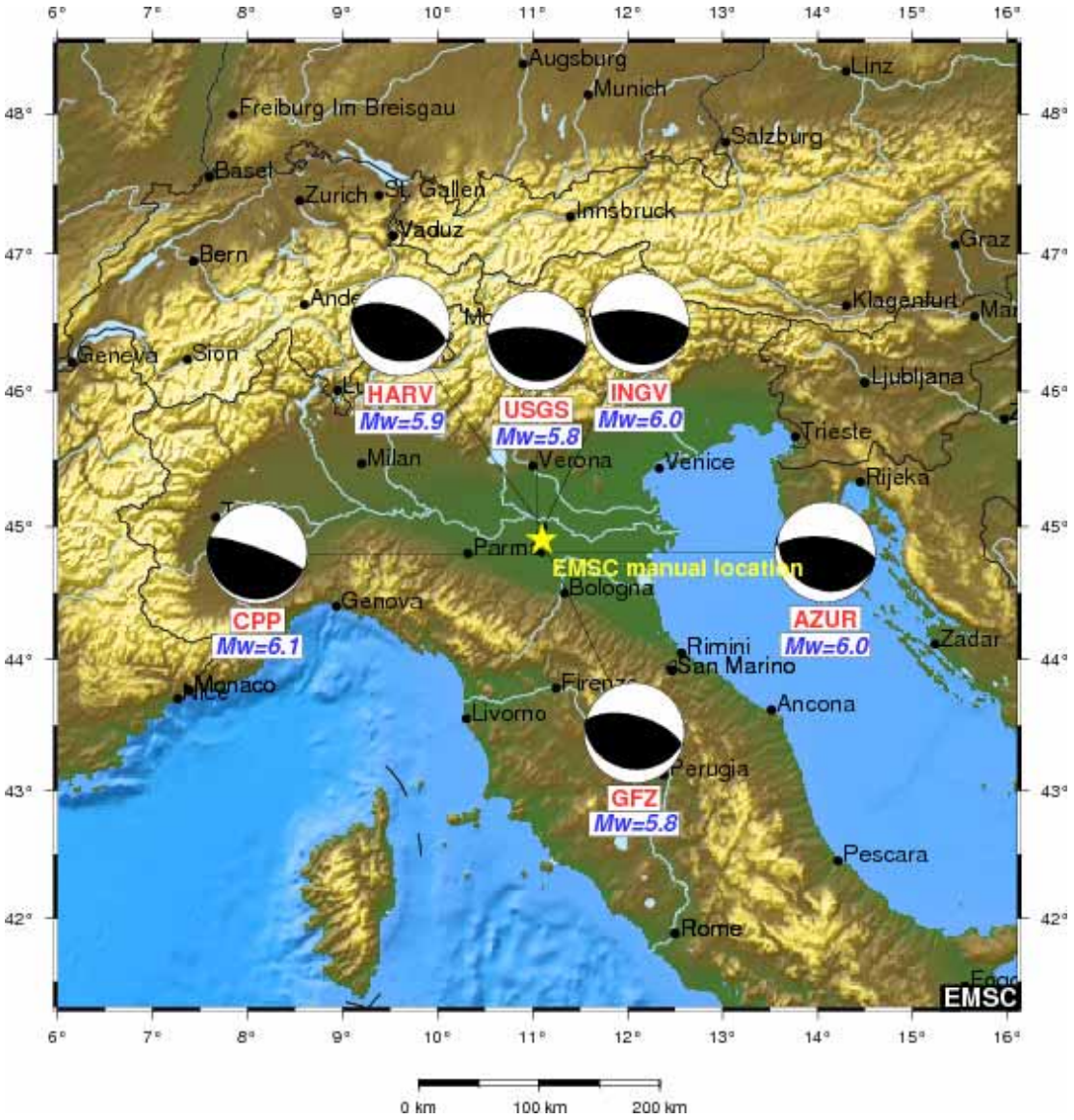
  146km NW of San Marino, San Marino

  Location Uncertainty : horizontal +/- 12.0 km; depth +/- 4.1 km
- Parameters: Nph= 401, Dmin=210 km, Rmss=1.32 sec, Gp= 25^{o} , M-type= regional moment magnitude (Mw), Version=A
- Source : USGS National Earthquake Information Center

Epicenter location

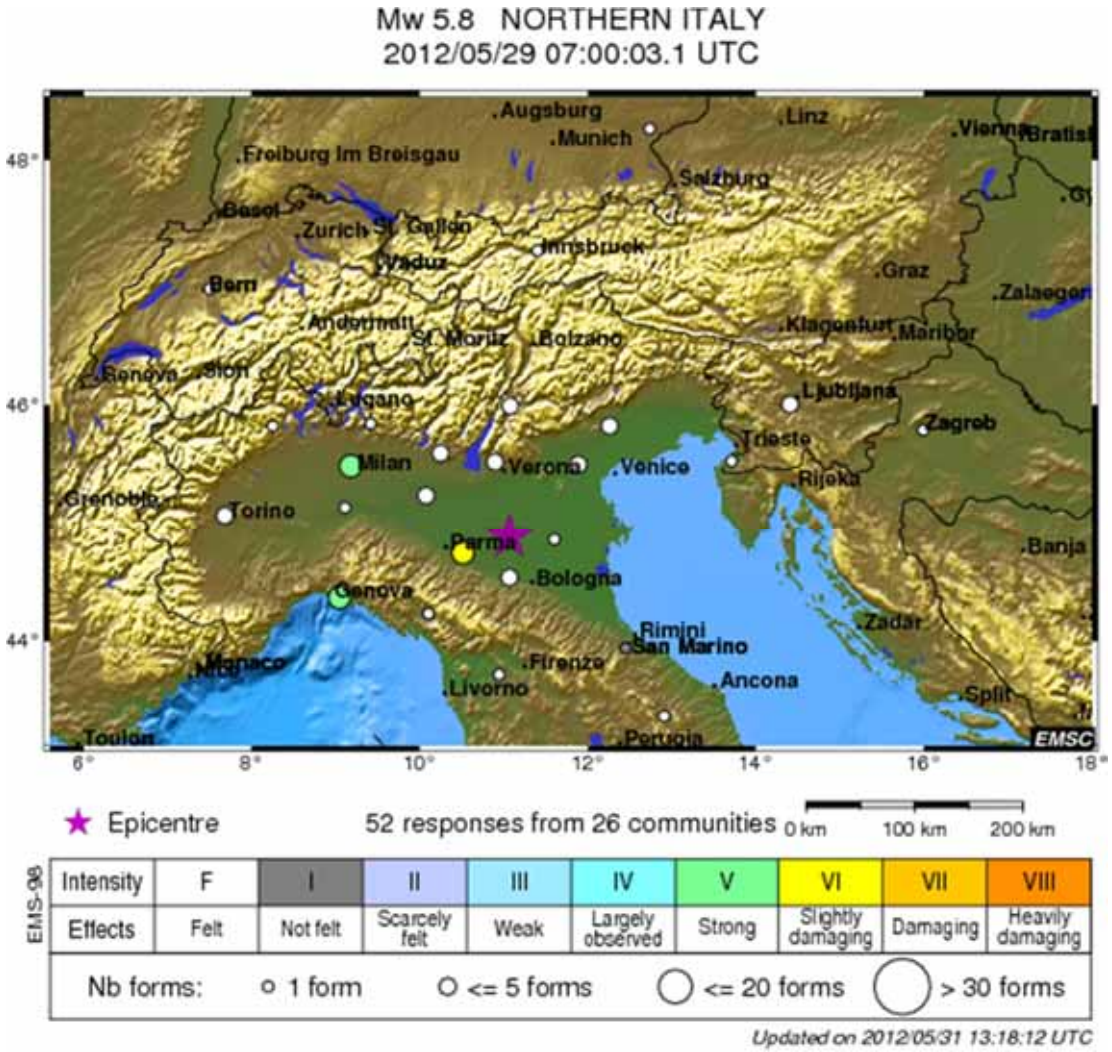
source: http://www.usgs.gov/

Magnitude estimation



source: www.emsc-csem.org

Intensity map



(generated with the results of the online questionnaire)

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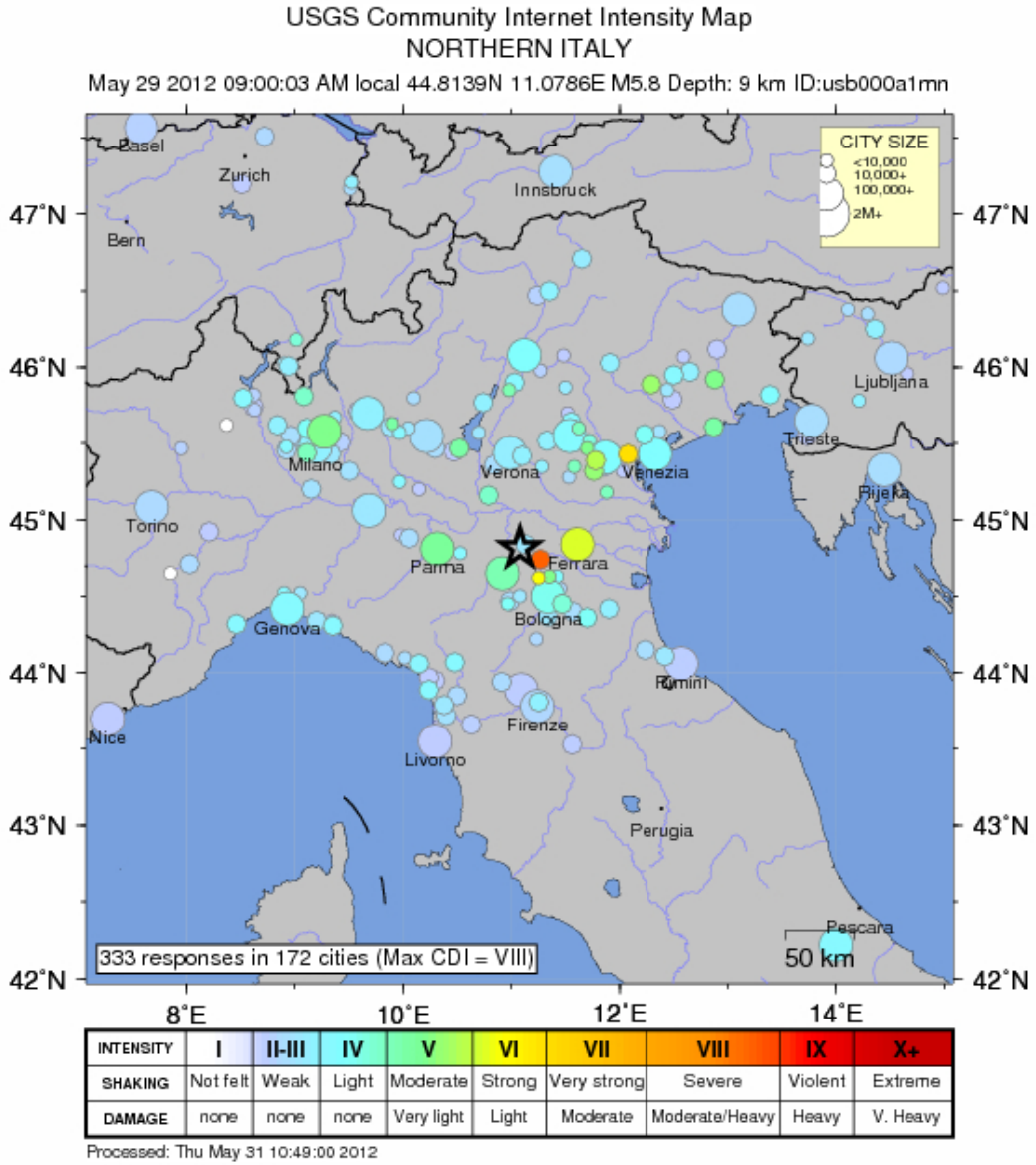

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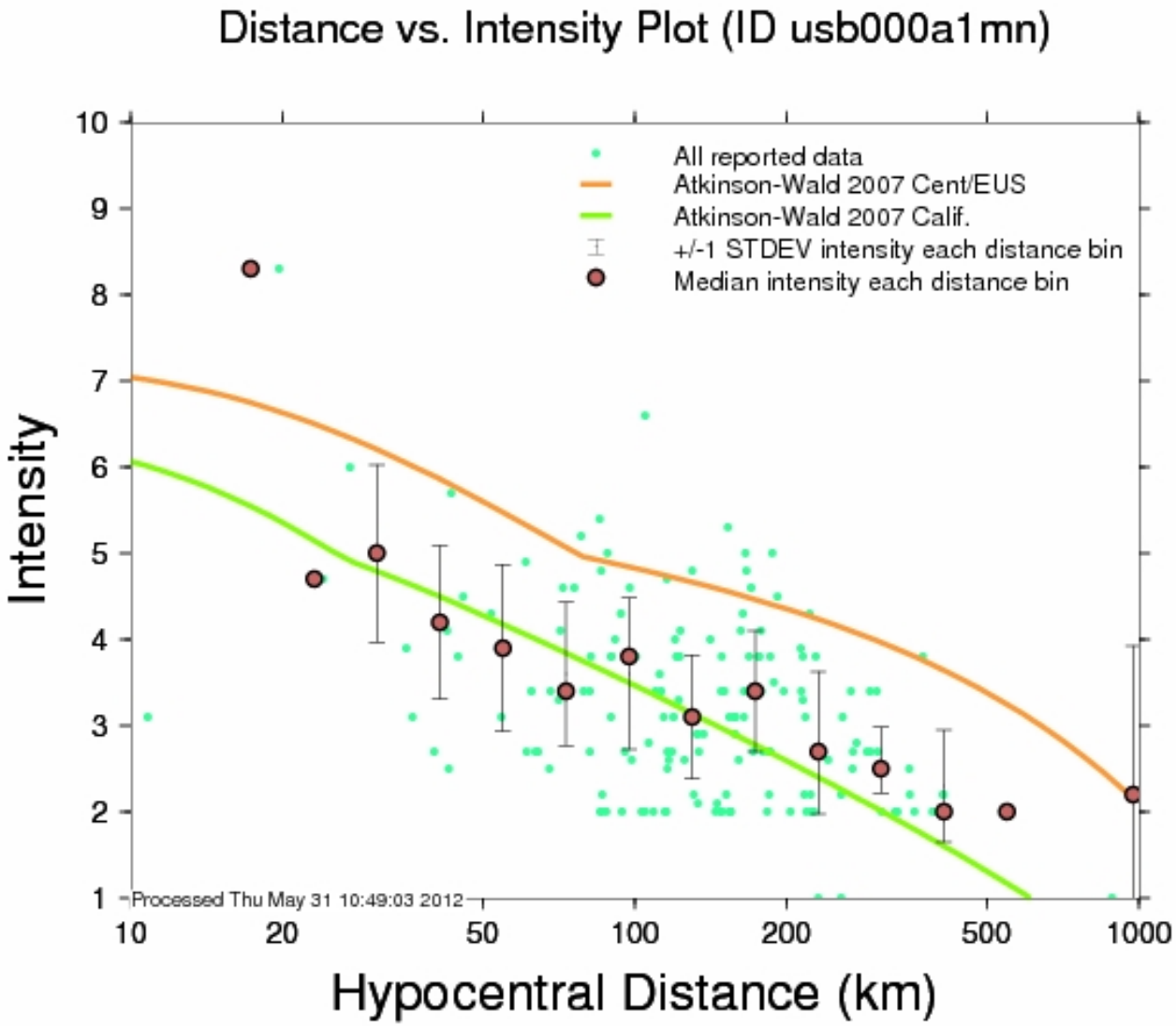
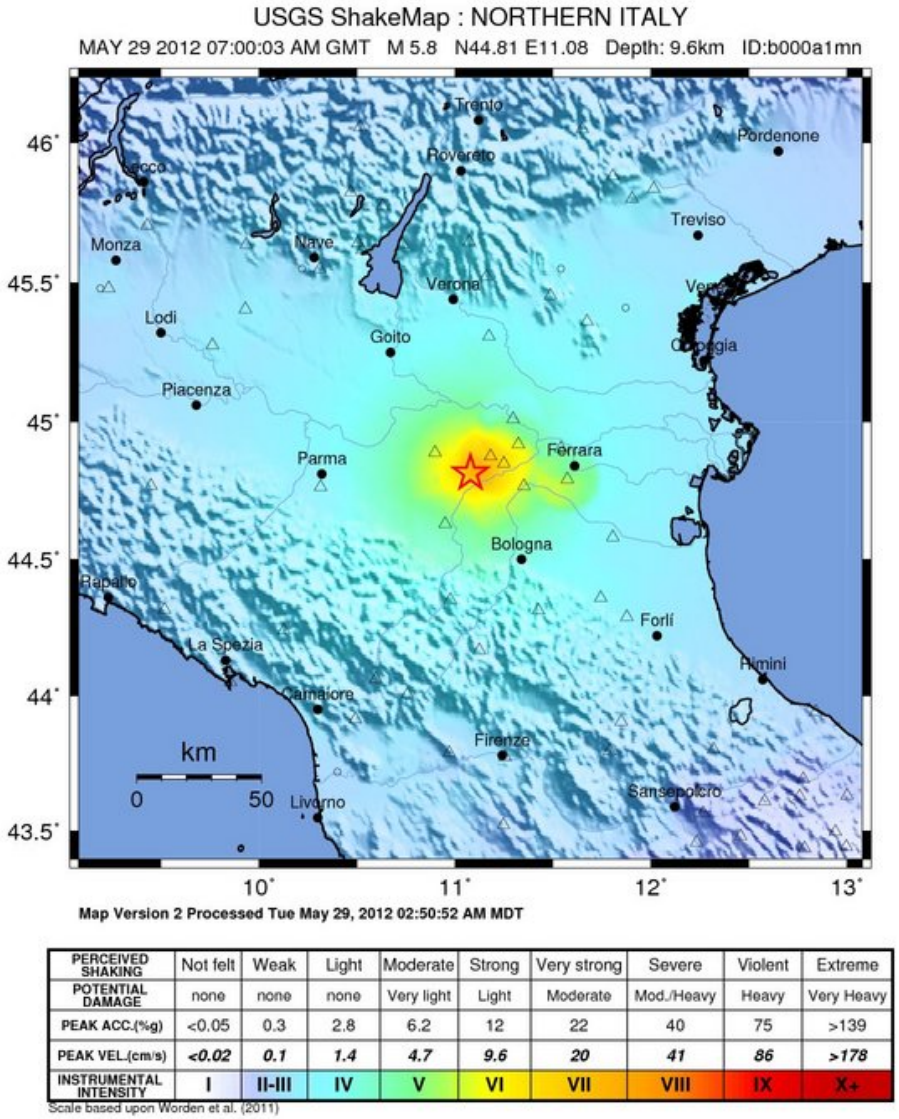
Intensity map



source: http://www.usgs.gov/

Shake maps - Intensity



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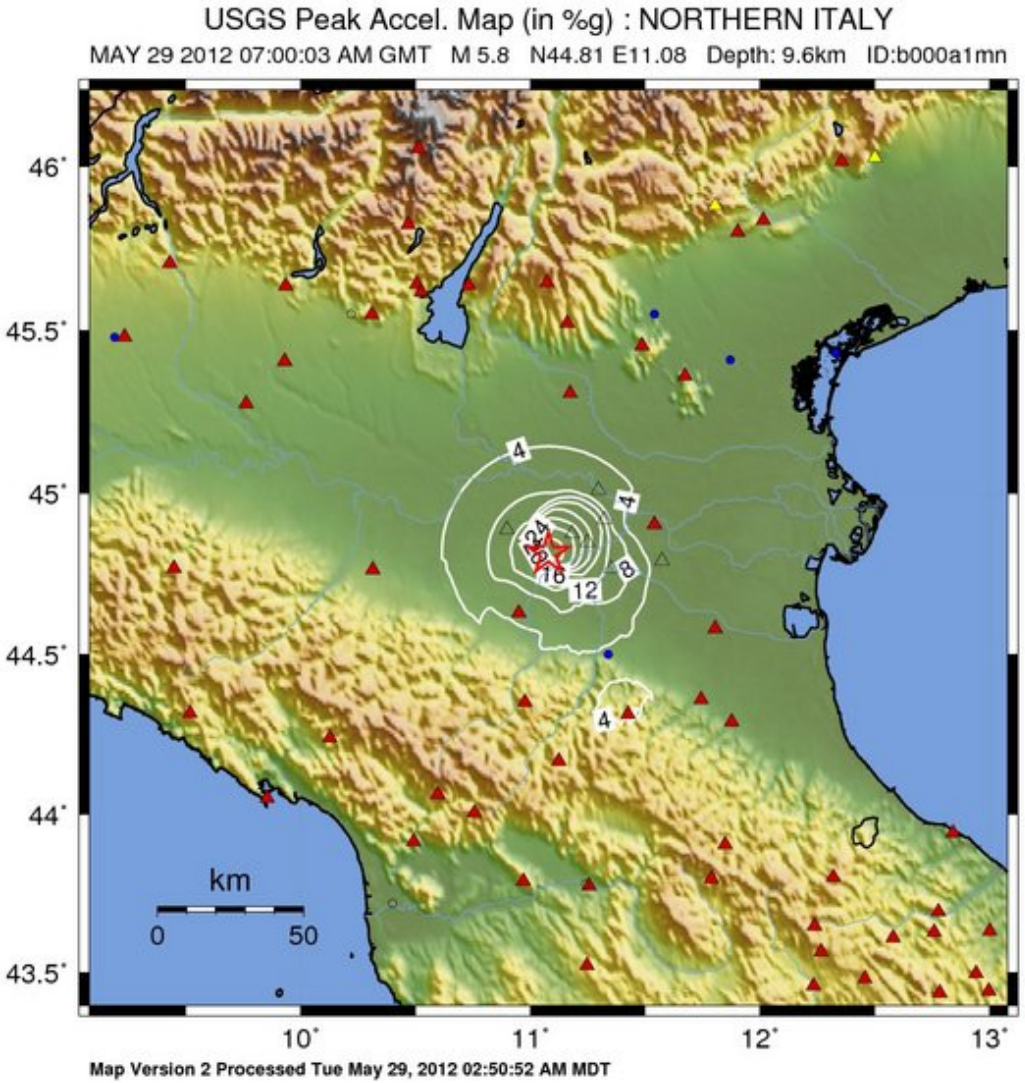
Scale based upon Worden et al. (2011)

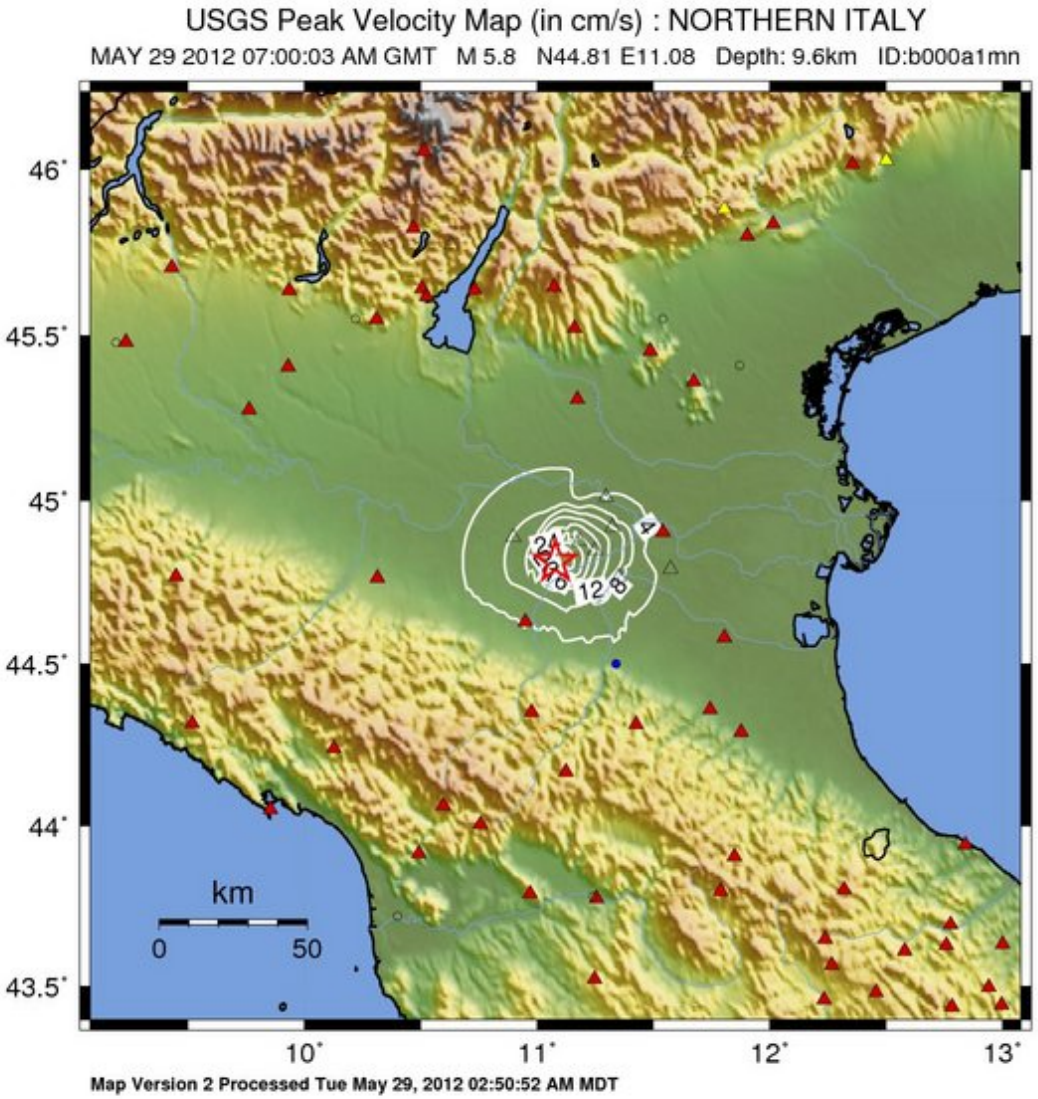
source: http://www.usgs.gov/

Shake maps - PGA



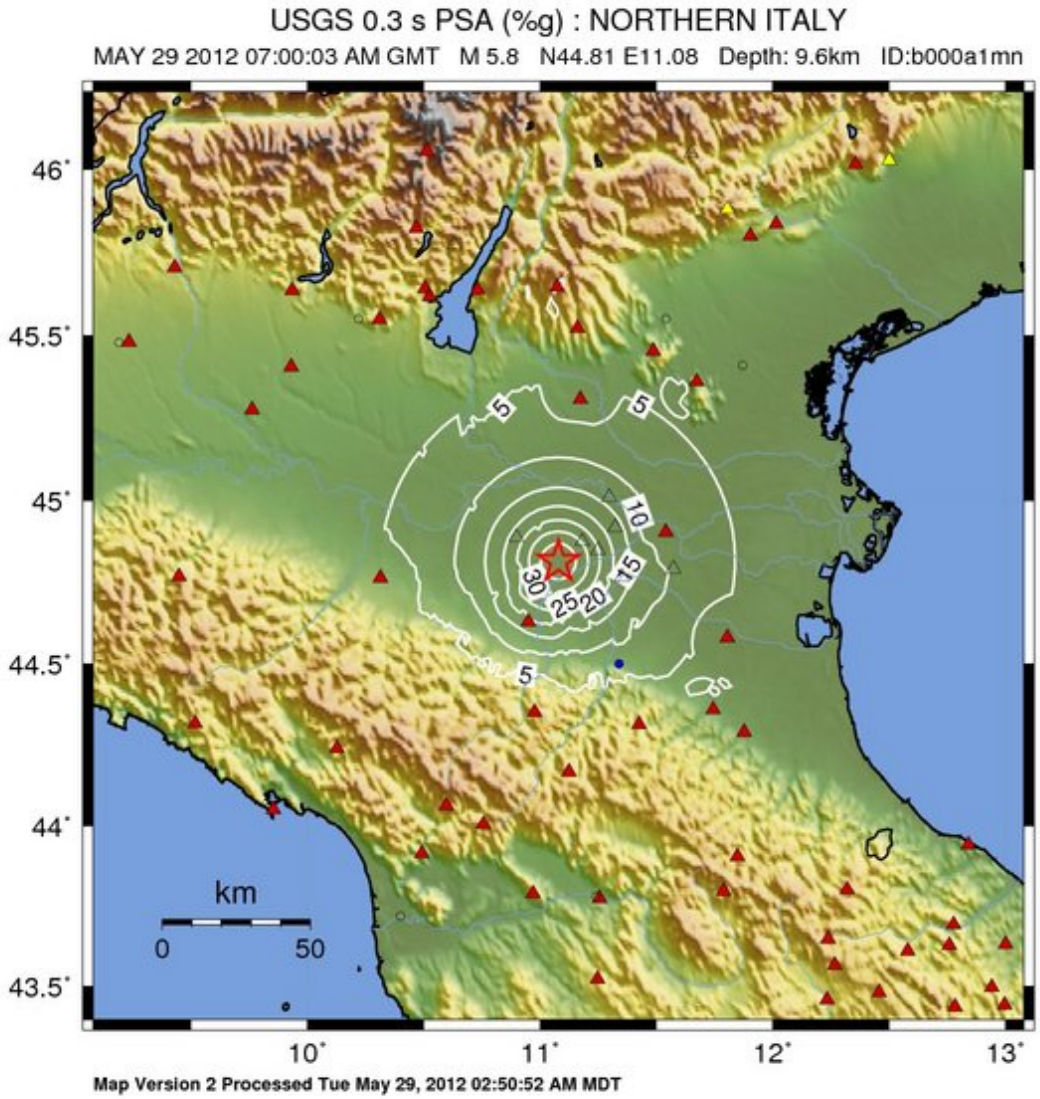
source: http://www.usgs.gov/

Shake maps - PGV



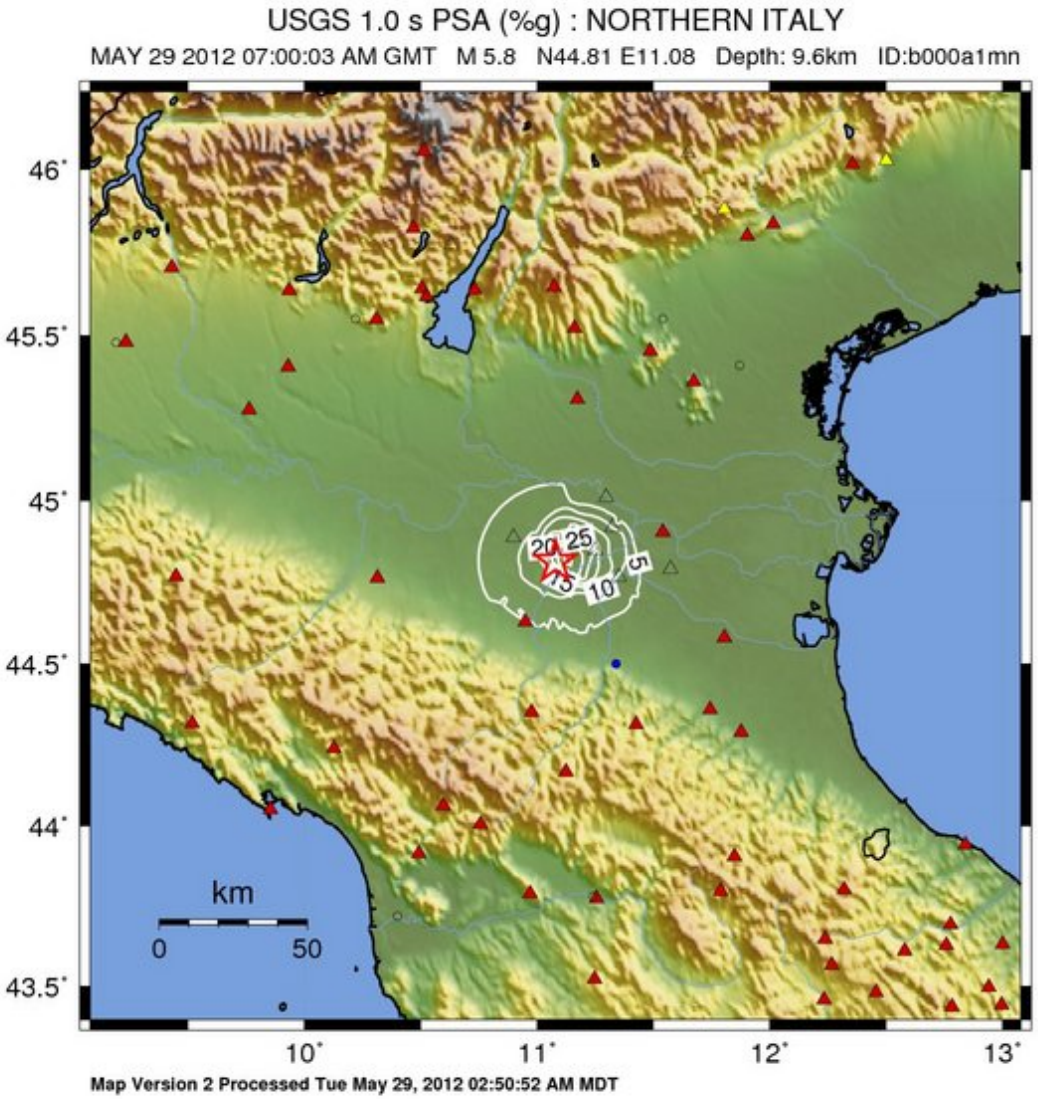
source: http://www.usgs.gov/

Shake maps – PSA T=0.3s



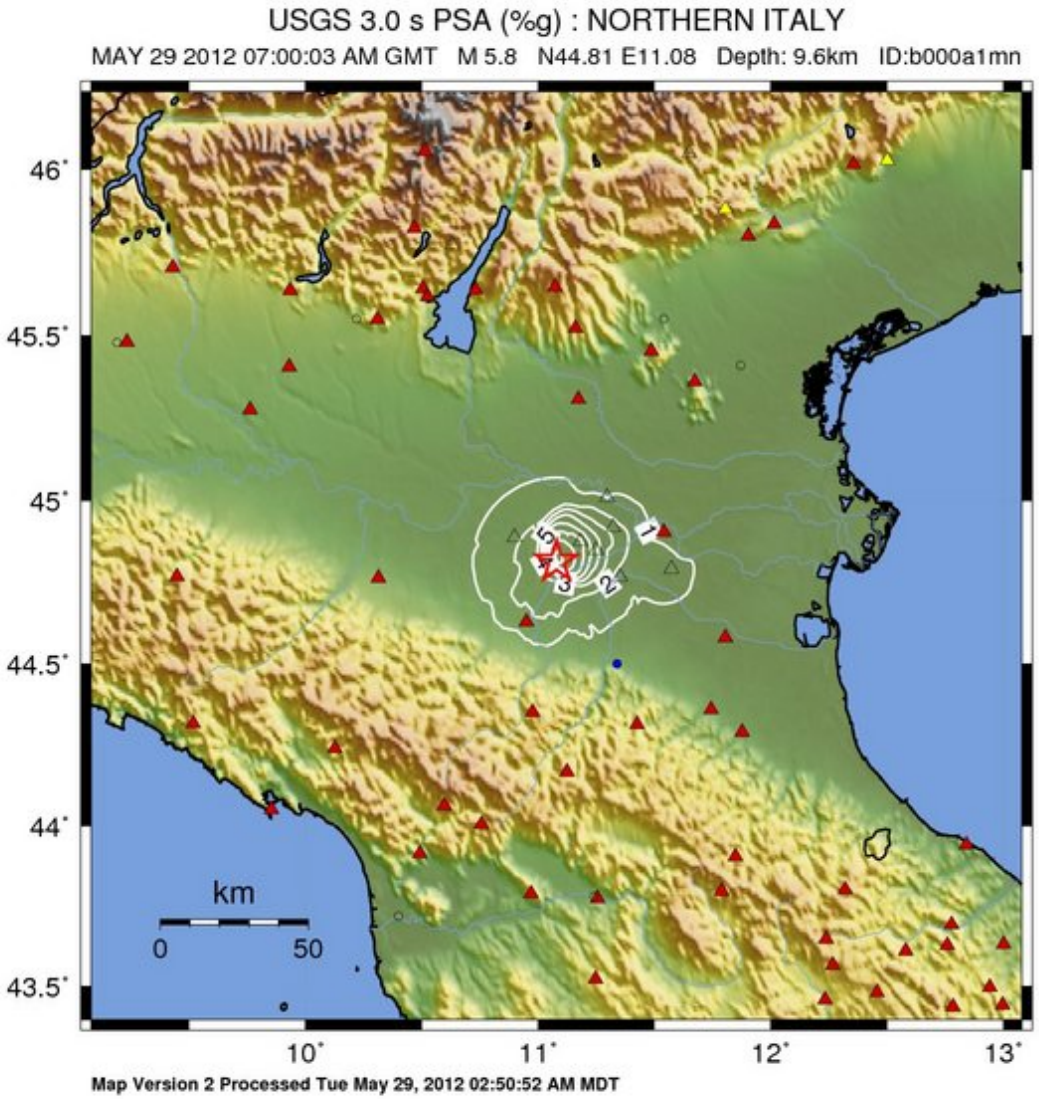
source: http://www.usgs.gov/

Shake maps – PSA T=1.0s



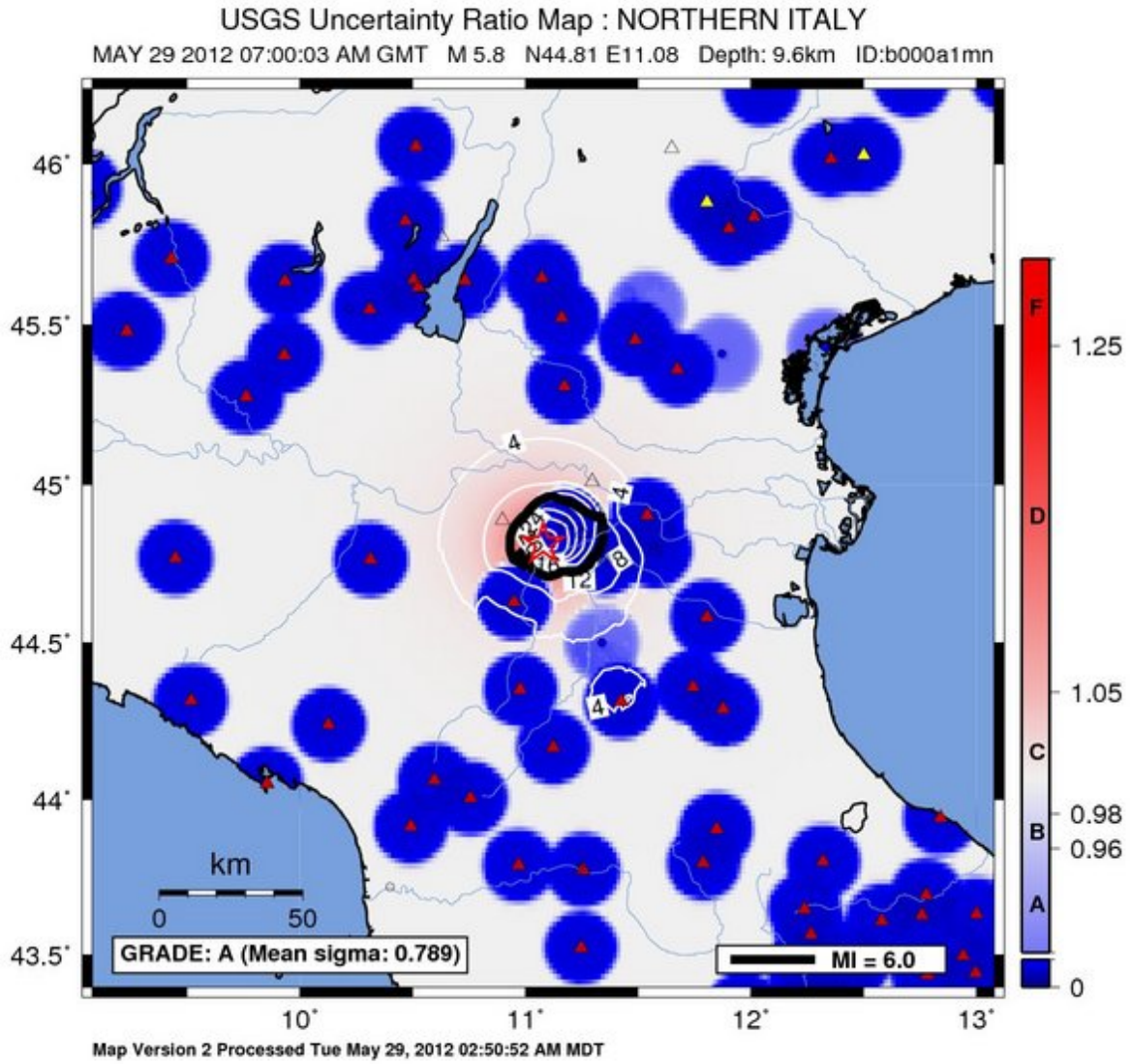
source: http://www.usgs.gov/

Shake maps – PSA T=3.0s



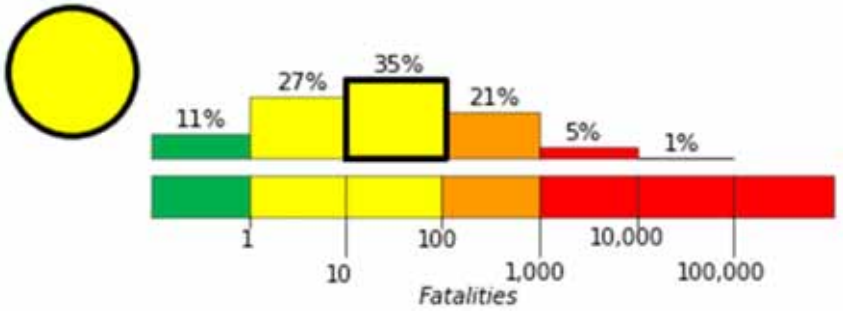
source: http://www.usgs.gov/

Shake maps – Uncertainty

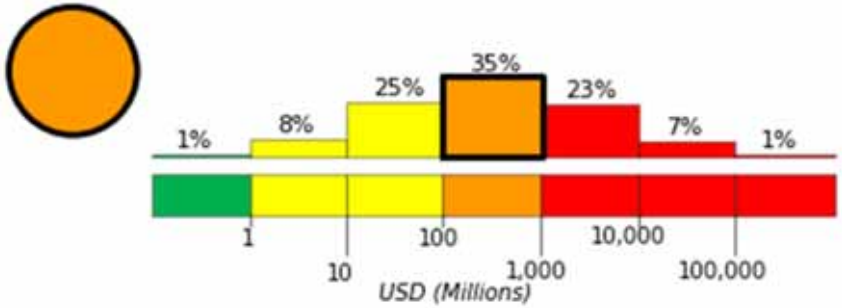


source: http://www.usgs.gov/

Fatalities – Economic loses



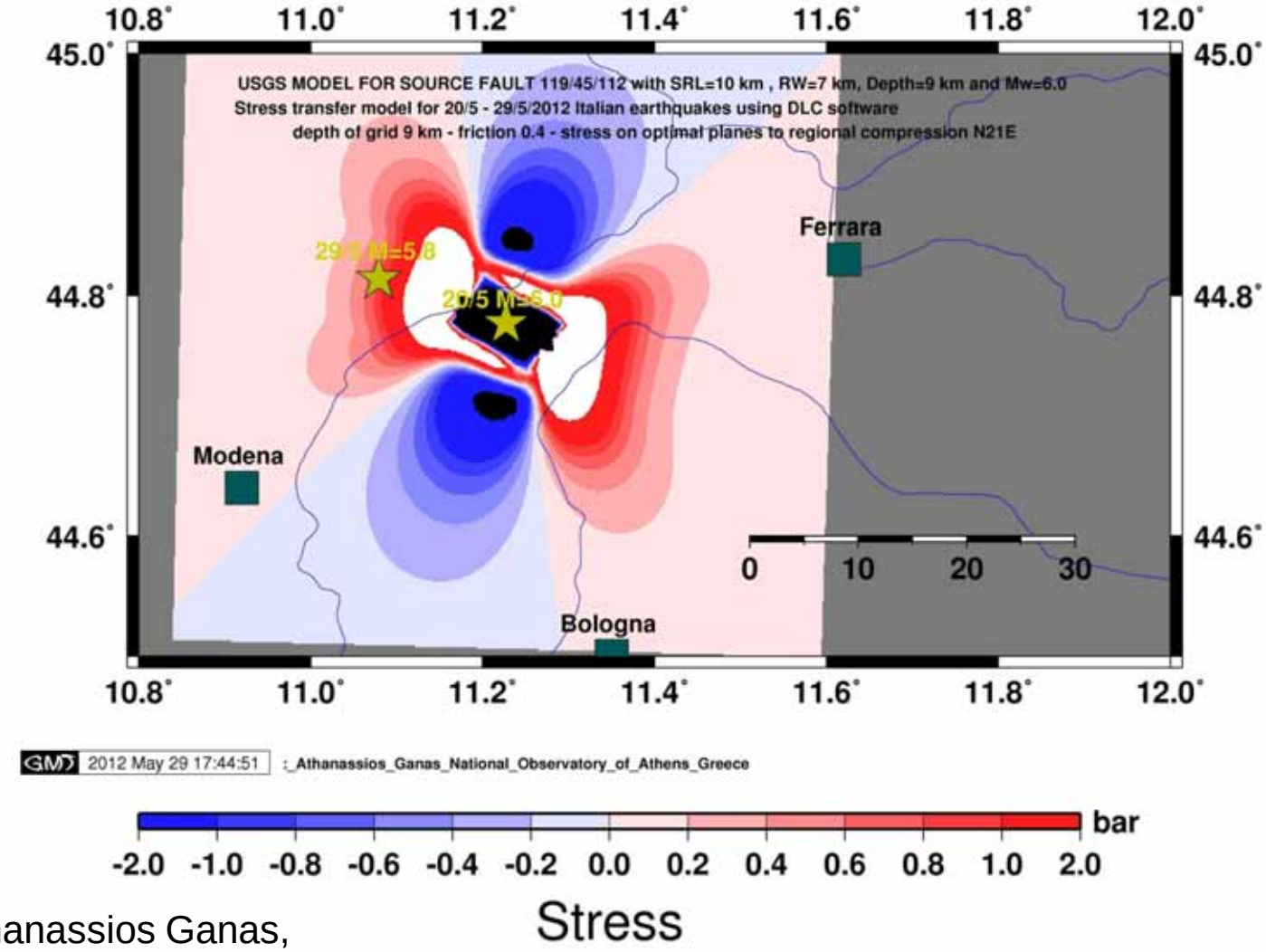
Yellow alert level for shaking-related fatalities. Some casualties are possible.



Orange alert level for economic losses. Significant damage is likely and the disaster is potentially widespread. Estimated economic losses are less than 1% of GDP of Italy. Past events with this alert level have required a regional or national level response.

source: http://www.usgs.gov/

Coulomb stress study

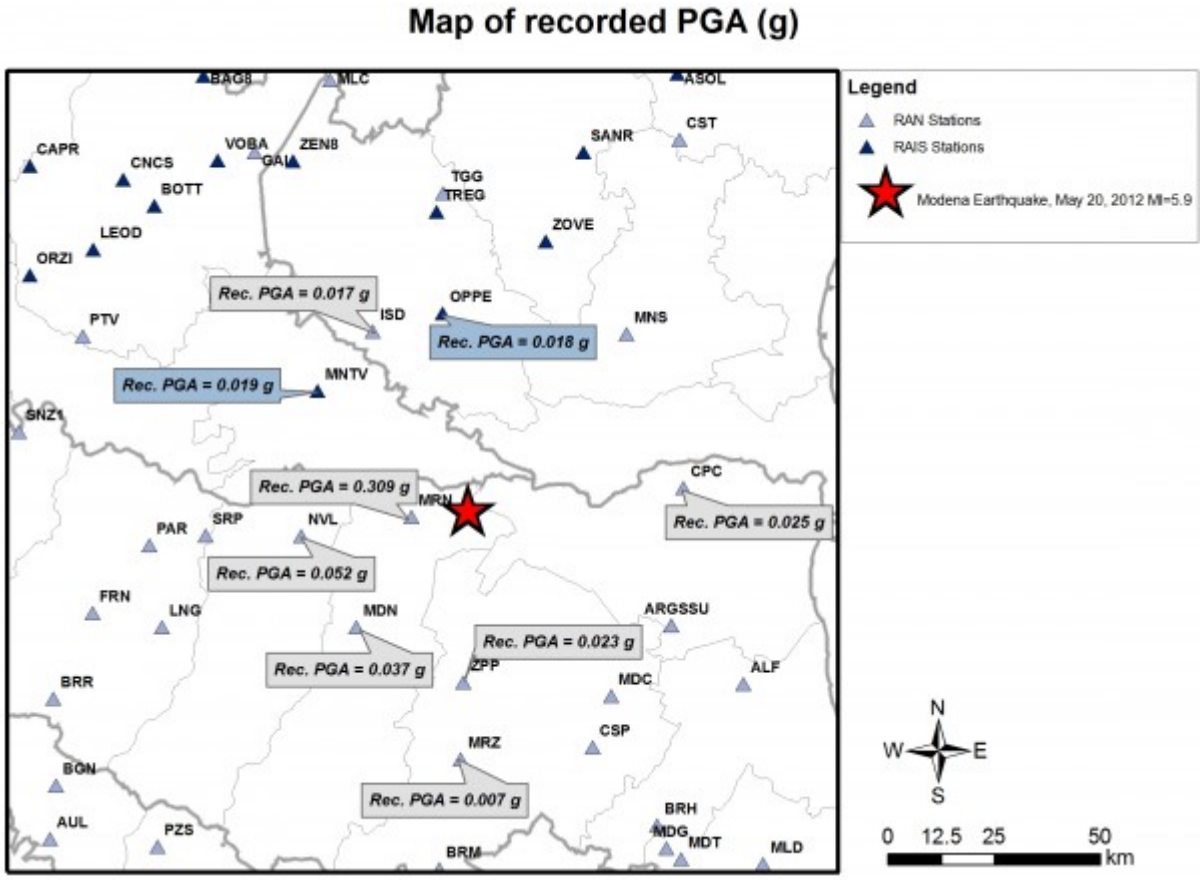


Dr Athanassios Ganas,
Research Director NOA

source: www.emsc-csem.org

Strong Motion Records

M6.0 20.05.2012



M6.0 20.05.2012

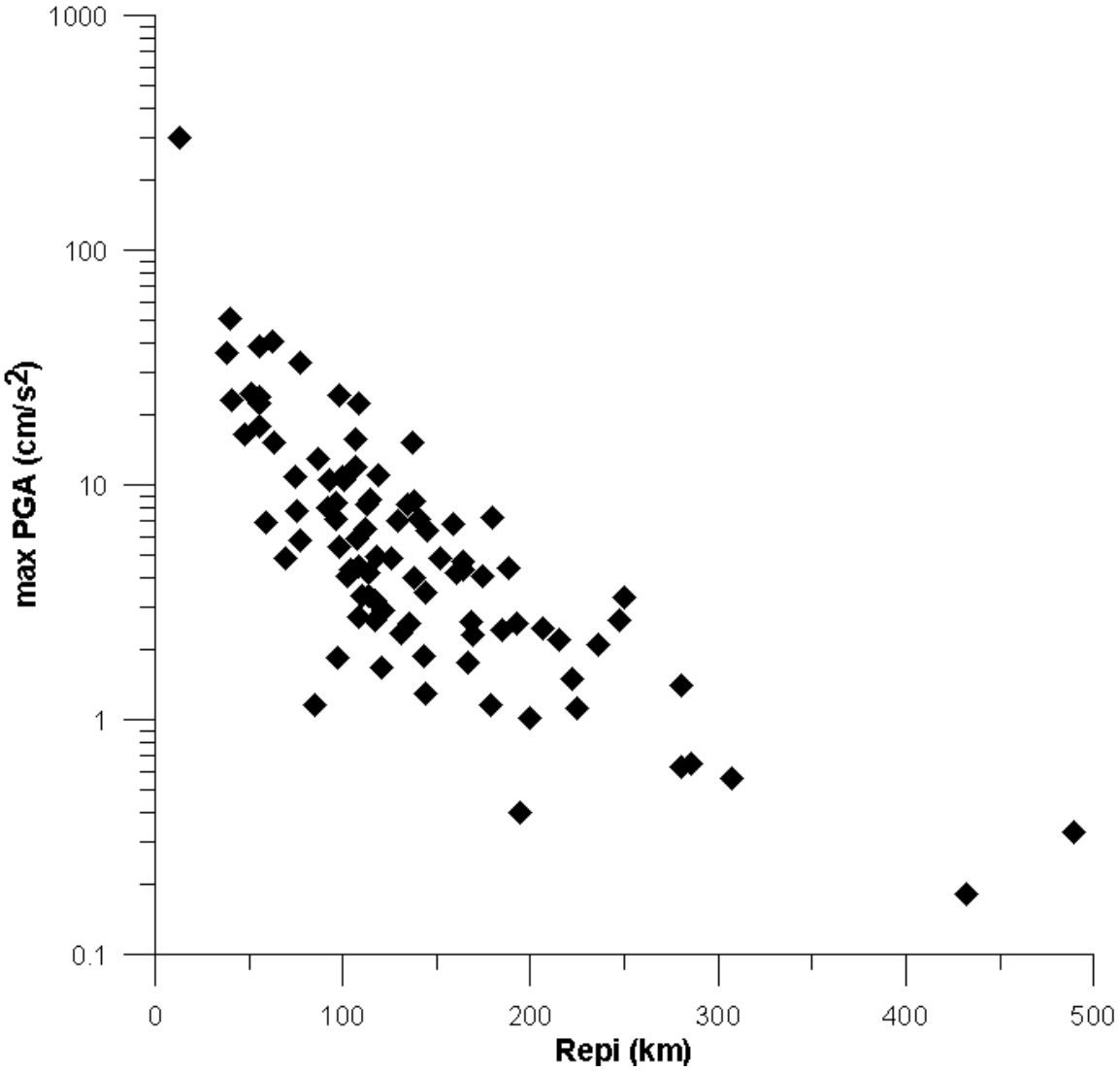
UFFICIO RISCHIO SISMICO E VULCANICO
SERVIZIO MONITORAGGIO SISMICO DEL TERRITORIO

RAN - RETE ACCELEROMETRICA NAZIONALE

Terremoto del 20 Maggio 2012 ore 02:03:52 (UTC) MI= 5.9 - Pianura Padana Emiliana

Codice stazione	Località	Provincia	Regione	Lat. N	Long. E	Dist.epi. (km)	PGA max (cm/sec**)
MRN	Mirandola	Modena	EMILIA R.	44,878	11,062	13,4	303,30
NVL	Novellara	Reggio Emilia	EMILIA R.	44,843	10,732	39,7	51,07
SRP	Sorbolo	Parma	EMILIA R.	44,848	10,447	62,1	40,75
MDC	Medicina	Bologna	EMILIA R.	44,486	11,640	55,4	38,89
MDN	Modena	Modena	EMILIA R.	44,647	10,890	38,3	36,32
ALF	Alfonsine	Ravenna	EMILIA R.	44,502	12,033	76,8	33,06
CPC	Copparo Coccanile	Ferrara	EMILIA R.	44,921	11,876	51,1	24,52
GAI	Gaino	Brescia	LOMBARDIA	45,659	10,616	98,2	24,00
ARG	Argenta	Ravenna	EMILIA R.	44,631	11,825	55,2	23,81
ZPP	Zola Pedrosa Piana	Bologna	EMILIA R.	44,524	11,204	40,7	22,83
MLD	Meldola	Forli - Cesena	EMILIA R.	44,118	12,071	108,8	22,34
SSU	Sassuolo	Ravenna	EMILIA R.	44,631	11,825	55,3	22,24
MNS	Monselice	Padova	VENETO	45,252	11,722	55,8	17,74
ISD	Isola Della Scala	Verona	VENETO	45,273	10,960	47,7	16,33

M6.0 20.05.2012



M6.0 20.05.2012

UFFICIO RISCHIO SISMICO E VULCANICO
SERVIZIO MONITORAGGIO SISMICO DEL TERRITORIO

RAN - RETE ACCELEROMETRICA NAZIONALE

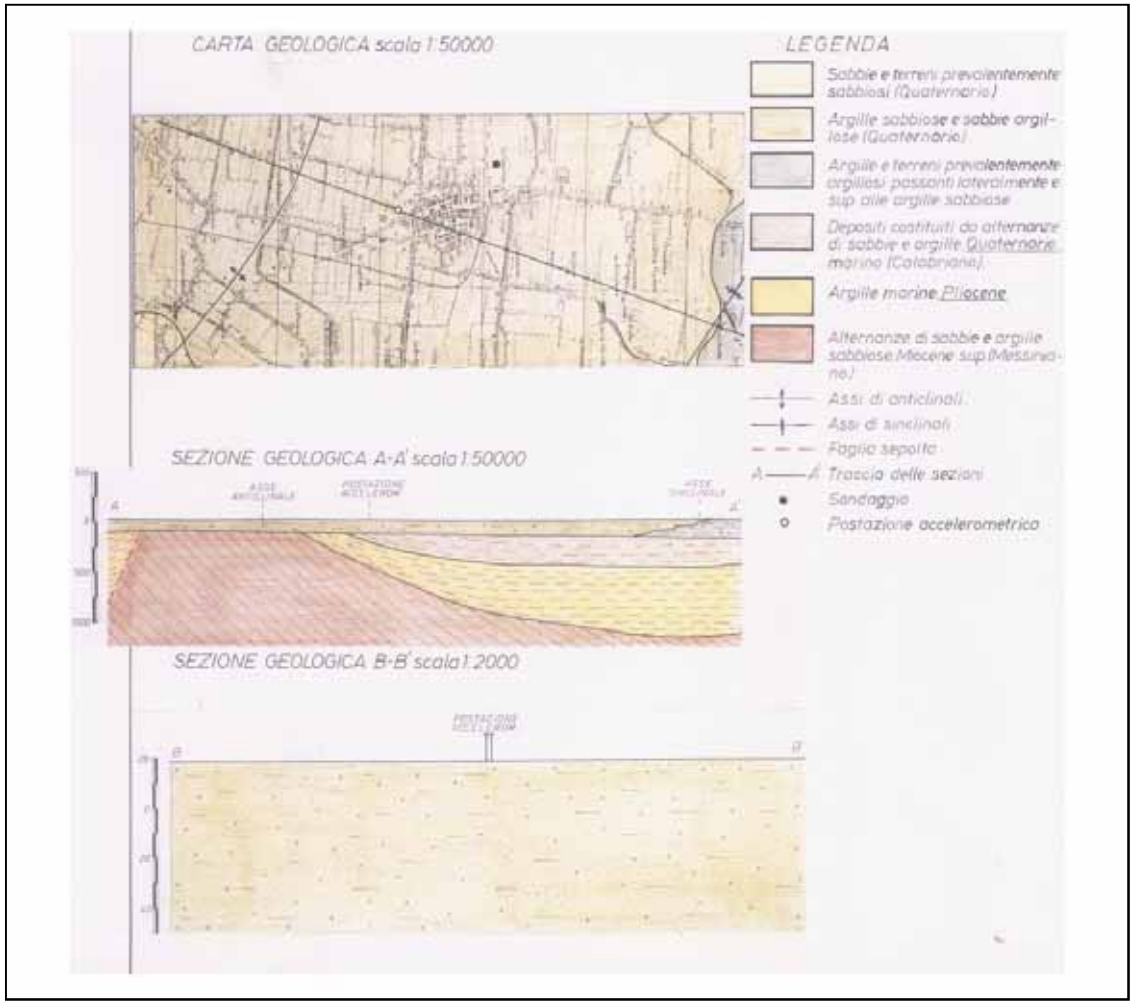
Terremoto del 20 Maggio 2012 ore 02:03:52 (UTC) MI= 5.9 - Pianura Padana Emiliana

Codice stazione	Località			Lat. N	Long. E	PGA max (cm/sec**)	
MRN	Mirandola	Modena		,878	11,062	303,30	
				,843	10,732		
				,848	10,447		
MDC	Medicina	Bologna	EMILIA R.	44,486	11,640	55,4	38,89
MDN	Modena	Modena	EMILIA R.	44,647	10,890	38,3	36,32
ALF	Alfonsine	Ravenna	EMILIA R.	44,502	12,033	76,8	33,06
CPC	Copparo Coccanile	Ferrara	EMILIA R.	44,921	11,876	51,1	24,52
GAI	Gaino	Brescia	LOMBARDIA	45,659	10,616	98,2	24,00
ARG	Argenta	Ravenna	EMILIA R.	44,631	11,825	55,2	23,81
ZPP	Zola Pedrosa Piana	Bologna	EMILIA R.	44,524	11,204	40,7	22,83
MLD	Meldola	Forli - Cesena	EMILIA R.	44,118	12,071	108,8	22,34
SSU	Sassuolo	Ravenna	EMILIA R.	44,631	11,825	55,3	22,24
MNS	Monselice	Padova	VENETO	45,252	11,722	55,8	17,74
ISD	Isola Della Scala	Verona	VENETO	45,273	10,960	47,7	16,33


Mirandola Station
M5.8 29.05
M6.0 20.05.
Verona
Padua
Venice
Ferrara
Modena
Bologna
Ravenna
Chioggia
Rovigo
Legnago
Vicenza
Treviso
Mestre
Mira
Lido di Jesolo
Porto Tolle
Mesola
Comacchio
Lido di Spina
Argenta
Voltana
Lugo
Cento
Mantua
Villafranca di Verona
Negrar
Valdagno
Castelfranco Veneto
Schio
Montebelluna
Oderzo
Villorba
San Donà di Piave
Cavarzere
Adria
Olmo
Formigine
Sassuolo
Emilia
A22
A4
A13
E70
E45
E35
20 mi
50 km

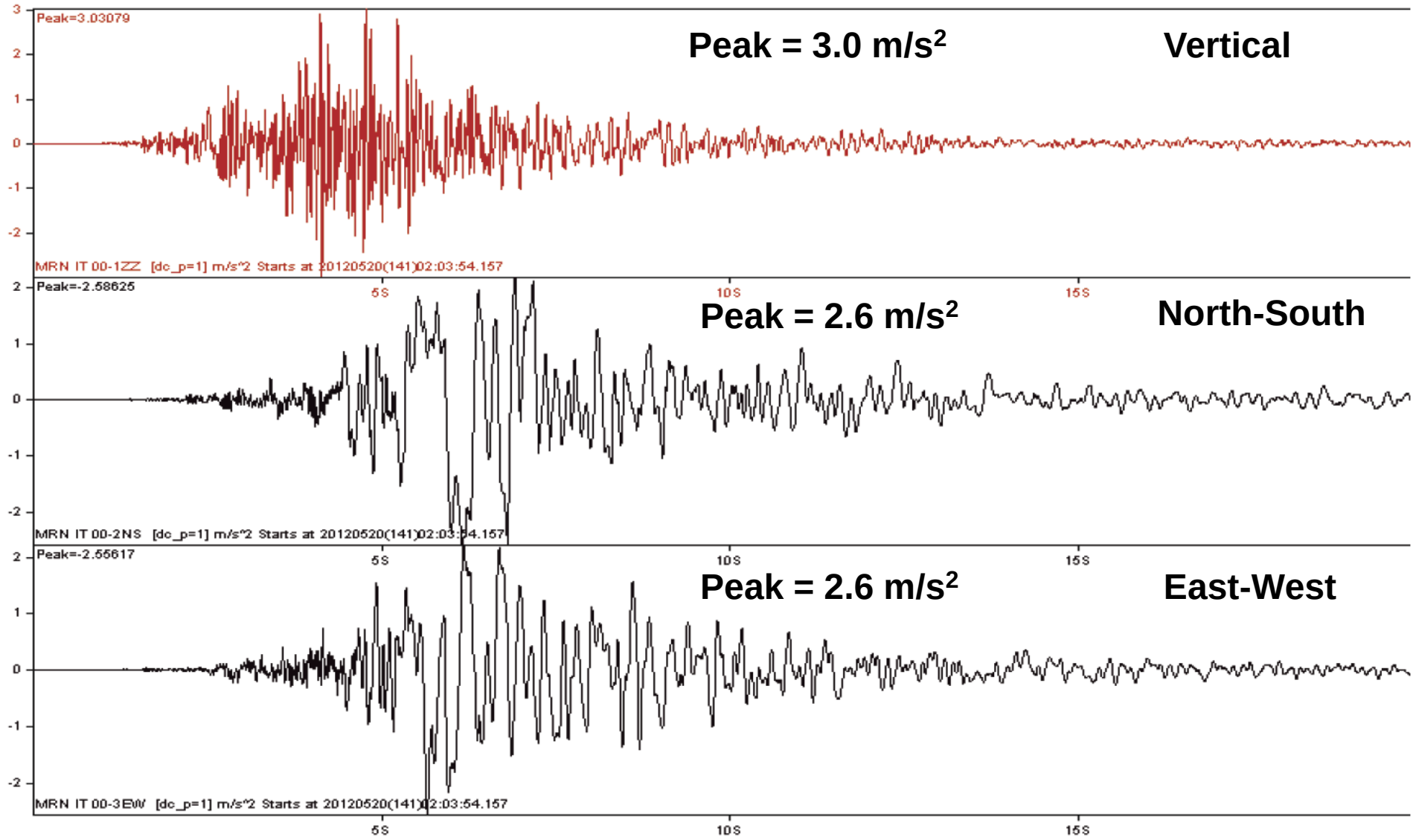
Google Inc.

Mirandola Station M6.0 20.05.2012, Repi=13.4km

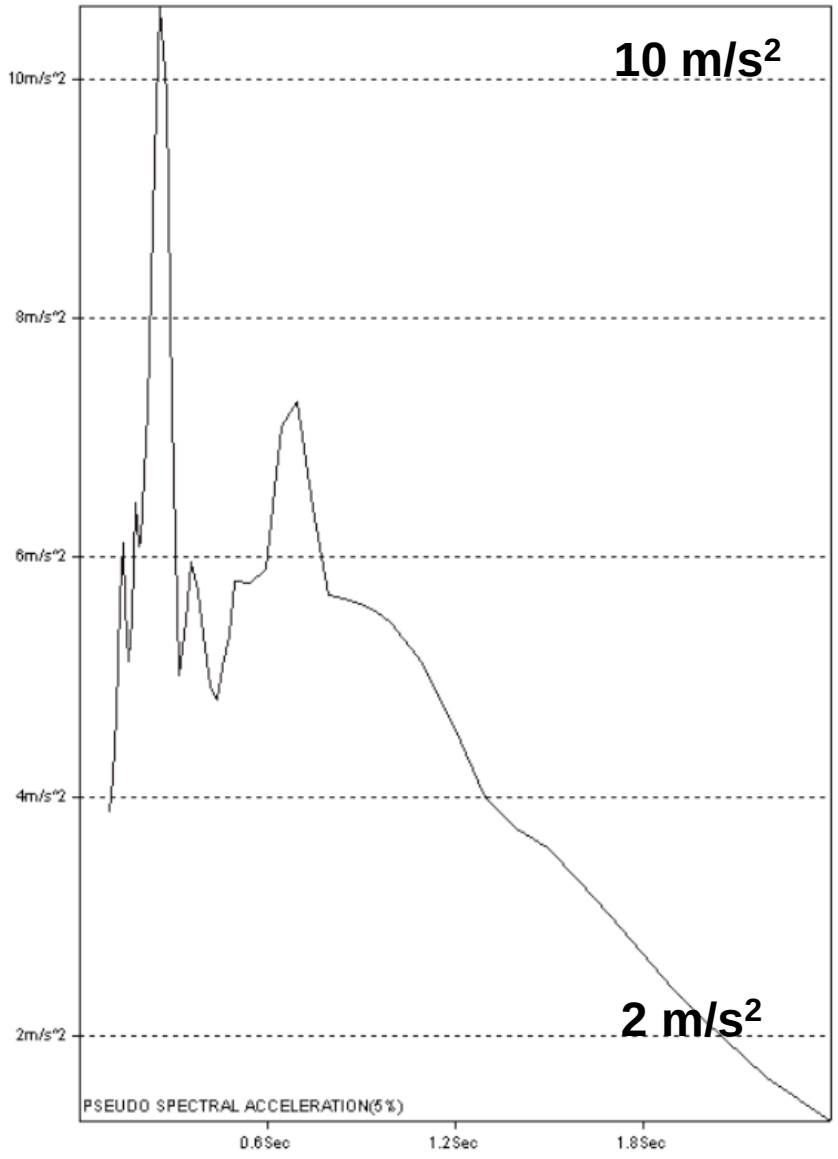


Soil class C
(inferred from geology)

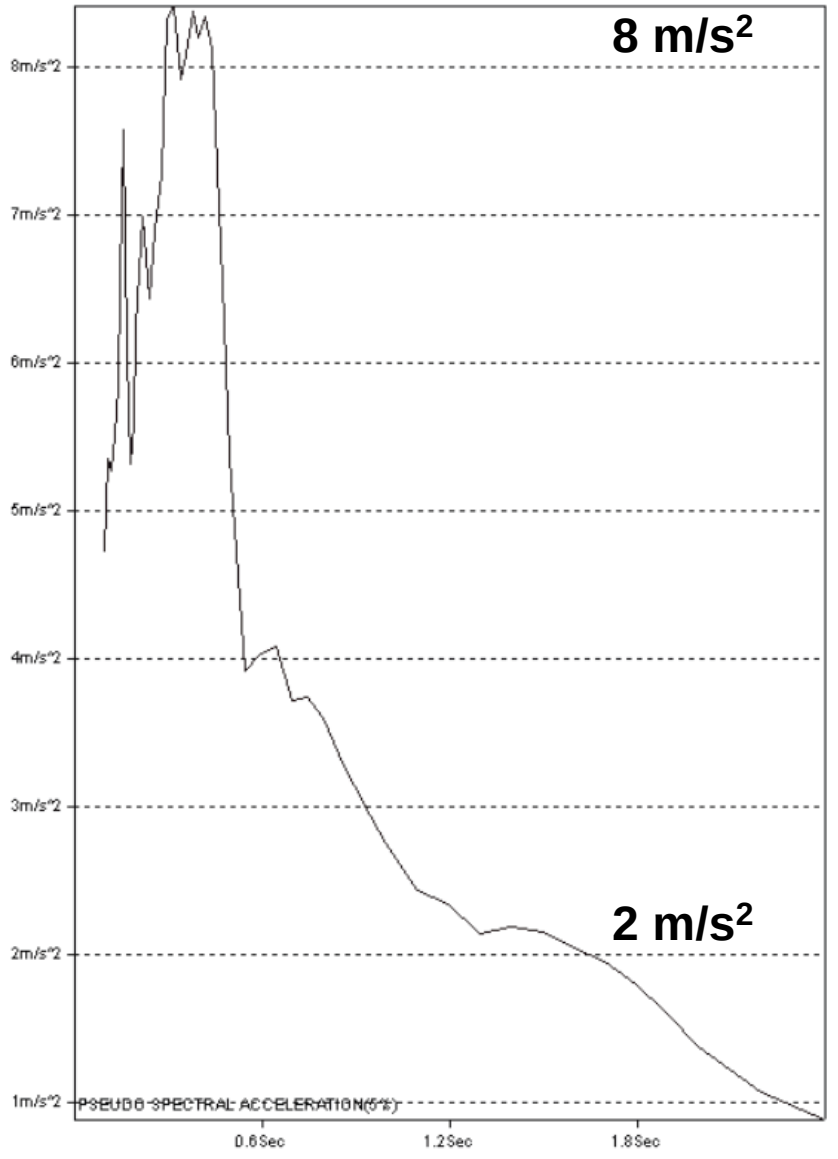
Mirandola Station M6.0 20.05.2012, Repi=13.4km



Mirandola Station M6.0 20.05.2012, Repi=13.4km



0.6 s 1.8 s



0.6 s 1.8 s

M6.0 20.05.2012

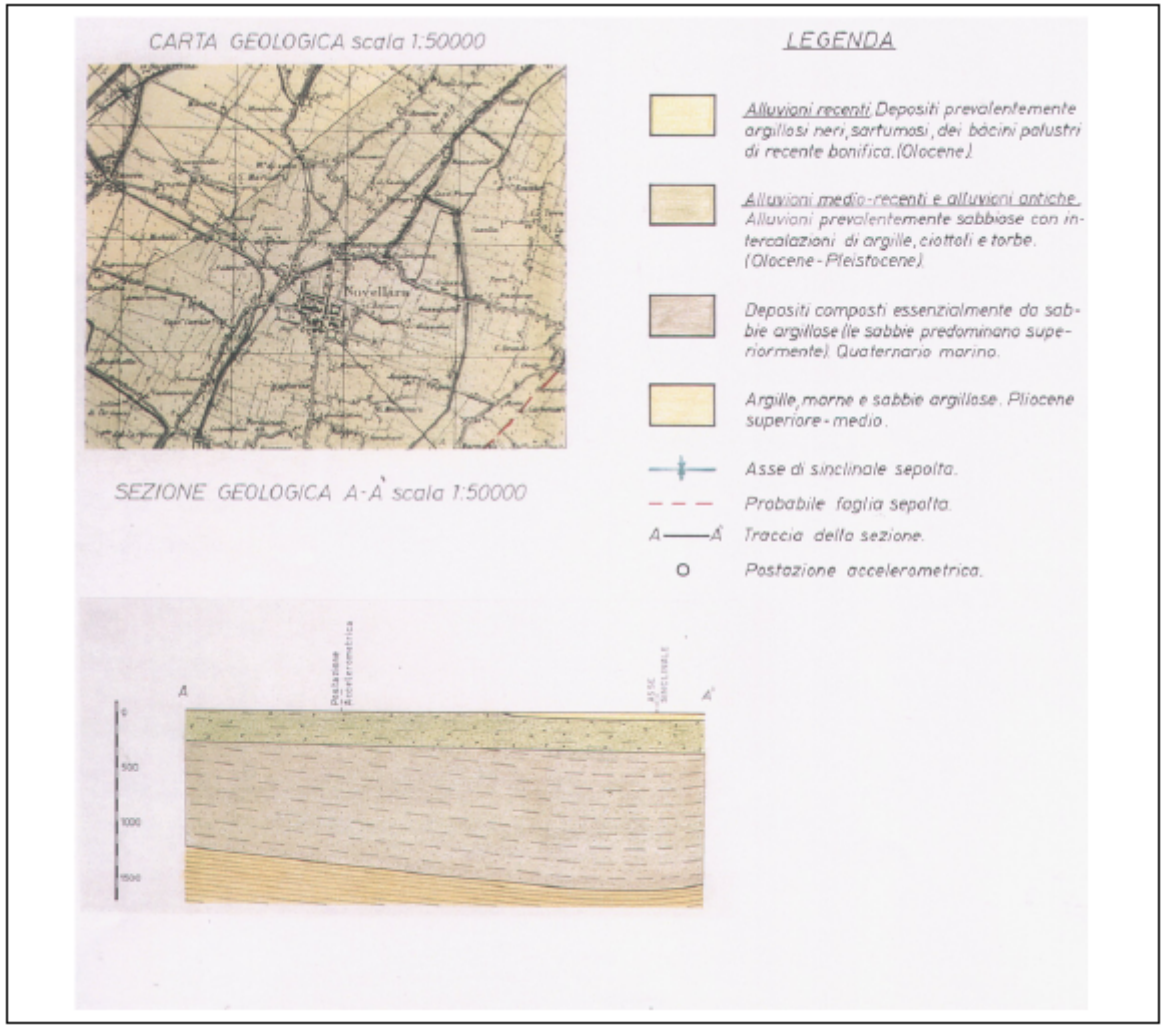
UFFICIO RISCHIO SISMICO E VULCANICO
SERVIZIO MONITORAGGIO SISMICO DEL TERRITORIO

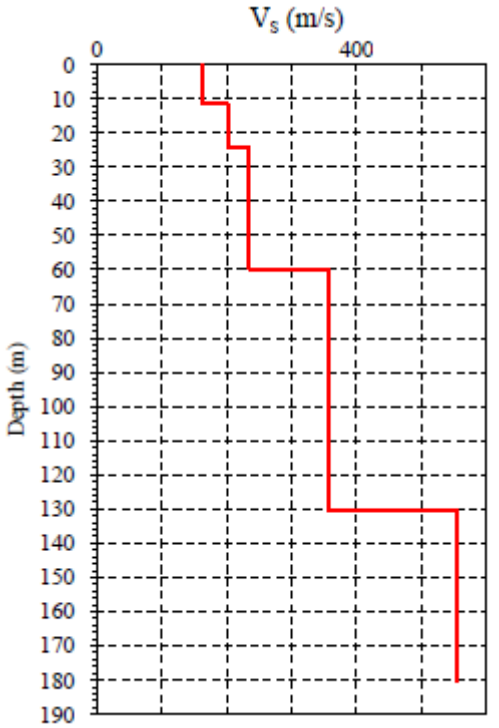
RAN - RETE ACCELEROMETRICA NAZIONALE

Terremoto del 20 Maggio 2012 ore 02:03:52 (UTC) MI= 5.9 - Pianura Padana Emiliana

Codice stazione	Località	Provincia	Regione	Lat. N	Long. E	PGA max (cm/sec**)	
MRN	Mirandola	Modena	EMILIA R.	44,878	11,06		
NVL	Novellara	Reggio Emilia				51,07	
MDN	Modena	Modena	EMILIA R.	44,647	10,890	38,3	36,32
ALF	Alfonsine	Ravenna	EMILIA R.	44,502	12,033	76,8	33,06
CPC	Copparo Coccanile	Ferrara	EMILIA R.	44,921	11,876	51,1	24,52
GAI	Gaino	Brescia	LOMBARDIA	45,659	10,616	98,2	24,00
ARG	Argenta	Ravenna	EMILIA R.	44,631	11,825	55,2	23,81
ZPP	Zola Pedrosa Piana	Bologna	EMILIA R.	44,524	11,204	40,7	22,83
MLD	Meldola	Forli - Cesena	EMILIA R.	44,118	12,071	108,8	22,34
SSU	Sassuolo	Ravenna	EMILIA R.	44,631	11,825	55,3	22,24
MNS	Monselice	Padova	VENETO	45,252	11,722	55,8	17,74
ISD	Isola Della Scala	Verona	VENETO	45,273	10,960	47,7	16,33

Novellara Station M6.0 20.05.2012, Repi=40km

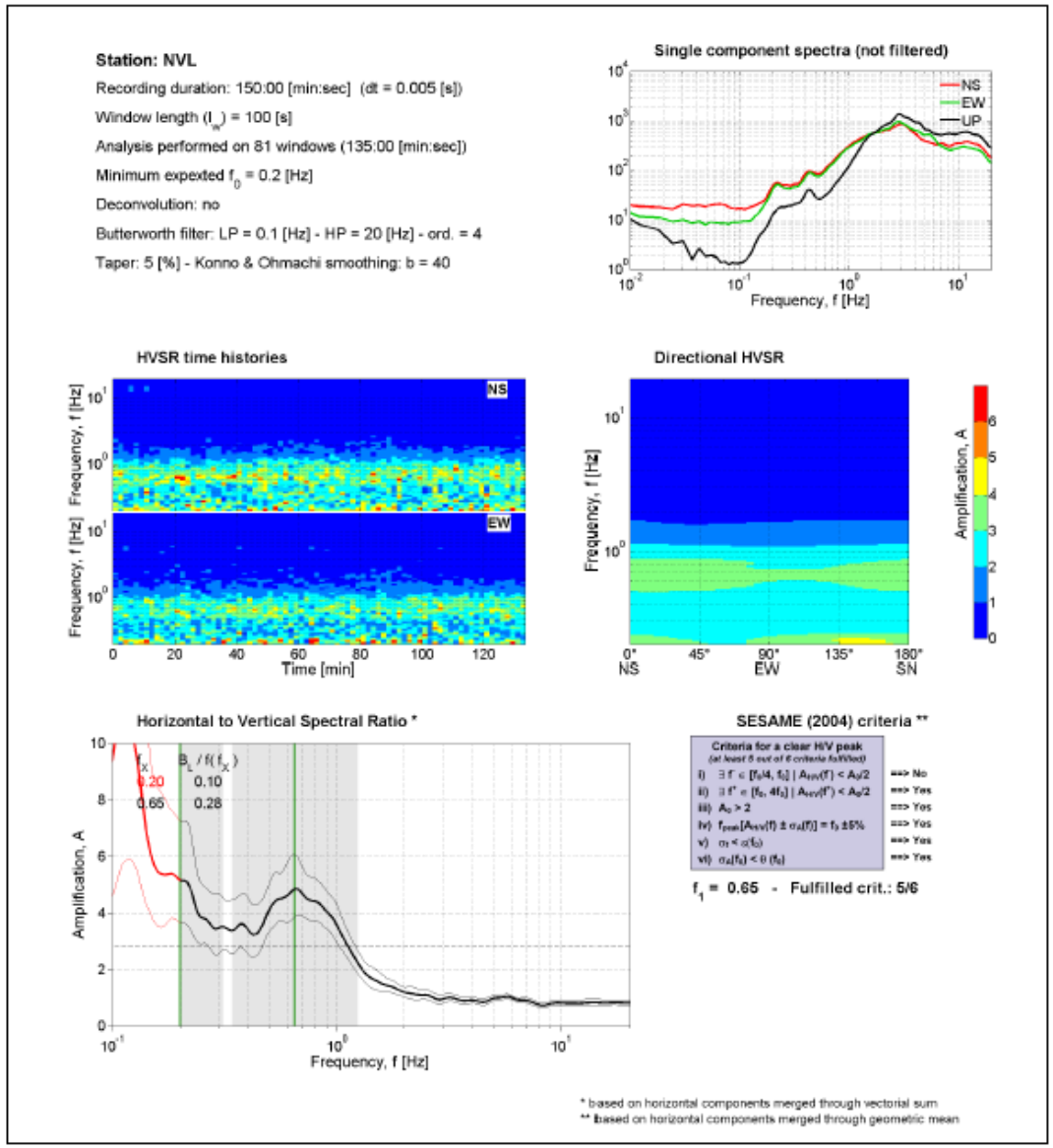




Vs [m/s]	Thickness [m]
164	11,6
202	12,4
234	35,7
358	70,9
555	49,5

Vs,30=190 m/s → soil class C

Novellara Station M6.0 20.05.2012, Repi=40km



f_0=0.65 Hz

http://itaca.mi.ingv.it/ItacaNet/

M6.0 20.05.2012

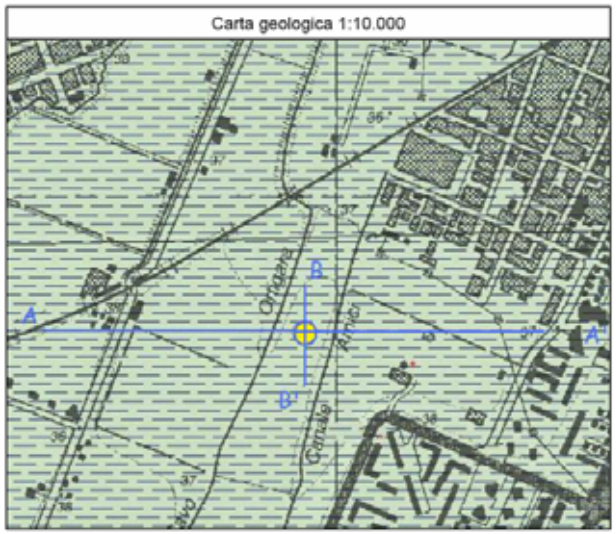
UFFICIO RISCHIO SISMICO E VULCANICO
SERVIZIO MONITORAGGIO SISMICO DEL TERRITORIO

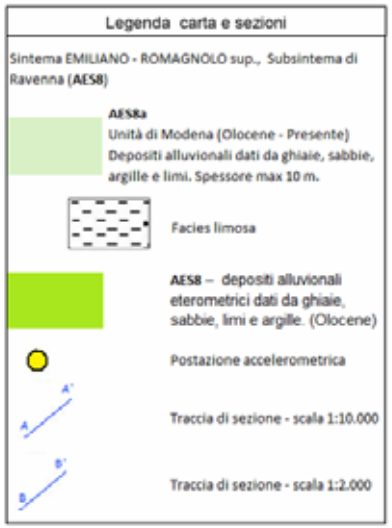
RAN - RETE ACCELEROMETRICA NAZIONALE

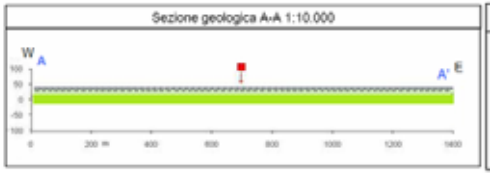
Terremoto del 20 Maggio 2012 ore 02:03:52 (UTC) MI= 5.9 - Pianura Padana Emiliana

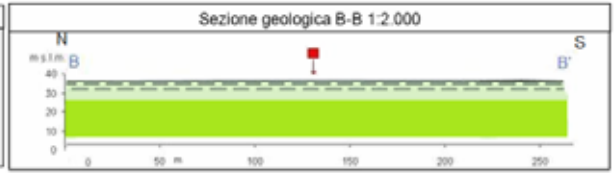
Codice stazione	Località	Provincia	Regione	Lat. N	Long. E	PGA max (cm/sec**)	
MRN	Mirandola	Modena	EMILIA R.	44,878	11,061		
NVL	Novellara	Reggio Emilia	EMILIA R.	44,843	10,732	39,7	31,07
SRP	Sorbolo	Parma	EMILIA R.	44,848	10,447	62,1	40,75
MDN	Modena	Modena					36,32
ALF	Alfonsine	Ravenna	EMILIA R.	44,502	12,033	76,8	33,06
CPC	Copparo Coccanile	Ferrara	EMILIA R.	44,921	11,876	51,1	24,52
GAI	Gaino	Brescia	LOMBARDIA	45,659	10,616	98,2	24,00
ARG	Argenta	Ravenna	EMILIA R.	44,631	11,825	55,2	23,81
ZPP	Zola Pedrosa Piana	Bologna	EMILIA R.	44,524	11,204	40,7	22,83
MLD	Meldola	Forli - Cesena	EMILIA R.	44,118	12,071	108,8	22,34
SSU	Sassuolo	Ravenna	EMILIA R.	44,631	11,825	55,3	22,24
MNS	Monselice	Padova	VENETO	45,252	11,722	55,8	17,74
ISD	Isola Della Scala	Verona	VENETO	45,273	10,960	47,7	16,33

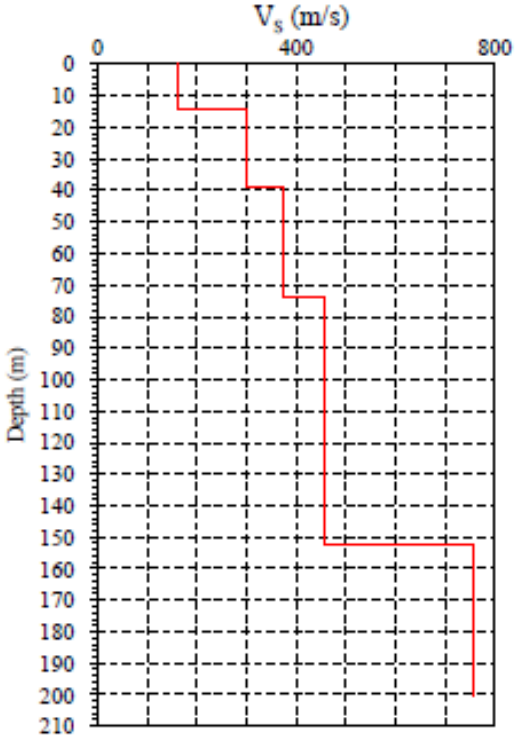
Modena Station M6.0 20.05.2012, Repi=38km







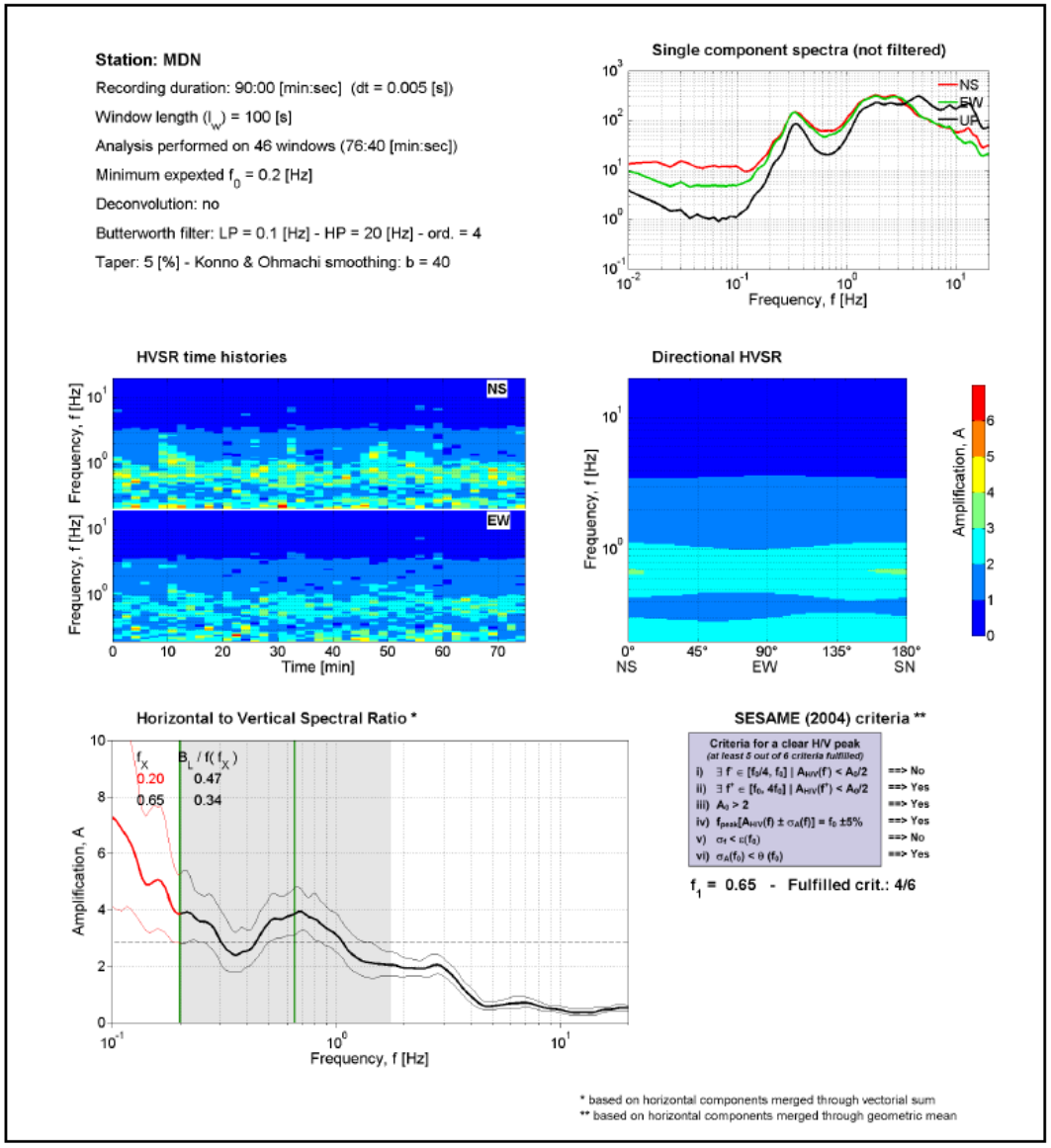




Vs [m/s]	Thickness [m]
161	14,3
300	24,6
375	35,1
456	78,6
759	47,5

Vs,30=213 m/s → soil class C

Modena Station M6.0 20.05.2012, Repi=38km



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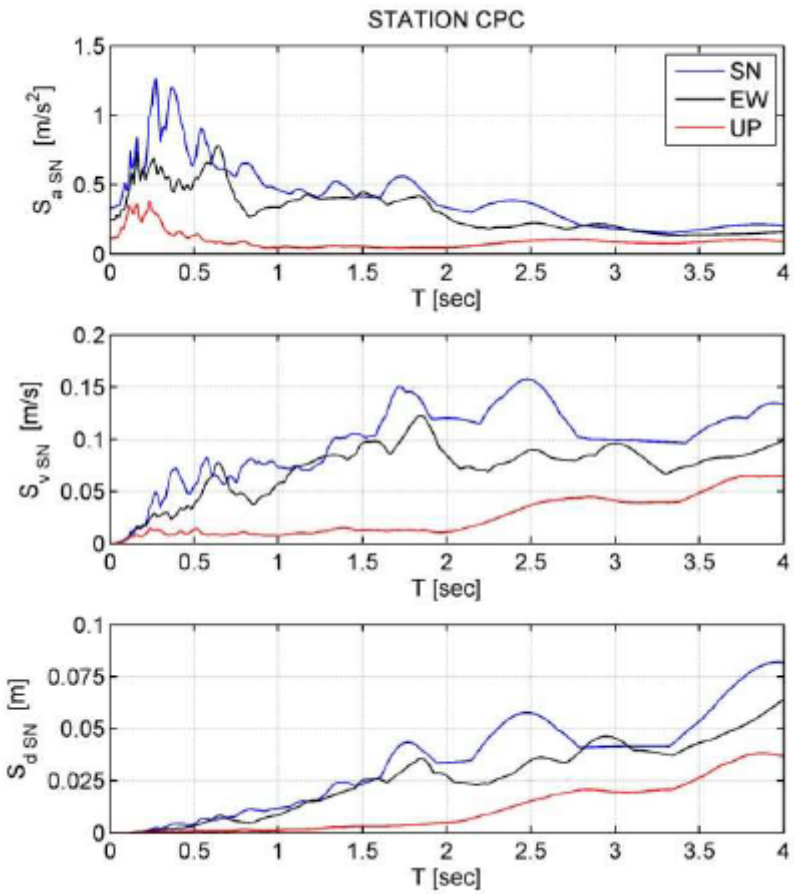
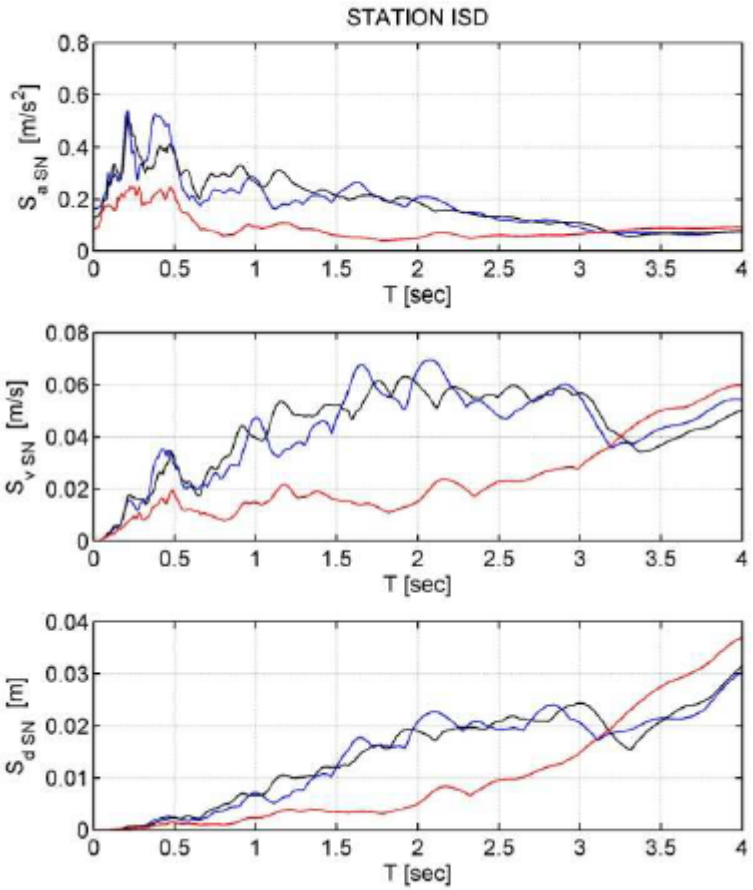
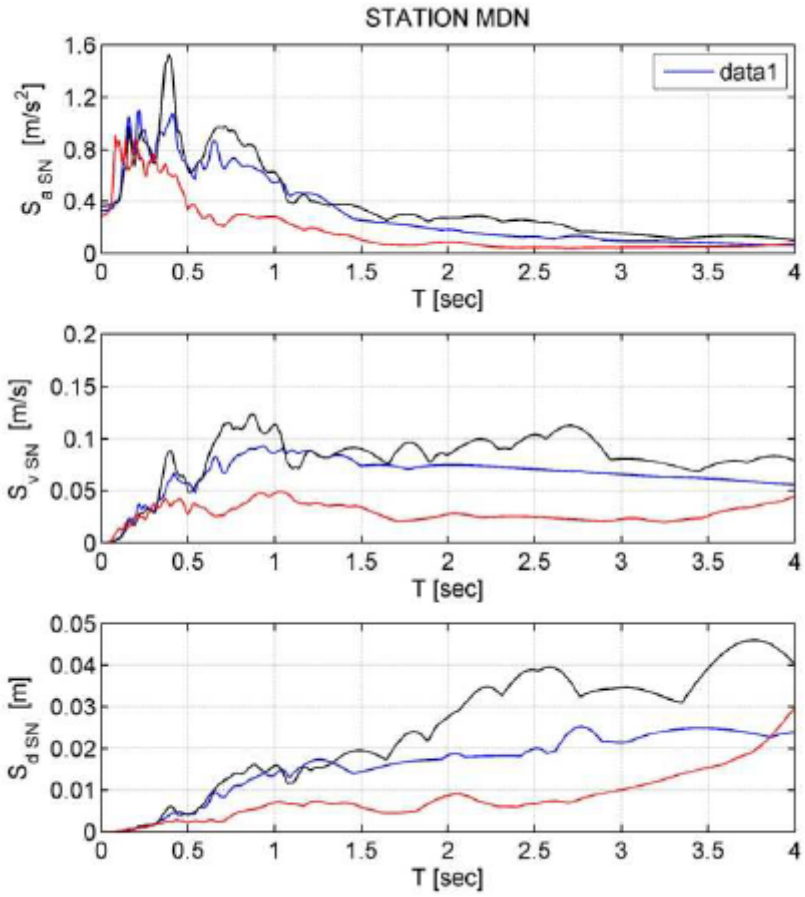
http://itaca.mi.ingv.it/ItacaNet/

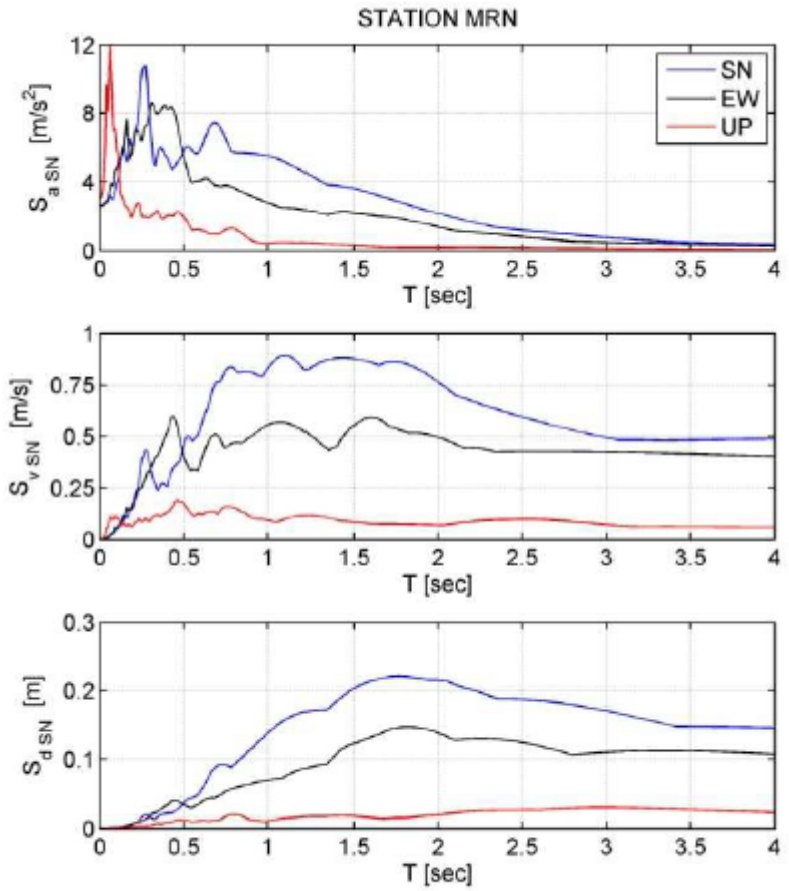
M6.0 20.05.2012 Response spectra



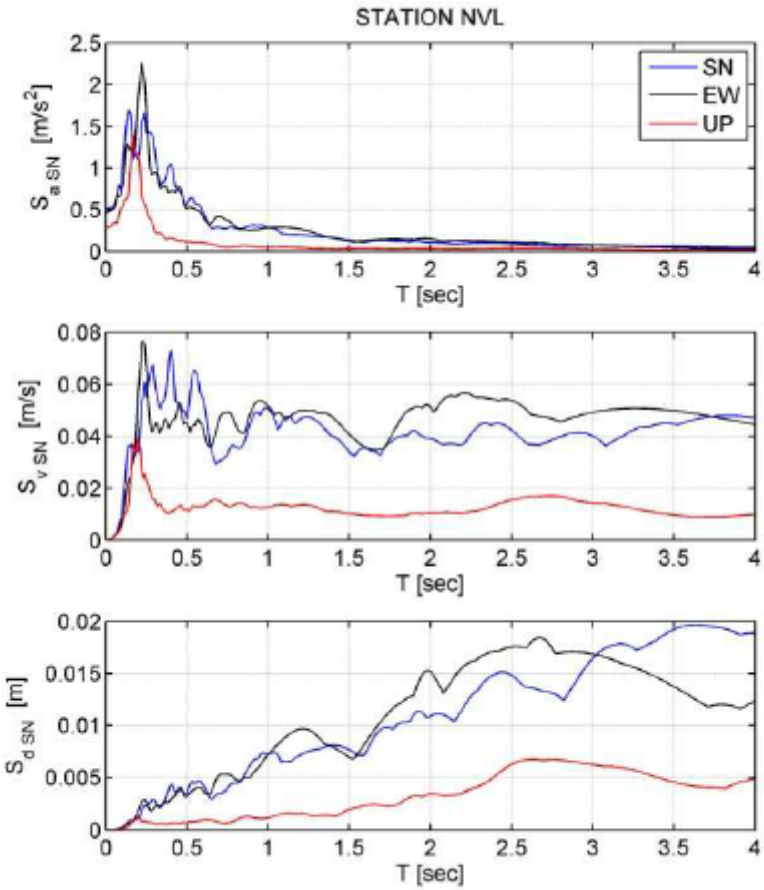


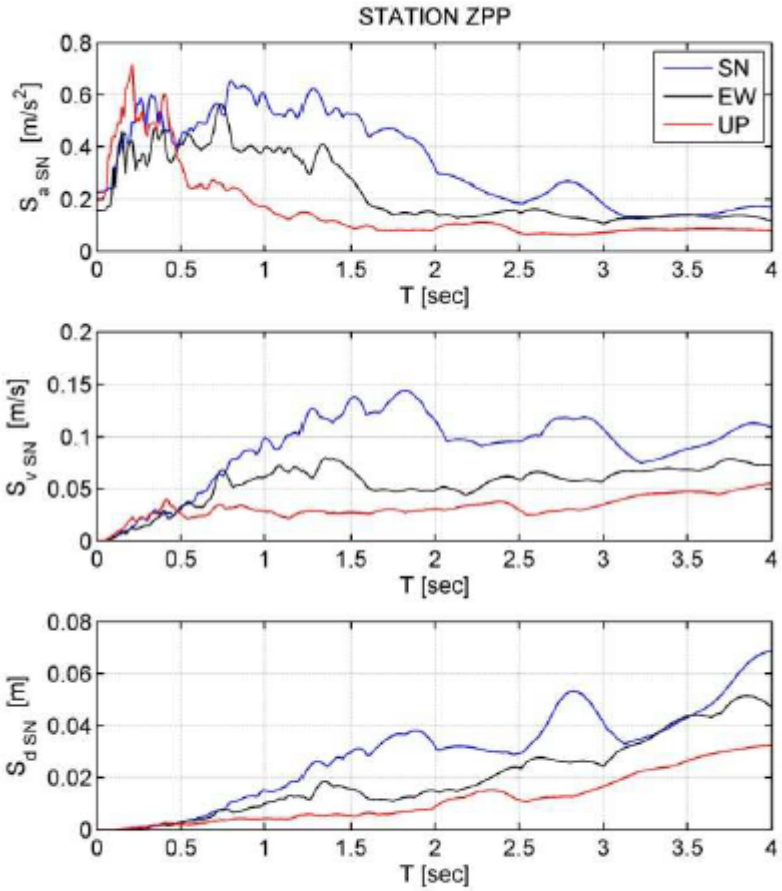
M6.0 20.05.2012 Response spectra





M6.0 20.05.2012 Response spectra





M5.8 29.05.2012

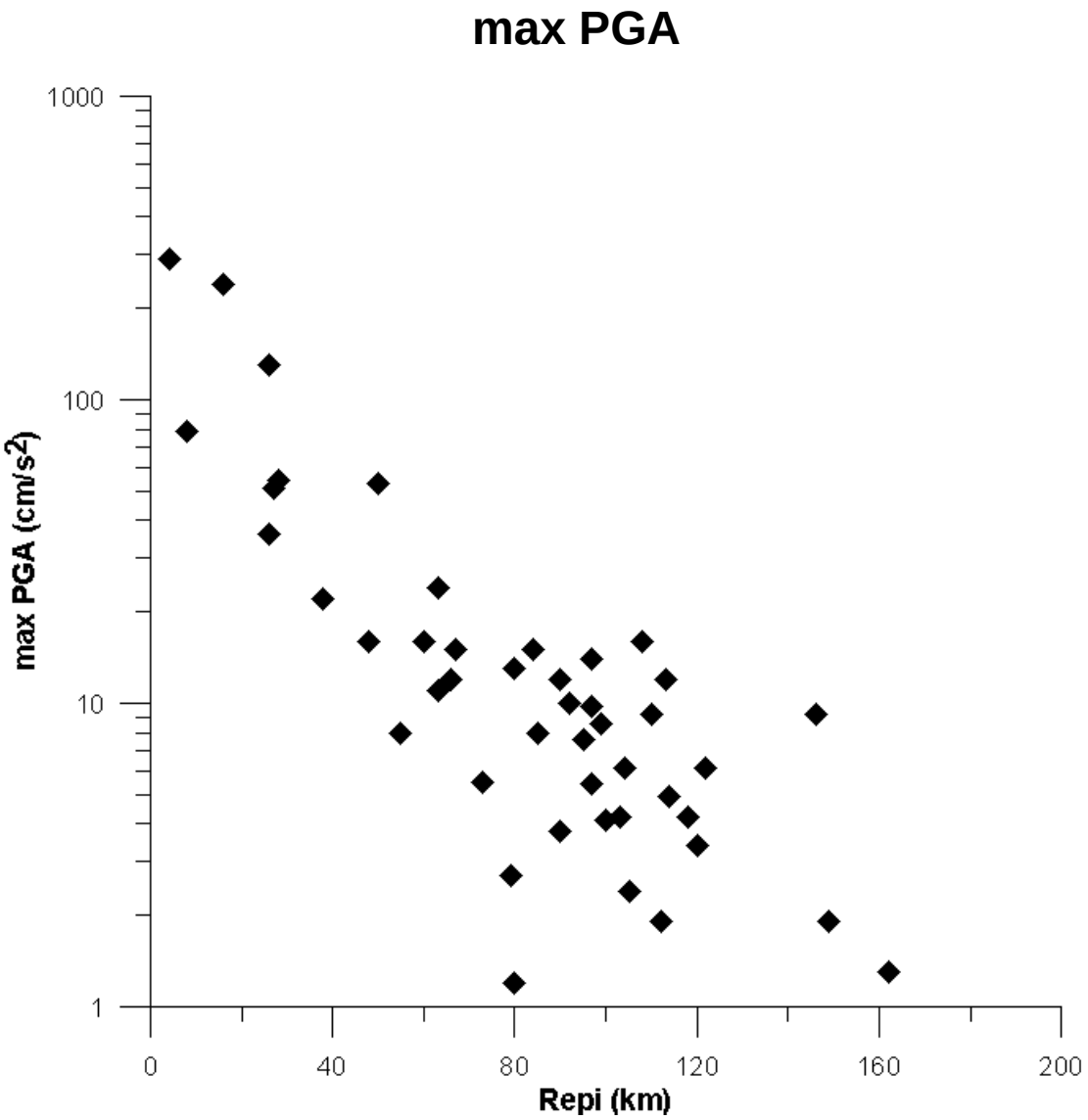
UFFICIO RISCHIO SISMICO E VULCANICO
SERVIZIO MONITORAGGIO SISMICO DEL TERRITORIO

RAN - RETE ACCELEROMETRICA NAZIONALE

Terremoto del 29 Maggio 2012 ore 07:00:03 (UTC) MI= 5.8 - Pianura Padana

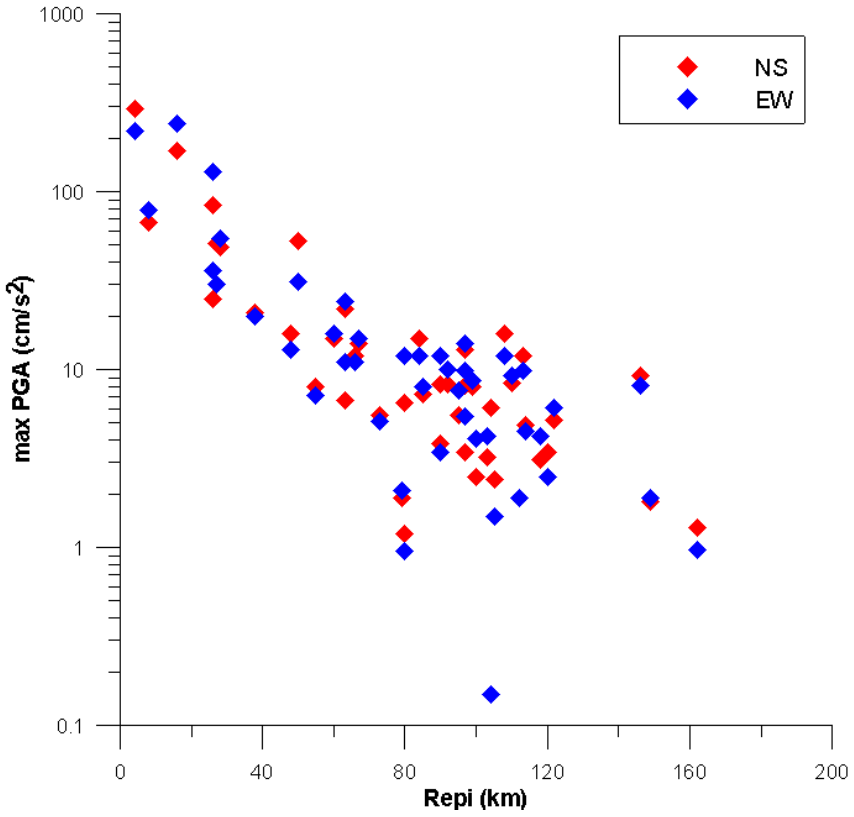
sta	chan	Lat.	Long.	dist (INGV)	Td	PGA	PGV	PGD	PSA03	PSA10	PSA30	Location
				km	s	cm/s*s	cm/s	cm	cm/s*s	cm/s*s	cm/s*s	
MRN	HGE	44.878231	11.061743	4	53	220	29	8.7	500	170	81	Mirandola
MRN	HGN	44.878231	11.061743	4	53	290	57	17	700	370	150	Mirandola
MRN	HGZ***	44.878231	11.061743	4	***	***	***	***	***	***	***	Mirandola
SAG0	HGE	44.791100	11.142700	8	47	79	7.7	1.9	290	51	17	Sant Agostino
SAG0	HGN	44.791100	11.142700	8	42	67	6.2	2.1	180	63	17	Sant Agostino
SAG0	HGZ	44.791100	11.142700	8	45	67	2.2	0.87	76	17	14	Sant Agostino
MOG0	HGE	44.931800	10.911500	16	21	240	29	44	550	230	16	Moglia
MOG0	HGN	44.931800	10.911500	16	25	170	22	24	440	210	31	Moglia
MOG0	HGZ	44.931800	10.911500	16	22	130	5.2	1.9	250	31	19	Moglia
CAS0	HGE	45.025200	11.311400	26	44	130	15	4.4	340	89	35	Castelmassa
CAS0	HGN	45.025200	11.311400	26	64	84	14	8.2	220	130	54	Castelmassa
CAS0	HGZ	45.025200	11.311400	26	64	61	2.6	1.1	110	21	18	Castelmassa

M5.8 29.05.2012

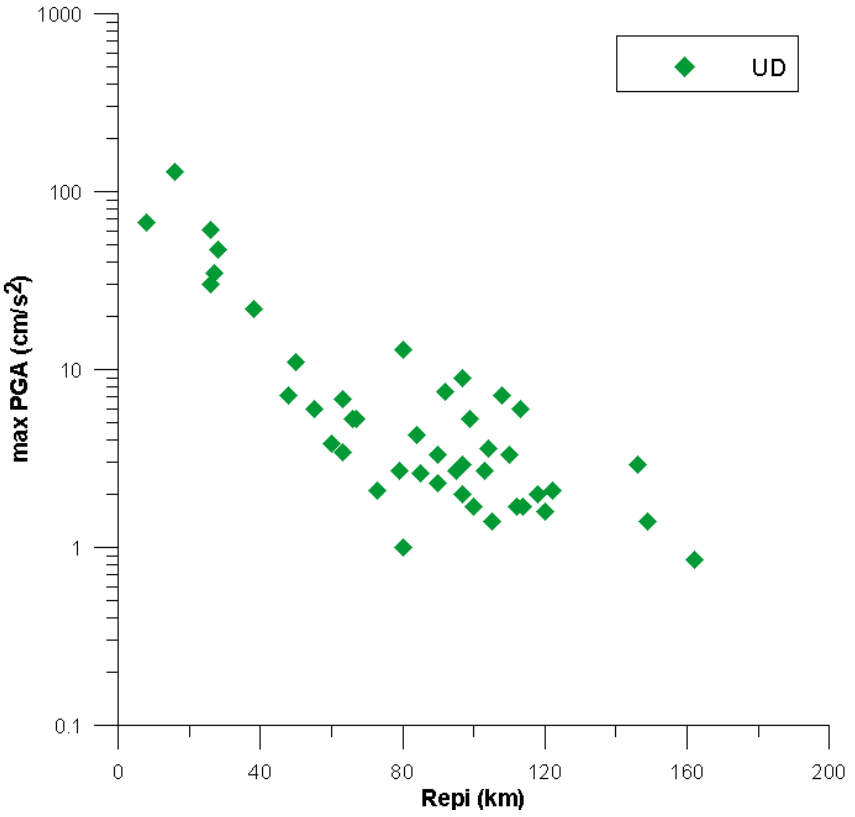


M5.8 29.05.2012

Horizontal components



Vertical component



M5.8 29.05.2012

UFFICIO RISCHIO SISMICO E VULCANICO
SERVIZIO MONITORAGGIO SISMICO DEL TERRITORIO

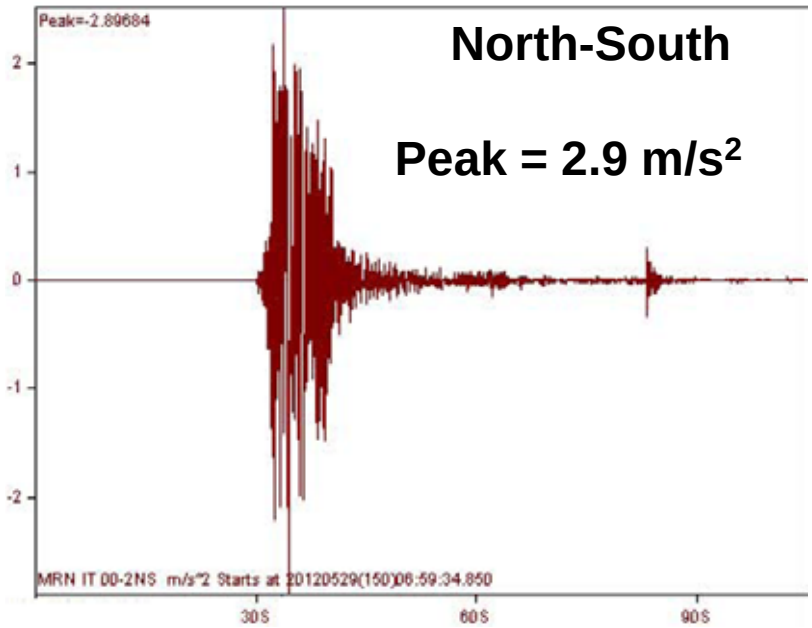
RAN - RETE ACCELEROMETRICA NAZIONALE

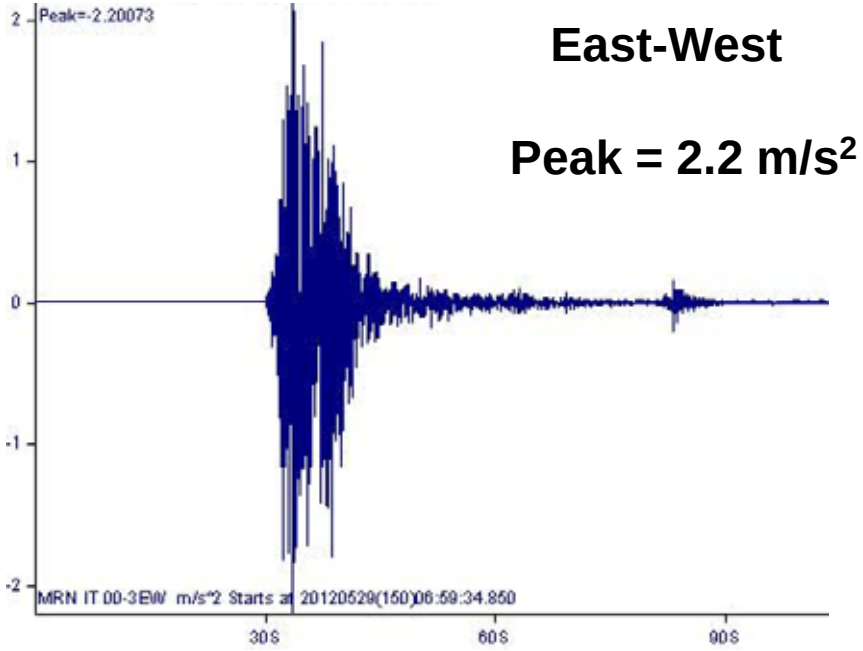
PROTEZIONE CIVILE NAZIONALE

Terremoto del 29 Maggio 2012 ore 07:00:03 (UTC) MI= 5.8 - Pianura Padana

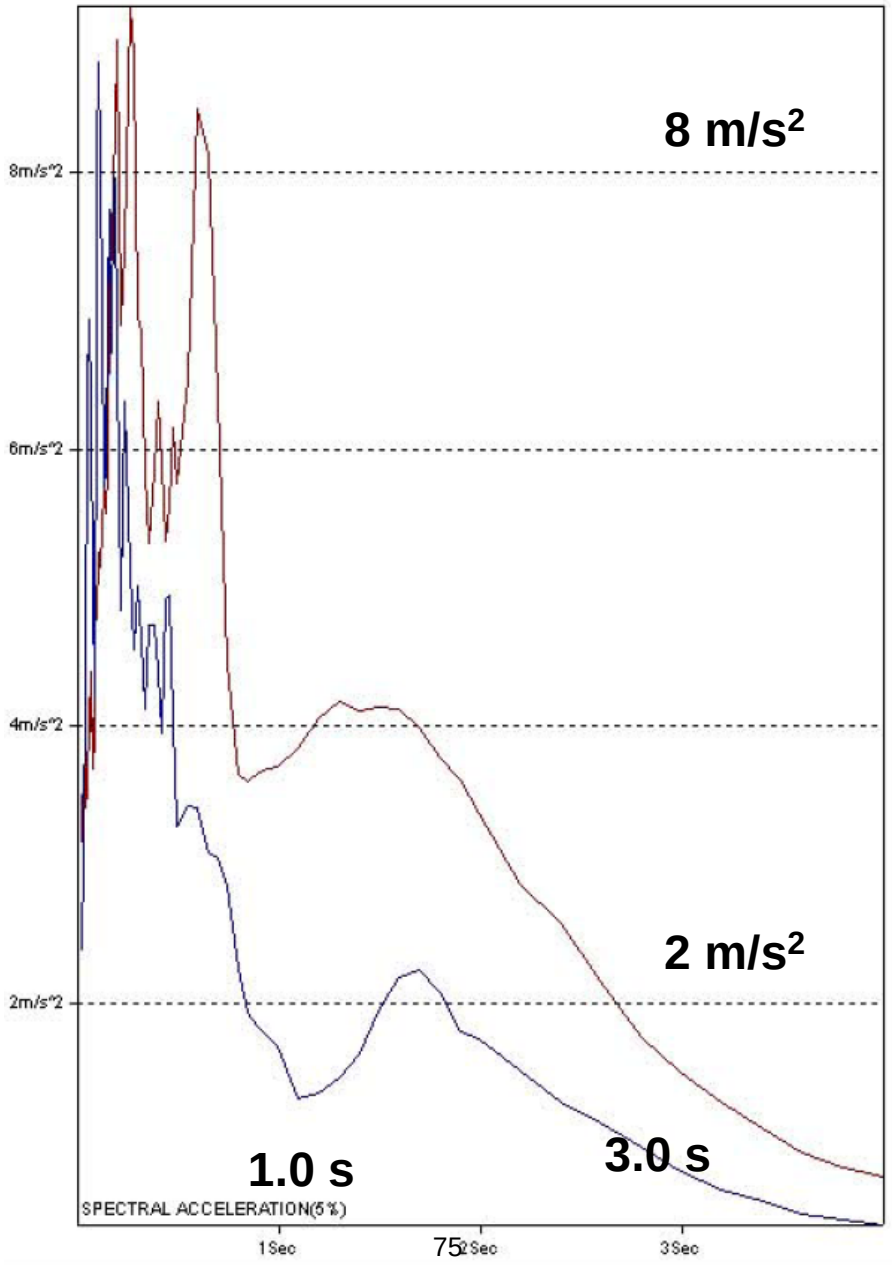
sta	chan	Lat.	Long.	dist (INGV)	Td	PGA		PGD	PSA03	Location		
				km	s	cm/s*s		cm	cm/s*s			
MRN	HGE	44.878231	11.061743	4	53			8.7	500			
MRN	HGN	44.878231	11.061743	4	53			17	700			
MRN	HGZ***	44.878231	11.061743	4	***			***	***	Mirandola		
SAG0	HGE	44.791100	11.142700	8	47	220		1.9	290			
SAG0	HGN	44.791100	11.142700	8	42	290		2.1	180	Mirandola		
SAG0	HGZ	44.791100	11.142700	8	45			0.87	76			
MOG0	HGE	44.931800	10.911500	16	21	***		44	550	Mirandola		
MOG0	HGN	44.931800	10.911500	16	25			24	440	210	31	Moglia
MOG0	HGZ	44.931800	10.911500	16	22	130	5.2	1.9	250	31	19	Moglia
CAS0	HGE	45.025200	11.311400	26	44	130	15	4.4	340	89	35	Castelmassa
CAS0	HGN	45.025200	11.311400	26	64	84	14	8.2	220	130	54	Castelmassa
CAS0	HGZ	45.025200	11.311400	26	64	61	2.6	1.1	110	21	18	Castelmassa

Mirandola Station M6.0 20.05.2012





Mirandola Station M5.8 29.05.2012



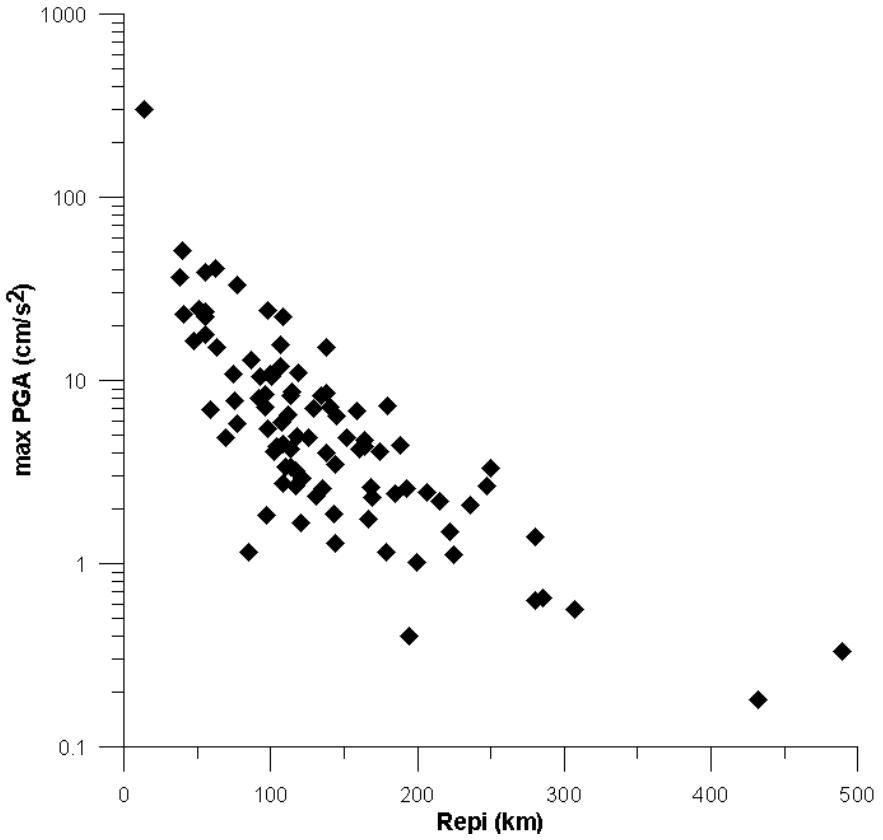
0.6 s

AUTH

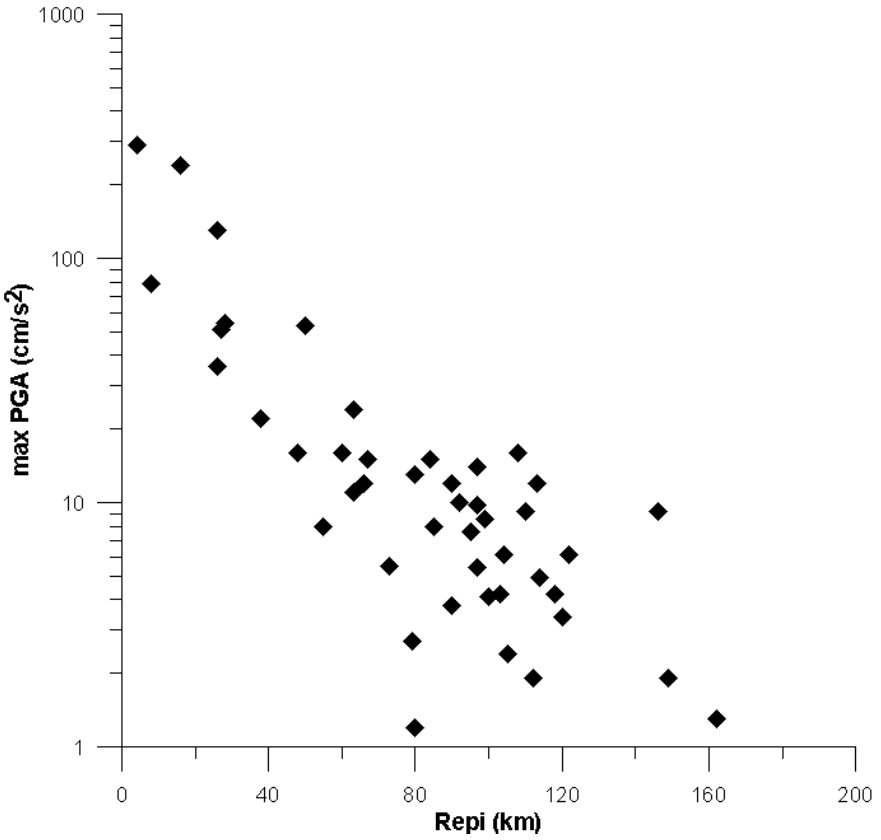
SDGEE

Comparison of the two events in terms of recorded PGA

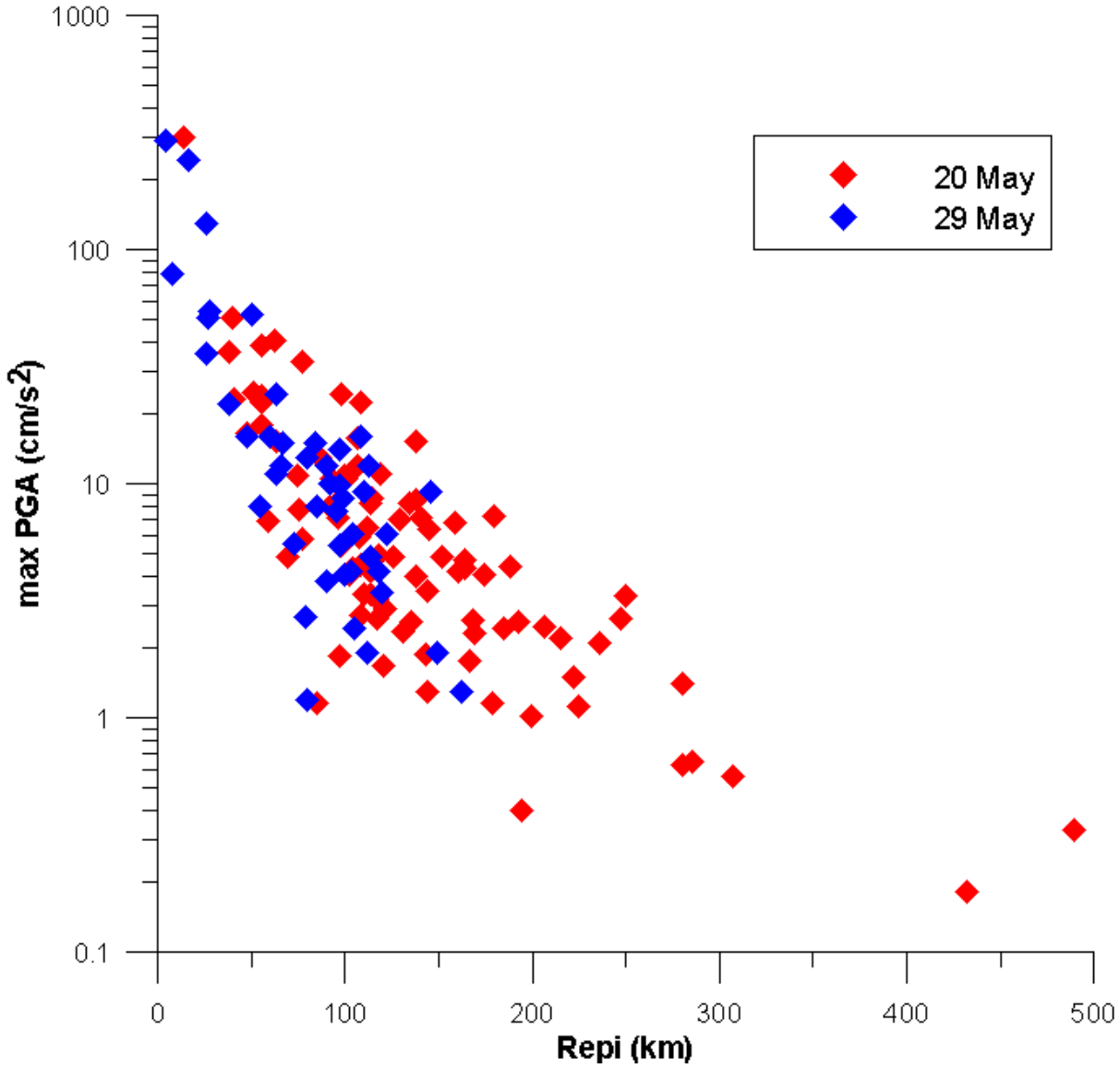
M6 20.05.2012 - max PGA



M5.8 29.05.2012 - max PGA



Comparison of the two events in terms of recorded PGA



Salient aspects of the impact to the built and natural environment

Preliminary comments

by Professor Ezio Faccioli

(personal communication)

Collapse of, or heavy damage to, industrial buildings, mostly prefabricated shed structures, in a number of cases lacking displacement capacity between the top of the columns and the beam ends resting on them. Because of these collapses, the majority of the fatalities were industrial workers. The epicentral area especially for the second event, coincides with densely industrialized district, with vocation for precision mechanics and biomedical apparel: hundreds of firms, small and large were directly affected. As to the role of seismic codes, only for structures built after 2003 was the design for earthquake resistance compulsory, with 10% in 50years probability PGA of 0.12-0.15g. In the first event the largest PGA of 0.3g was recorded at some 13km epicentral distance (station MRN). In the second event the same MRN station recorded much closer to the source with roughly the same PGA.

Damages to monumental structures of historical and architectural value, especially castles of the Middle Age. It will take time to assess properly the real extent of this damage and losses

Extensive impact of liquefaction and lateral spreading affecting, in many cases, surficial layers of silty sands. These effects were especially pervasive in some places, like the hamlet of San Carlo, close to the commune of San Agostino (Modena province). Never was liquefaction observed so extensively in Italian earthquakes since many decades.

The picture of the faults whose rupture generated the earthquakes, beyond the fact that they were pure E-W oriented thrusts compatible with regional tectonics, is complicated: all faults occur under 3 to 7 km of sedimentary layers and come in complex fault systems which the INGV fault database classifies as “composite sources”, assumed to be capable of Mmax=5.9. A similar sequence of earthquakes was observed (and well documented) for the last time in this region (Ferrara) in 1571 AD.

Ezio Faccioli 30.5.2012

Structural damage

Important damages are reported in the cities of Finale Emilia, Ferrara and Modena, where significant cultural heritage and industrial buildings have been affected

Building collapse

source: http://www.repubblica.it/cronaca/2012/05/20/foto/terremoto_in_emilia_le_foto_su_twitter-35523594/1/?ref=NRCT-35524731-2

Complete collapse of a building

San Carlo

source: www.flickr.com/photos/ingv/page4/

Collapse of industrial building

source: http://www.repubblica.it/cronaca/2012/05/20/foto/terremoto_in_emilia_le_foto_su_twitter-35523594/1/?ref=NRCT-35524731-2

Building collapse

source: www.repubblica.it/cronaca/2012/05/20/foto/terremoto_cosa_rimane_di_san_felice-35555032/1/?ref=FRAG-15

Building collapse

source: www.repubblica.it/cronaca/2012/05/20/foto/terremoto_cosa_rimane_di_san_felice-35555032/1/?ref=FRAG-15

Damage to RC buildings

San Felice sul Panaro

source: www.flickr.com/photos/ingv/page3/

Damage to RC buildings

source: emsc-csem.org

Collapse of non-structural elements

source: www.repubblica.it/cronaca/2012/05/20/foto/terremoto_a_nord_di_bologna-35518751/1/

source: www.repubblica.it/cronaca/2012/05/22/foto/terremoto_l_ecatombe_delle_rondini-35698499/1/?ref=FRAG-12

source: emsc-csem.org

Collapse of non-structural elements

source: emsc-csem.org

Collapse of non-structural elements

source: emsc-csem.org

Collapse of non-structural elements

source: emsc-csem.org

Overturning of simple elements

source: emsc-csem.org

Damage to non-structural elements

source: emsc-csem.org

Damage to non-structural elements

source: emsc-csem.org

By the **CNN Wire Staff**

May 30, 2012 -- Updated 2316 GMT (0716 HKT)

A car is crushed by falling rubble from a building in Carvezzo, Italy following the 5.8-magnitude earthquake on May 29, 2012.

HIDE CAPTION

Deadly earthquake hits Italy

<< < 1 2 3 4 5 6 7 8 9 10 11 12 > >>

By the **CNN Wire Staff**

May 30, 2012 -- Updated 2316 GMT (0716 HKT)

A building's roof collapsed after the earthquake in Cavezzo, Italy, where eyewitnesses say about 70% of the town was destroyed.

HIDE CAPTION

Deadly earthquake hits Italy

<< < 1 2 3 4 5 6 7 8 9 10 11 12 > >>

By the **CNN Wire Staff**

May 30, 2012 -- Updated 2316 GMT (0716 HKT)

This tower collapsed in the quake on May 29, 2012. The earthquake rocked northeastern Italy just days after another quake in the same region.

HIDE CAPTION

Deadly earthquake hits Italy

<< < 1 2 3 4 5 6 7 8 9 10 11 12 > >>

By the **CNN Wire Staff**

May 30, 2012 -- Updated 2316 GMT (0716 HKT)

Fallen buildings fill the street in Mirandola; one of the towns closest to the quake's epicentre and an area that eyewitnesses say was most heavily damaged.

HIDE CAPTION

Deadly earthquake hits Italy

<< < 1 2 3 4 5 6 7 8 9 10 11 12 > >>

Rubbles after the earthquake

source: www.repubblica.it/cronaca/2012/05/20/foto/terremoto_a_nord_di_bologna-35518751/1/

Water-tower damage

source: emsc-csem.org

Masonry & Monumental Structures

Collapsed chrurch, San Carlo

mirror.co.uk, google.com

Severely damaged building, San Felice sul Panaro

source: http://www.flickr.com/photos/ingv/page4/

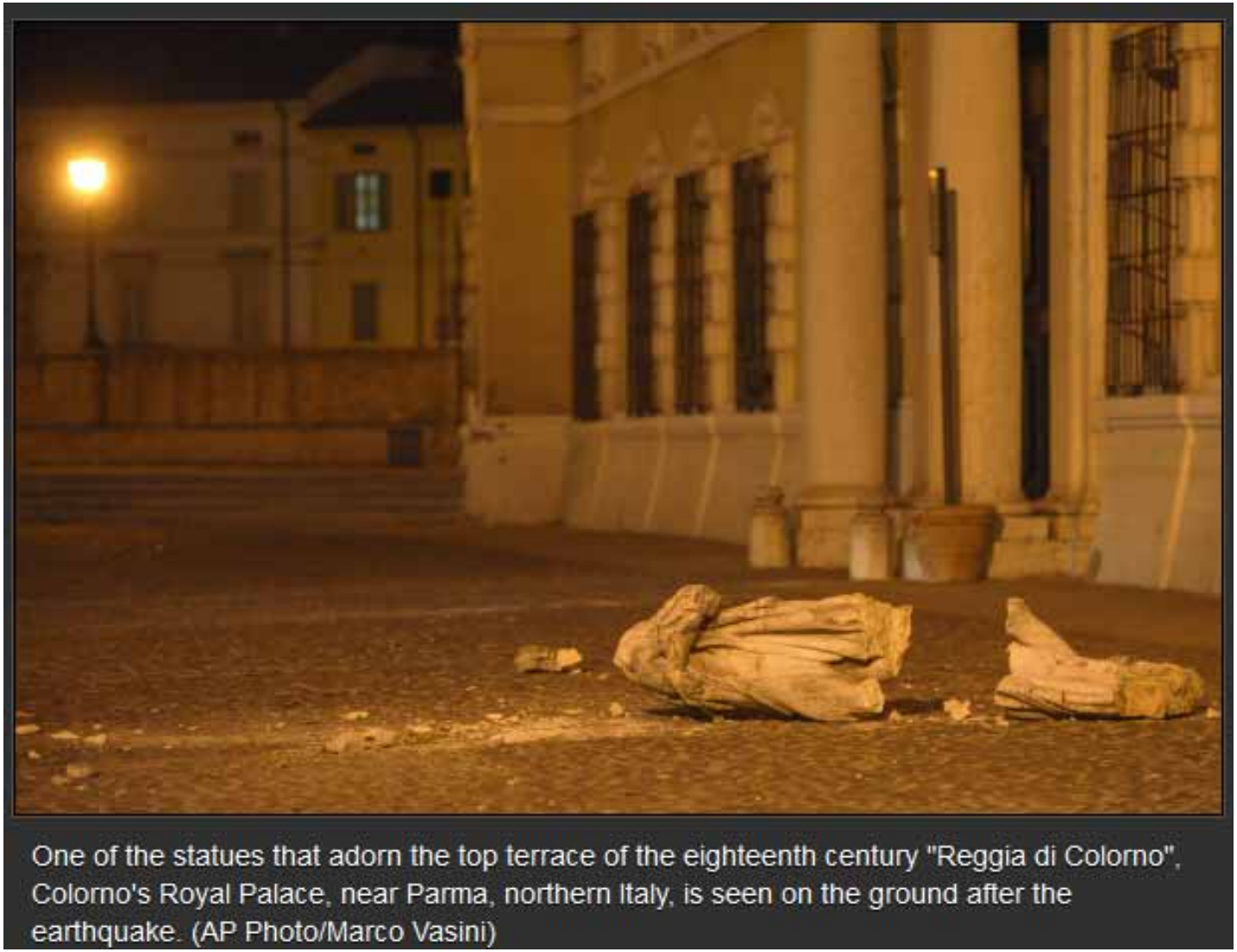
Collapsed building, San Felice sul Panaro

source: www.repubblica.it/cronaca/2012/05/20/foto/terremoto_a_nord_di_bologna-35518751/1/

source: www.repubblica.it/cronaca/2012/05/20/foto/terremoto_a_nord_di_bologna-35518751/1/

source: www.flickr.com/photos/ingv/page4/

Reggia di Colorno (18th c.), Colorno



One of the statues that adorn the top terrace of the eighteenth century "Reggia di Colorno", Colorno's Royal Palace, near Parma, northern Italy, is seen on the ground after the earthquake. (AP Photo/Marco Vasini)

N 44.930130, E 10.376237

thejournal.ie, google.com

La Rocca castle, San Felice Sul Panaro

N 44.838845, E 11.141171

huffingtonpost.co.uk, google.com

La Rocca castle, San Felice Sul Panaro

http://bologna.repubblica.it

Torre dell'orologio, Finale Emilia

Prior to the earthquakes

N 44.832228, E 11.293947

panoramio.com/photo/3661242, google.com

Torre dell'orologio, Finale Emilia

N 44.832228, E 11.293947

emsc-csem.org, google.com

Torre dell'orologio, Finale Emilia

source: http://thewatchers.adorraeli.com/2012/05/20/strong-very-dangerous-shallow-and-deadly-earthquake-m6-0-struck-northern-italy/

Torre dell'orologio, Finale Emilia

source: www.repubblica.it/cronaca/2012/05/20/foto/terremoto_a_nord_di_bologna-35518751/1/

Castello Delle Rocche, Finale Emilia

N 44.833345, E 11.296895

emsc-csem.org, google.com

Castello Lambertini, Poggio Renatico

N 44.833345, E 11.296895

www.flickr.com/photos/ingv/page4/, google.com

Castello Lambertini, Poggio Renatico

http://bologna.repubblica.it

La Chiesa di Buonacompra, Cento

La Chiesa di Buonacompra, nel comune di Cento, Ferrara

Town Hall, Sant Agostino

N 44.791797, E 11.386739

huffingtonpost.co.uk, google.com

Town Hall, Sant Agostino

Town Hall, Sant Agostino

source: www.flickr.com/photos/ingv/page4/

Town Hall, Sant Agostino

Possible damage to works of art (Murano glass chandelier)

City Hall, Finale Emilia

source: http://www.flickr.com/photos/ingv/page3/

Finale Emilia

Instituto Nazionale di Geofisica e Vulcanologia
http://www.flickr.com/photos/ingv/7260616122/sizes/o/in/photostream/

Severely damaged masonry structure, Finale Emilia

independentmail.com

Bridges

Finale Emilia Viaduct

Detail of the three most transversally displaced spans of the bridge

Finale Emilia Viaduct

Transverse residual dislocation
(approximately 4 cm increased following the May 29th aftershocks)

Finale Emilia Viaduct

Peak displacement equals 20 cm

Finale Emilia Viaduct

Induced earthquake joint

Finale Emilia Viaduct

Peak residual vertical displacement (2 cm) in correspondence of the north abutment

Finale Emilia Viaduct

Transverse residual displacement of the deck in correspondence of south pier (20 cm)

Finale Emilia Viaduct

Preparation of hydraulic jacks

Bridge at San Benedetto Po

Detail of the four spans in the river bed

Bridge at San Benedetto Po

Damage prior to earthquakes:
Eccentric load acting on pier foundations and differential subsidence ~ 20 cm

Bridge at San Benedetto Po

Damage prior to earthquakes:
Detail of a pier: concrete cover ejection and re-bars oxidation

Bridge at Bomporto

Bridge view

Bridge at Bomporto

Bridge view

Bridge at San Felice sul Panaro

Peak residual transverse displacement equal to 27 cm

Bridge at San Felice sul Panaro

Displacement at south abutment

Bridge at San Felice sul Panaro

Another detail of the support in correspondence of the south abutment

Bridge at San Felice sul Panaro

Another detail in correspondence of the south abutment: containment vertical spandrel

Bridge at San Felice sul Panaro

Residual longitudinal displacement (approximately 20 cm)

Industrial Facilities

Collapsed factory, Mirandola

huffingtonpost.co.uk, google.com

source: www.repubblica.it/cronaca/2012/05/20/foto/terremoto_a_nord_di_bologna-35518751/1/

Collapsed silo

mirror.co.uk

Factory, Medolle

news.nationalpost.com

Factory,Sant Agostino

independentmail.com

Collapsed ceramics factory, Sant Agostino

mirror.co.uk

Collapsed ceramics factory, Sant Agostino

source://www.flickr.com/photos/ingv/page4/

Collapsed ceramics factory, Sant Agostino

http://dsg.uniroma1.it/Sorrentino/Download/Emilia2012_DecaniniLiberatoreLiberatoreSorrentino_v1.pdf

Collapsed ceramics factory, Sant Agostino

http://dsg.uniroma1.it/Sorrentino/Download/Emilia2012_DecaniniLiberatoreLiberatoreSorrentino_v1.pdf

Precast RC industrial building, Sant Agostino

http://dsg.uniroma1.it/Sorrentino/Download/Emilia2012_DecaniniLiberatoreLiberatoreSorrentino_v1.pdf

Precast RC industrial building, Sant Agostino

http://dsg.uniroma1.it/Sorrentino/Download/Emilia2012_DecaniniLiberatoreLiberatoreSorrentino_v1.pdf

RC industrial building, Sant Agostino

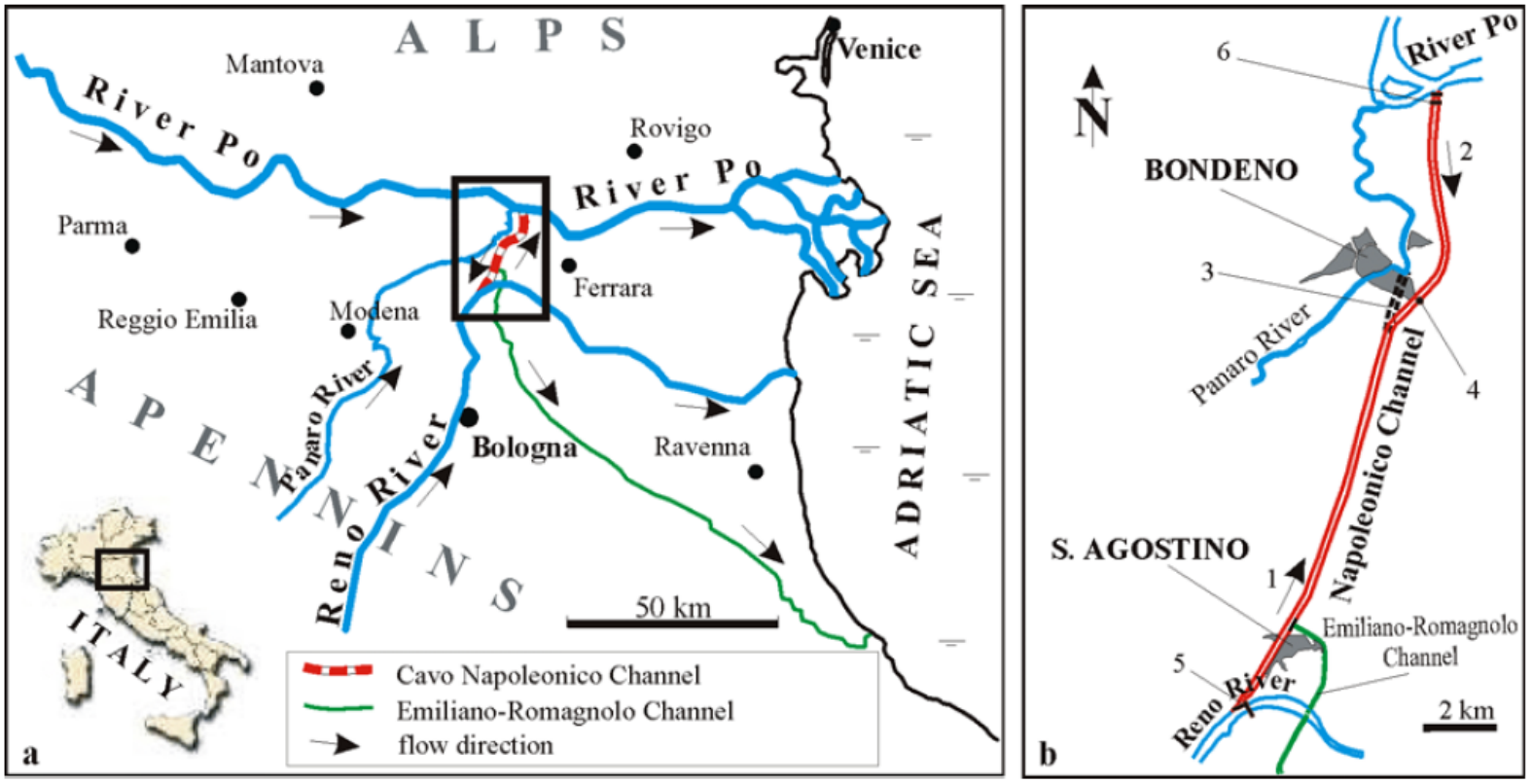
http://dsg.uniroma1.it/Sorrentino/Download/Emilia2012_DecaniniLiberatoreLiberatoreSorrentino_v1.pdf

RC industrial building, Sant Agostino

http://dsg.uniroma1.it/Sorrentino/Download/Emilia2012_DecaniniLiberatoreLiberatoreSorrentino_v1.pdf

Damages related to ground failures

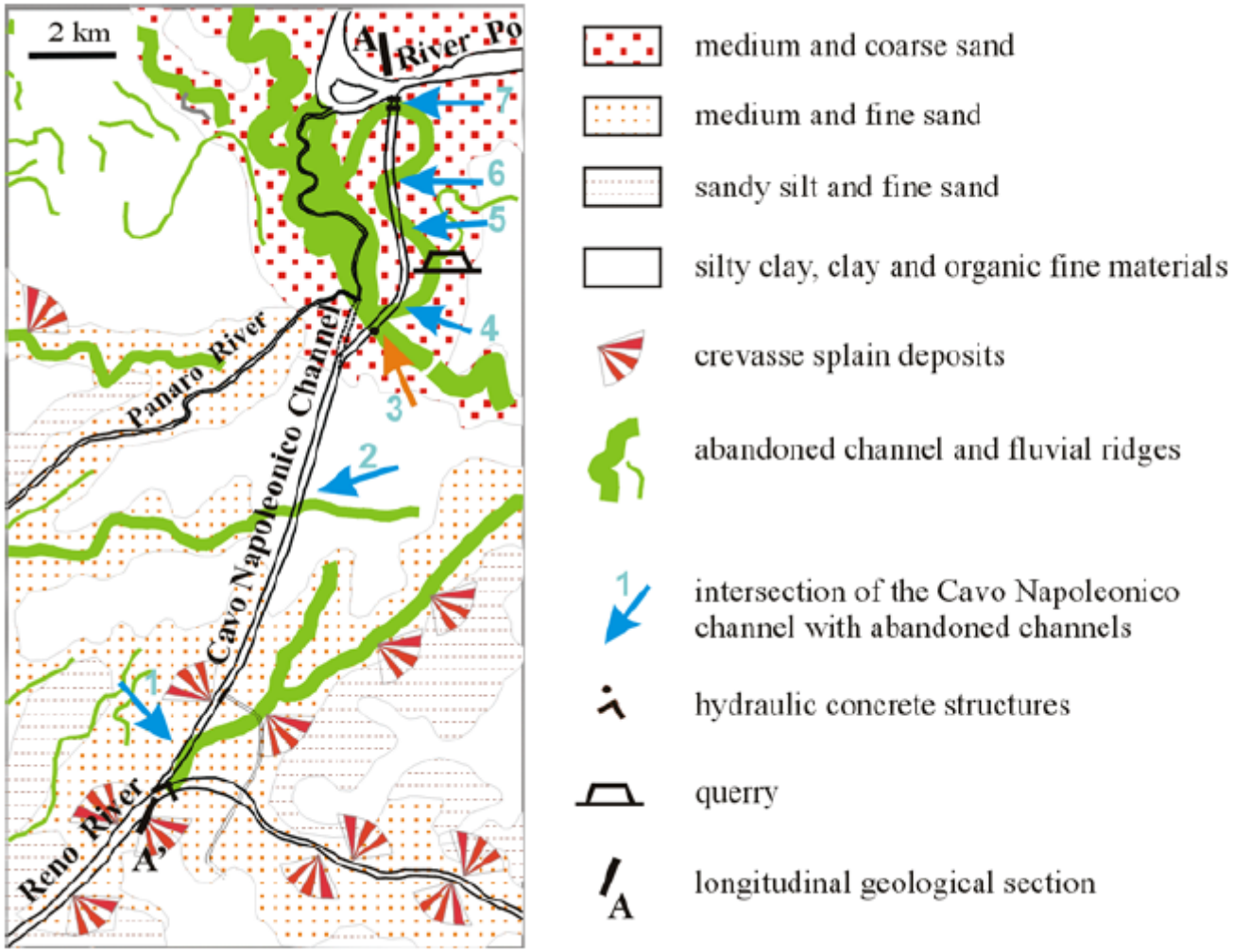
Soil liquefaction



Mazzini et al. 2006

Soil liquefaction

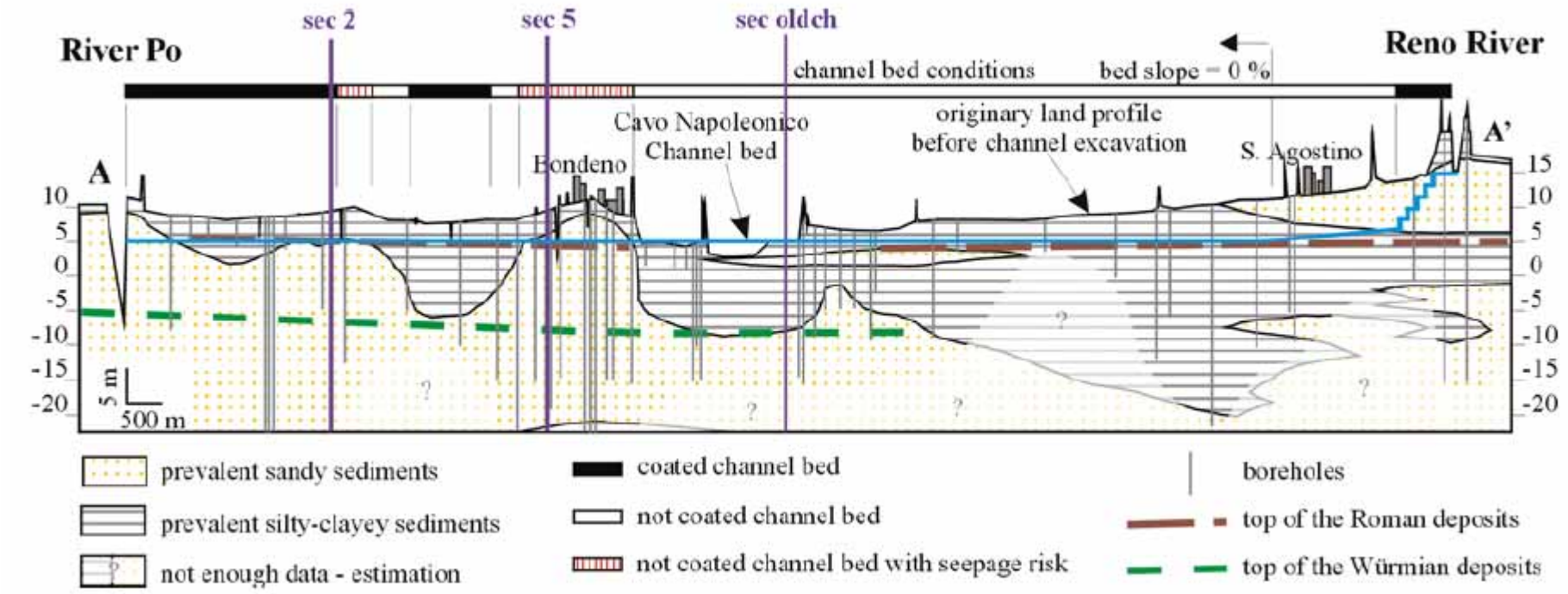
Geomorphologic and lithologic sketch of the area



Mazzini et al. 2006

Soil liquefaction

Longitudinal geological section of the axis of “Cavo Napoleonico” channel



Mazzini et al. 2006

Soil liquefaction

San Carlo

source: www.flickr.com/photos/ingv/page4/

Soil liquefaction

San Carlo

source: www.flickr.com/photos/ingv/page4/

Soil liquefaction

San Carlo

source: www.flickr.com/photos/ingv/page4/

Soil liquefaction

Mirabello

source: www.flickr.com/photos/ingv/page4/

Soil liquefaction

source: http://eqgeogr.weebly.com

Soil liquefaction

source: http://eqgeogr.weebly.com

Soil liquefaction

source: http://eqgeogr.weebly.com

Soil liquefaction

source: http://eqgeogr.weebly.com

Soil liquefaction

source: http://eqgeogr.weebly.com

Soil liquefaction

Mission Pots-Sismique INSU: Photos de L. Benedetti (CEREGE), J. Van der Woerd (EOST) et E. Jacques (IPGP)

M6.0 20.05.2012

https://sites.google.com/site/cellulepostsismique/

Soil liquefaction

Mission Pots-Sismique INSU: Photos de L. Benedetti (CEREGE), J. Van der Woerd (EOST) et E. Jacques (IPGP)

Soil liquefaction

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M6.0 20.05.2012

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Soil liquefaction

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M6.0 20.05.2012

https://sites.google.com/site/cellulepostsismique/

Soil liquefaction

Tilting of a building

source: www.flickr.com/photos/ingv/page3/

Fault rupture

Source: Agi.it

Fault rupture

M6.0 20.05.2012

Mission Pots-Sismique INSU: Photos de L. Benedetti (CEREGE), J. Van der Woerd (EOST) et E. Jacques (IPGP)

Source: https://sites.google.com/site/cellulepostsismique/

Fault rupture

M6.0 20.05.2012

Source: https://sites.google.com/site/cellulepostsismique/

Fault rupture

M6.0 20.05.2012

Source: https://sites.google.com/site/cellulepostsismique/

Fault rupture

Mission Pots-Sismique INSU: Photos de L. Benedetti (CEREGE), J. Van der Woerd (EOST) et E. Jacques (IPGP)

M6.0 20.05.2012

Source: https://sites.google.com/site/cellulepostsismique/

Fault rupture

San Carlo

source: www.flickr.com/photos/ingv/page4/

Fault rupture

San Carlo

source: www.flickr.com/photos/ingv/page4/

Ground fractures

San Carlo

source: www.flickr.com/photos/ingv/page4/

Ruptures

San Felice sul Panaro

source: www.flickr.com/photos/ingv/page3/

Ruptures

San Felice sul Panaro

source: www.flickr.com/photos/ingv/page3/

Landslide toward the center of a channel

Mirabello

source: www.flickr.com/photos/ingv/page4/

Losses in Economic Sector

Parmigiano production drop by 10%

Years before recovery

Source: guardian.co.uk

By the **CNN Wire Staff**

May 30, 2012 -- Updated 2316 GMT (0716 HKT)

Hundreds of blocks of cheese fell on top of one another at a parmigiano factory in San Giovanni, Parsiceto. The owner of the factory surveys the damage on May 21, 2012, following an earlier quake.

HIDE CAPTION

Deadly earthquake hits Italy

<< < 1 2 3 4 5 6 7 8 9 10 11 12 > >>

Photograph locations

- Mirandola Station
  41037 Mirandola MO, Italy
- M5.8 29.05.2012
  +44° 48' 50.40", +11° 4' 44.40"
- M6.0 20.05.2012
  +44° 46' 37.20", +11° 13' 37.20"
- La Rocca castle, San Felice Sul Panaro
  44.838845, 11.141171 +44° 50' 19.84", +11° 8' 28.22"
- Town Hall building, Sant Agostino
  44.791797, 11.386739 +44° 47' 30.47", +11° 23' 12.26"
- Torre dell'orologio, Finale Emilia
  44.832228, 11.293947 +44° 49' 56.02", +11° 17' 38.21"
- Castello Delle Rocche
  44.833345, 11.296895 +44° 50' 0.04", +11° 17' 48.82"
- Ducal Palace of Colorno
  44.930130, 10.376237 +44° 55' 48.47", +10° 22' 34.45"

google.com

Population affected

Impact on the population

source: www.nytimes.com/2012/05/21/world/europe/earthquake-in-northern-italy.html?_r=1

Impact on the population

source: www.nytimes.com/2012/05/21/world/europe/earthquake-in-northern-italy.html?_r=1

Impact on the population

source: www.nytimes.com/2012/05/21/world/europe/earthquake-in-northern-italy.html?_r=1

Impact on the population

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May 30, 2012 -- Updated 2316 GMT (0716 HKT)

Impact on the population

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