Seismic Ground Motion Assessment

REVISION OF THE PO PLAIN EARTHQUAKE CATALOGUE IN PROBABILISTIC TERMS

AUTHORS			REVIEW			APPROVAL		
NOM	DATE	VISA	NOM	DATE	VISA	NOM	DATE	VISA
M. MUCCIARELLI UNIVERSITY OF POTENZA)	18.05.14		G. WOO			M. Corigliano		
			J. SAVY (SRC Consulting)			G. Senfaute		

***DISSEMINATION**: Authors; Steering Committee; Work Package leaders, Scientific Committee, Archiving.*

Summary

The report SIGMA-2012-D1-51, concerned with the preliminary earthquake recurrence models with extensive use of intensity data concluded that the uncertainty on Mean Return Times caused by problem in intensity definition is of the order of 25-30%.

In this study, the historical catalogue of the Po Plain has been revised in a probabilistic fashion, with an expert judgement that used probability to express the degree of belief in different possible epicentral intensities.

Mean return times were the calculated from this new catalogue, and then compared with the result of a standard approach that forces uncertain intensities on nearest integer values.

The outcome showed that the minimum variation in the estimate of MRT is ranging from 15 to 30% for intensities comprised between VII and IX.

The presence of this uncertainty in PSHA estimates obtained from intensity data should be considered in the validation activities foreseen in Project SIGMA.

Introduction

This is the follow up of report SIGMA-2012-D1-51, that was concerned with the preliminary earthquake recurrence models with extensive use of site data

The previous report concluded that the uncertainty on Mean Return Times caused by problem in intensity definition for site seismic histories is of the order of 25-30%. The analysis of the rates from seismogenic zones suggest that the uncertainty due to epicentral intensity estimate is again about 25%, a relative error that will propagate in further steps of PSHA.This uncertainty could be reduced with a thorough revision of the catalogue, possibly in a probabilistic fashion, defining with the help of historians a “degree of belief” on each single intensity degree.

This report first describes the revision of the seismic historical catalogue for the four seismogenic zones relevant to Po Plain, the test area of Italian side of SIGMA project.

Then the seismic rates are calculated and compared with the previous statistic estimates of uncertainties on occurrence rates.

The probabilistic catalogue

The data for revising the catalogue and put it in a probabilistic format were taken from the Italian Parametric Catalogue (CPTI, Catalogo Parametrico dei Terremoti Italiani) and from the Italian database of Macroseismic Intensity (DBMI, Data Base Macrosismico Italiano), both available from INGV web page (www.ingv.it).

The available intensity maps are reported as annex of this report.

Some of the earthquakes to be revised do not have an associated intensity map. Another important feature to be described concerns the number of intensity point associated to each earthquake when a map is available.

Figure 1 reports the Cumulative Distribution Function of the number ov available intesnity points for each earthquake with half-degree intensity in CPTI.

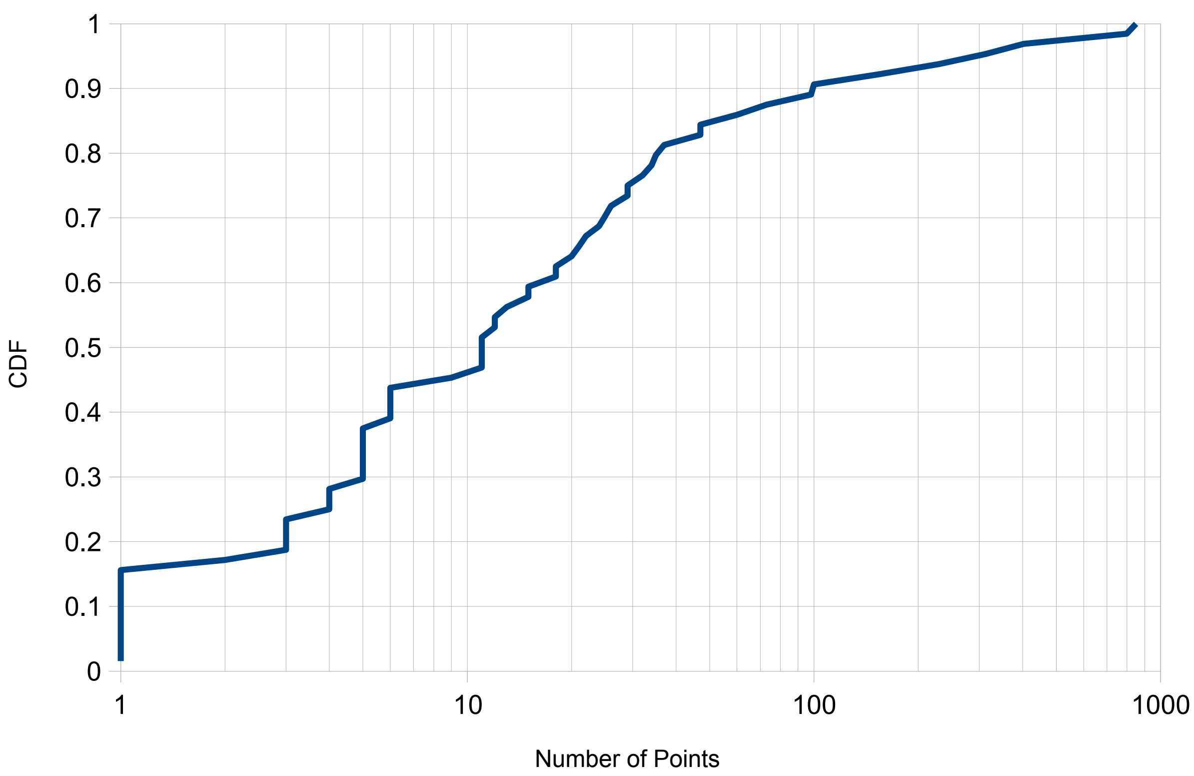


Fig. 1 Number of points in intensity maps for the revised earthquakes

It is worth noting that 15% of the revised events are known for just a single locality with associated intensity, and slightly less than 50% have a map with 10 points or less.

This means that any automated procedure for parametrizing epicentral data will encounter problems due to the limited number of points available.

Moreover, for the single point earthquakes, the only way to solve the uncertainty associated to epicentral intensity (and thus converted magnitude) would be to carry on a reappraisal of the original source behind this single point.

The inspection of intensities maps revealed some recurrent problems confirmed with interviews with historical seismologists:

!∀ the uncertainty in epicentral intensity due to the fact that the points are few, scattered and with large “jumps” in intensity values.

#∀ the uncertainty is attributed to the role of site effects, assuming that this is the cause of a single or few, higher values among a rather homogeneous distribution of lower intensity.

∃∀ The uncertainty is due to an apparent “anomalous” small area affected by high intensity with no or little evidence of lower values

The revision of a catalogue becomes then an expert judgement, using probability to express the degree of belief, that should be subjected to simple “conversion rules” such those listed in the EMS-98 scale for the definition of quantity such as “many”, “few”, or “most”. A possible conversion rule is given in table 1.

Absolutely true	1
Very likely	0.9
Uncertain	0.5
Unlikely	0.1
Absolutely false	0

Table 1: Proposal of conversion rule of expert judgment into probability for the statement "the intensity is equal to or greater than a given class".

The first attempt of probabilistic revision of the catalogue of the Po Plain is given in the following table. ***(NOTE: a second expert was asked to give its independent opinion. The result will be reported in the final version of the report)***

			Prob				
Year	**Int**	**Np**	**V**	**VI**	**VII**	**VIII**	**IX**
1065	7		1	1	1	0	0
1117	9.5	57	1	1	1	1	1
1222	8.5	18	1	1	1	1	0.5
1249	6.5	4	1	1	0.5	0	0
1285	6.5	1	1	1	0.5	0	0
1323	5.5	5	1	0.7	0	0	0
1334	5.5	4	1	0.5	0	0	0
1345	5.5	1	1	0.5	0	0	0
1365	6.5	1	1	1	0.5	0	0
1365	5.5	1	1	0.5	0	0	0
1396	7.5	2	1	1	1	0.5	0
1399	7		1	1	1	0	0
1402	6		1	1	0	0	0
1403	6		1	1	0	0	0
1409	6		1	1	0	0	0
1410	6.5	3	1	1	0.5	0	0
1425	6		1	1	0	0	0
1433	6		1	1	0	0	0
1438	8		1	1	1	1	0
1445	5.5	3	1	0.5	0	0	0
1455	7.5		1	1	1	0.5	0
1455	7		1	1	1	0	0
1465	6.5	11	1	1	0.5	0	0
1471	5.5		1	0.5	0	0	0
1474	6		1	1	0	0	0
1483	8		1	1	1	1	0
1483	5.5	1	1	0.5	0	0	0
1491	7.5		1	1	1	0.5	0
1501	8.5	20	1	1	1	1	0.8
1505	7		1	1	1	0	0
1505	5.5		1	0.5	0	0	0

1508	6		1	1	0	0	0
1521	6		1	1	0	0	0
1540	6		1	1	0	0	0
1547	7		1	1	1	0	0
1561	5.5	5	1	0.5	0	0	0
1570	7.5	60	1	1	1	0.8	0
1572	7		1	1	1	0	0
1574	7		1	1	1	0	0
1576	6		1	1	0	0	0
1586	6		1	1	0	0	0
1591	6.5	6	1	1	0.6	0	0
1591	6		1	1	0	0	0
1593	6.5	1	1	1	0.5	0	0
1606	6.5	1	1	1	0.5	0	0
1608	6		1	1	0	0	0
1624	7.5	18	1	1	1	0.5	0.1
1628	7		1	1	1	0	0
1642	6.5	11	1	1	0.5	0	0
1660	5.5		1	0.5	0	0	0
1661	7		1	1	1	0	0
1666	6		1	1	0	0	0
1671	7		1	1	1	0	0
1688	9		1	1	1	1	1
1688	7		1	1	1	0	0
1689	6		1	1	0	0	0
1693	7		1	1	1	0	0
1695	5.5	1	1	0.5	0	0	0
1732	6		1	1	0	0	0
1738	7		1	1	1	0	0
1743	6.5	1	1	1	0.5	0	0
1756	5.5	1	1	0.5	0	0	0
1771	6		1	1	0	0	0
1771	6		1	1	0	0	0
1774	6		1	1	0	0	0

1780	6.5	9	1	1	0.5	0	0
1780	5.5	5	1	0.5	0	0	0
1781	6.5	11	1	1	0.7	0	0
1783	6.5	4	1	1	0.5	0	0
1787	5.5	3	1	1	0.5	0	0
1796	7		1	1	1	0	0
1799	6.5	12	1	1	0.6	0	0
1801	5.5	6	1	1	1	0	0
1802	8		1	1	1	1	0
1806	7		1	1	1	0	0
1810	7		1	1	1	0	0
1810	6		1	1	0	0	0
1811	7		1	1	1	0	0
1815	5.5	3	0.5	0	0	0	0
1818	7.5		1	1	1	0.5	0
1826	5.5		1	0.5	0	0	0
1831	7.5	25	1	1	1	0.6	0
1832	7.5	98	1	1	1	0.6	0
1834	5.5	12	1	1	1	0	0
1836	7.5	26	1	1	1	0.9	0
1839	6		1	1	0	0	0
1850	6		1	1	0	0	0
1857	6.5	22	1	1	0.6	0	0
1864	6.5	13	1	1	0.6	0	0
1866	7		1	1	1	0	0
1868	6	5	1	1	0.5	0	0
1869	7.5	5	1	1	1	0.6	0
1869	6.5		1	1	0.5	0	0
1873	6.5	15	1	1	0.6	0	0
1876	7		1	1	1	0	0
1877	6.5	6	1	1	0.6	0	0
1879	5.5	6	1	0.5	0	0	0
1881	6.5	24	1	1	0.8	0	0
1882	7		1	1	1	0	0

1882	6.5	37	1	1	0.6	0	0
1884	6		1	1	0	0	0
1886	6		1	1	0	0	0
1889	6		1	1	0	0	0
1891	8.5	403	1	1	1	1	0.6
1891	6		1	1	0	0	0
1891	6		1	1	0	0	0
1892	7		1	1	1	0	0
1892	6.5	100	1	1	0.6	0.1	0
1892	6		1	1	0	0	0
1894	7		1	1	1	0	0
1894	6.5		1	1	0.5	0	0
1894	6.5	116	1	1	0	0	0
1895	6		1	1	0	0	0
1895	6		1	1	0	0	0
1895	6		1	1	0	0	0
1895	6		1	1	0	0	0
1896	6		1	1	0	0	0
1897	5.5	47	1	0.5	0	0	0
1898	6.5	313	1	1	1	0.2	0
1898	6.5	73	1	1	0.8	0	0
1898	5.5		1	0.5	0	0	0
1901	8		1	1	1	1	0
1904	6		1	1	0	0	0
1907	6		1	1	0	0	0
1908	6		1	1	0	0	0
1908	6		1	1	0	0	0
1908	4.5	18	0.5	0	0	0	0
1909	6.5	799	1	1	0.3	0	0
1909	6		1	1	0	0	0
1913	5		1	0	0	0	0
1915	6		1	1	0	0	0
1918	6		1	1	0	0	0
1923	6		1	1	0	0	0

1927	6		1	1	0	0	0
1928	6.5	35	1	1	0.6	0	0
1929	7		1	1	1	0	0
1930	6		1	1	0	0	0
1932	7.5	21	1	1	1	0.7	0
1934	5.5	29	1	1	0	0	0
1936	6		1	1	0	0	0
1937	6.5	34	1	1	1	0	0
1937	6		1	1	0	0	0
1940	6		1	1	0	0	0
1940	5		1	0	0	0	0
1942	6		1	1	0	0	0
1943	6.5	29	1	1	1	0	0
1943	6		1	1	0	0	0
1947	6		1	1	0	0	0
1948	5		1	0	0	0	0
1951	5	154	1	1	0.5	0	0
1956	6		1	1	0	0	0
1957	6		1	1	0	0	0
1960	6		1	1	0	0	0
1961	6		1	1	0	0	0
1962	6		1	1	0	0	0
1965	5.5	32	1	0.1	0	0	0
1965	5		1	0	0	0	0
1966	6		1	1	0	0	0
1967	6		1	1	0	0	0
1967	6		1	1	0	0	0
1967	5.5	47	1	0.4	0	0	0
1967	5		1	0	0	0	0
1968	6		1	1	0	0	0
1968	5		1	0	0	0	0
1969	5.5	15	1	0.4	0	0	0
1970	6		1	1	0	0	0
1970	6		1	1	0	0	0

1970	6		1	1	0	0	0
1971	7.5	229	1	1	1	0.9	0
1972	6		1	1	0	0	0
1975	5.5		1	0.5	0	0	0
1976	7		1	1	1	0	0
1983	6.5	850	1	1	0.7	0	0
1986	6		1	1	0	0	0
1987	6		1	1	0	0	0
1987	6		1	1	0	0	0
1989	6		1	1	0	0	0
1995	5.5		1	0.5	0	0	0
1996	7		1	1	1	0	0
1999	5		1	0	0	0	0
2004	7.5		1	1	1	0.1	0
2012	7.5		1	1	1	0.5	0

Table 2 – The probabilistic catalogue of the Po Plain test area

Comparing estimates of MRT

The previous report SIGMA-2012-D1-51, concluded that the uncertainty on Mean Return Times for seismogenic zones in the Po Plain is about 25%. The estimates obtained for the probabilistic catalogue are here compared with standard ones.

When dealing with semi-integer data, there are two customary approaches, either assigning all the intensities to the lower or to the higher value. The relevant results are described in the following as the Min and Max respectively.

Figure 2 reports the comparison between the Mean Return Times for the three different catalogues obtained as described in report SIGMA-2012-D1-51.

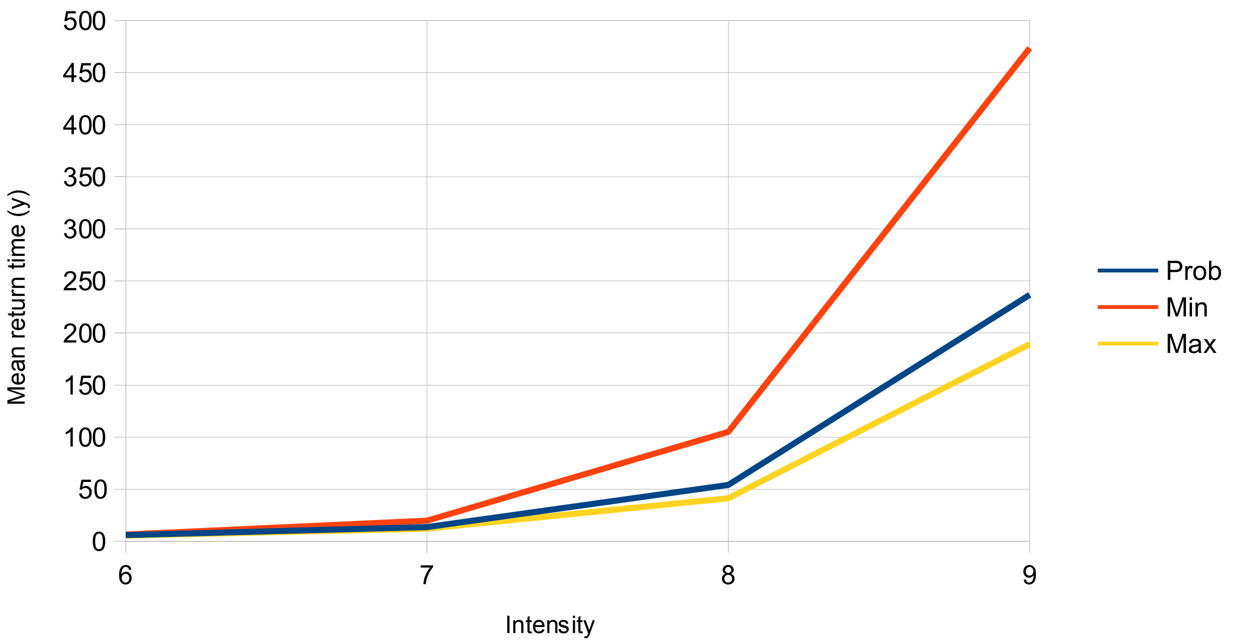


Fig. 2 - Comparison between the MRTs for three different catalogues

It is possible to note that the probabilistic approaches returns results closer to the Max approach, while the Min catalogue gives rather under-conservative values.

To better appreciate the relation between the different estimates for increasing intensities, Fig. 3 reports the variation between the estimates, calculated as:

%(M-Prob)/M

where **M** can be Min or Max.

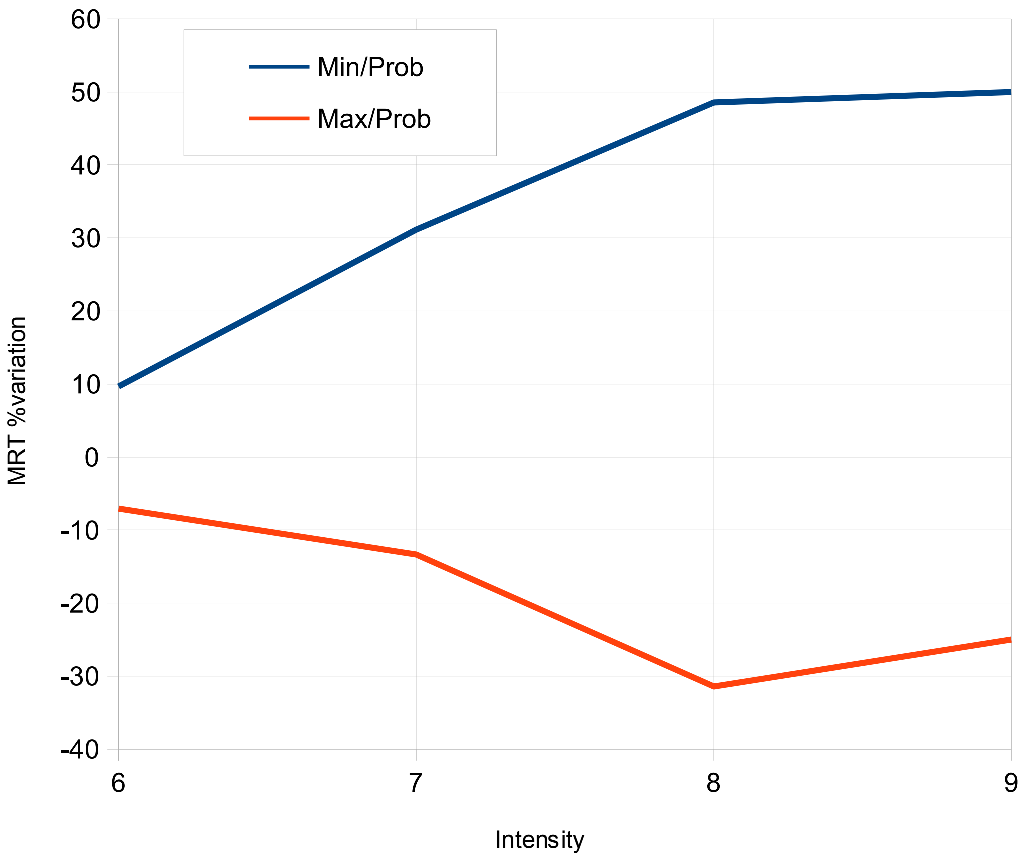


Fig. 3 - Variation between MRT for probabilistic and standard catalogue

With respect to the Max approach, the variation for the intensities between VII and IX is in the range 15-30%, thus confirming the results on uncertainties estimated for synthetic catalogues in report SIGMA-2012-D1-51.

Conclusions

The revision of the historical data to provide a probabilistic approach to the epicentral intensities highlighted some problems in parametrisation of intensity catalogues.

A expert judgement formalised as a probability intensity vector allowed for the calculation of Mean return times. These values were then compared with the result of a standard approach that forces uncertainty on intensity on nearest integer values.

The outcome showed that the minimum variation in the estimate of MRT is ranging from 15 to 30% for intensities comprised between VII and IX.

After this exercise, some open question remain:

1) it is difficult to parametrise intensities in a quantitative, formal scheme when the original data is scarce;
2) it would be interesting to compare the results obtained here with those that can be derived from an alternative probabilistic estimates of intensity provided from another, independent expert judgement;
3) a deeper reappraisal of the catalogue could be performed including also non-semi-integers epicentral intensity considering that also integer values could be attributed with a large associated uncertainty.

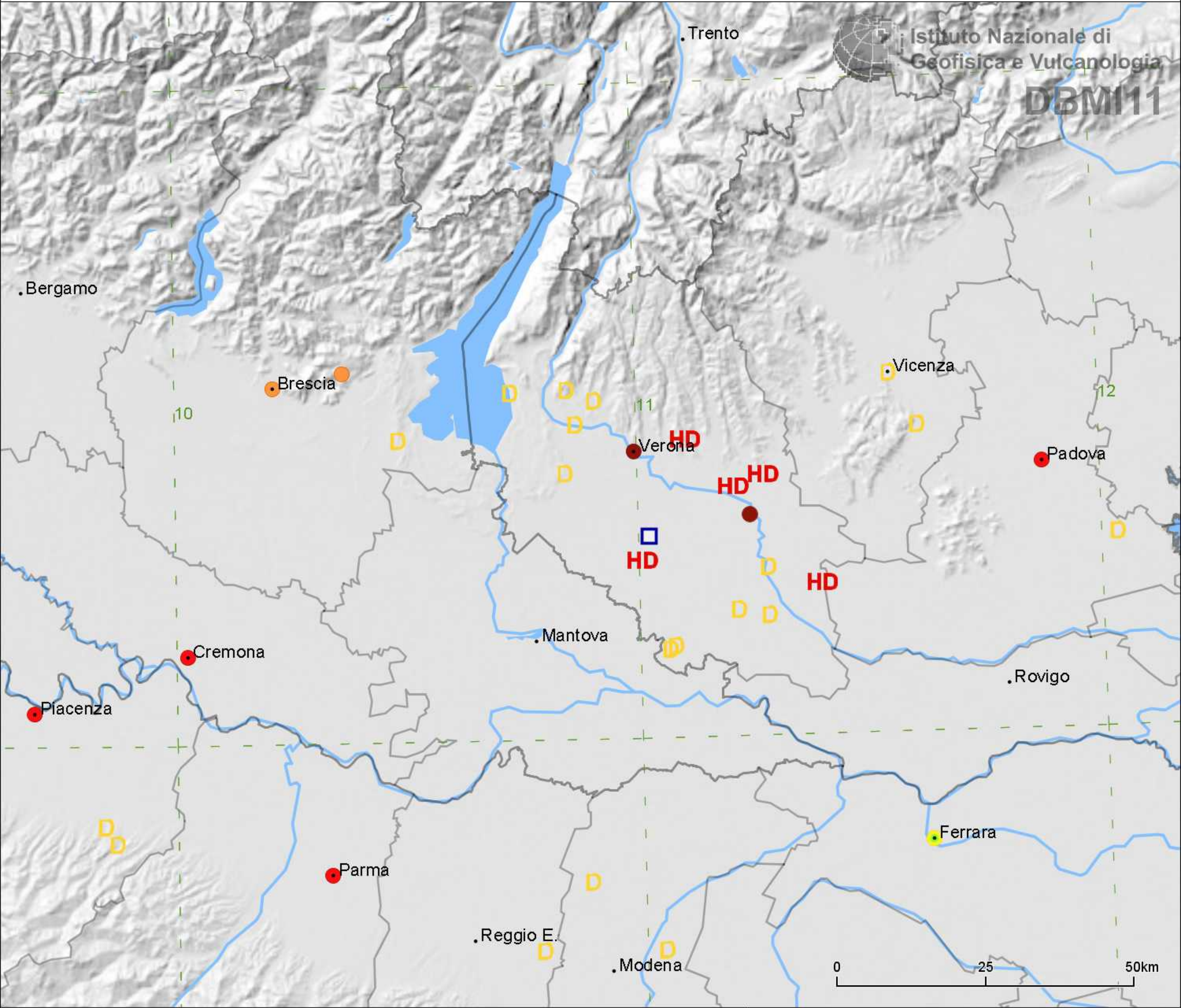
The presence of uncertainty in PSHA estimates obtained from intensity data should be considered in the validation activities foreseen in Project SIGMA.

APPENDIX

Intensity maps used in this study

Terremoto del 3 gennaio 1117 15:15:--, Veronese
Studio macrosismico Guidoboni et al., 2007 [Np 55, Imax 9]

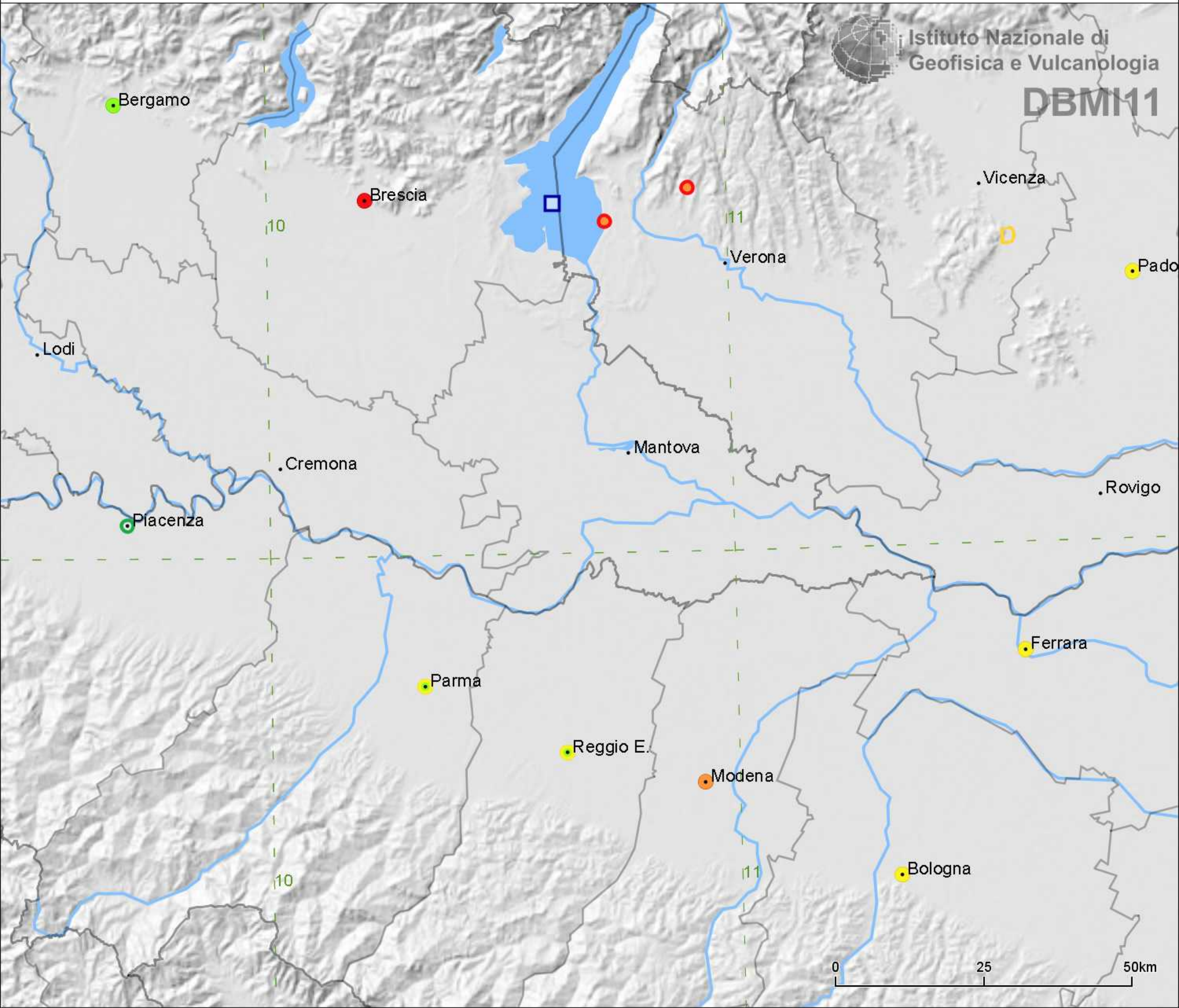
Epicentro CPTI11 Mw 6.69 ±0.20
macrosismico Mw 6.69 ±0.20



Int.	1	2	3	4	5	6	7	8	9	10	11
	2-3	3-4	F	4-5	5-6	6-7	7-8	8-9	9-10	10-11	

Terremoto del 25 dicembre 1222 12:30:--, Basso Bresciano
Studio macrosismico Guidoboni et al., 2007 [Np 18, Imax 9]

Epicentro CPTI11 Mw 5.84 ±0.56
macrosismico Mw 5.84 ±0.56



Istituto Nazionale di Geofisica e Vulcanologia | DBMI11

Int. 1 2 3 4 5 6 7 8 9 10 11
2-3 3-4 F 4-5 5-6 6-7 7-8 8-9 9-10 10-11

Terremoto del settembre 1249, Modena
Studio macrosismico Guidoboni et al., 2007 [Np 4, Imax 7-8]

Epicentro CPTI11 Mw 4.93 ±0.34
macrosismico Mw 4.93 ±0.34

Istituto Nazionale di Geofisica e Vulcanologia | DBMI11

Int. 1 2 3 4 5 6 7 8 9 10 11
2-3 3-4 F 4-5 5-6 6-7 7-8 8-9 9-10 10-11

Terremoto del 13 dicembre 1285, FERRARA
Studio macrosismico ENEL, 1985 [Np 2, Imax 7]

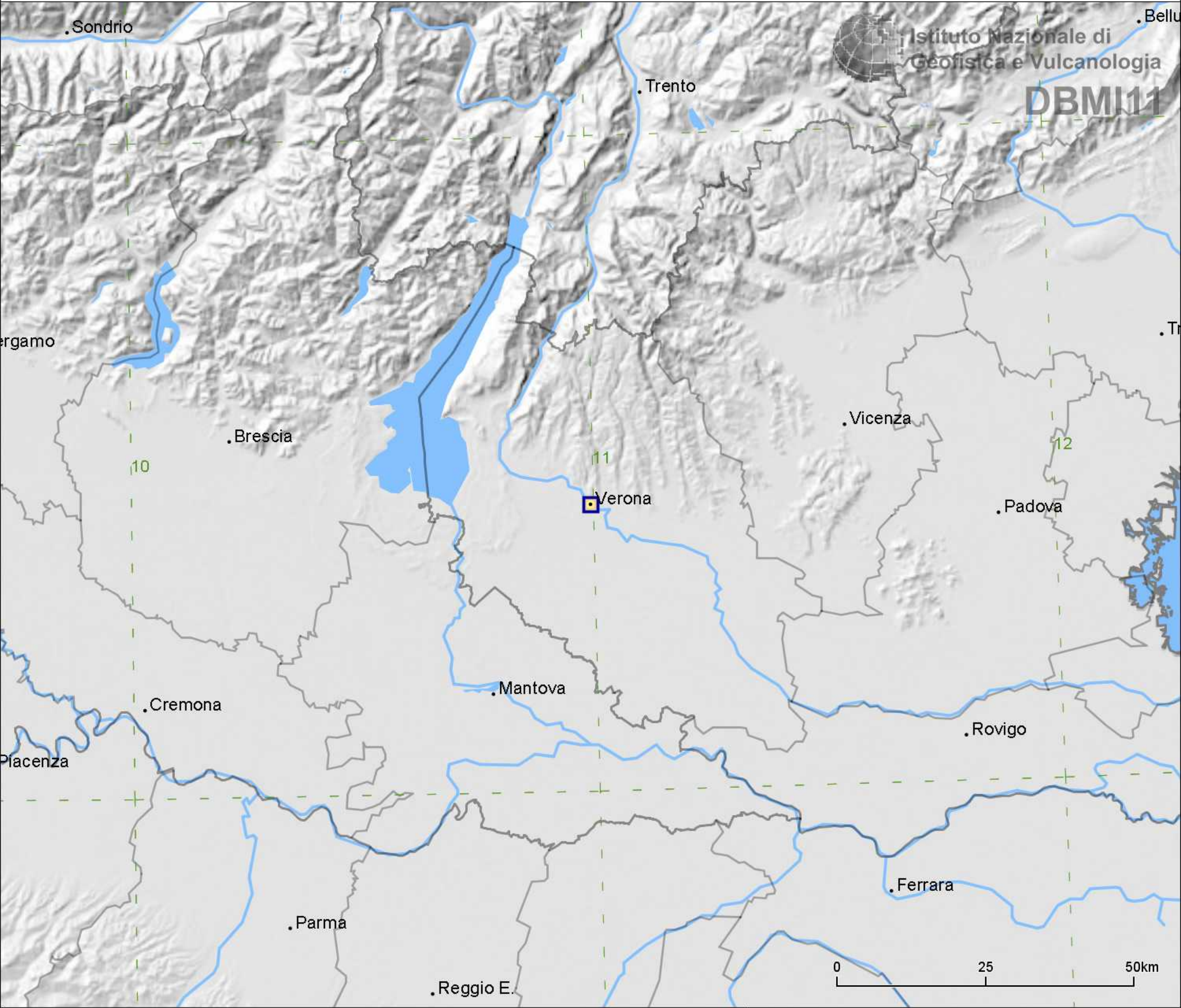
Epicentro CPTI11 Mw 5.14 ±0.34
macrosismico Mw 5.14 ±0.34

Istituto Nazionale di Geofisica e Vulcanologia | DBMI11

Int. 1 2 3 4 5 6 7 8 9 10 11
2-3 3-4 F 4-5 5-6 6-7 7-8 8-9 9-10 10-11

Terremoto del 4 dicembre 1334, Verona
Studio macrosismico Guidoboni et al., 2007 [Np 4, Imax 6-7]

Epicentro CPTI11 Mw 4.93 ±0.34
macrosismico Mw 4.93 ±0.34

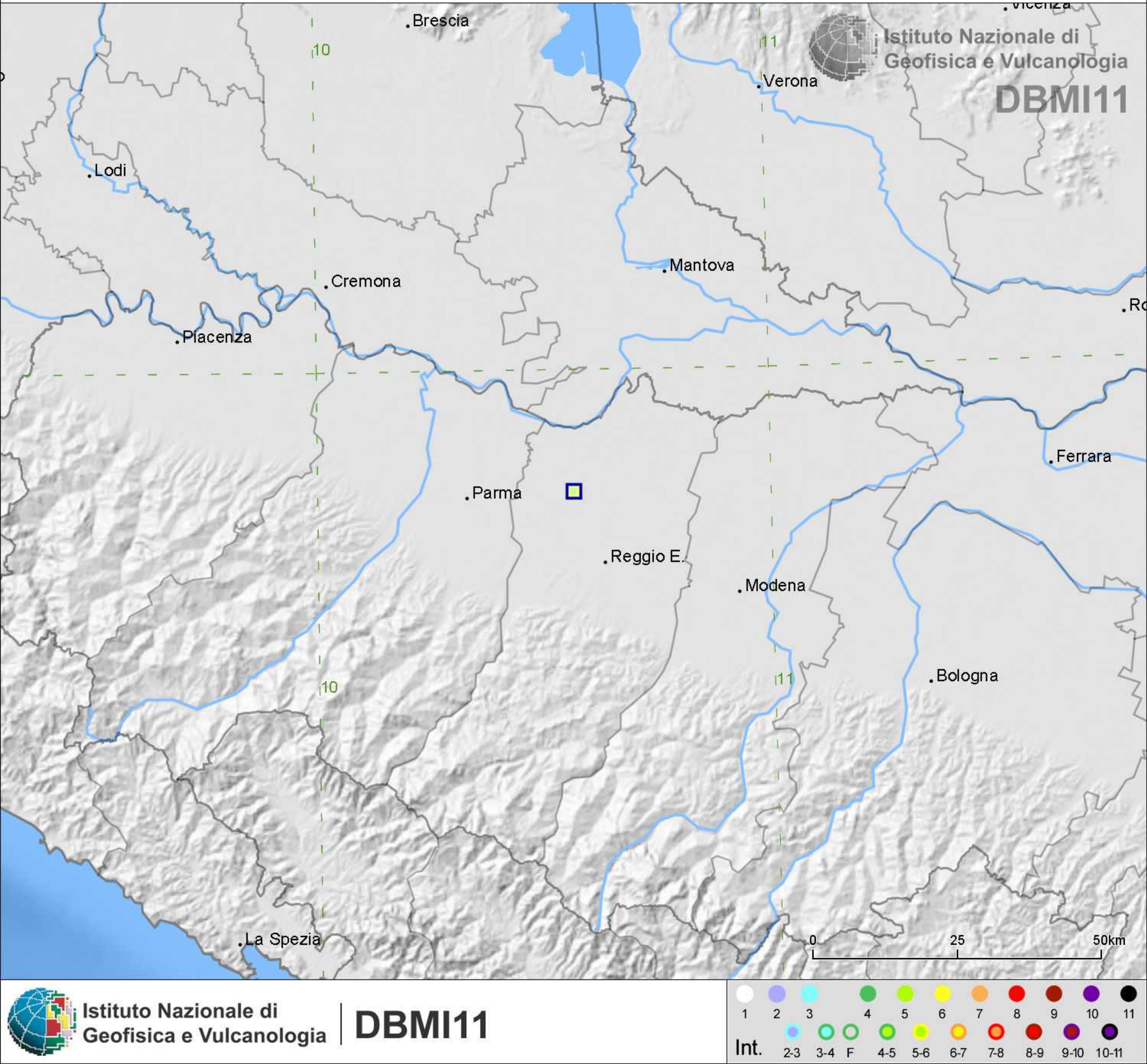


Istituto Nazionale di Geofisica e Vulcanologia | DBMI11

1	2	3		4	5	6	7	8	9	10	11
Int. 2-3	3-4	F		4-5	5-6	6-7	7-8	8-9	9-10	10-11	

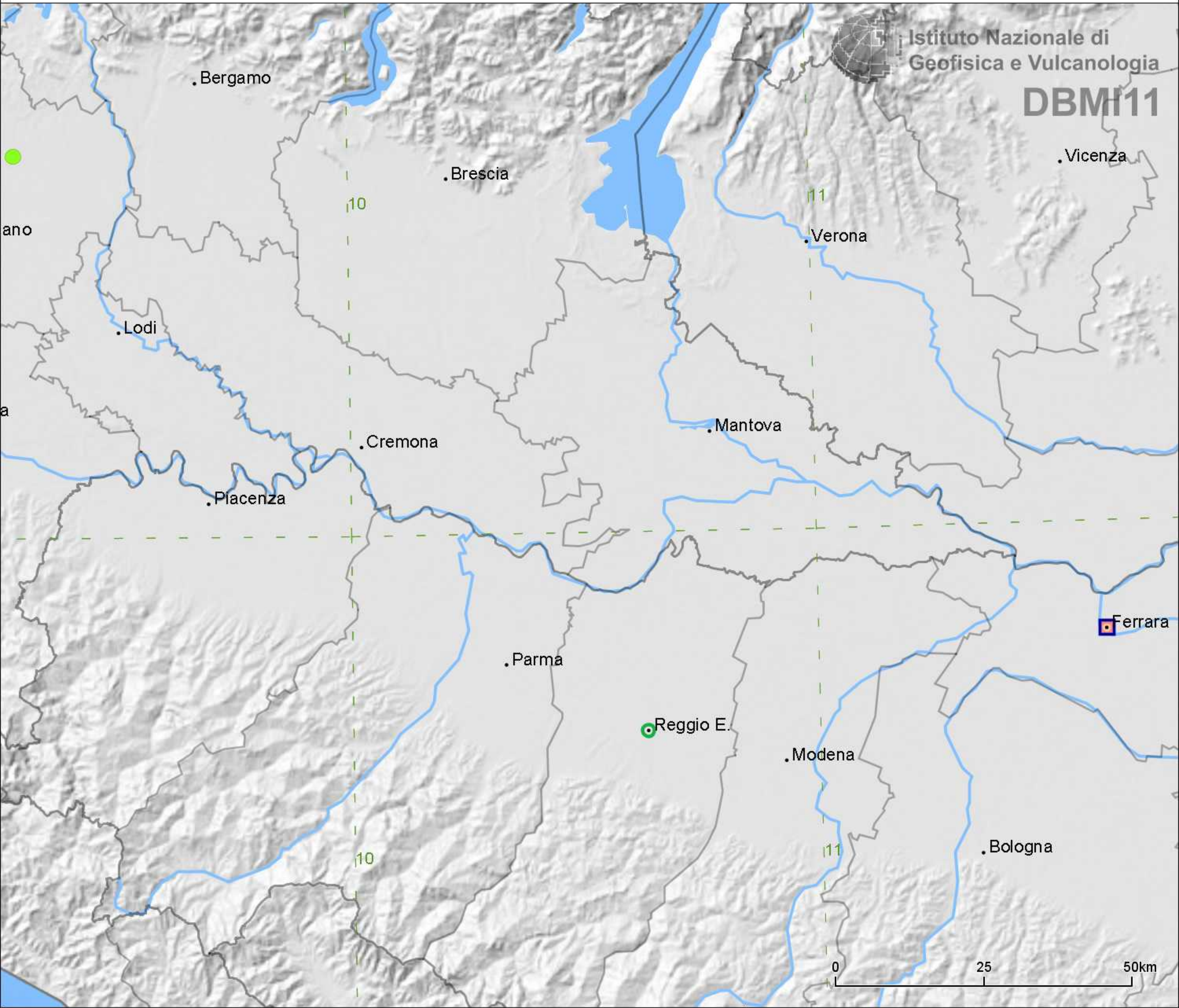
Terremoto del 31 gennaio 1345, CASTELNUOVO
Studio macrosismico ENEL, 1985 [Np 1, Imax 5-6]

Epicentro CPTI11 Mw 4.51 ±0.34
macrosismico Mw 4.51 ±0.34

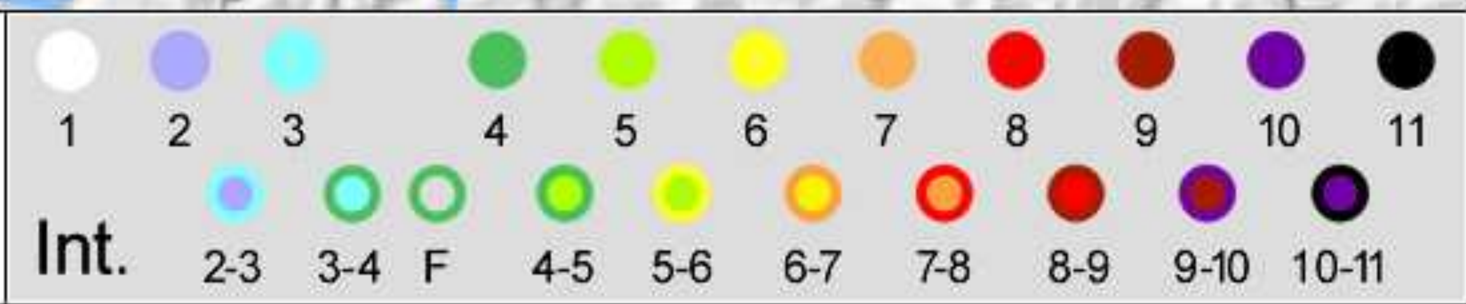


Terremoto del 22 febbraio 1346 11:--:--, Ferrara
Studio macrosismico Guidoboni et al., 2007 [Np 5, Imax 7-8]

Epicentro CPTI11 Mw 4.93 ±0.34
macrosismico Mw 4.93 ±0.34



Istituto Nazionale di Geofisica e Vulcanologia | DBMI11



Terremoto del 25 luglio 1365 18:--:--, Bologna
Studio macrosismico Guidoboni et al., 2007 [Np 1, Imax 7-8]

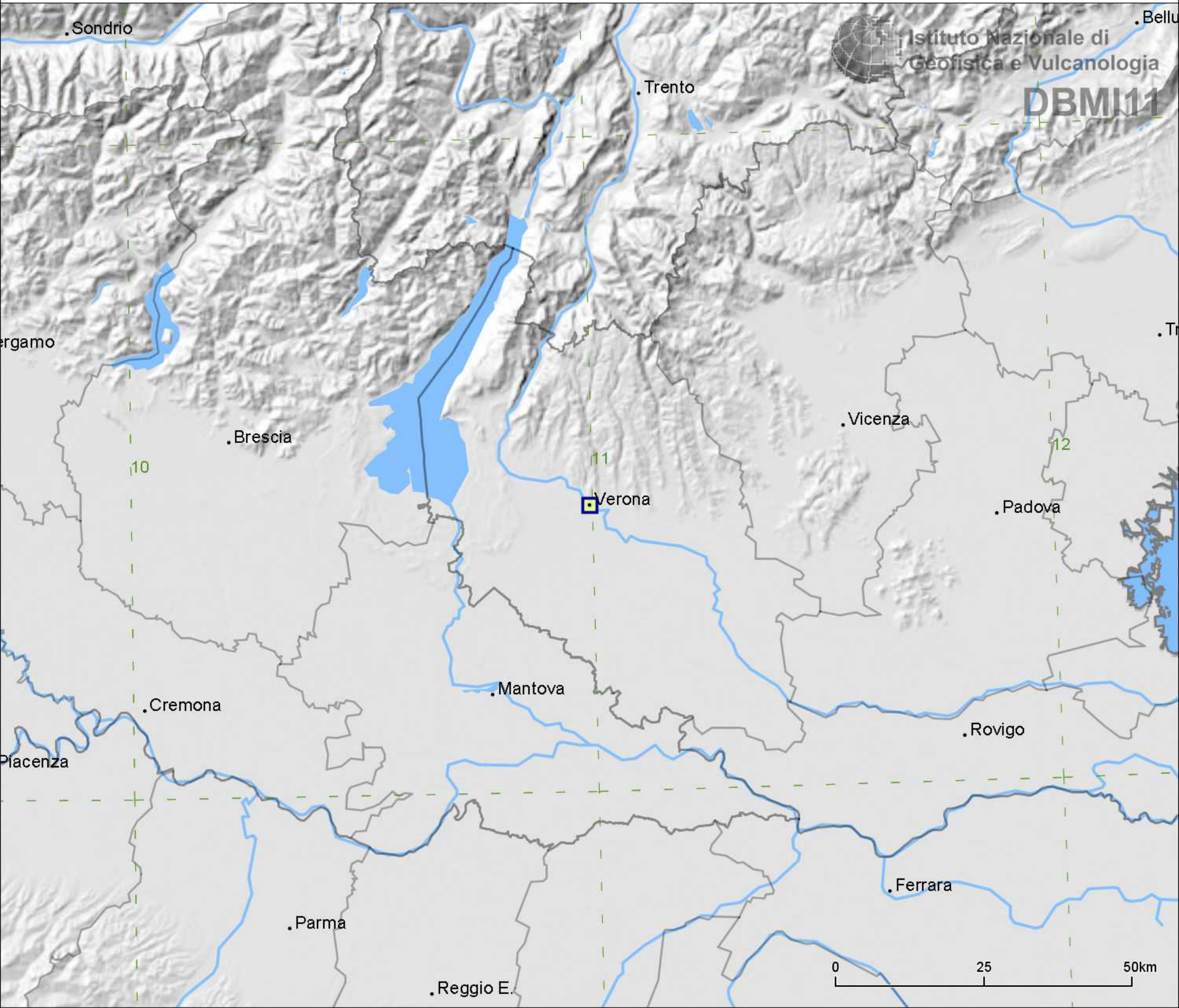
Epicentro CPTI11 Mw 5.35 ±0.34
macrosismico Mw 5.35 ±0.34

Istituto Nazionale di Geofisica e Vulcanologia | DBMI11

1	2	3	4	5	6	7	8	9	10	11
Int. 2-3	3-4	F	4-5	5-6	6-7	7-8	8-9	9-10	10-11	

Terremoto del 21 settembre 1365 05:45:--, Verona
Studio macrosismico Guidoboni et al., 2007 [Np 2, Imax 5-6]

Epicentro CPTI11 Mw 4.51 ±0.34
macrosismico Mw 4.51 ±0.34



Istituto Nazionale di Geofisica e Vulcanologia | DBMI11

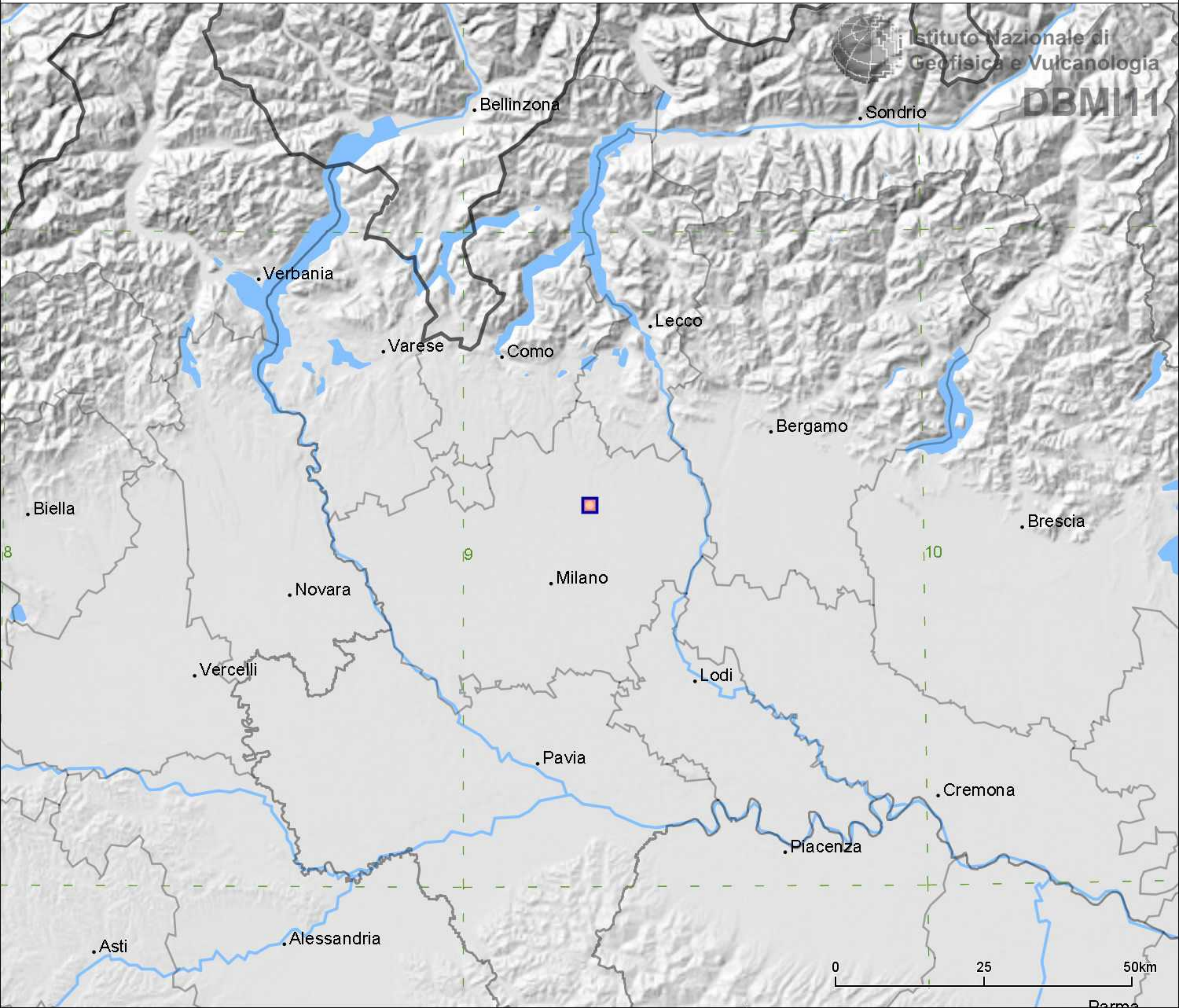
Int. 1 2 3 4 5 6 7 8 9 10 11
2-3 3-4 F 4-5 5-6 6-7 7-8 8-9 9-10 10-11

Terremoto del 26 novembre 1396, Monza

Studio macrosismico Guidoboni et al., 2007 [Np 2, Imax 7-8]

Epicentro CPTI11 Mw 5.35 ±0.34

macrosismico Mw 5.35 ±0.34



Istituto Nazionale di Geofisica e Vulcanologia | DBMI11

1	2	3		4	5	6	7	8	9	10	11
Int. 2-3	3-4	F		4-5	5-6	6-7	7-8	8-9	9-10	10-11	

Terremoto del 9 maggio 1410 22:30:--, FERRARA
Studio macrosismico ENEL, 1985 [Np 3, Imax 6-7]

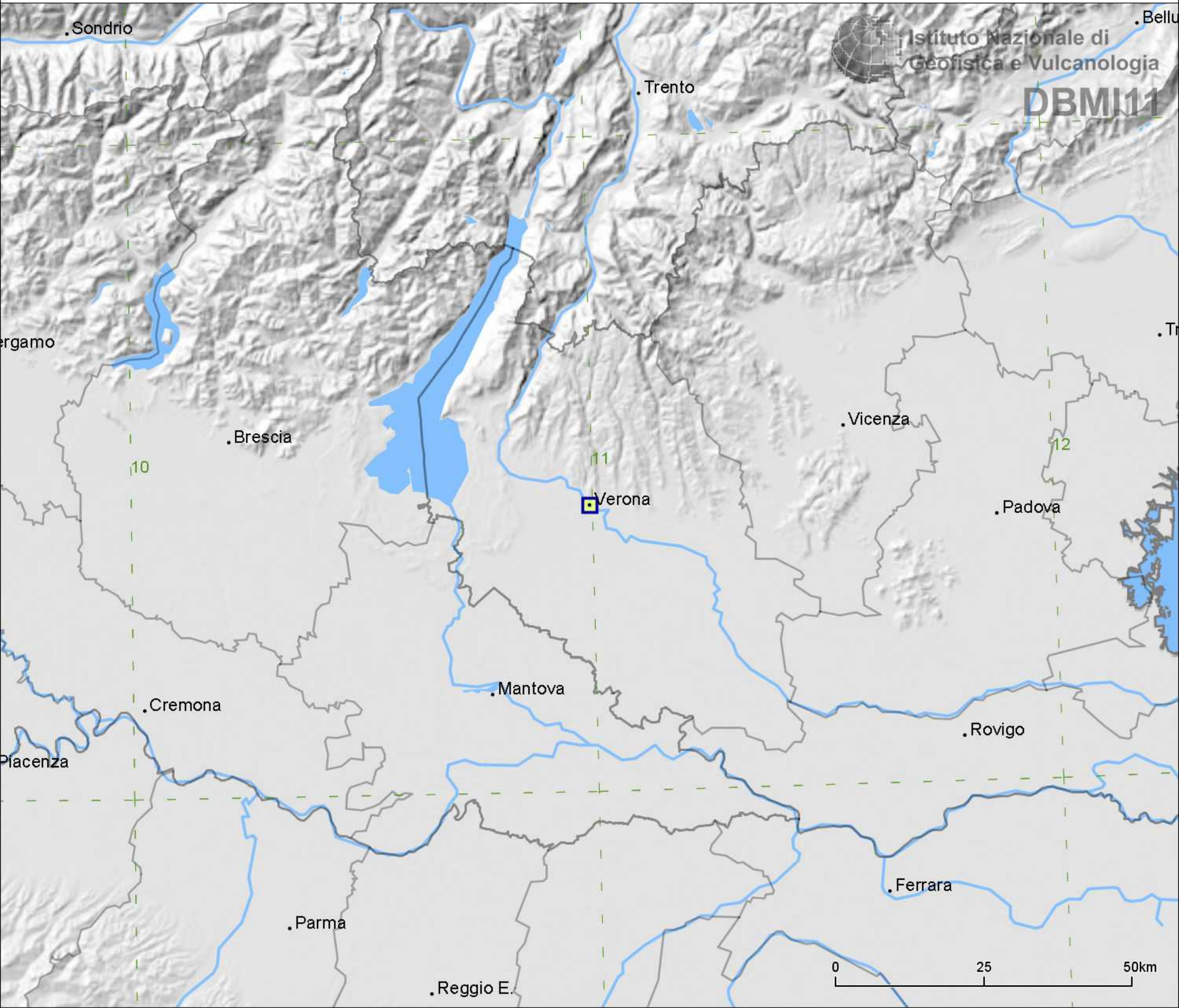
Epicentro CPTI11 Mw 4.93 ±0.34
macrosismico Mw 4.93 ±0.34

Istituto Nazionale di Geofisica e Vulcanologia | DBMI11

Int.	1	2	3	4	5	6	7	8	9	10	11
	2-3	3-4	F	4-5	5-6	6-7	7-8	8-9	9-10	10-11	

Terremoto del 21 marzo 1445 13:30:--, VERONA
Studio macrosismico ENEL, 1985 [Np 3, Imax 5-6]

Epicentro CPTI11 Mw 4.51 ±0.34
macrosismico Mw 4.51 ±0.34

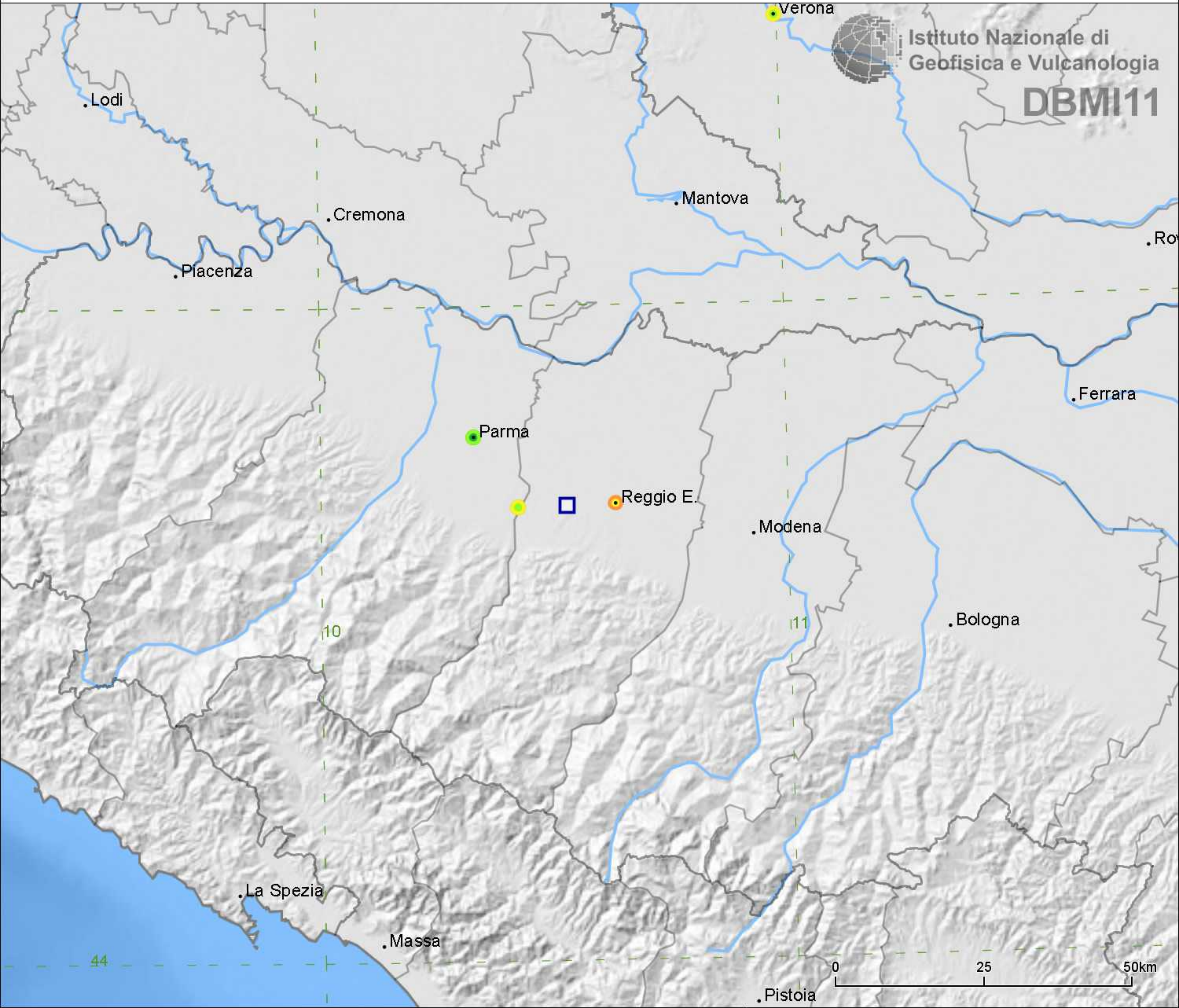


1	2	3		4	5	6	7	8	9	10	11
2-3	3-4	F		4-5	5-6	6-7	7-8	8-9	9-10	10-11	

Int.

Terremoto del 7 aprile 1465 15:30:--, Pianura Padana
Studio macrosismico Guidoboni et al., 2007 [Np 11, Imax 6-7]

Epicentro CPTI11 Mw 4.51 ±0.34
macrosismico Mw 4.51 ±0.34



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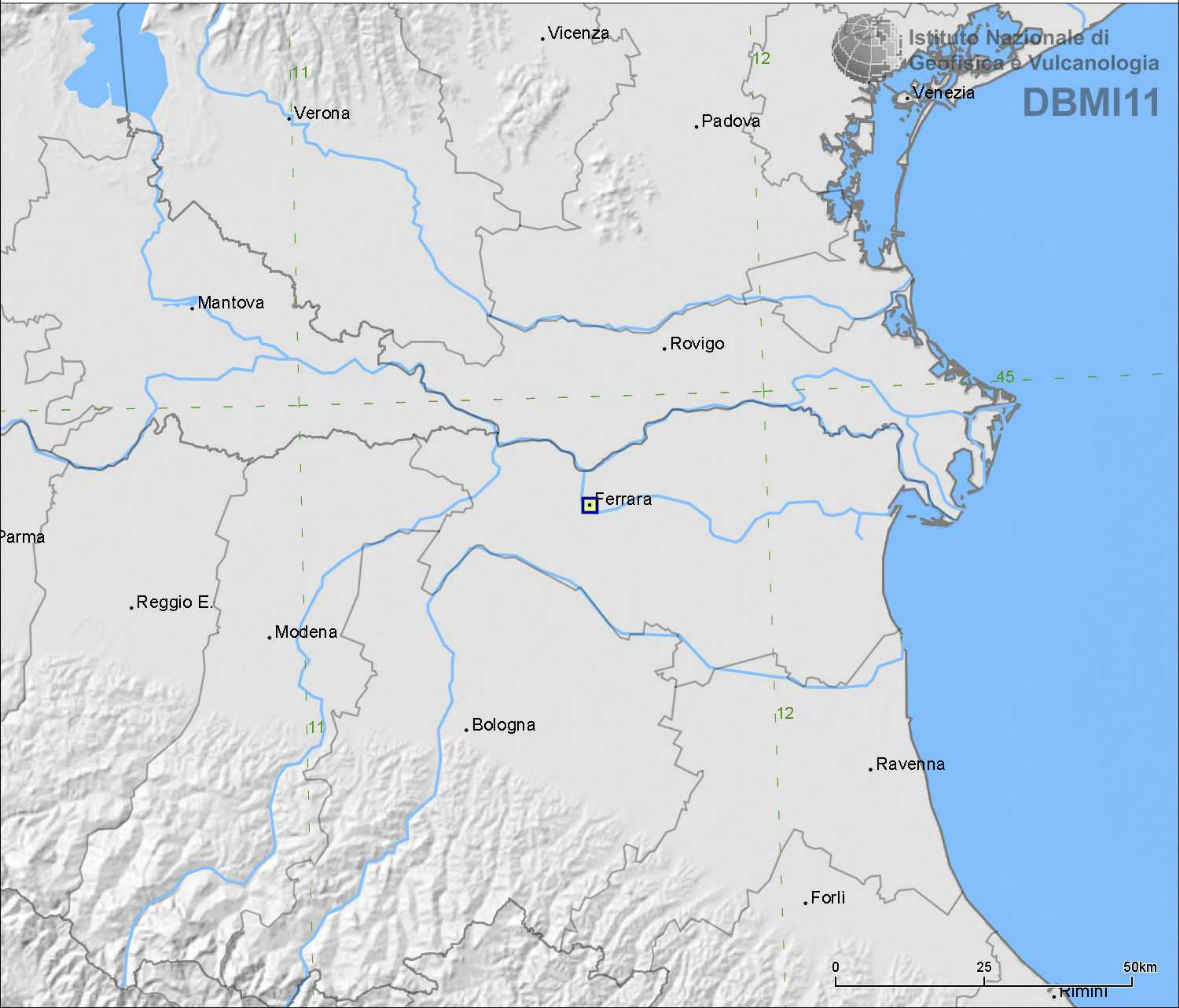
1	2	3		4	5	6	7	8	9	10	11
Int. 2-3	3-4	F		4-5	5-6		6-7	7-8	8-9	9-10	10-11

Terremoto del 3 marzo 1483 22:--:--, FERRARA
Studio macrosismico ENEL, 1985 [Np 1, Imax 5-6]

Epicentro CPTI11 □ Mw 4.51 ±0.34
macrosismico □ Mw 4.51 ±0.34



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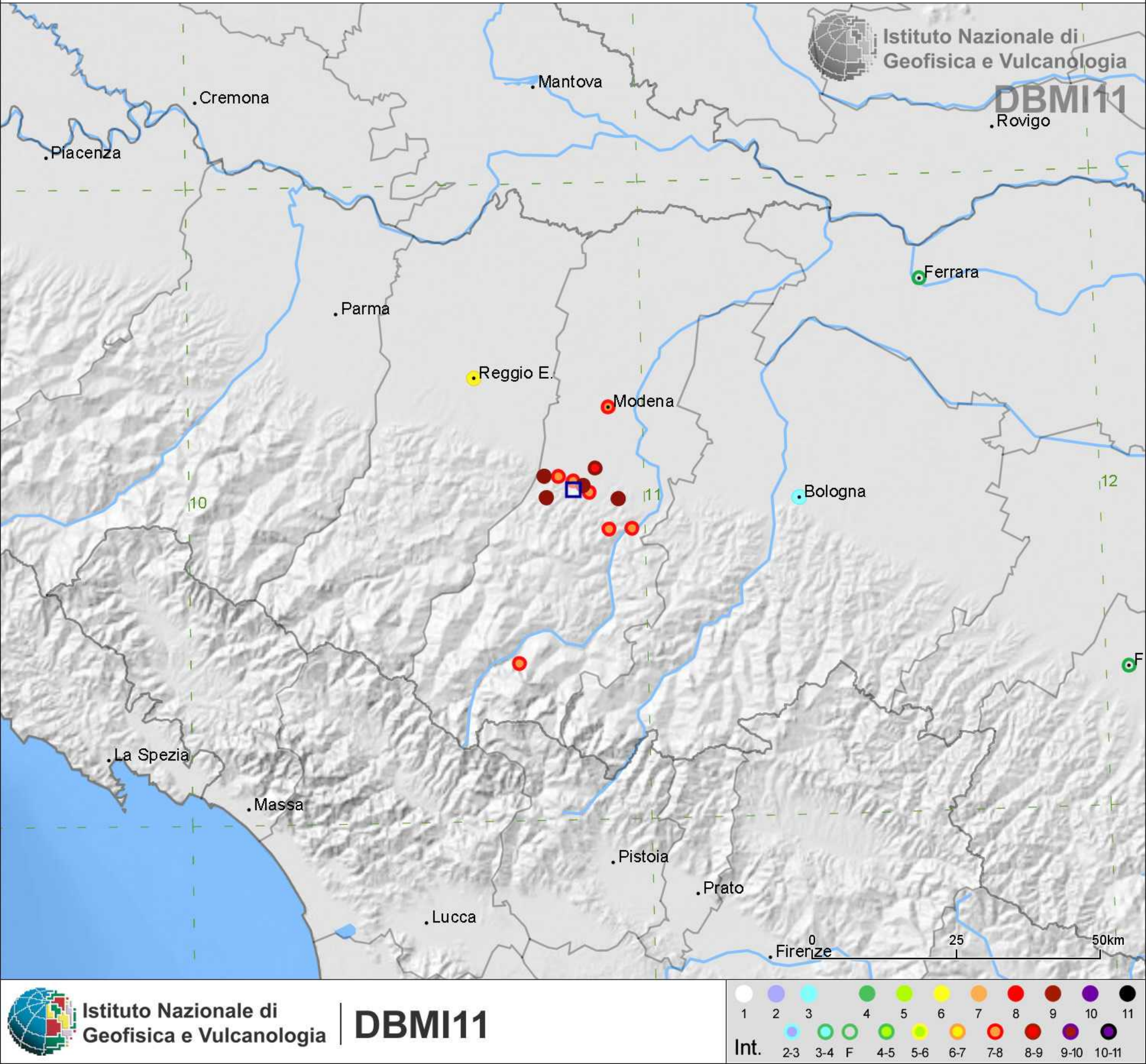
Int.
1 2 3 4 5 6 7 8 9 10 11
2-3 3-4 F 4-5 5-6 6-7 7-8 8-9 9-10 10-11

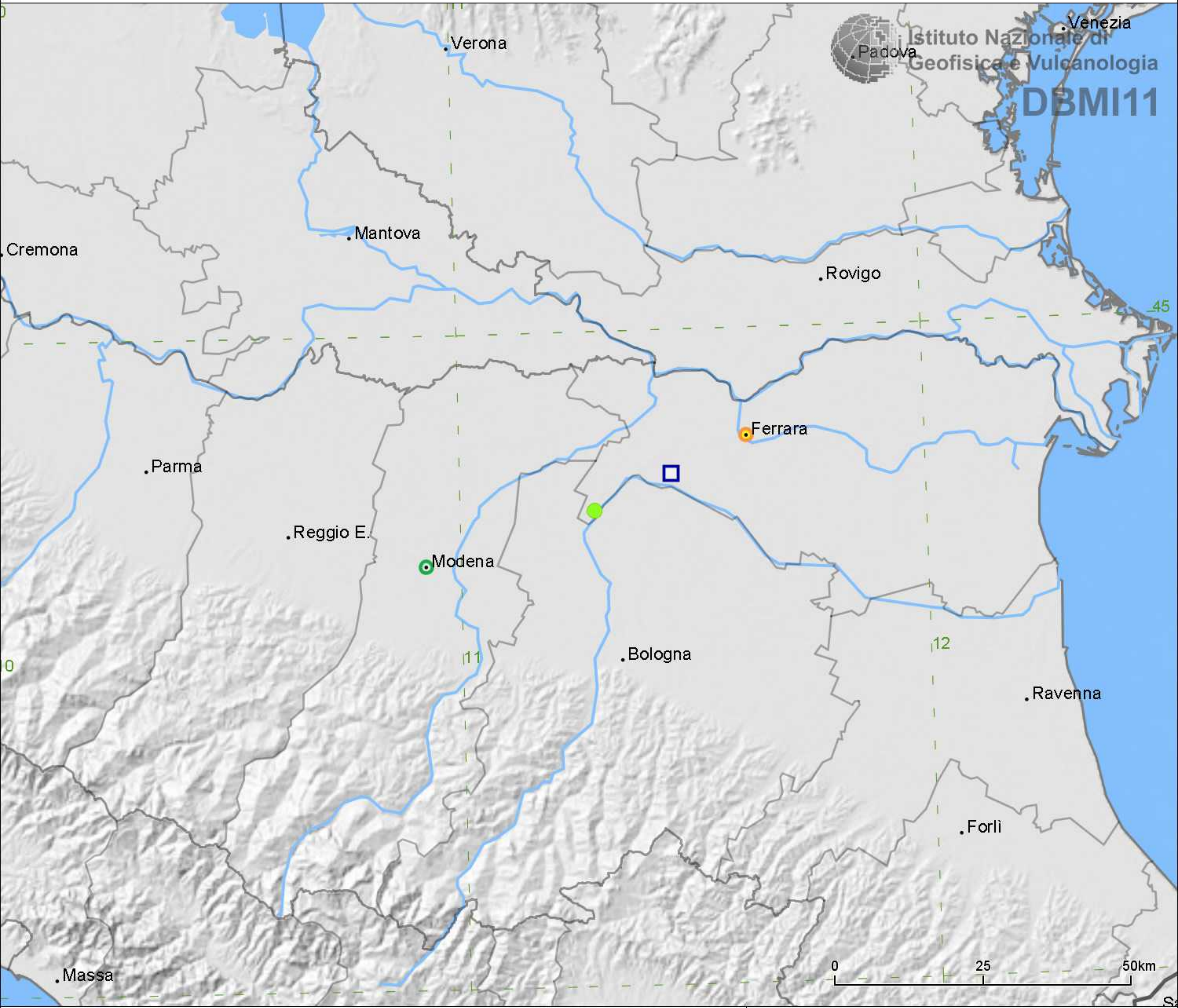
Terremoto del 5 giugno 1501 10:--:--, Appennino modenese
Studio macrosismico Guidoboni et al., 2007 [Np 20, Imax 9]

Epicentro CPTI11 Mw 5.98 ±0.32
macrosismico Mw 5.98 ±0.32



Terremoto del 24 novembre 1561 01:25:--, Ferrara
Studio macrosismico Guidoboni et al., 2007 [Np 5, Imax 6-7]

Epicentro CPTI11 Mw 4.51 ±0.34
macrosismico Mw 4.51 ±0.34



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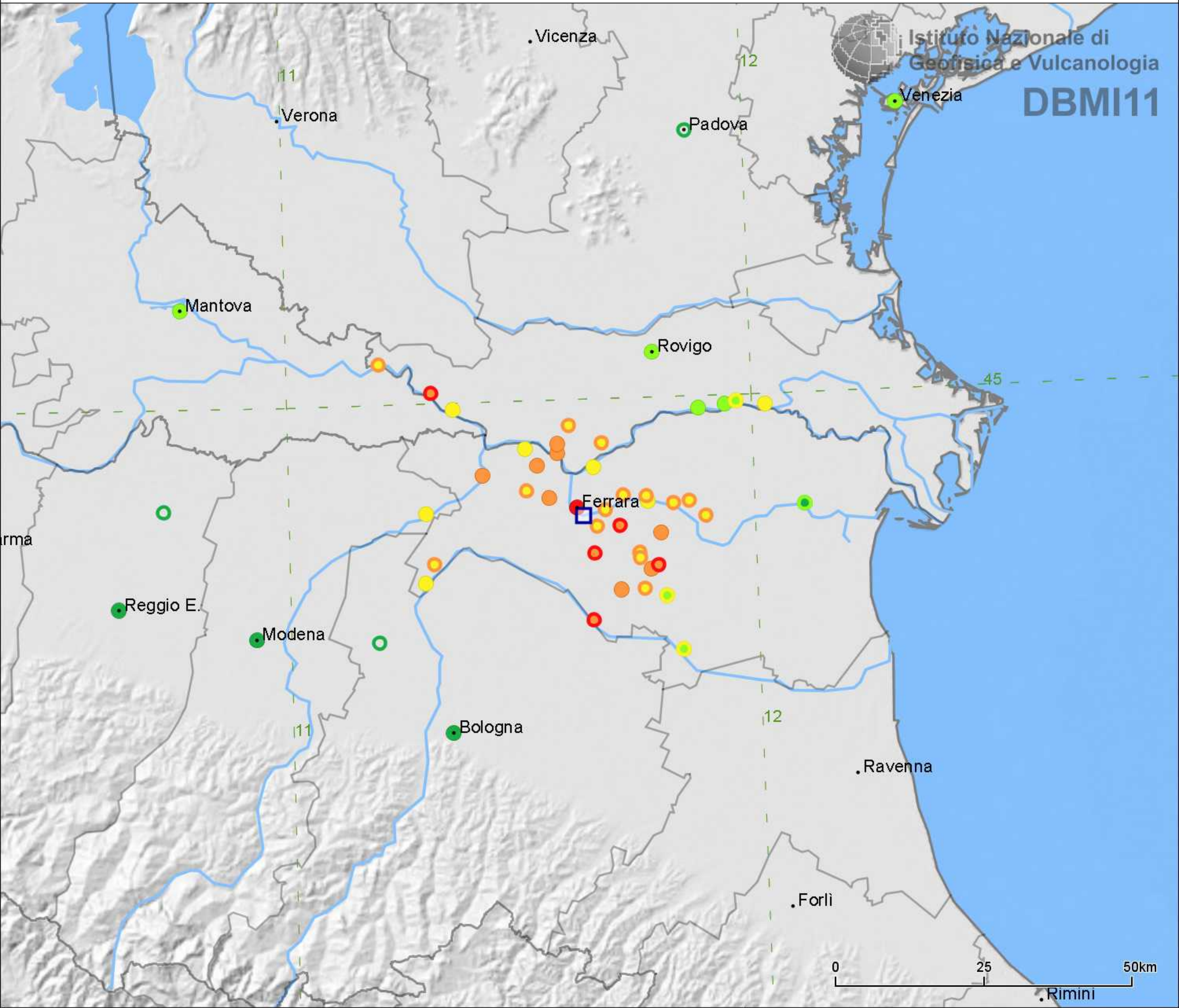
Int.	1	2	3	4	5	6	7	8	9	10	11
	2-3	3-4	F	4-5	5-6	6-7	7-8	8-9	9-10	10-11	

Terremoto del 17 novembre 1570 19:10:--, Ferrara
Studio macrosismico Guidoboni et al., 2007 [Np 60, Imax 8]

Epicentro CPTI11 Mw 5.46 ±0.25
macrosismico Mw 5.46 ±0.25



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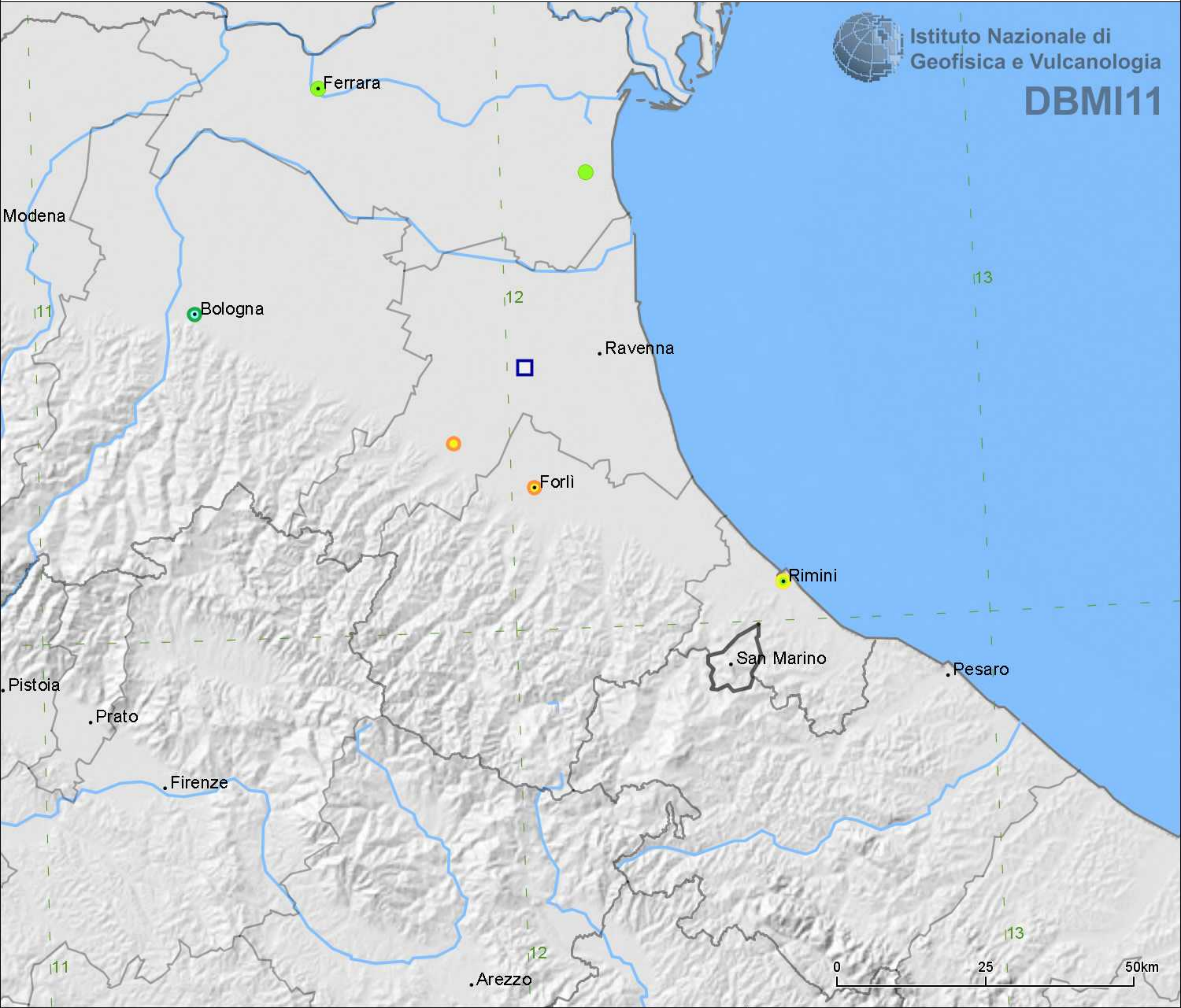
Int. 1 2 3 4 5 6 7 8 9 10 11
2-3 3-4 F 4-5 5-6 6-7 7-8 8-9 9-10 10-11

Terremoto del 10 luglio 1591, FORLI'

Studio macrosismico Postpischl, 1990 [Np 6, Imax 6-7]

Epicentro CPTI11 □ Mw 5.19 ±0.79

macrosismico □ Mw 5.19 ±0.79



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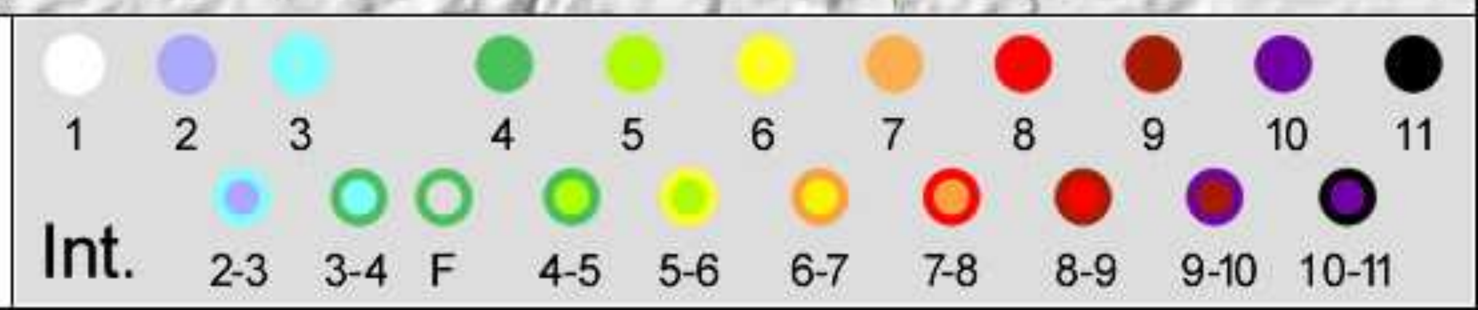
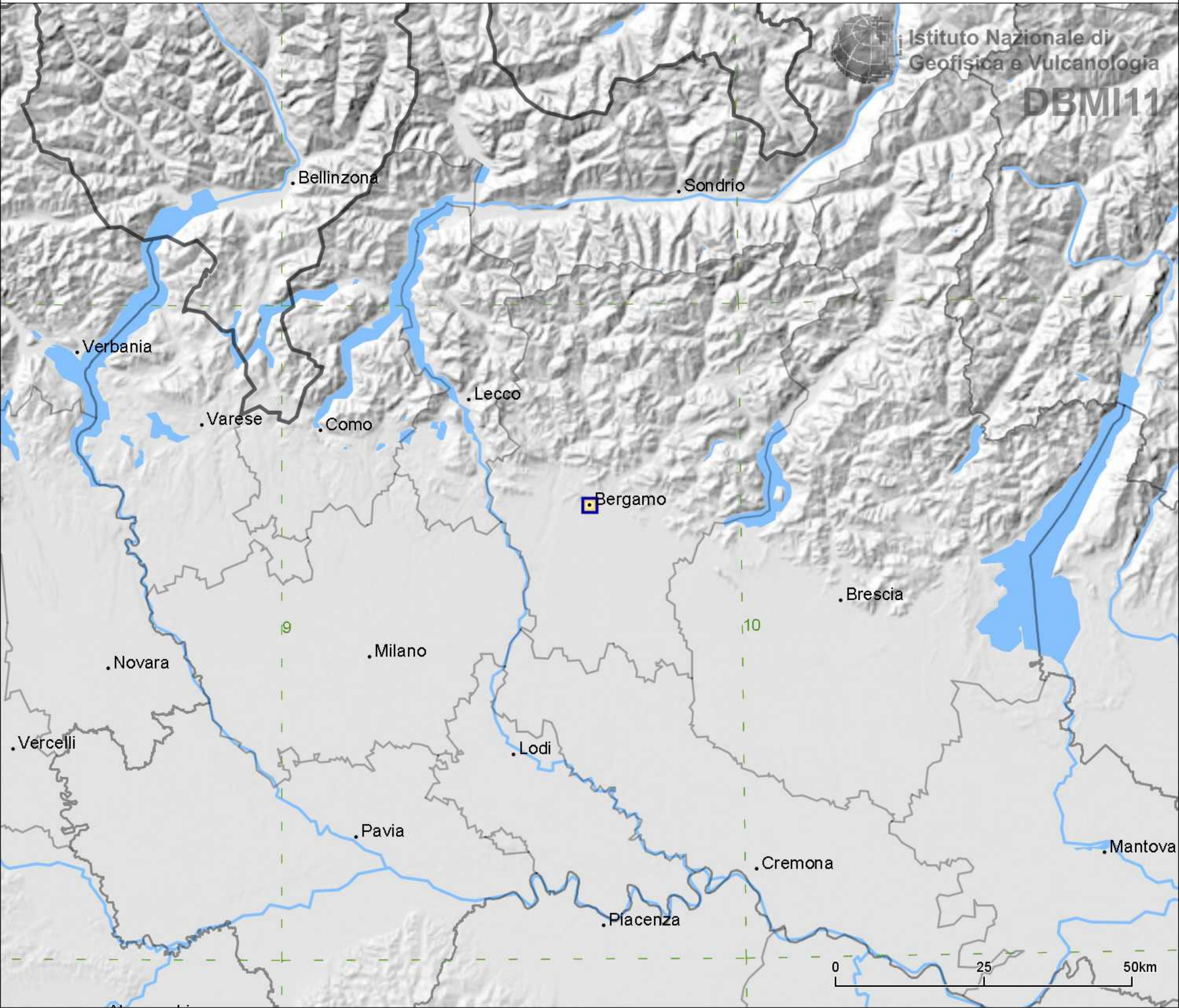


Terremoto del 8 marzo 1593, BERGAMO
Studio macrosismico Arch.Mac.GNDT, 1995 [Np 1, Imax 6-7]

Epicentro CPTI11 Mw 4.93 ±0.34
macrosismico Mw 4.93 ±0.34



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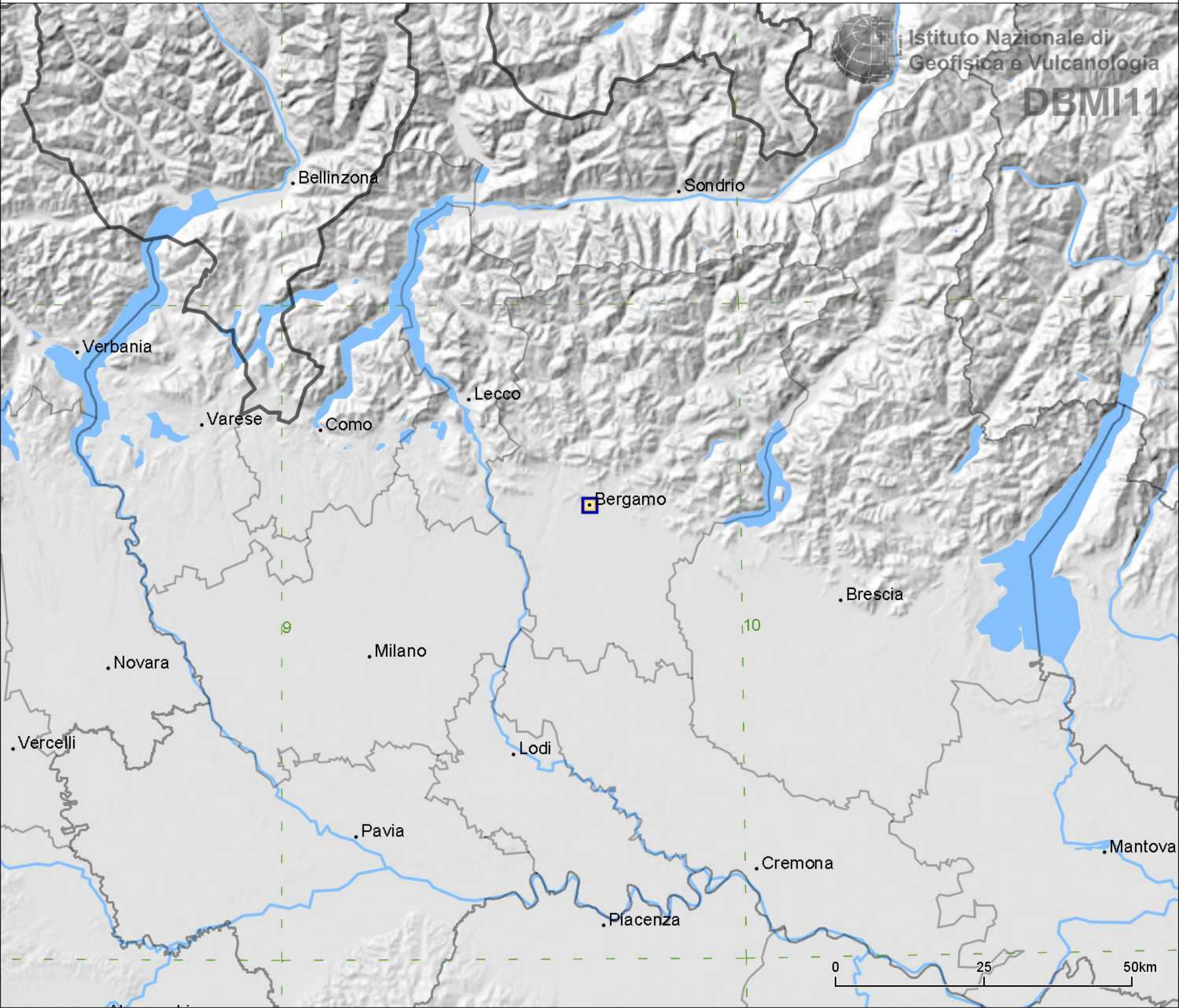
Terremoto del 22 agosto 1606, BERGAMO
Studio macrosismico Arch.Mac.GNDT, 1995 [Np 1, Imax 6-7]

Epicentro CPTI11 Mw 4.93 ±0.34
macrosismico Mw 4.93 ±0.34



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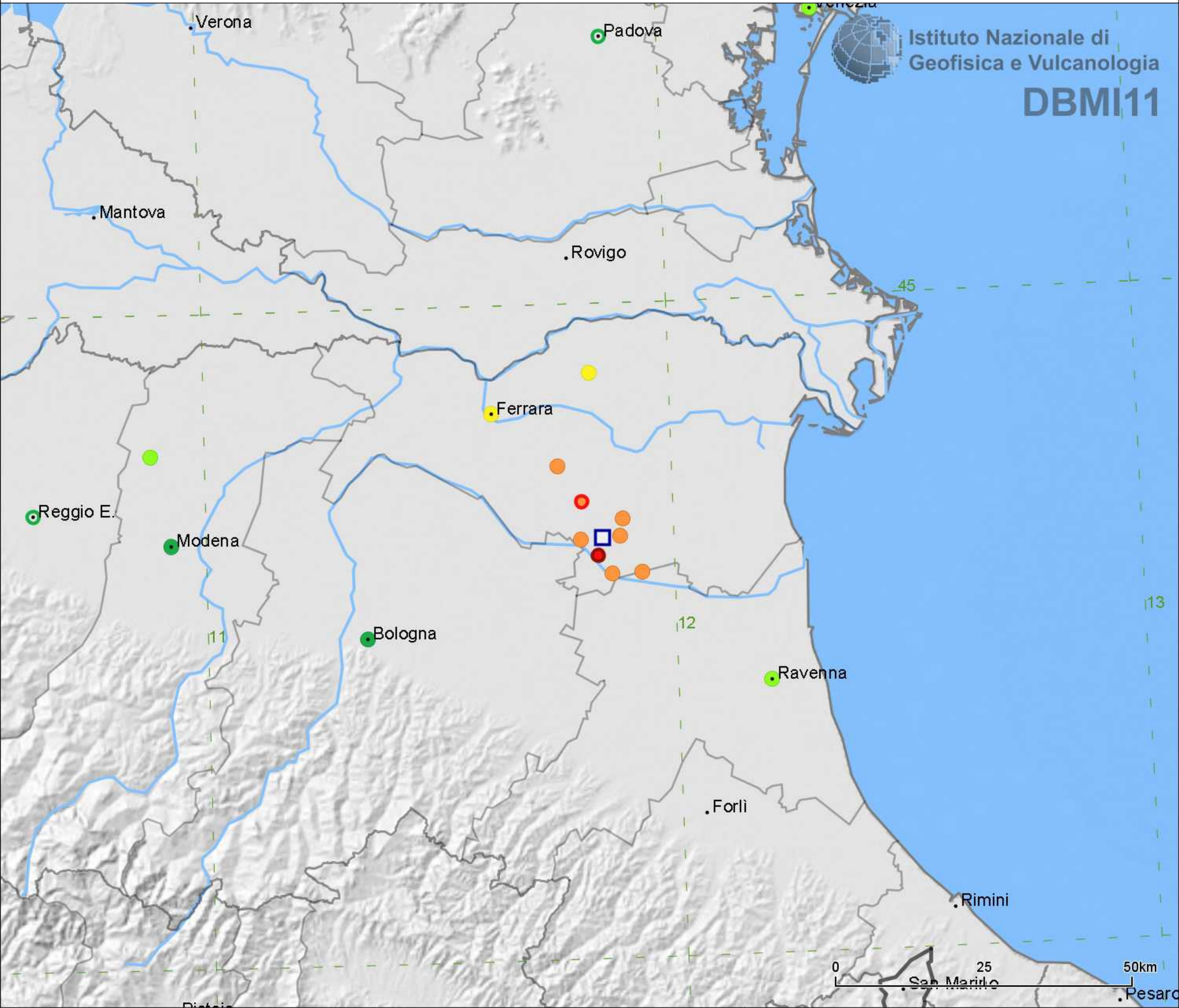
Int. 1 2 3 4 5 6 7 8 9 10 11
2-3 3-4 F 4-5 5-6 6-7 7-8 8-9 9-10 10-11

Terremoto del 19 marzo 1624 19:45:--, Argenta
Studio macrosismico Guidoboni et al., 2007 [Np 18, Imax 8-9]

Epicentro CPTI11 Mw 5.47 ±0.49
macrosismico Mw 5.47 ±0.49



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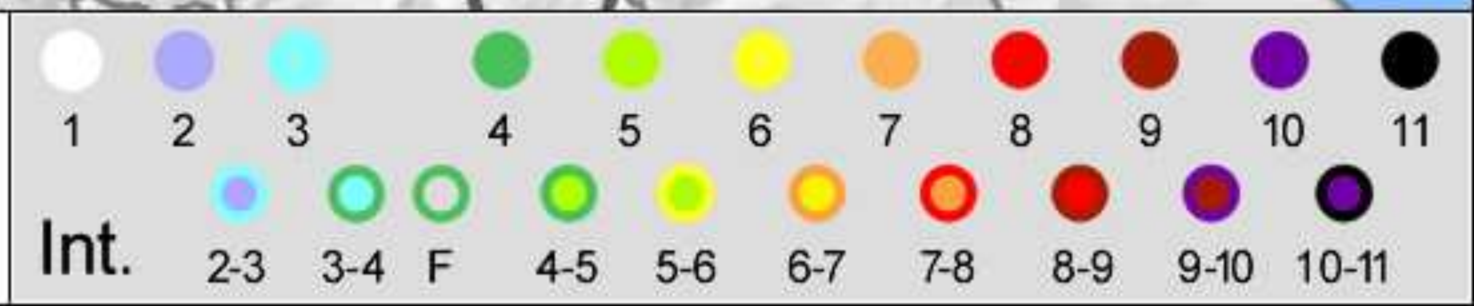
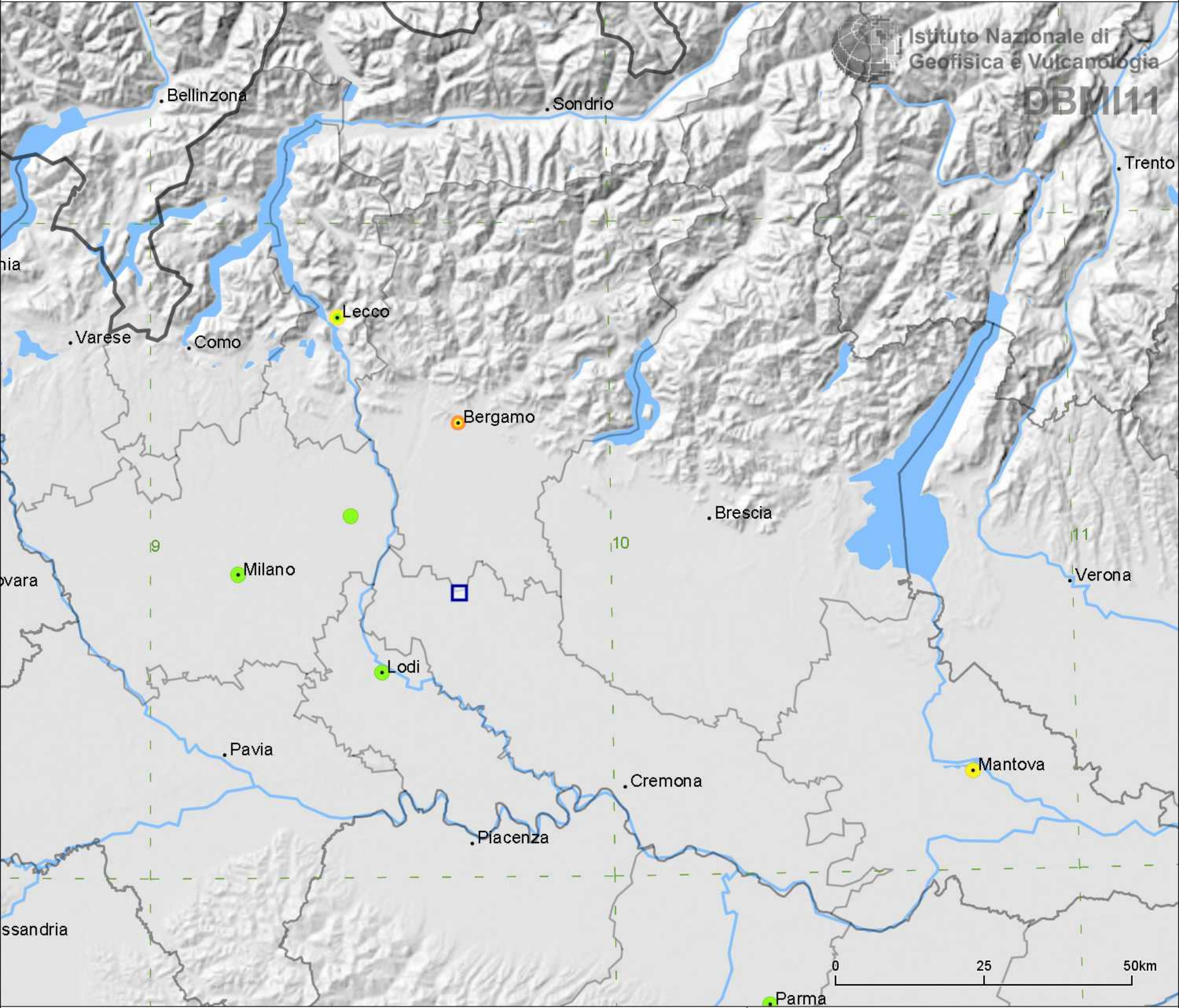


Terremoto del 13 giugno 1642, Bergamo
Studio macrosismico Stucchi et al., 2008 [Np 8, Imax 6-7]

Epicentro CPTI11 □ Mw 5.04 ±0.72
macrosismico □ Mw 5.04 ±0.72



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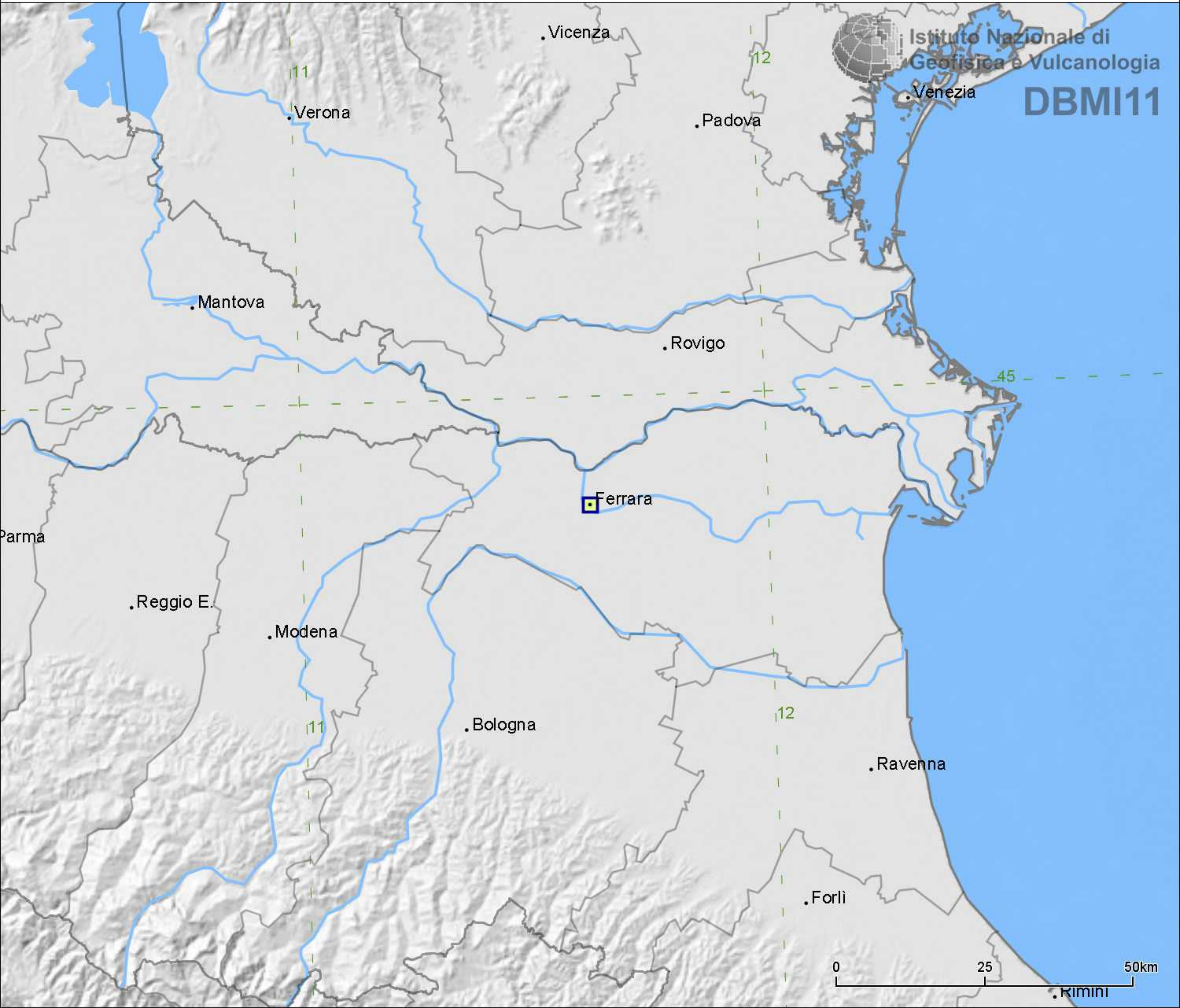
Int.: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11; 2-3, 3-4, F, 4-5, 5-6, 6-7, 7-8, 8-9, 9-10, 10-11

Terremoto del 28 febbraio 1695, FERRARA
Studio macrosismico Arch.Mac.GNDT, 1995 [Np 1, Imax 5-6]

Epicentro CPTI11 Mw 4.51 ±0.34
macrosismico Mw 4.51 ±0.34



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Int.	1	2	3	4	5	6	7	8	9	10	11
	2-3	3-4	F	4-5	5-6	6-7	7-8	8-9	9-10	10-11	

Terremoto del 29 maggio 1743, FERRARA
Studio macrosismico Arch.Mac.GNDT, 1995 [Np 1, Imax 6-7]

Epicentro CPTI11 Mw 4.93 ±0.34
macrosismico Mw 4.93 ±0.34

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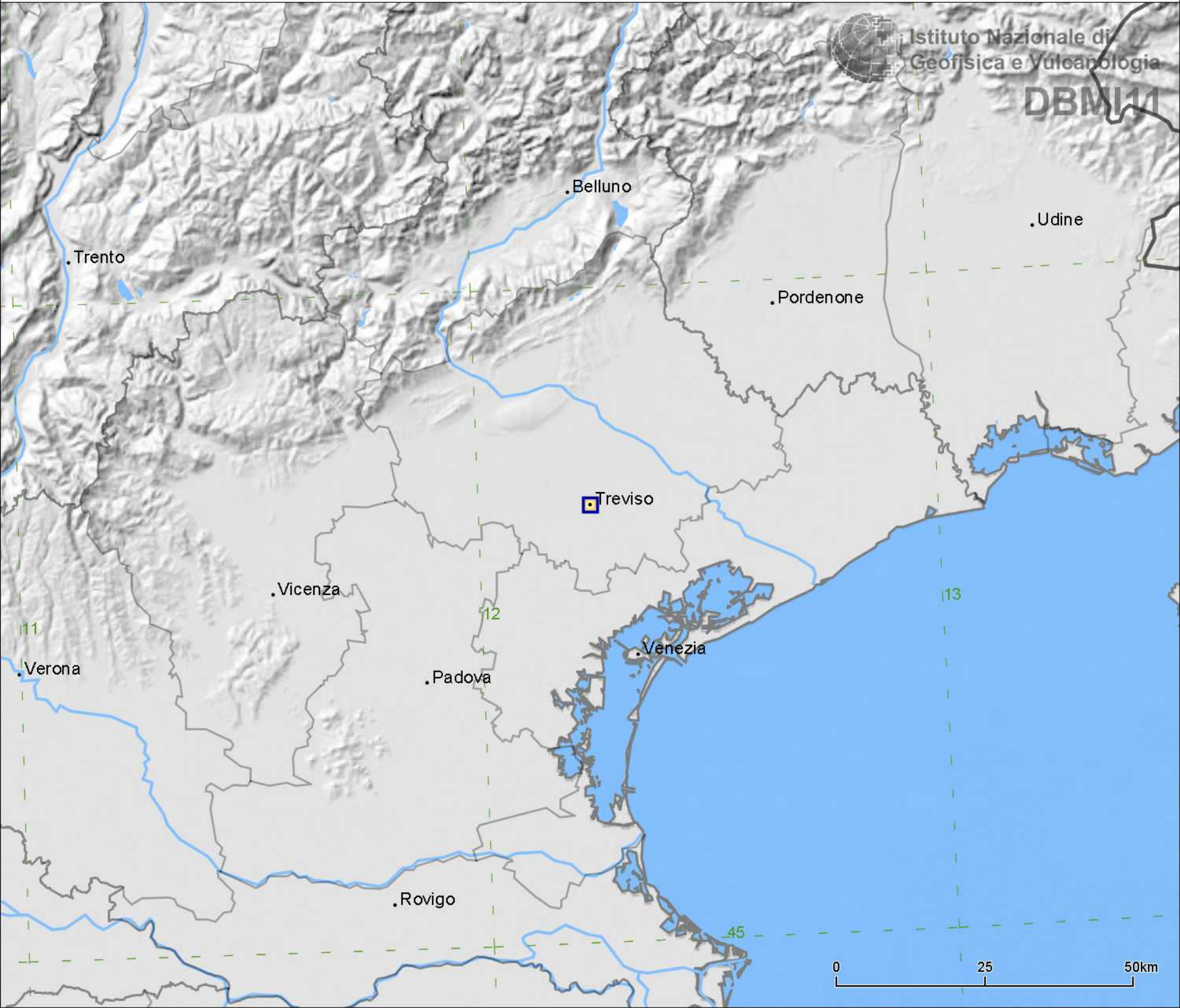
1	2	3	4	5	6	7	8	9	10	11

Int. 2-3 3-4 F 4-5 5-6 6-7 7-8 8-9 9-10 10-11

Terremoto del 13 aprile 1756, TREVISO
Studio macrosismico Arch.Mac.GNDT, 1995 [Np 1, Imax 6-7]

Epicentro CPTI11 Mw 4.93 ±0.34
macrosismico Mw 4.93 ±0.34



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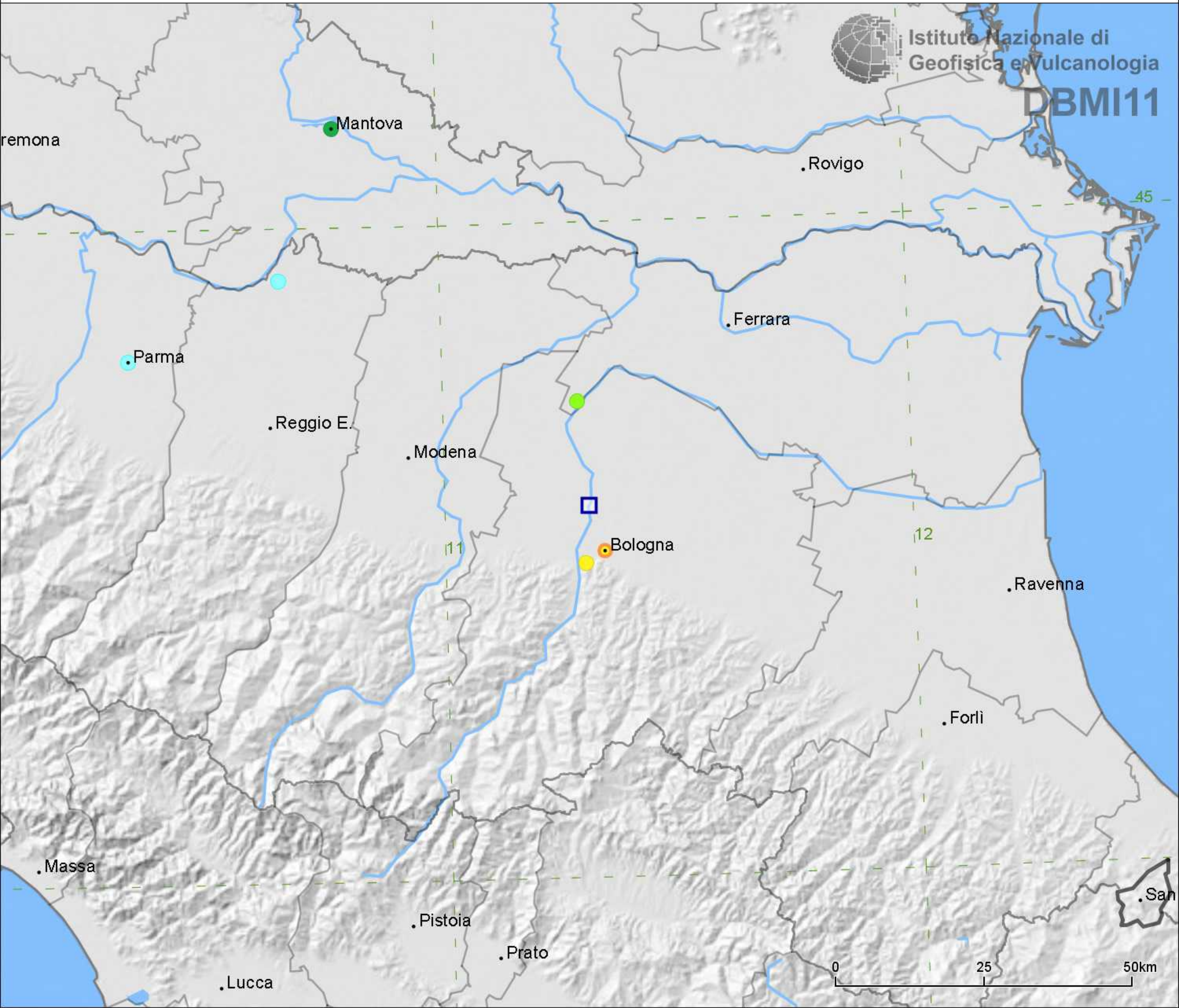
Int. 1 2 3 4 5 6 7 8 9 10 11
2-3 3-4 F 4-5 5-6 6-7 7-8 8-9 9-10 10-11

Terremoto del 6 febbraio 1780 04:--:--, Bolognese
Studio macrosismico Guidoboni et al., 2007 [Np 9, Imax 6-7]

Epicentro CPTI11 Mw 5.13 ±0.57
macrosismico Mw 5.13 ±0.57



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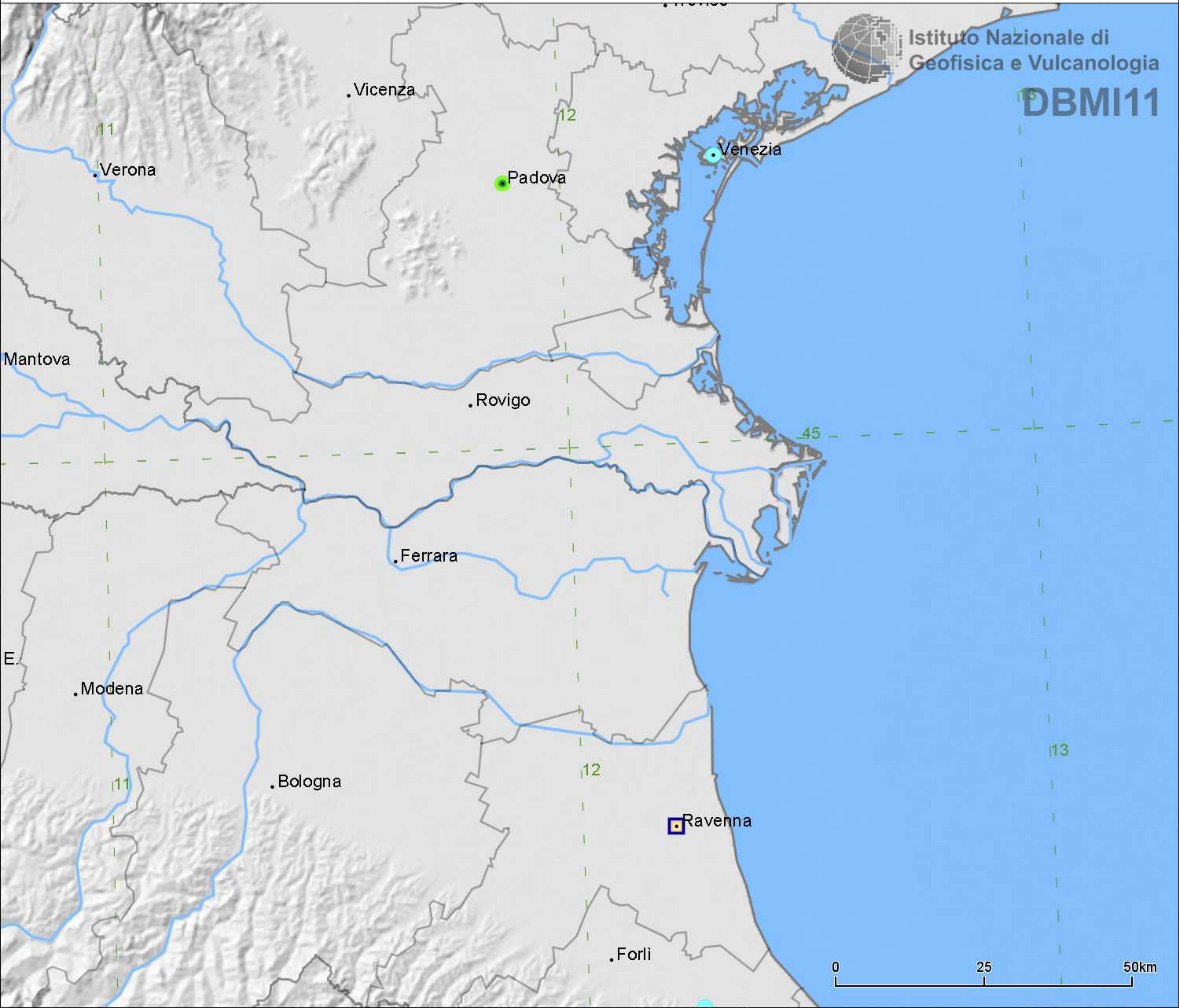
Terremoto del 25 maggio 1780, RAVENNA
Studio macrosismico ENEL, 1985 [Np 5, Imax 6-7]

Epicentro CPTI11 Mw 4.51 ±0.34
macrosismico Mw 4.51 ±0.34



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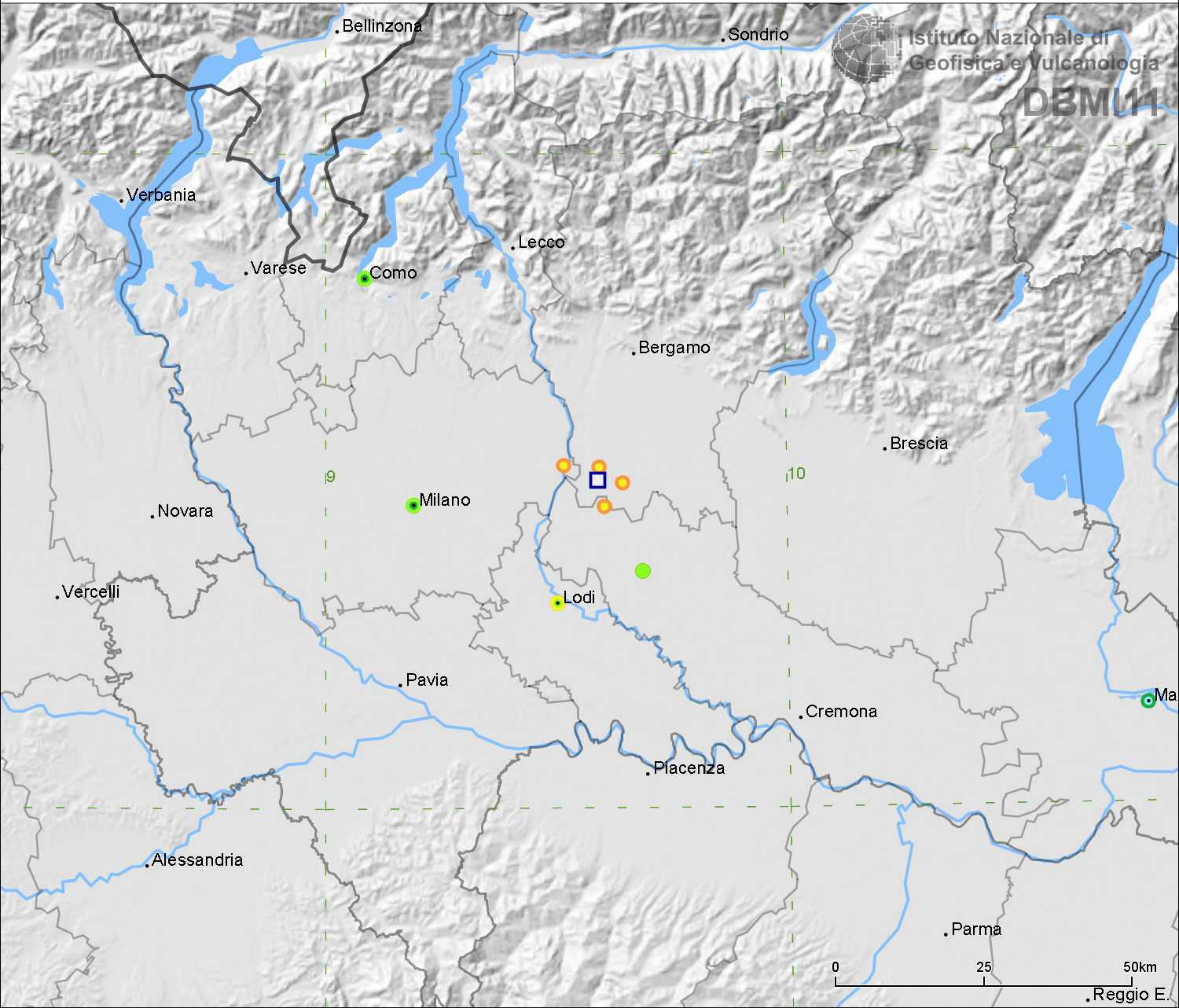
Int. 1 2 3 4 5 6 7 8 9 10 11
2-3 3-4 F 4-5 5-6 6-7 7-8 8-9 9-10 10-11

Terremoto del 10 settembre 1781 11:30:--, Media valle dell'Adda
Studio macrosismico Guidoboni et al., 2007 [Np 11, Imax 6-7]

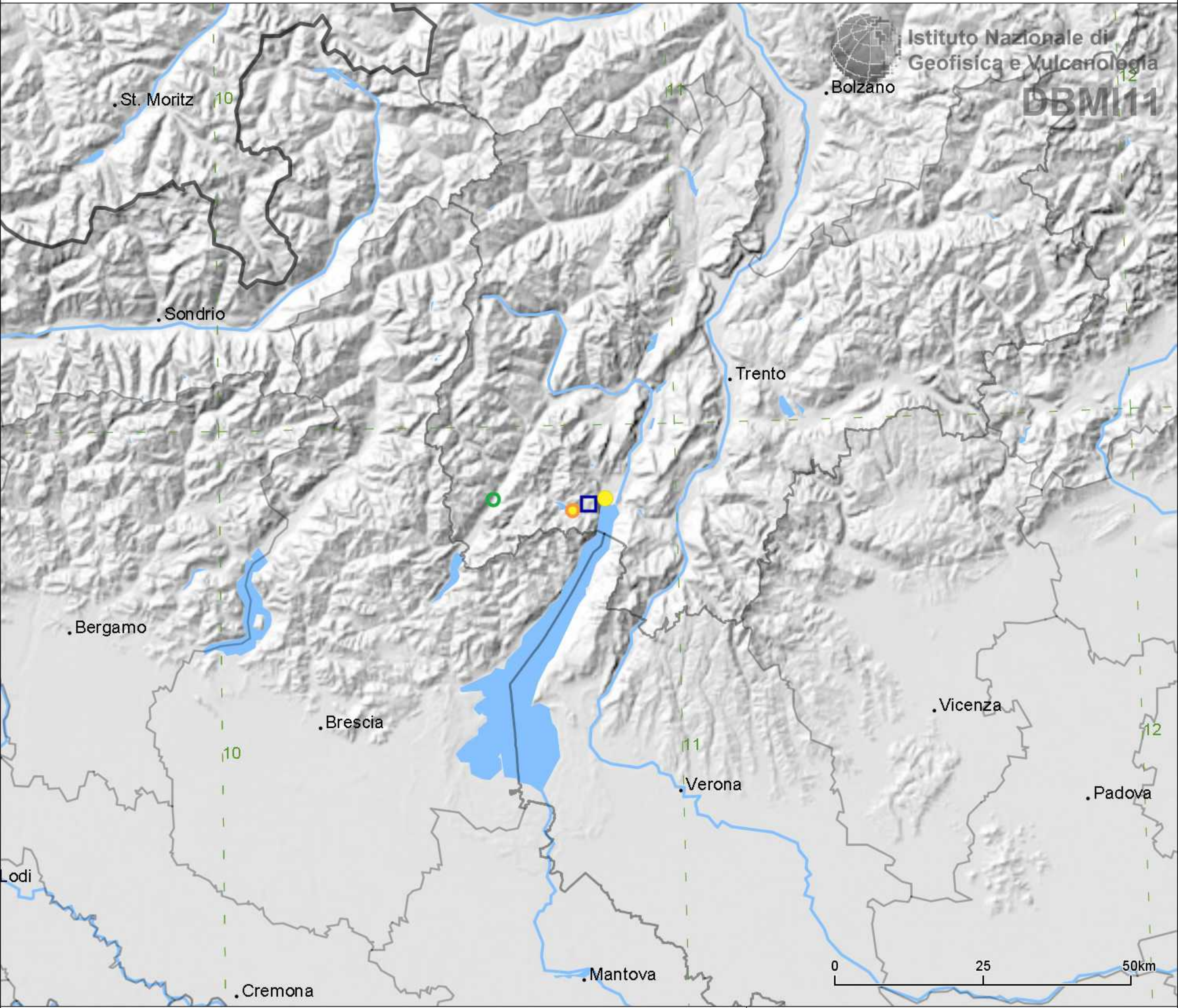
Epicentro CPTI11 Mw 4.90 ±0.67
macrosismico Mw 4.90 ±0.67



Int.: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11; 2-3, 3-4, F, 4-5, 5-6, 6-7, 7-8, 8-9, 9-10, 10-11

Terremoto del 28 luglio 1783, VAL DI LEDRO
Studio macrosismico Albini et al., 1994a [Np 4, Imax 6-7]

Epicentro CPTI11 Mw 4.72 ±0.34
macrosismico Mw 4.72 ±0.34



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Int.
1 2 3 4 5 6 7 8 9 10 11
2-3 3-4 F 4-5 5-6 6-7 7-8 8-9 9-10 10-11

Terremoto del 16 luglio 1787 10:--:--, Ferrara
Studio macrosismico Guidoboni et al., 2007 [Np 3, Imax 6-7]

Epicentro CPTI11 Mw 4.51 ±0.34
macrosismico Mw 4.51 ±0.34

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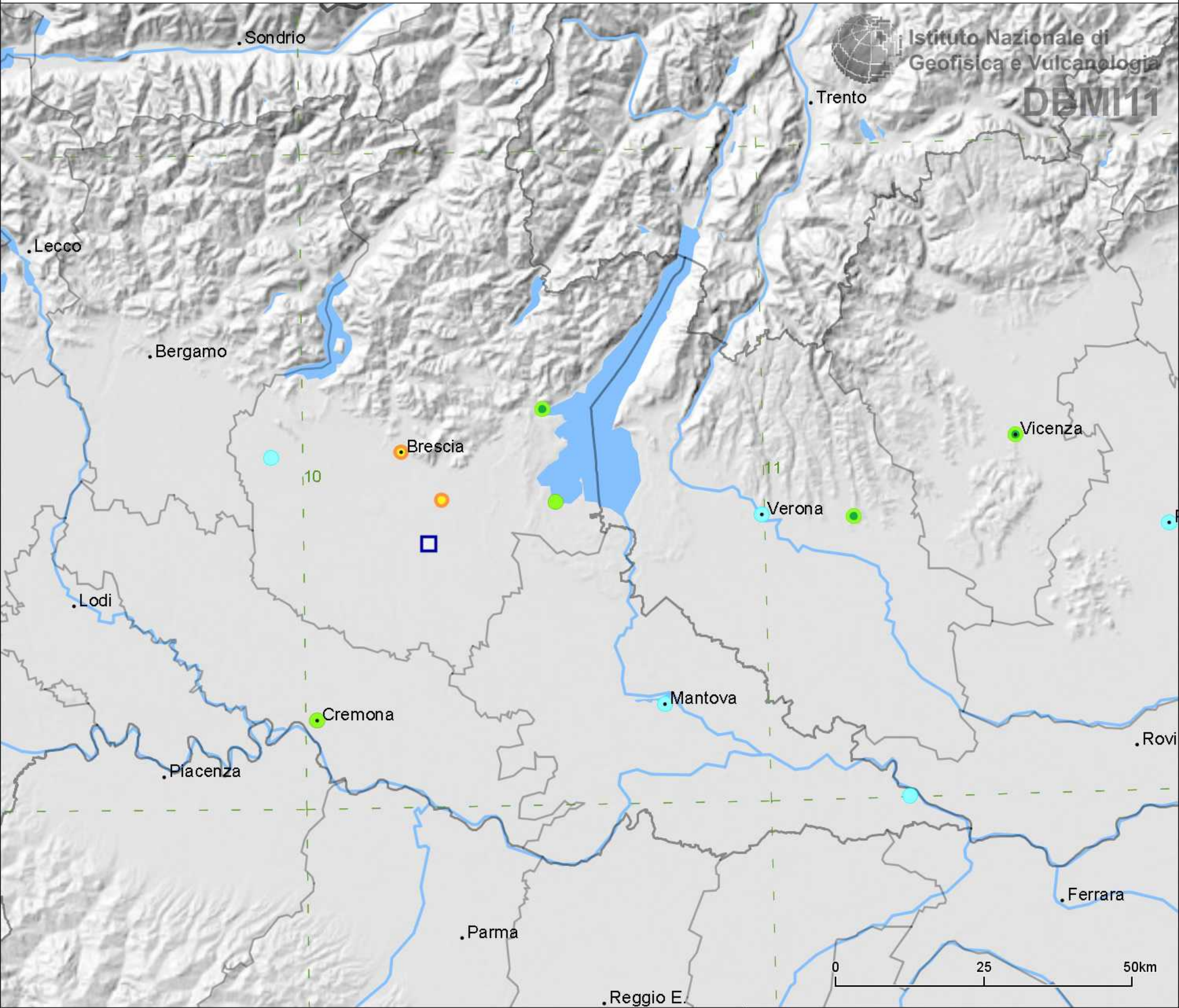
1	2	3	4	5	6	7	8	9	10	11

Int. 2-3 3-4 F 4-5 5-6 6-7 7-8 8-9 9-10 10-11

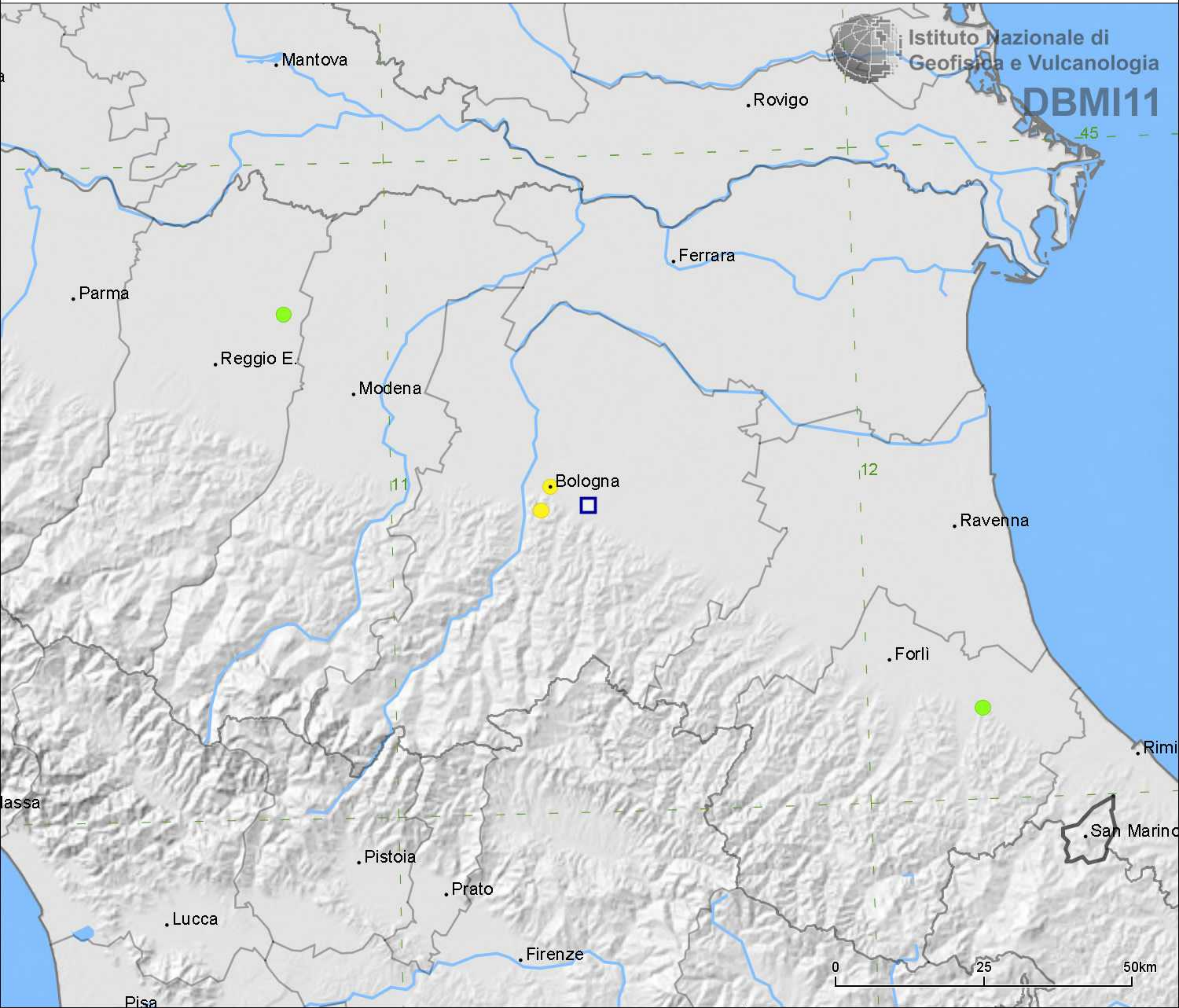
Terremoto del 29 maggio 1799 19:--:--, CASTENEDOLO
Studio macrosismico ENEL, 1985 [Np 12, Imax 6-7]

Epicentro CPTI11 Mw 5.01 ±0.51
macrosismico Mw 5.01 ±0.51



Terremoto del 8 ottobre 1801 07:52:53, Bologna
Studio macrosismico Guidoboni et al., 2007 [Np 6, Imax 6]

Epicentro CPTI11 □ Mw 5.07 ±0.83
macrosismico □ Mw 5.07 ±0.83



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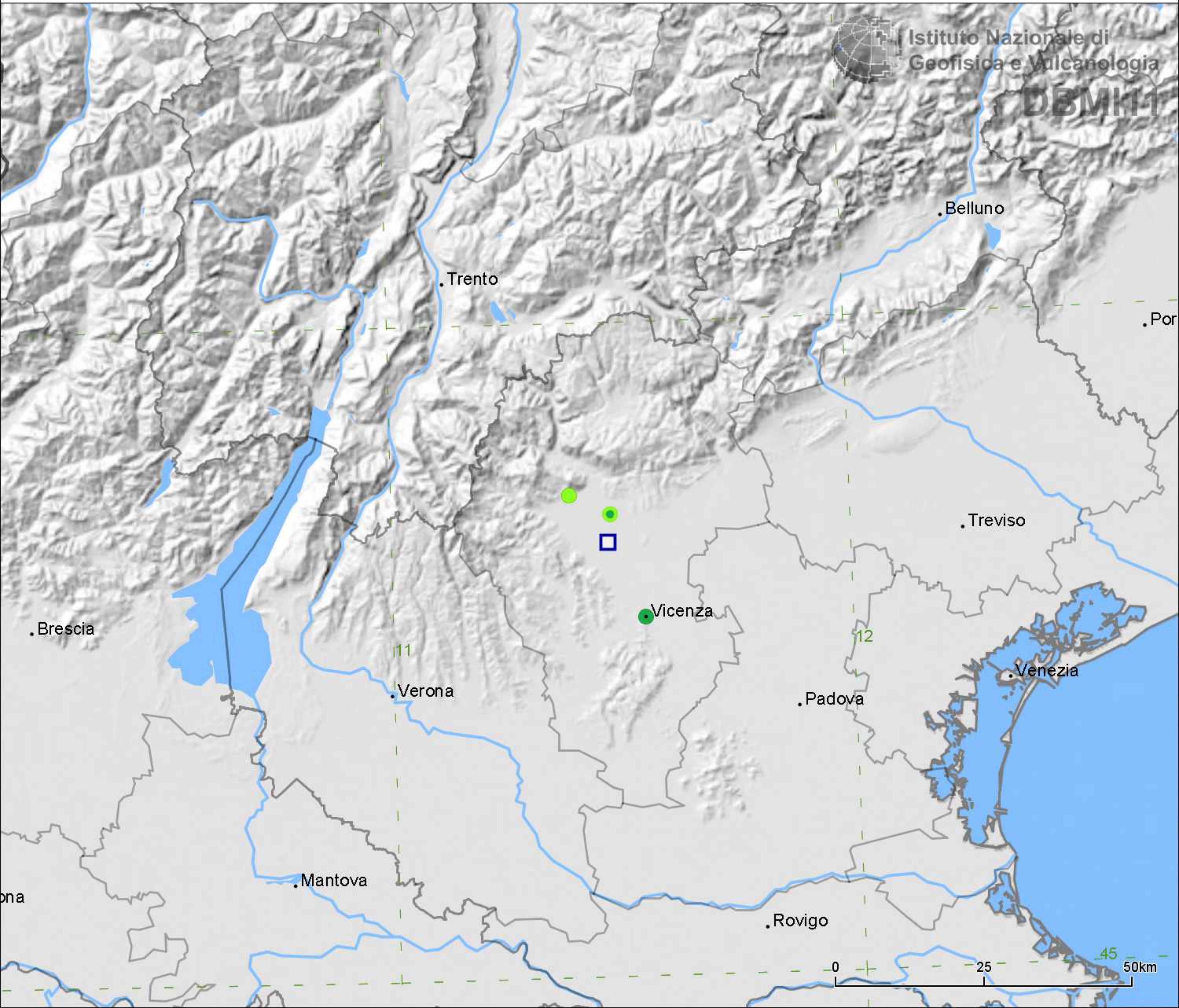
Terremoto del 26 febbraio 1815 19:--:--, Santorso
Studio macrosismico Albini et al., 2003 [Np 3, Imax 5]

Epicentro CPTI11 Mw 4.09 ±0.34
macrosismico Mw 4.09 ±0.34



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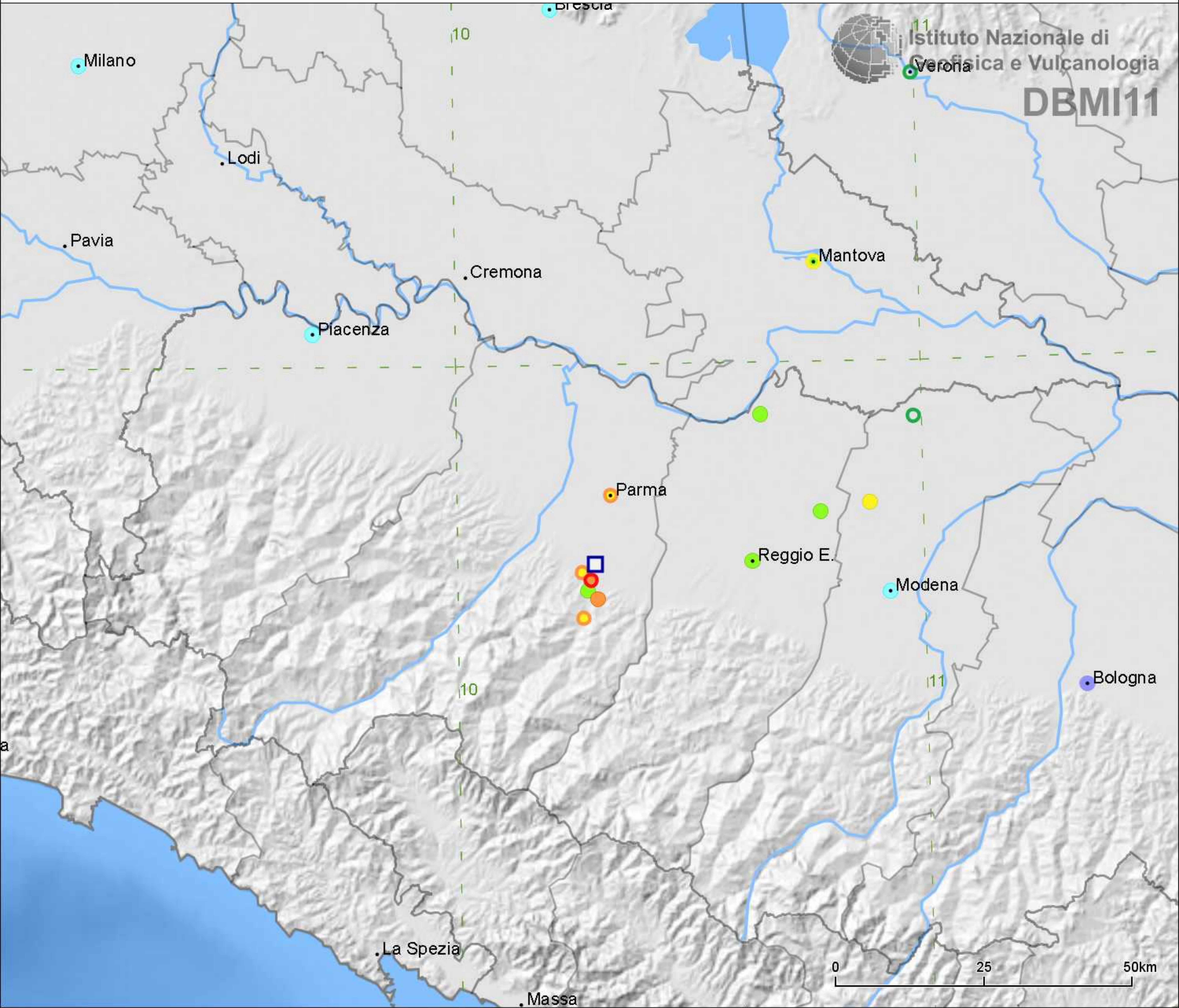
1	2	3	4	5	6	7	8	9	10	11
2-3	3-4	F	4-5	5-6	6-7	7-8	8-9	9-10	10-11	

Int.

Terremoto del 9 dicembre 1818 18:55:--, Parmense
Studio macrosismico Guidoboni et al., 2007 [Np 26, Imax 7-8]

Epicentro CPTI11 Mw 5.28 ±0.35
macrosismico Mw 5.28 ±0.35



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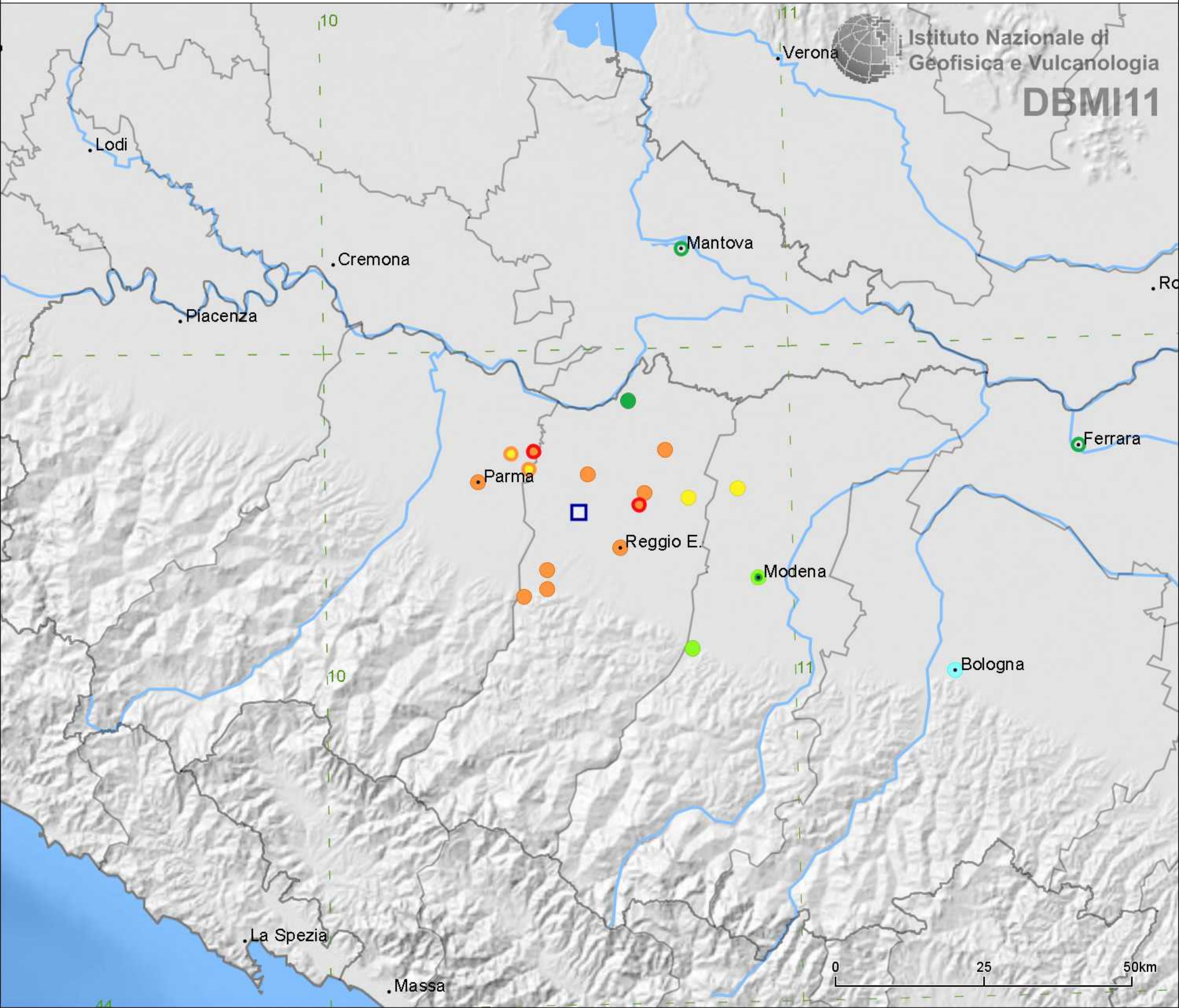
Int.											
	1	2	3	4	5	6	7	8	9	10	11
	2-3	3-4	F	4-5	5-6	6-7	7-8	8-9	9-10	10-11	

Terremoto del 11 settembre 1831 18:15:--, Reggiano

Studio macrosismico Guidoboni et al., 2007 [Np 25, Imax 7-8]

Epicentro CPTI11 Mw 5.54 ±0.32

macrosismico Mw 5.54 ±0.32



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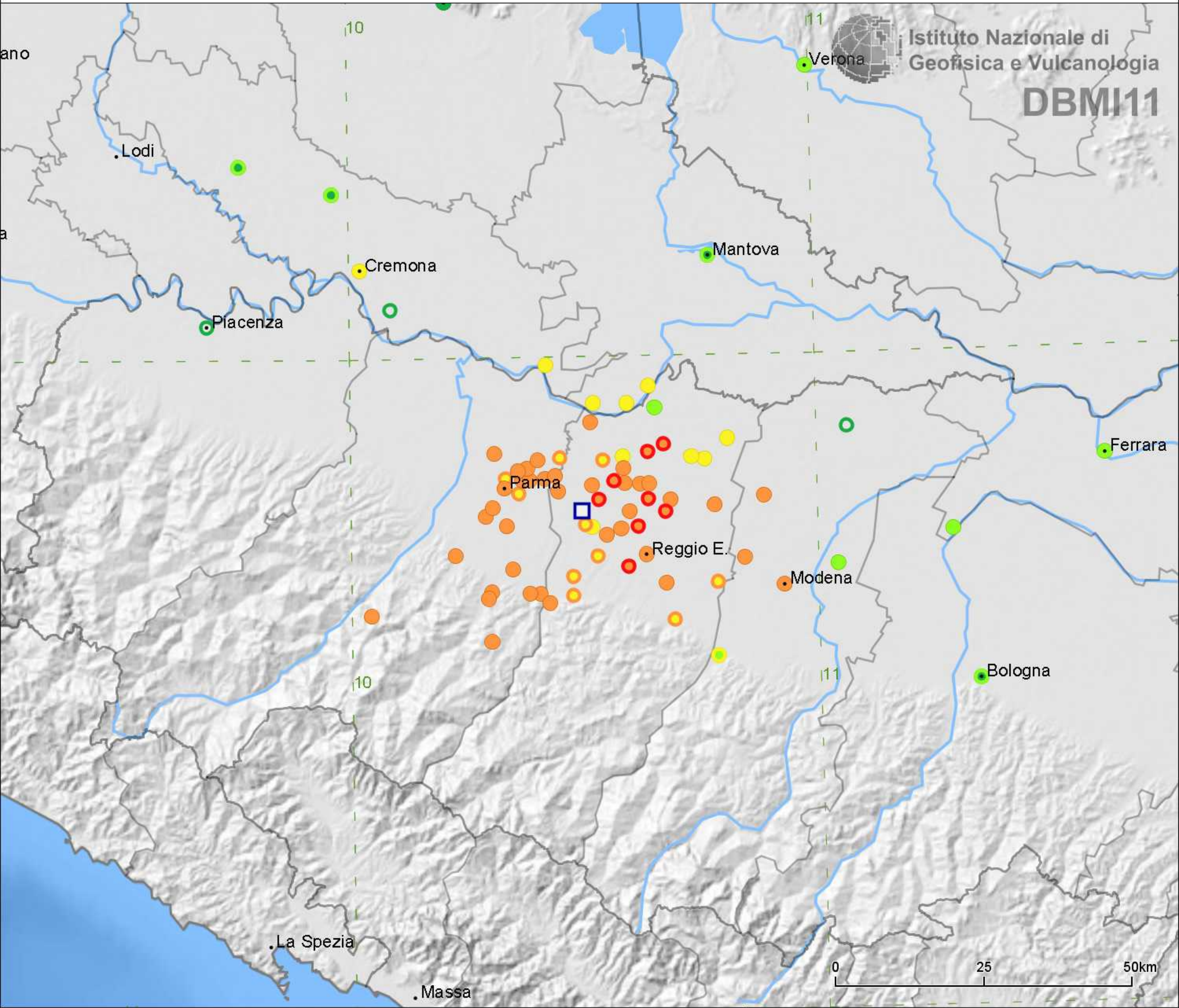
Terremoto del 13 marzo 1832 03:30:--, Reggiano
Studio macrosismico Guidoboni et al., 2007 [Np 98, Imax 7-8]

Epicentro CPTI11 Mw 5.53 ±0.18
macrosismico Mw 5.53 ±0.18



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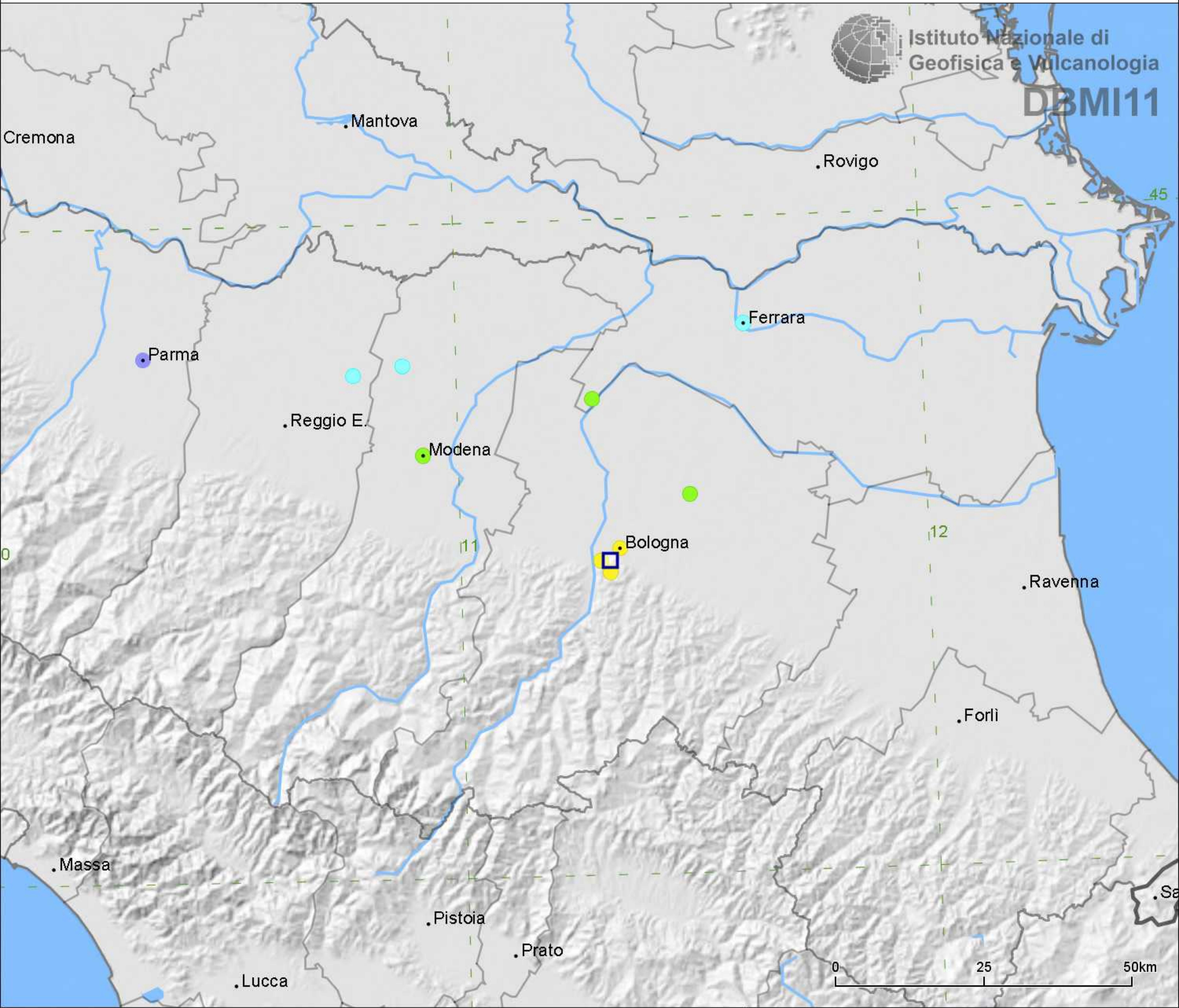
Int. 1 2 3 4 5 6 7 8 9 10 11
2-3 3-4 F 4-5 5-6 6-7 7-8 8-9 9-10 10-11

Terremoto del 4 ottobre 1834 19:--:--, Bolognese
Studio macrosismico Guidoboni et al., 2007 [Np 12, Imax 6]

Epicentro CPTI11 Mw 4.85 ±0.43
macrosismico Mw 4.85 ±0.43



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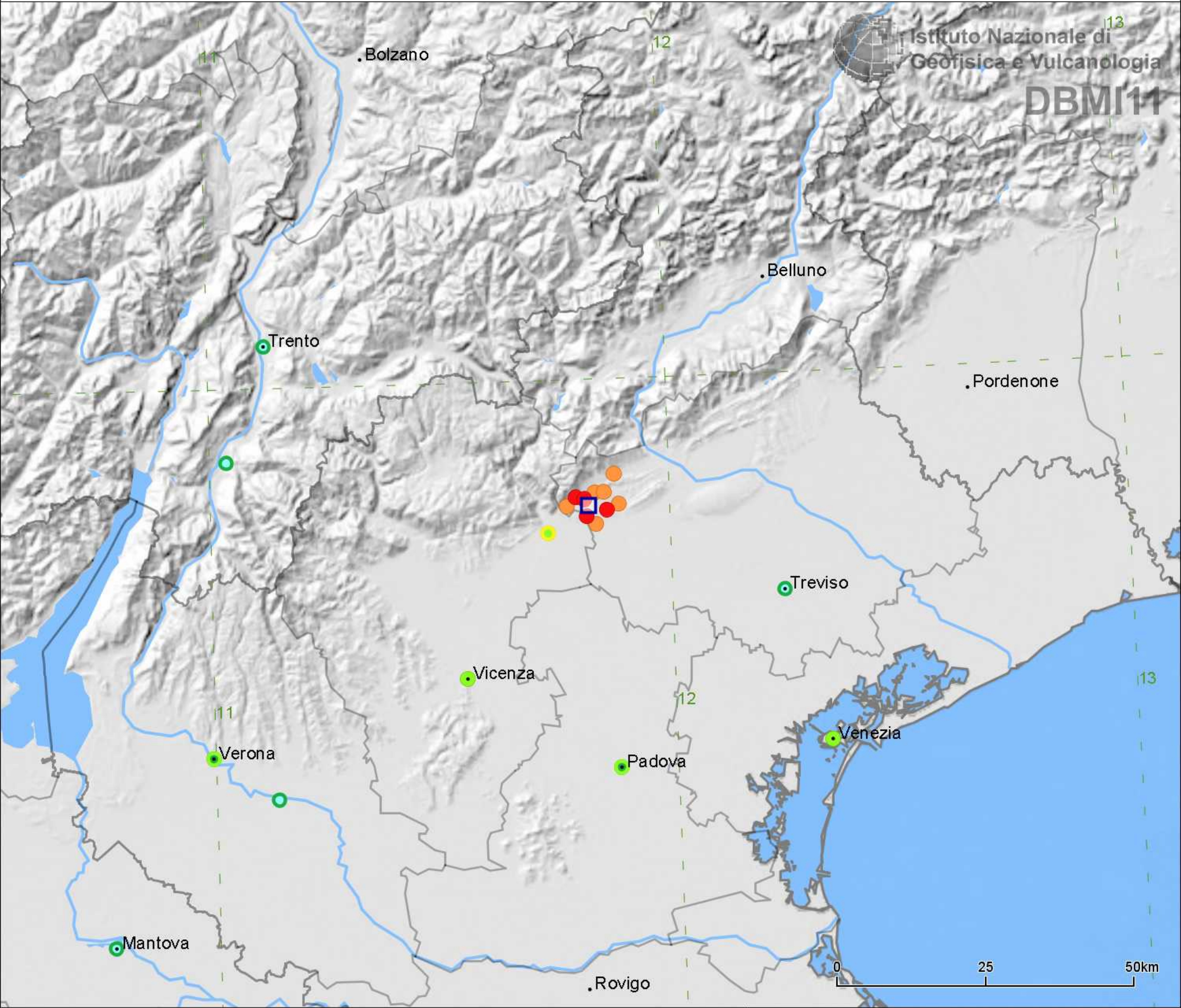
Int. 1 2 3 4 5 6 7 8 9 10 11
2-3 3-4 F 4-5 5-6 6-7 7-8 8-9 9-10 10-11

Terremoto del 12 giugno 1836 02:30:--, BASSANO
Studio macrosismico Arch.Mac.GNDT, 1995 [Np 26, Imax 8]

Epicentro CPTI11 Mw 5.50 ±0.32
macrosismico Mw 5.50 ±0.32



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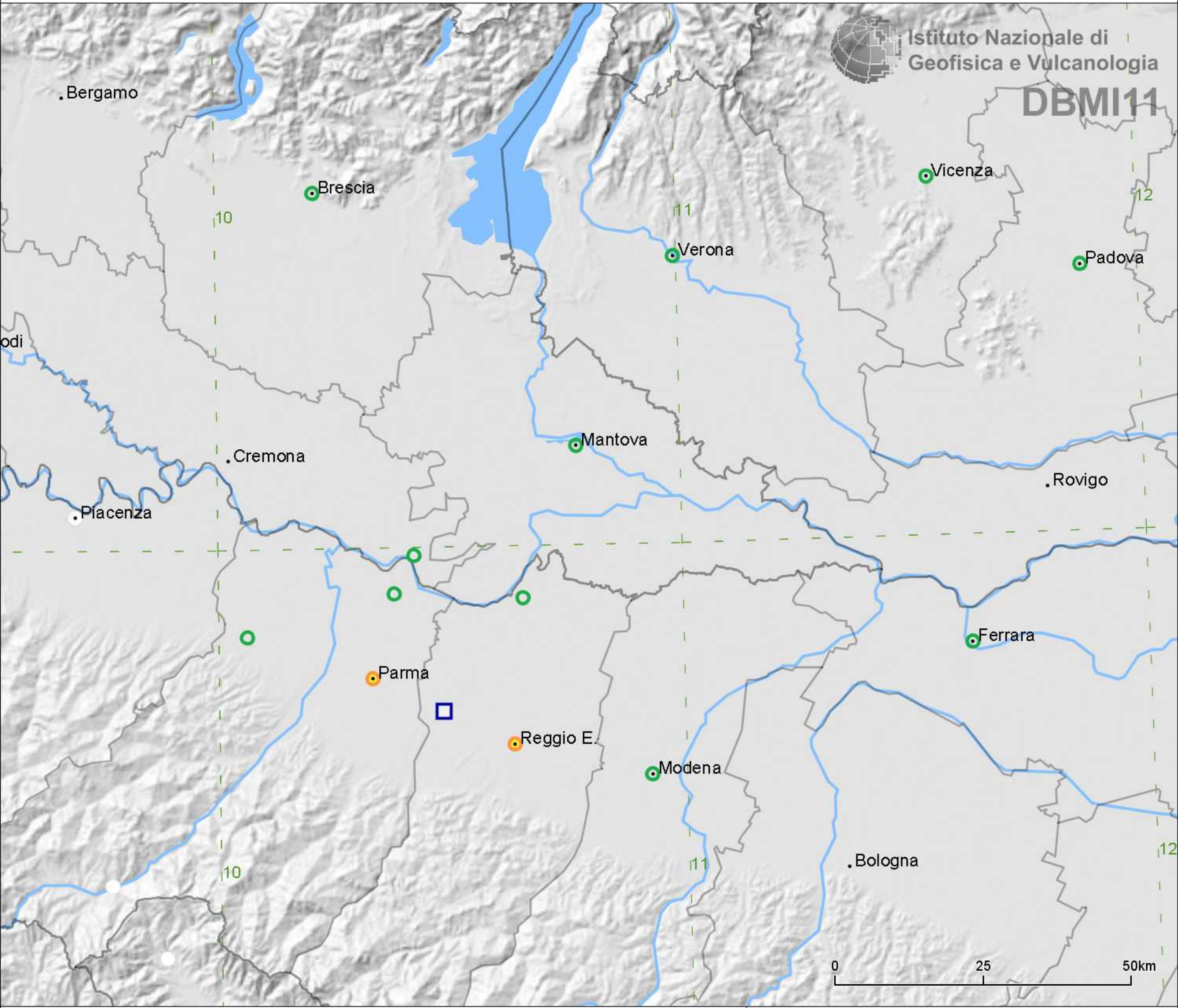
Terremoto del 1 febbraio 1857, PARMENSE
Studio macrosismico Arch.Mac.GNDT, 1995 [Np 22, Imax 6-7]

Epicentro CPTI11 □ Mw 5.09 ±0.25
macrosismico □ Mw 5.09 ±0.25



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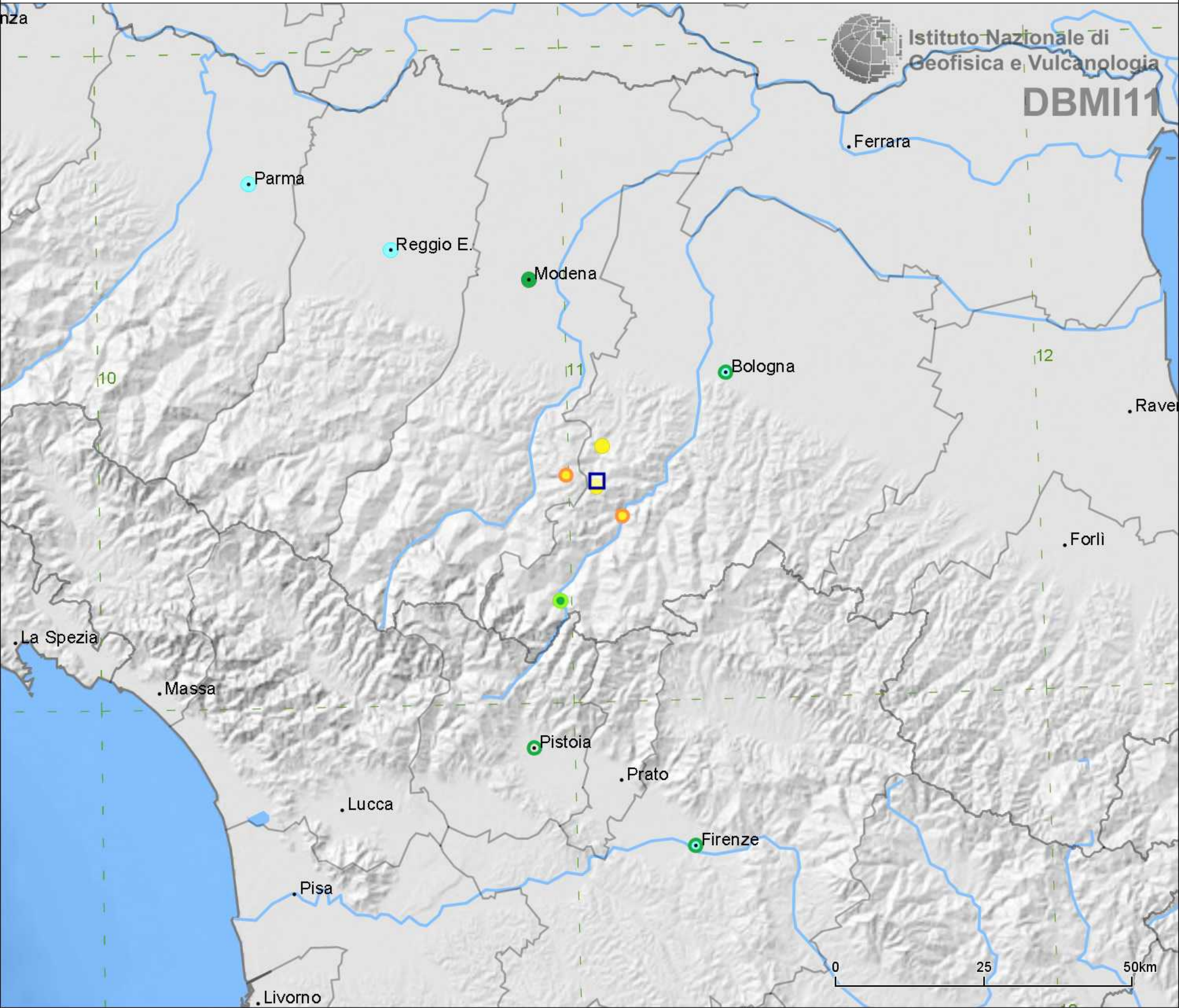
Int. 1 2 3 4 5 6 7 8 9 10 11
2-3 3-4 F 4-5 5-6 6-7 7-8 8-9 9-10 10-11

Terremoto del 15 marzo 1864, ZOCCA
Studio macrosismico Arch.Mac.GNDT, 1995 [Np 13, Imax 6-7]

Epicentro CPTI11 Mw 4.90 ±0.71
macrosismico Mw 4.90 ±0.71



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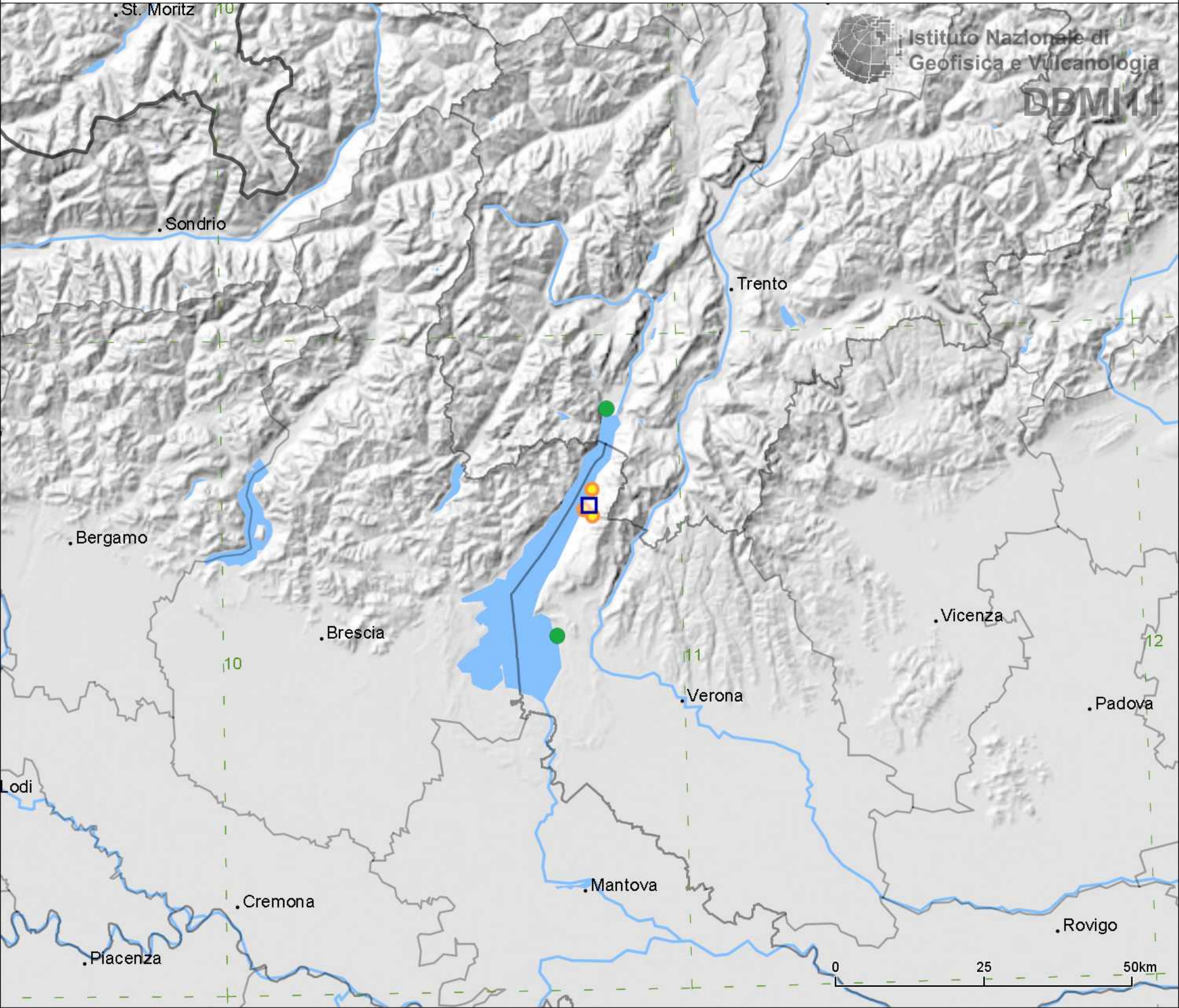
	1	2	3	4	5	6	7	8	9	10	11
Int.	2-3	3-4	F	4-5	5-6	6-7	7-8	8-9	9-10	10-11	

Terremoto del 20 febbraio 1868 19:45:--, Monte Baldo
Studio macrosismico Guidoboni et al., 2007 [Np 5, Imax 6-7]

Epicentro CPTI11 □ Mw 4.67 ±0.68
macrosismico □ Mw 4.67 ±0.68



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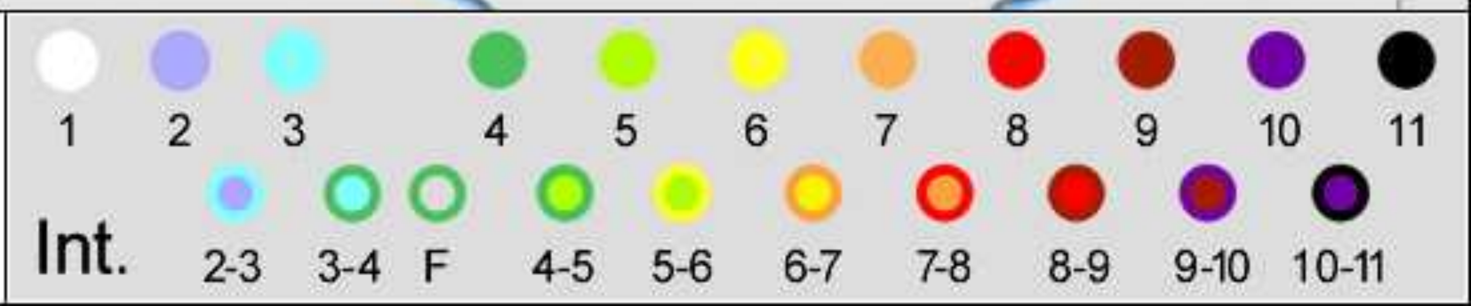
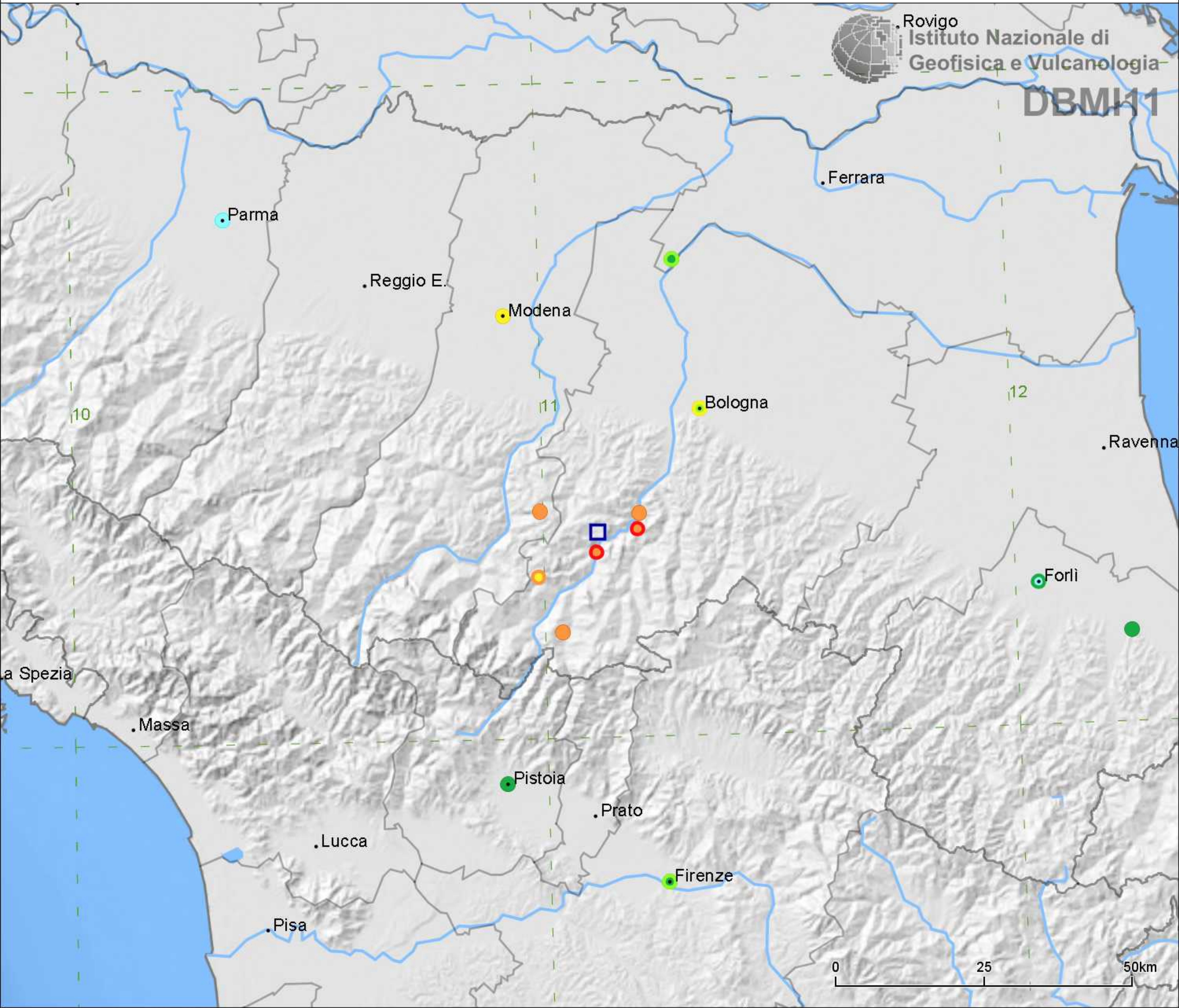


Terremoto del 25 giugno 1869 13:58:--, Media valle del Reno
Studio macrosismico Guidoboni et al., 2007 [Np 18, Imax 7-8]

Epicentro CPTI11 ◻ Mw 5.42 ±0.48
macrosismico ◻ Mw 5.42 ±0.48



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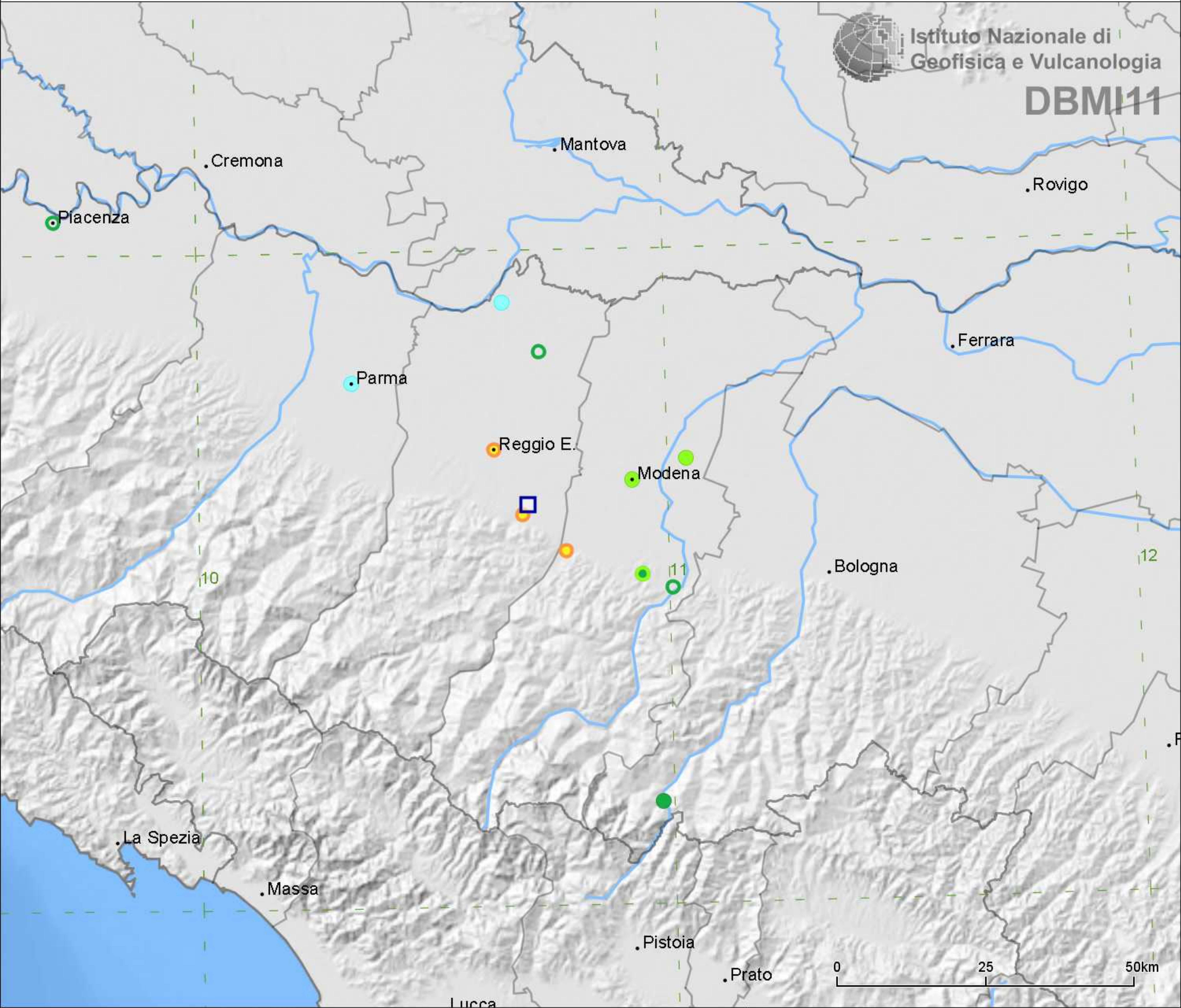
Int.											
	1	2	3	4	5	6	7	8	9	10	11
	2-3	3-4	F	4-5	5-6	6-7	7-8	8-9	9-10	10-11	

Terremoto del 16 maggio 1873 19:35:--, REGGIANO
Studio macrosismico ENEL, 1985 [Np 15, Imax 6-7]

Epicentro CPTI11 Mw 5.09 ±0.59
macrosismico Mw 5.09 ±0.59



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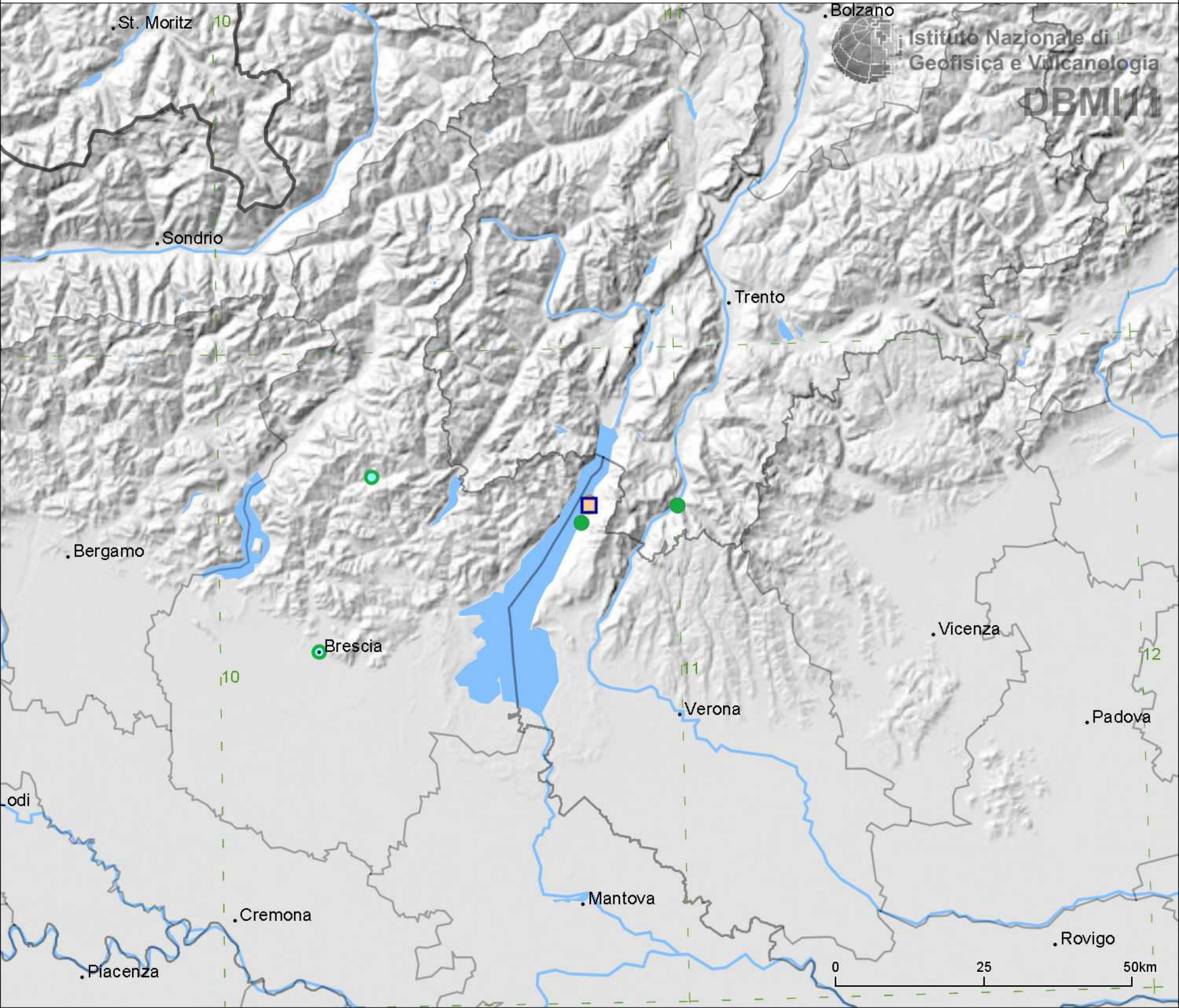
Terremoto del 1 ottobre 1877 07:20:--, Monte Baldo
Studio macrosismico Guidoboni et al., 2007 [Np 6, Imax 7]

Epicentro CPTI11 Mw 4.56 ±0.64
macrosismico Mw 4.56 ±0.64



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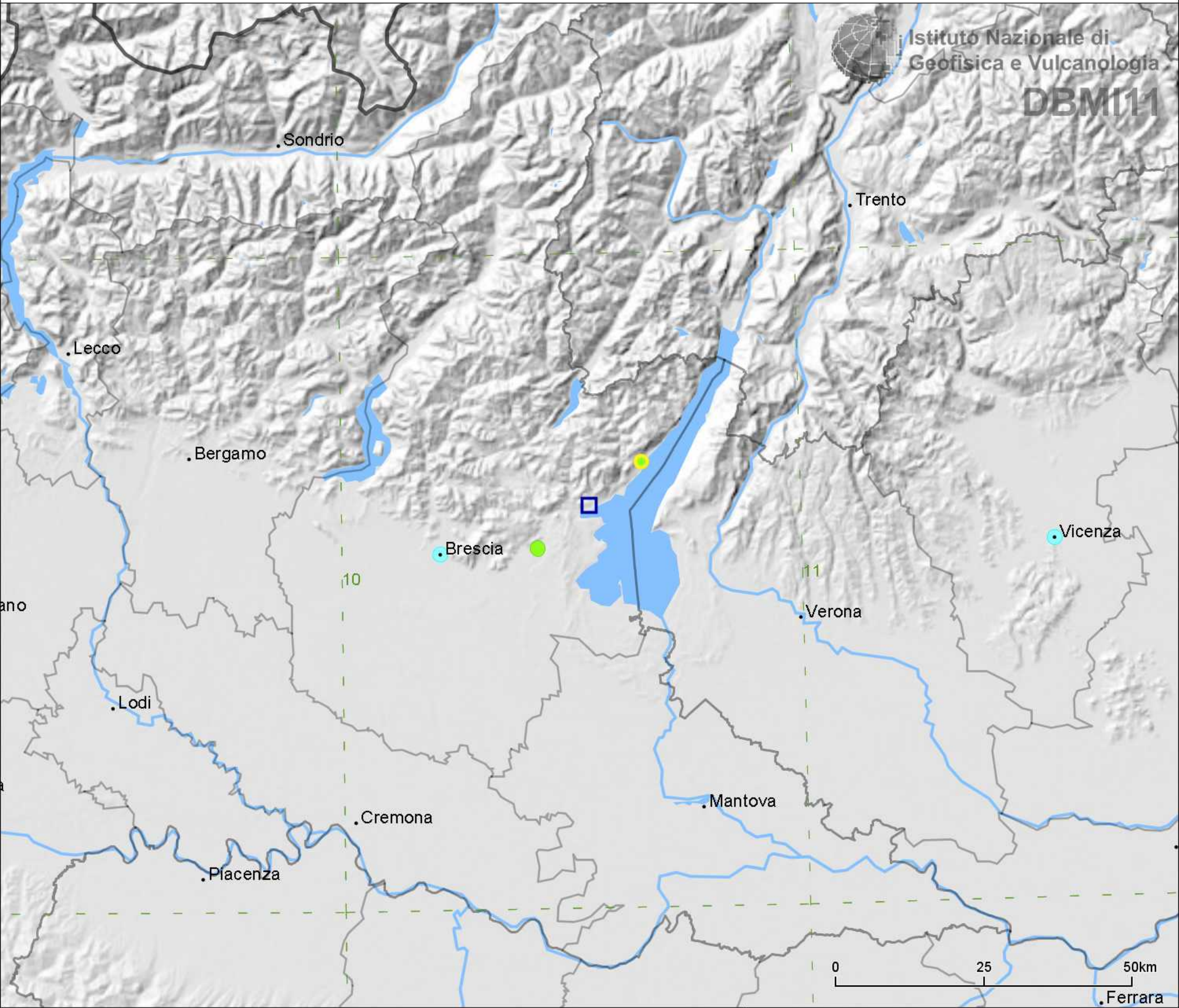
Terremoto del 14 febbraio 1879, GARGNANO
Studio macrosismico ENEL, 1985 [Np 6, Imax 5-6]

Epicentro CPTI11 Mw 4.83 ±0.63
macrosismico Mw 4.83 ±0.63



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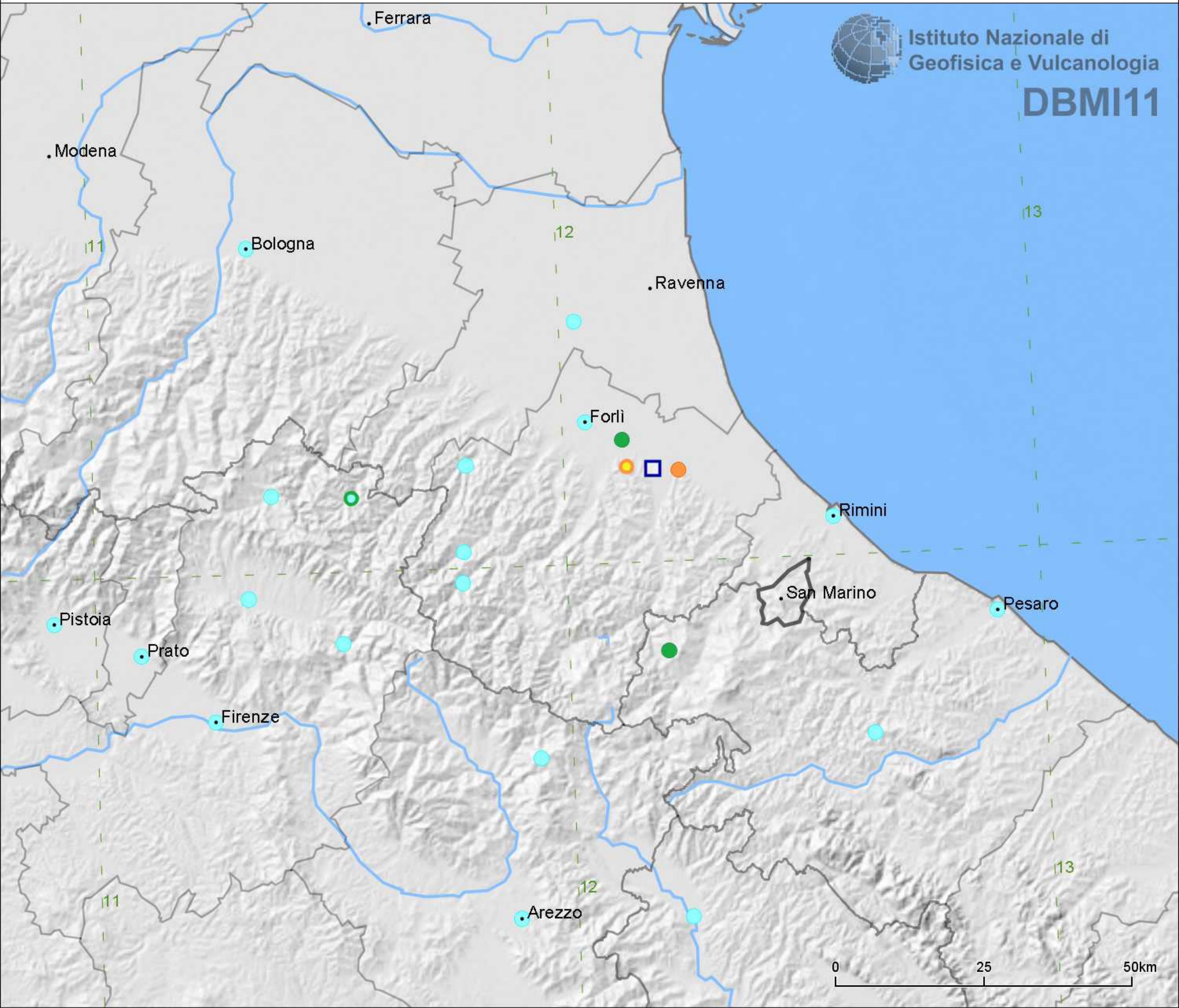
Int. 1 2 3 4 5 6 7 8 9 10 11
2-3 3-4 F 4-5 5-6 6-7 7-8 8-9 9-10 10-11

Terremoto del 28 settembre 1881, CESENA
Studio macrosismico Postpischl, 1990 [Np 24, Imax 7]

Epicentro CPTI11 Mw 4.82 ±0.27
macrosismico Mw 4.82 ±0.27



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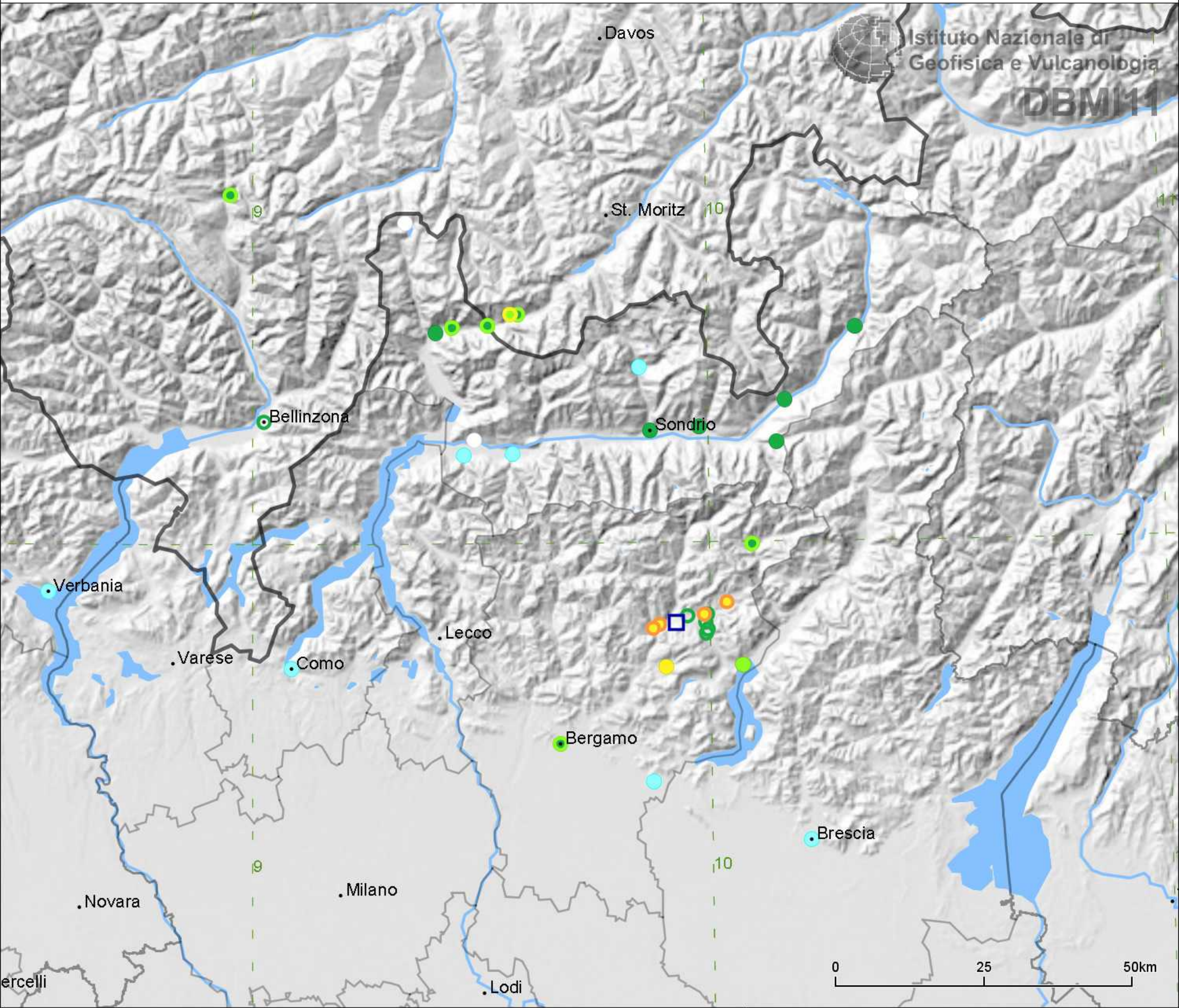
Int. 1 2 3 4 5 6 7 8 9 10 11
2-3 3-4 F 4-5 5-6 6-7 7-8 8-9 9-10 10-11

Terremoto del 27 febbraio 1882 06:30:--, ROVETTA
Studio macrosismico Stucchi & Albini, 1988 [Np 37, Imax 6-7]

Epicentro CPTI11 Mw 4.91 ±0.32
macrosismico Mw 4.91 ±0.32

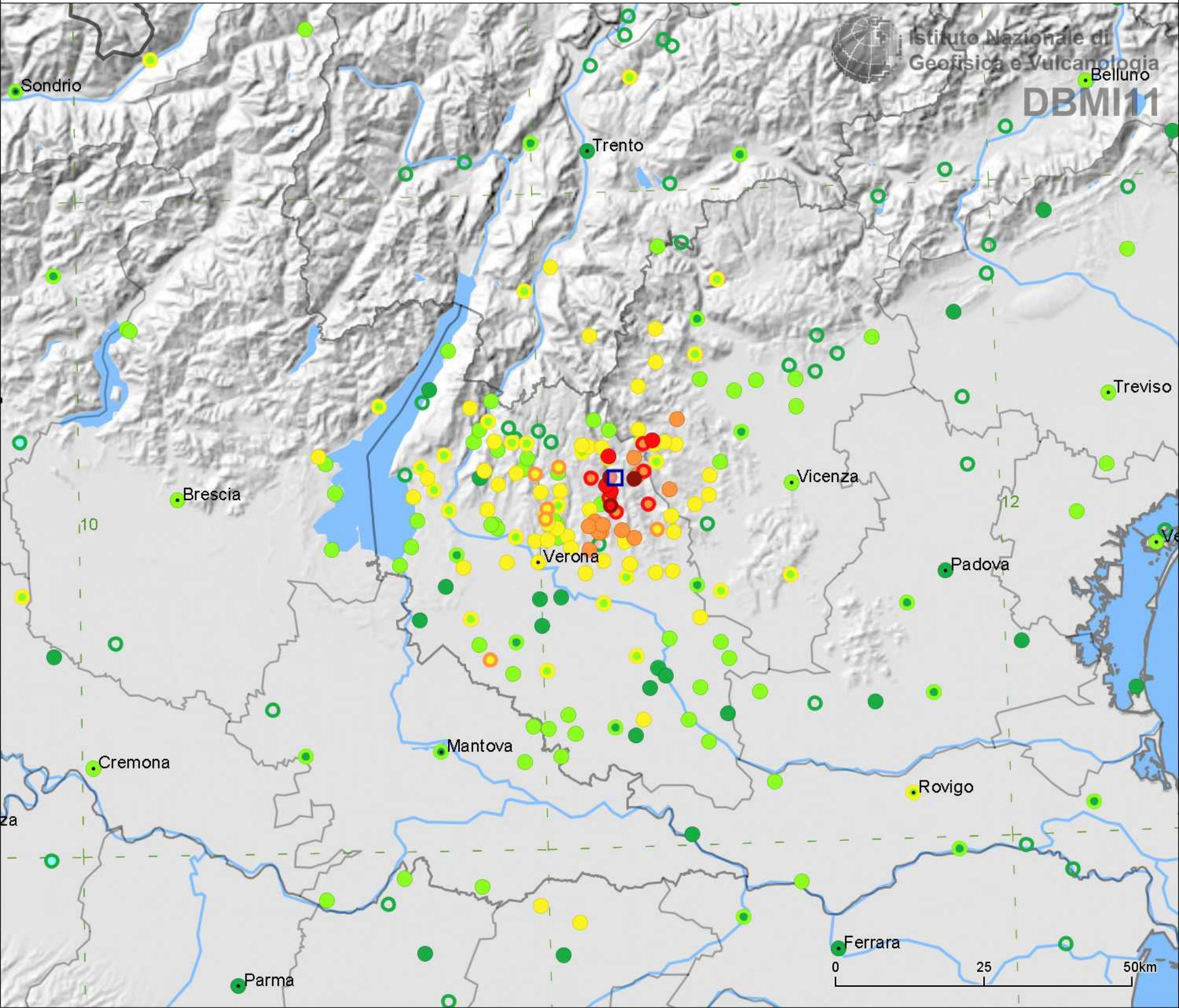


Istituto Nazionale di Geofisica e Vulcanologia | DBMI11

Int.
1 2 3 4 5 6 7 8 9 10 11
2-3 3-4 F 4-5 5-6 6-7 7-8 8-9 9-10 10-11

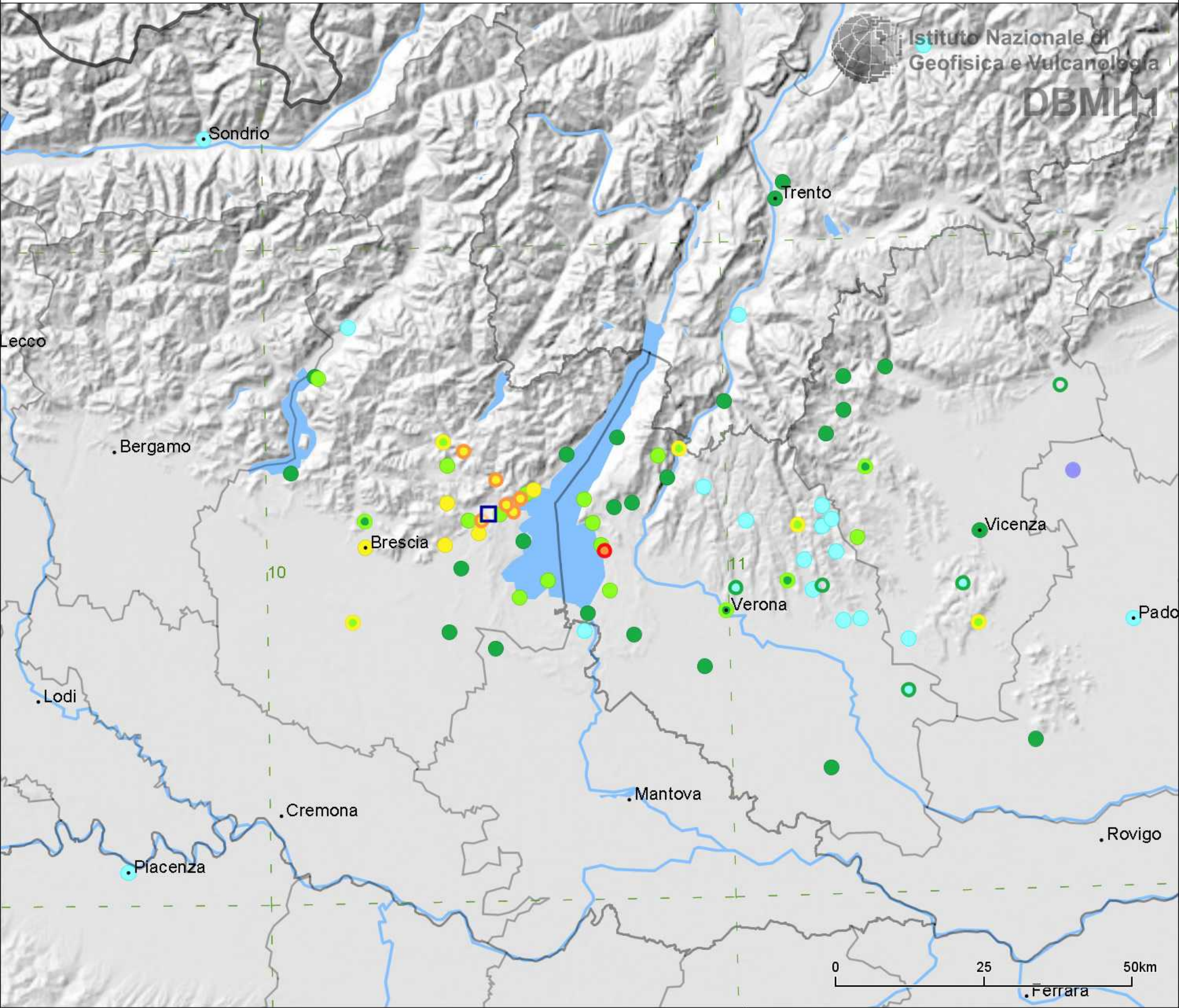
Terremoto del 7 giugno 1891 01:06:14, Valle d'Illasi
Studio macrosismico Guidoboni et al., 2007 [Np 403, Imax 9]

Epicentro CPTI11 Mw 5.86 ±0.06
macrosismico Mw 5.86 ±0.06



Terremoto del 5 gennaio 1892, GARDA OCC.
Studio macrosismico ENEL, 1985 [Np 100, Imax 7-8]

Epicentro CPTI11 Mw 5.02 ±0.15
macrosismico Mw 5.02 ±0.15



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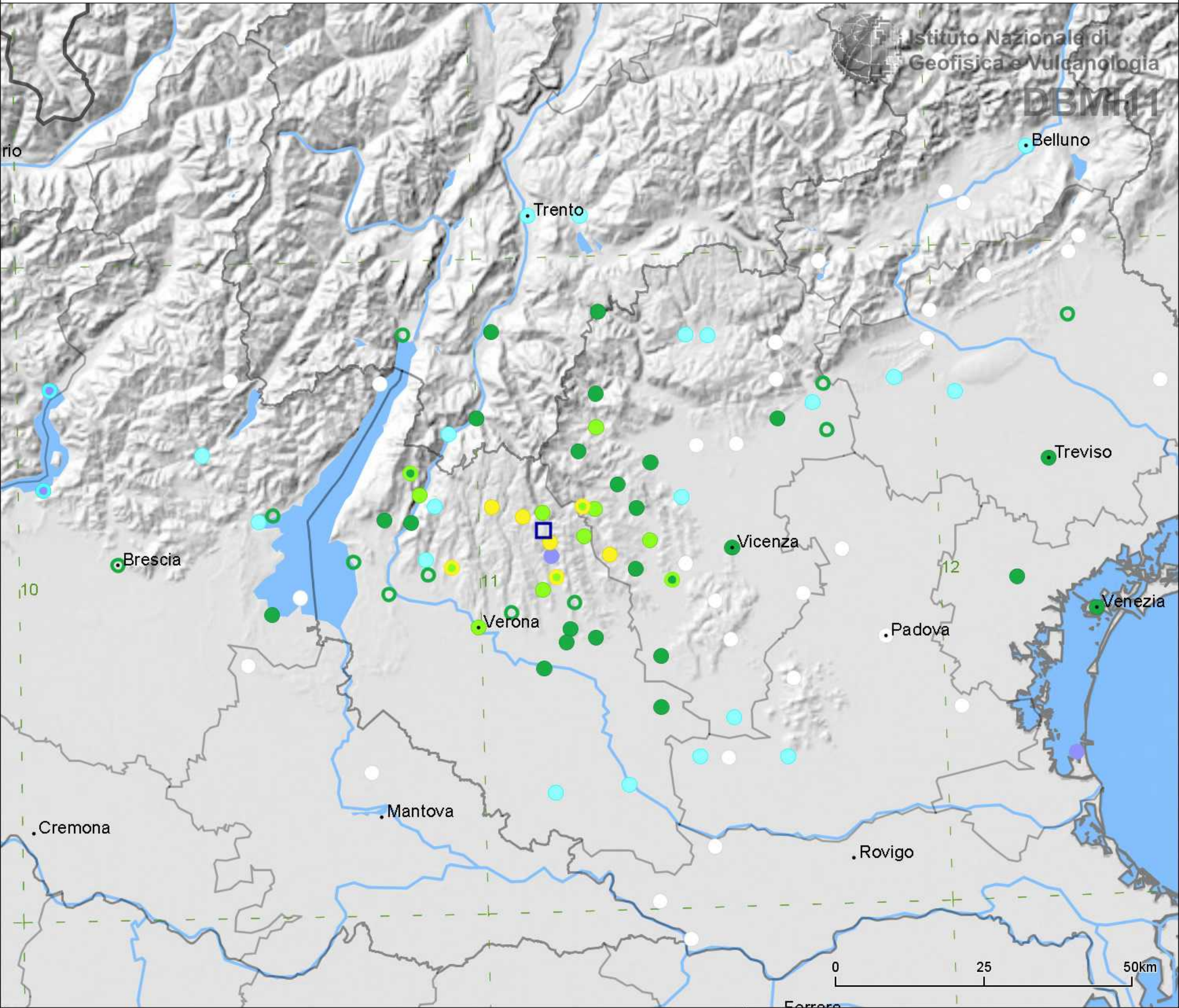
Int.: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 2-3, 3-4, F, 4-5, 5-6, 6-7, 7-8, 8-9, 9-10, 10-11

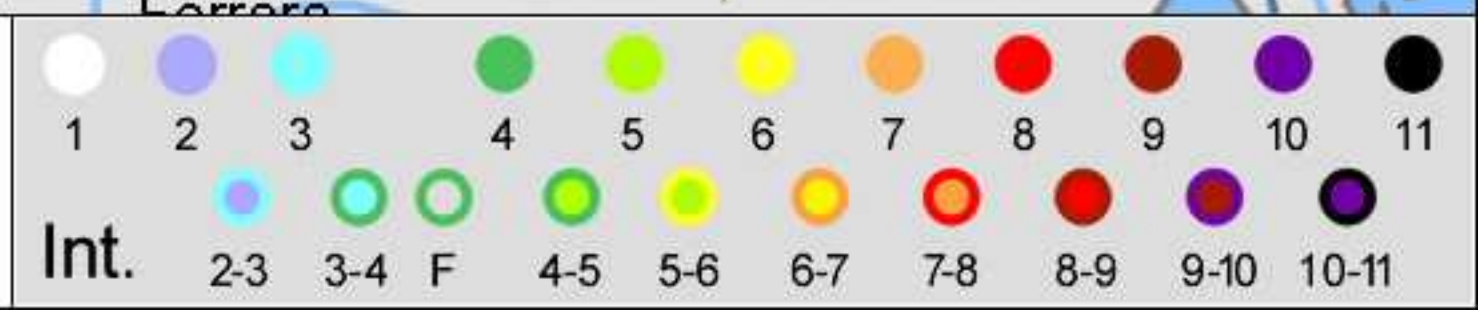
Terremoto del 9 febbraio 1894 12:48:05, Valle d'Illasi

Studio macrosismico Guidoboni et al., 2007 [Np 116, Imax 6]

Epicentro CPTI11 □ Mw 4.77 ±0.15

macrosismico □ Mw 4.77 ±0.15





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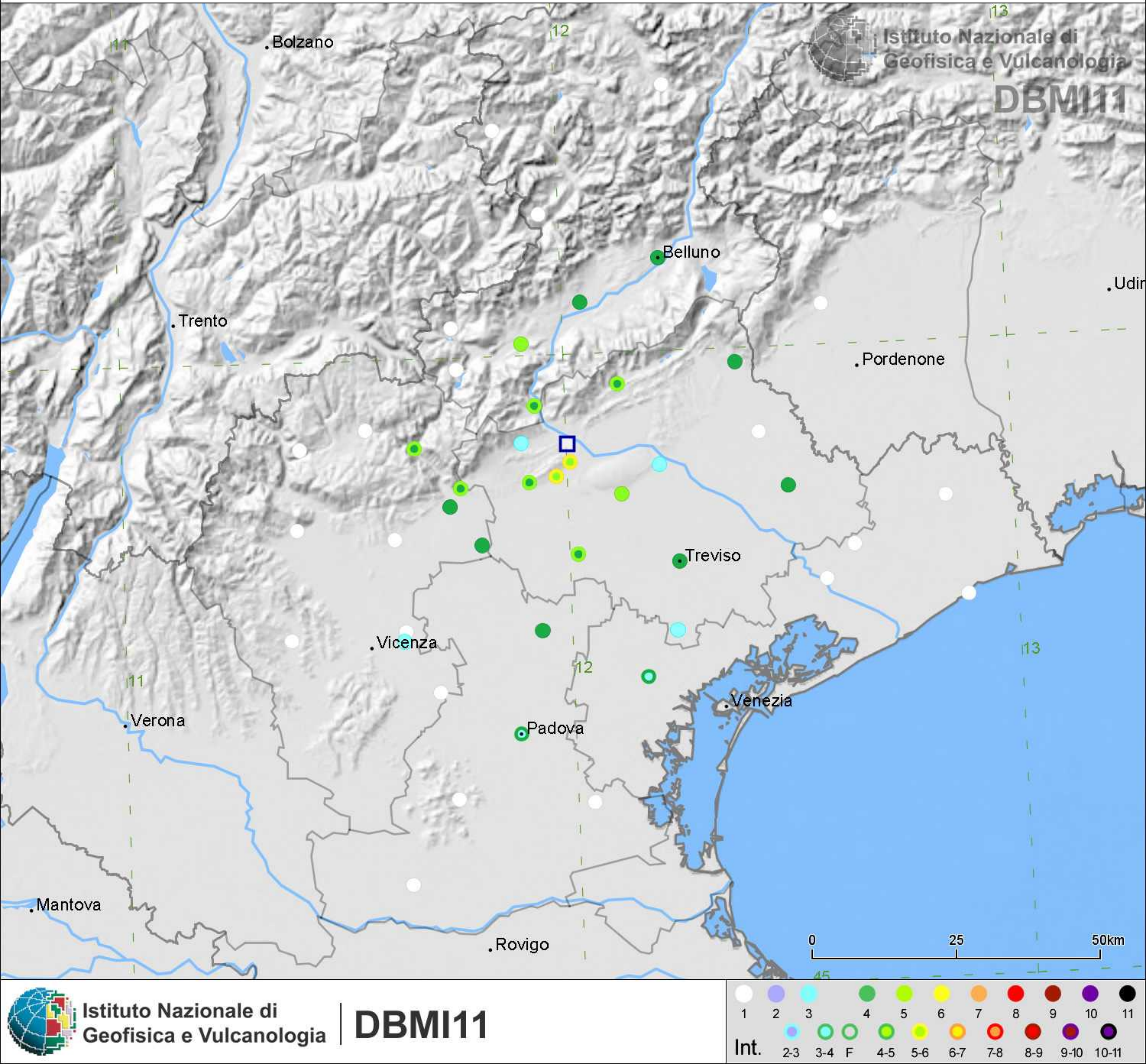
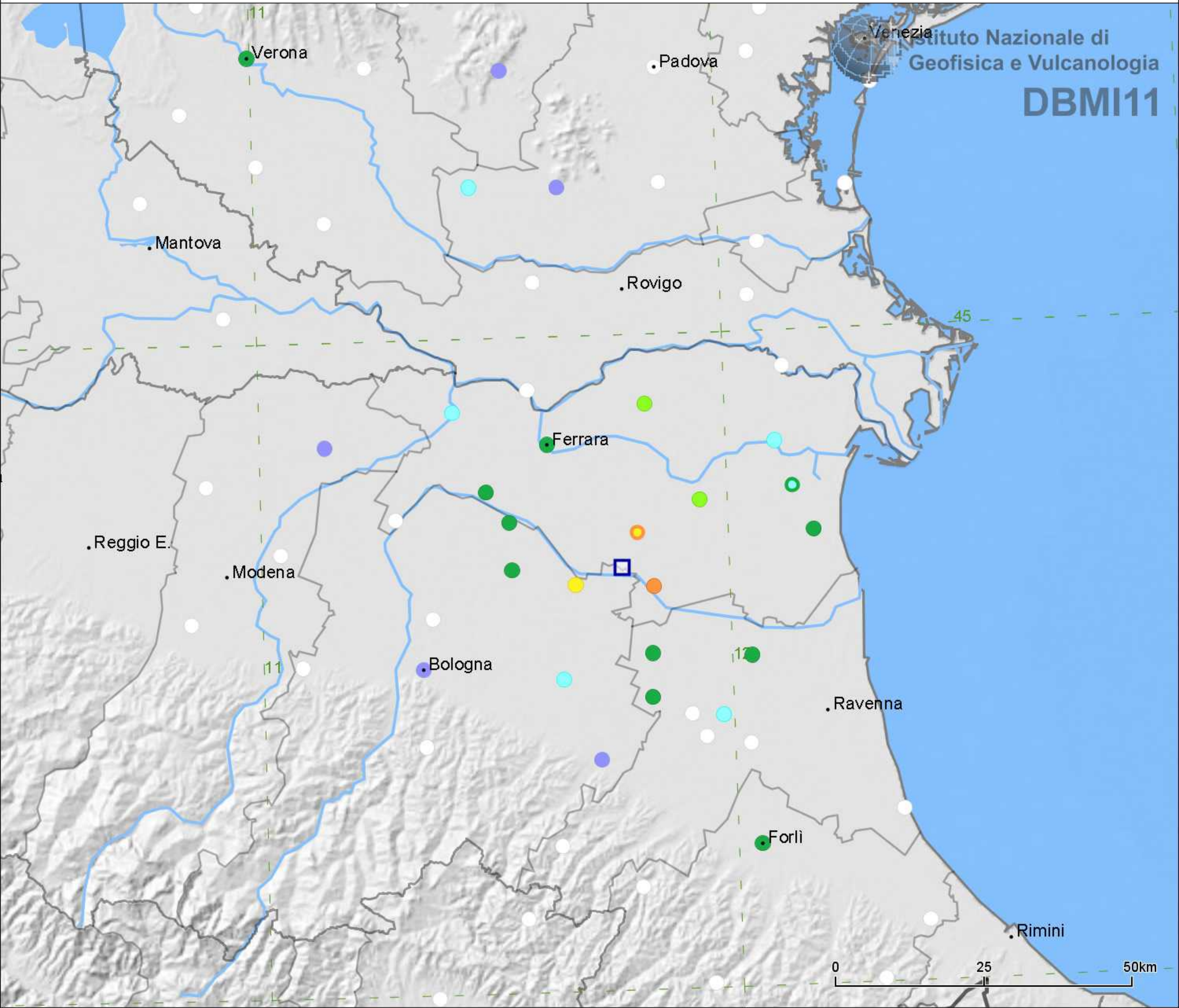
Terremoto del 11 giugno 1897 12:45:--, Cornuda
Studio macrosismico Albini et al., 2003 [Np 47, Imax 5-6]

Epicentro CPTI11 Mw 4.54 ±0.33
macrosismico Mw 4.54 ±0.33



Terremoto del 16 gennaio 1898 12:10:05, Romagna settentrionale
Studio macrosismico Guidoboni et al., 2007 [Np 73, Imax 7]

Epicentro CPTI11 Mw 4.79 ±0.33
macrosismico Mw 4.79 ±0.33



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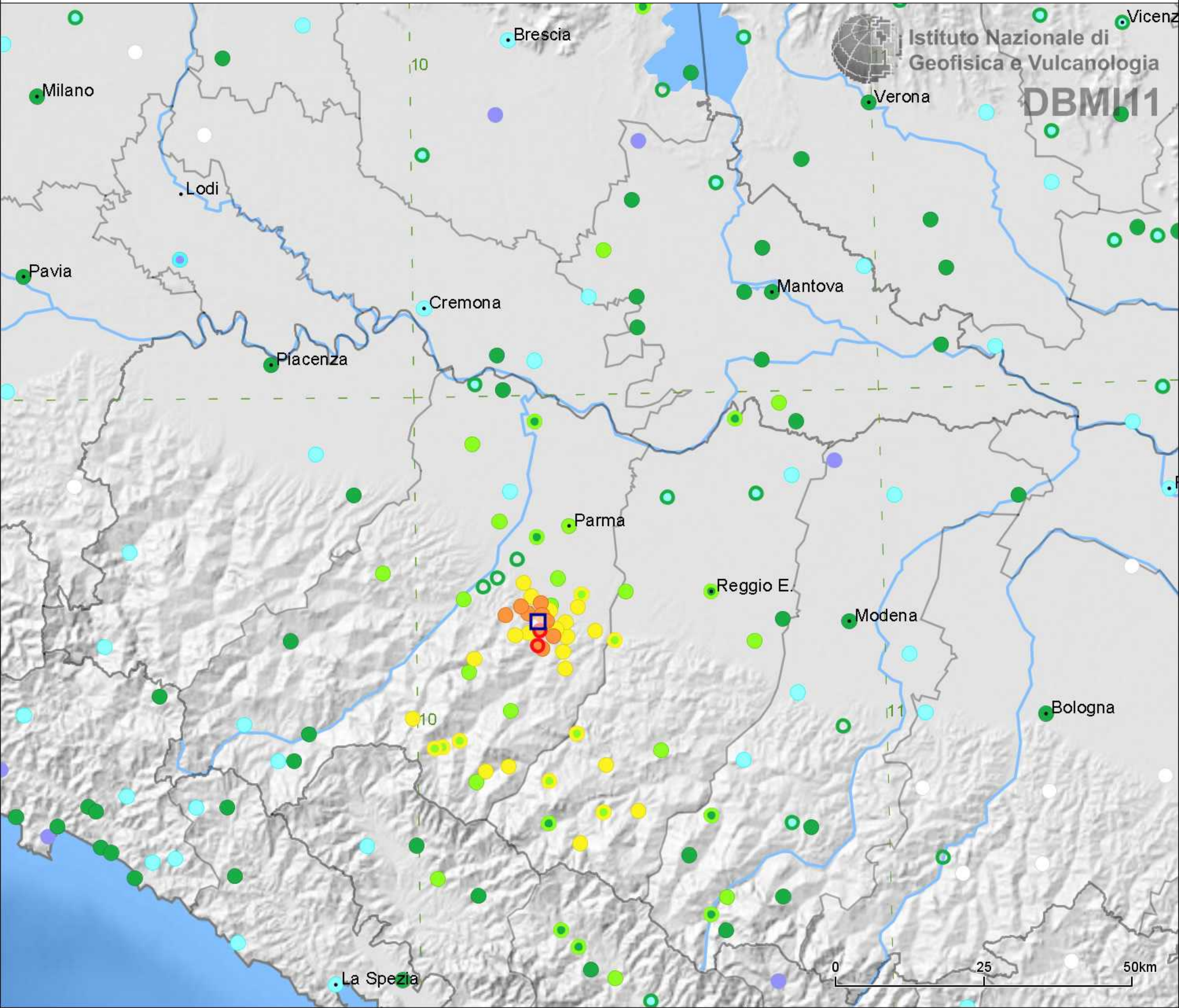
Int.: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 2-3, 3-4, F, 4-5, 5-6, 6-7, 7-8, 8-9, 9-10, 10-11

Terremoto del 4 marzo 1898 21:05:--, Valle del Parma

Studio macrosismico Guidoboni et al., 2007 [Np 313, Imax 7-8]

Epicentro CPTI11 Mw 5.41 ±0.09

macrosismico Mw 5.41 ±0.09



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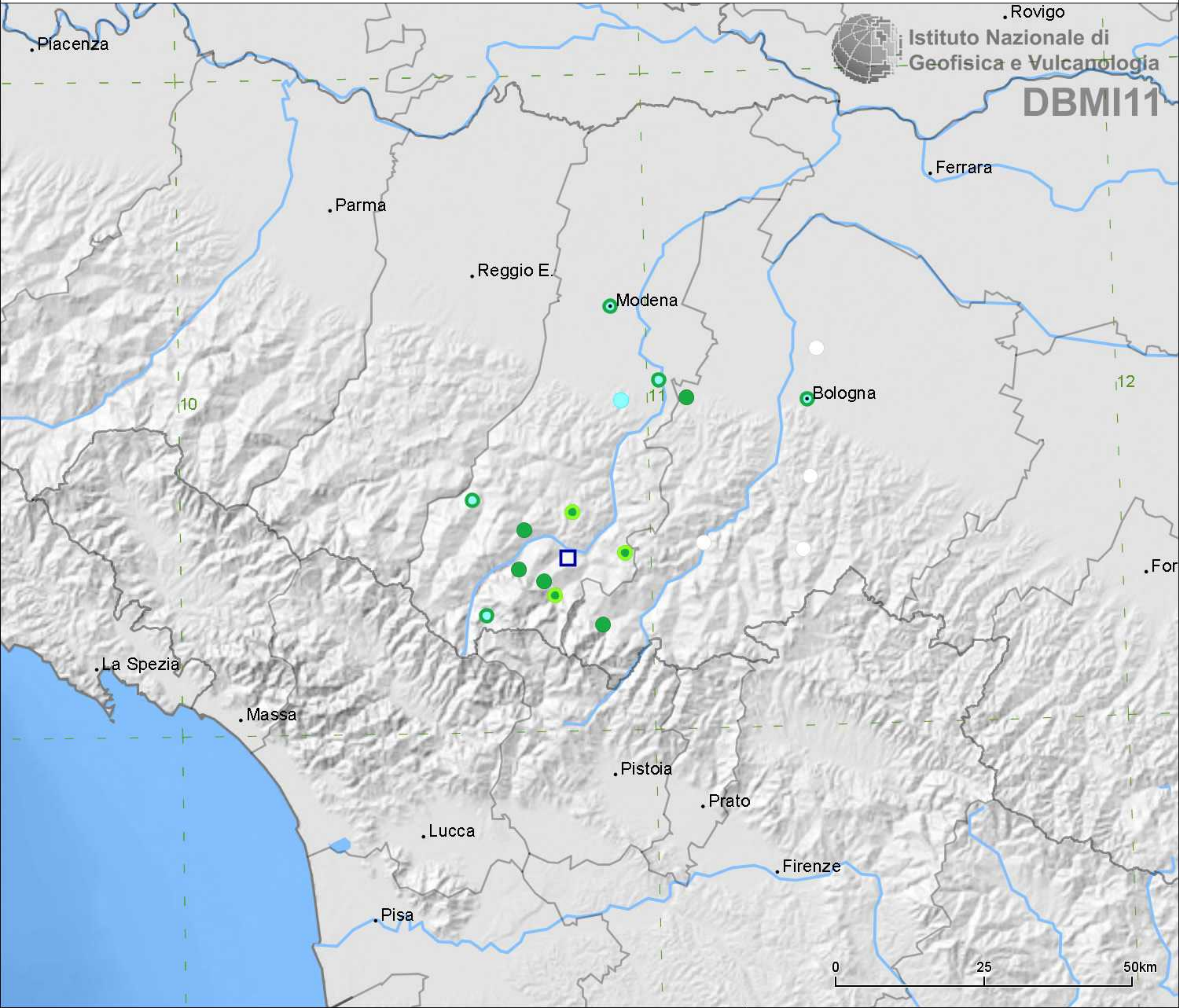
Int. 1 2 3 4 5 6 7 8 9 10 11

2-3 3-4 F 4-5 5-6 6-7 7-8 8-9 9-10 10-11

Terremoto del 2 giugno 1908 22:30:--, FRIGNANO
Studio macrosismico Arch.Mac.GNDT, 1995 [Np 18, Imax 4-5]

Epicentro CPTI11 □ Mw 4.52 ±0.25
macrosismico □ Mw 4.10 ±0.36
strumentale ☆ Mw 4.97 ±0.37



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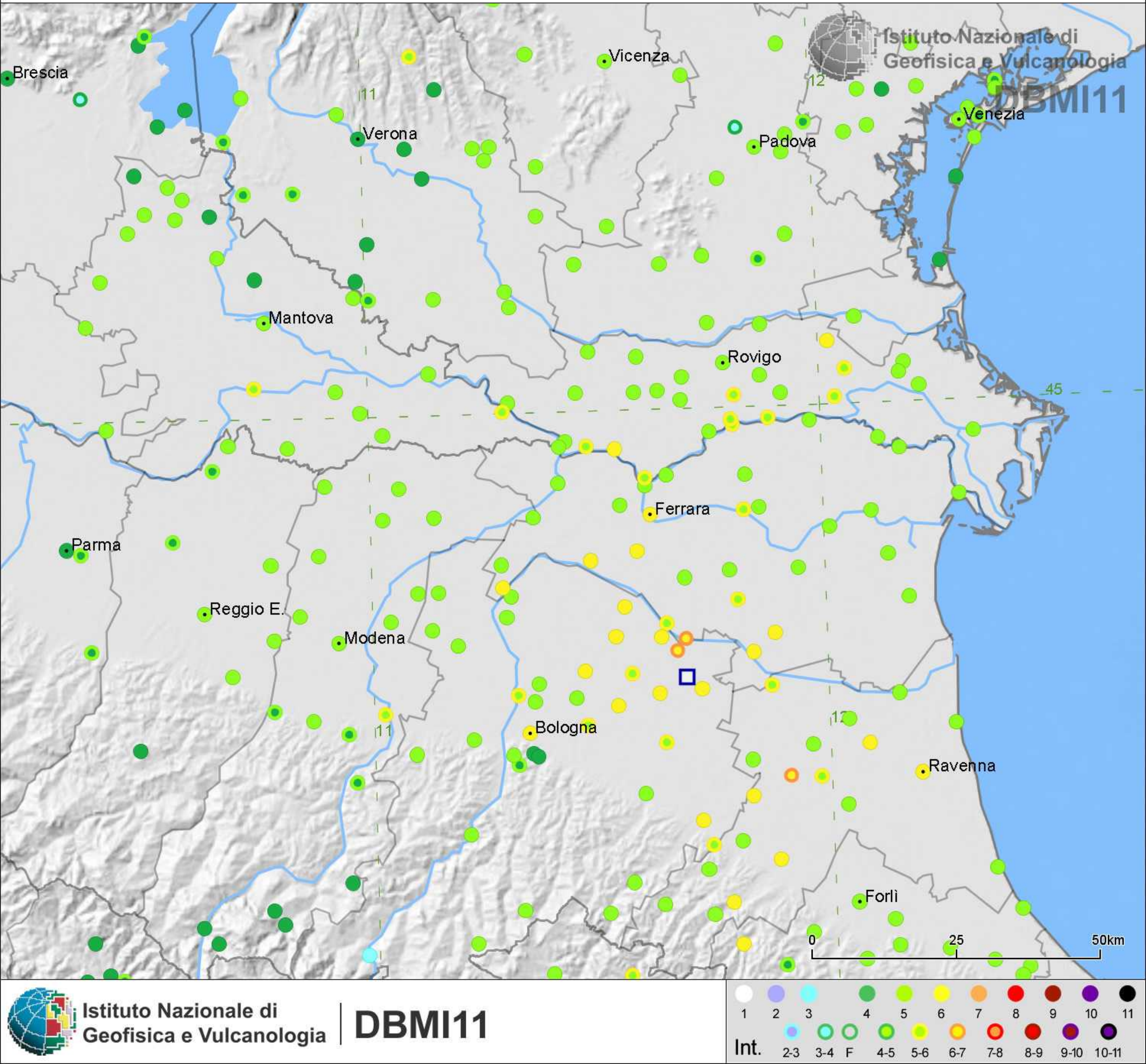
DBMI11

Terremoto del 13 gennaio 1909 00:45:--, BASSA PADANA

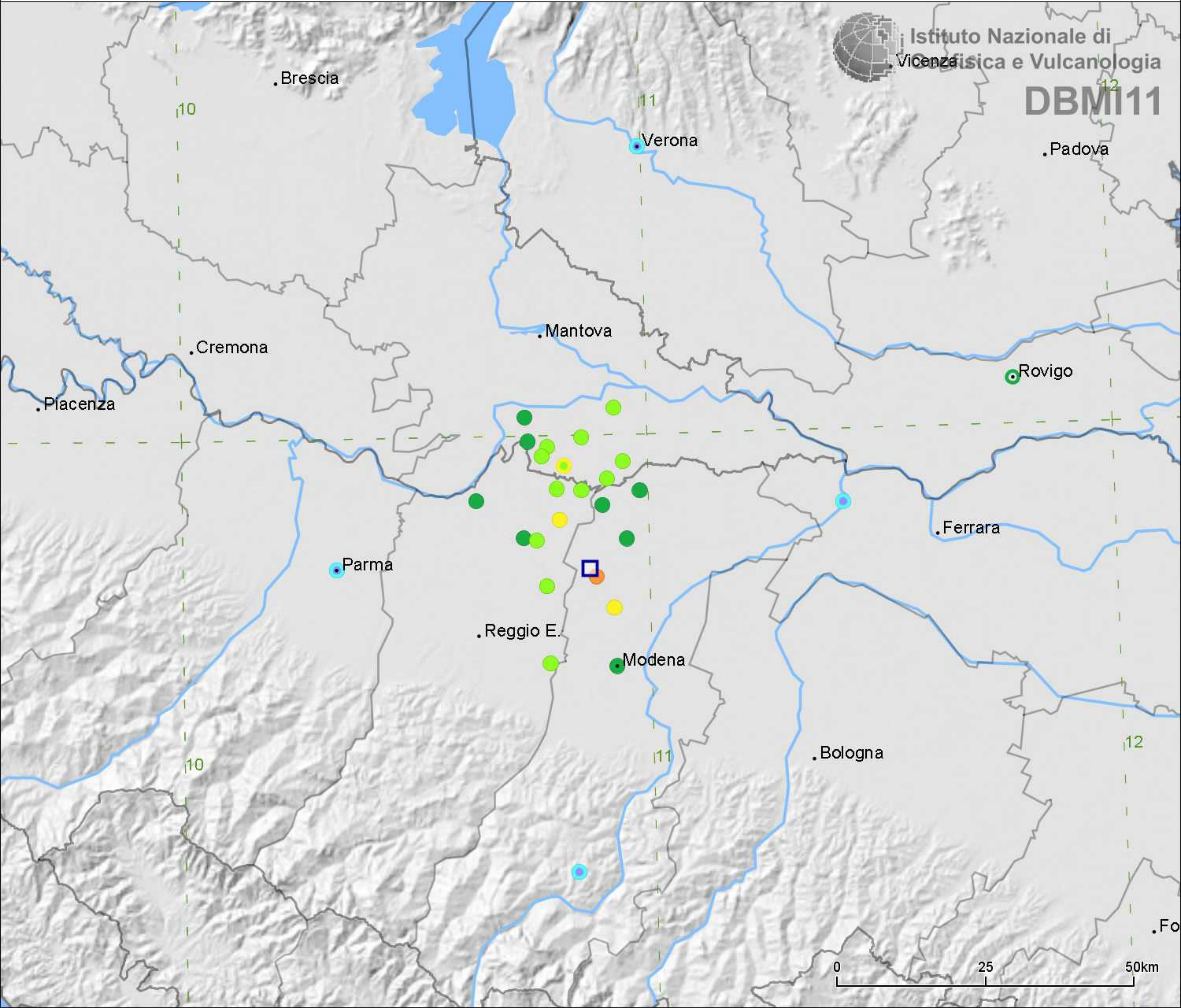
Studio macrosismico Meloni & Molin, 1987 [Np 799, Imax 6-7]

Epicentro CPTI11 □ Mw 5.53 ±0.09
macrosismico □ Mw 5.53 ±0.09
strumentale ☆ Mw 5.55 ±0.37



Terremoto del 13 giugno 1928 08:--:--, CARPI
Studio macrosismico ENEL, 1985 [Np 35, Imax 7]

Epicentro CPTI11 Mw 4.78 ±0.23
macrosismico Mw 4.74 ±0.30
strumentale Mw 4.83 ±0.37

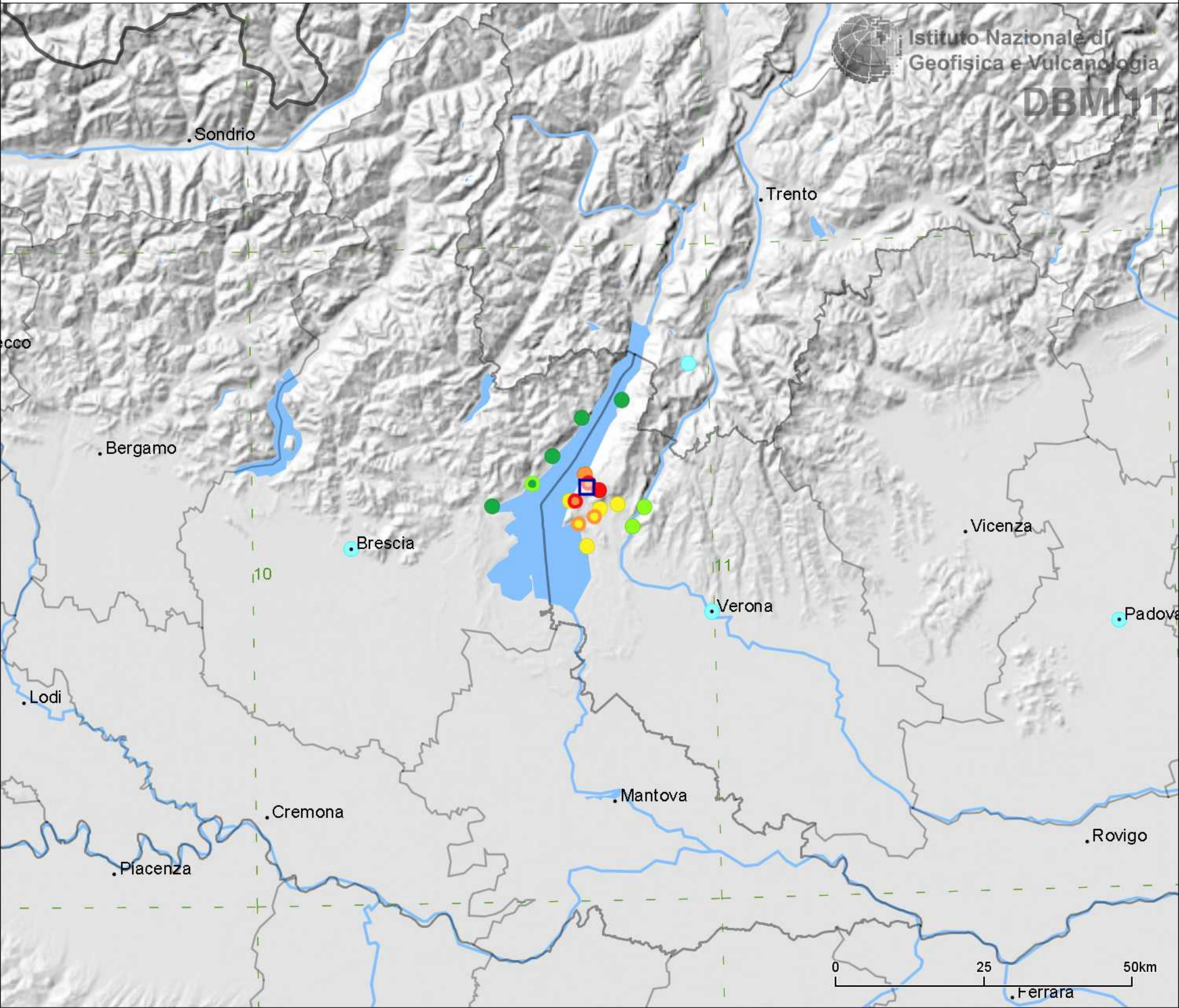


Istituto Nazionale di Geofisica e Vulcanologia | DBMI11

Int.	1	2	3	4	5	6	7	8	9	10	11
	2-3	3-4	F	4-5	5-6	6-7	7-8	8-9	9-10	10-11	

Terremoto del 19 febbraio 1932 12:57:11, Monte Baldo
Studio macrosismico Guidoboni et al., 2007 [Np 21, Imax 8]

Epicentro CPTI11 Mw 5.02 ±0.28
macrosismico Mw 5.08 ±0.44
strumentale Mw 4.97 ±0.37

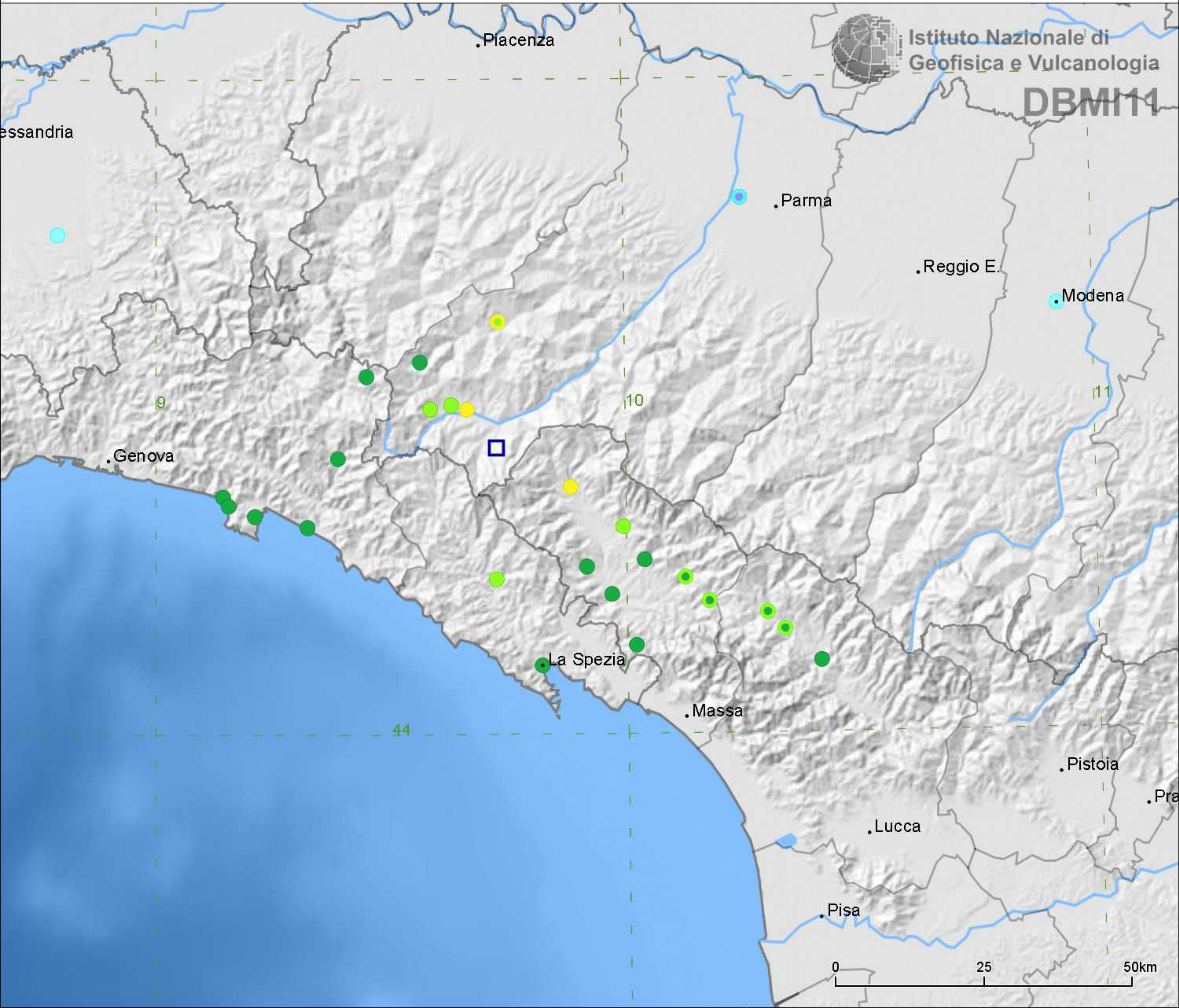


Istituto Nazionale di Geofisica e Vulcanologia | DBMI11

Int.	1	2	3	4	5	6	7	8	9	10	11
	2-3	3-4	F	4-5	5-6	6-7	7-8	8-9	9-10	10-11	

Terremoto del 13 giugno 1934 09:06:26, BORGO VAL DI TARO
Studio macrosismico Castelli et al., 1996 [Np 29, Imax 6]

Epicentro		
CPTI11	□	Mw 4.99 ±0.24
macrosismico	□	Mw 4.80 ±0.31
strumentale	☆	Mw 5.26 ±0.37

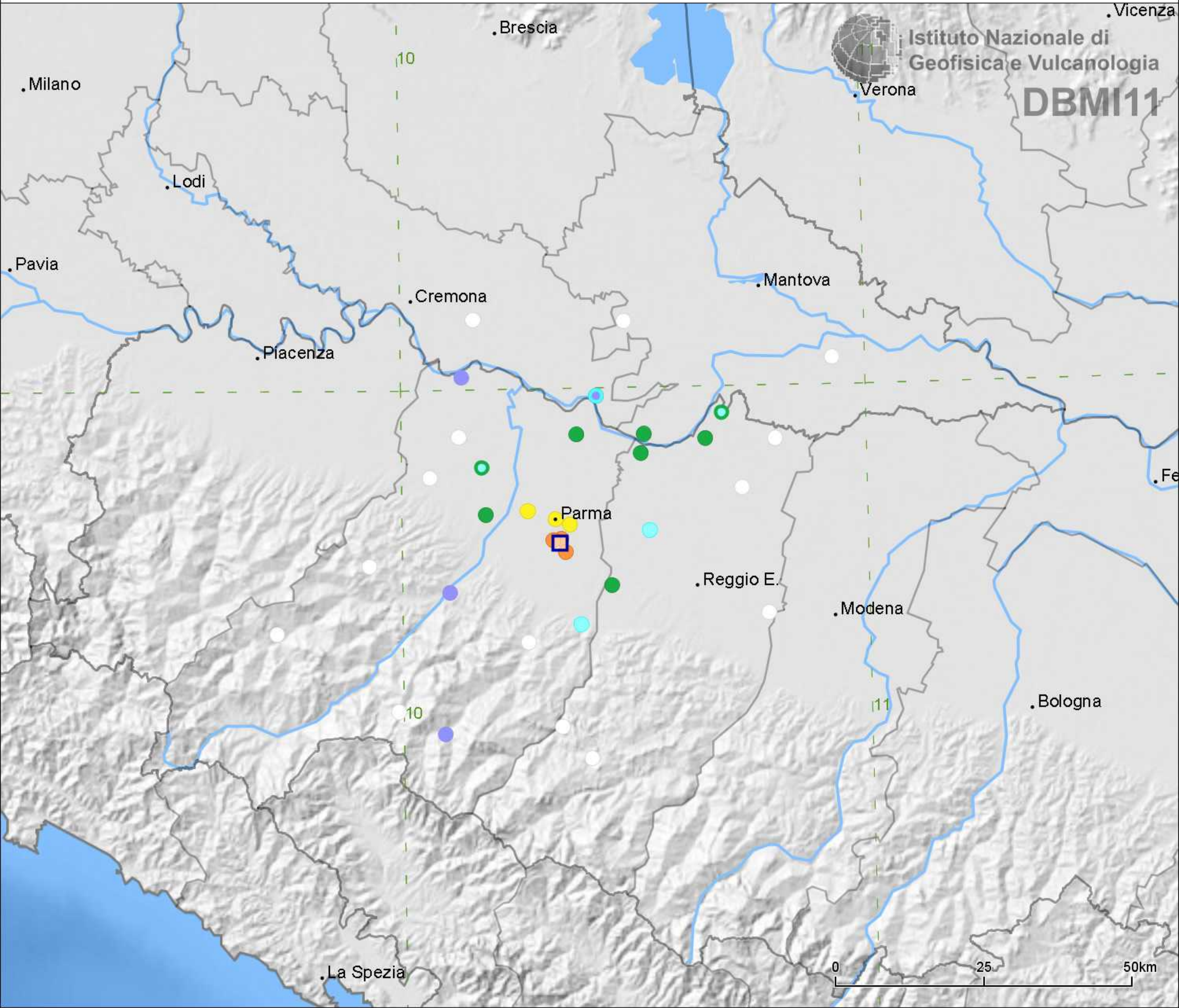


Istituto Nazionale di Geofisica e Vulcanologia | DBMI11

Int.: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11
2-3, 3-4, F, 4-5, 5-6, 6-7, 7-8, 8-9, 9-10, 10-11

Terremoto del 17 settembre 1937 12:19:05, Parmense
Studio macrosismico Guidoboni et al., 2007 [Np 34, Imax 7]

Epicentro CPTI11 Mw 4.65 ±0.25
macrosismico Mw 4.76 ±0.33
strumentale Mw 4.50 ±0.37

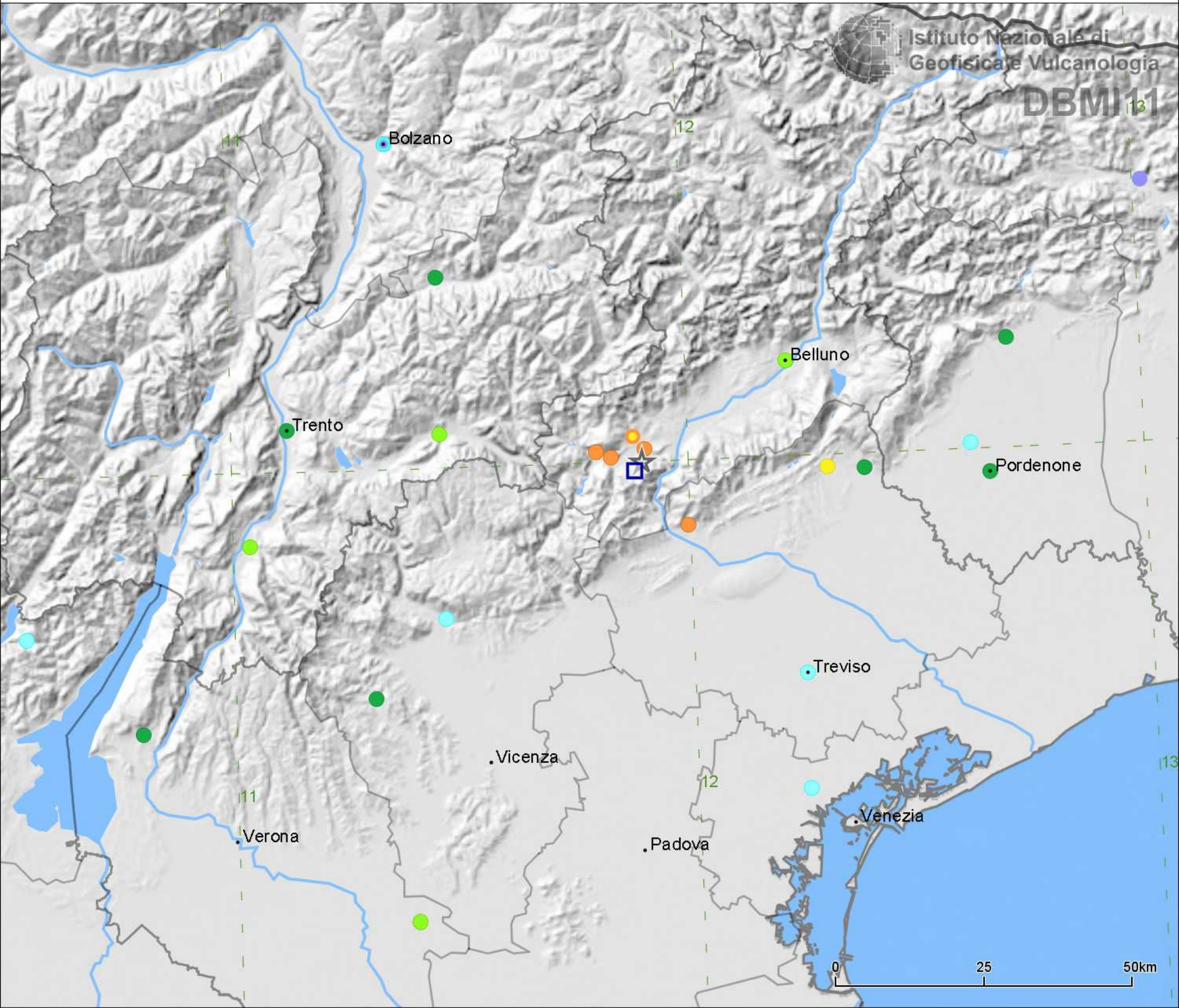


Istituto Nazionale di Geofisica e Vulcanologia | DBMI11

Int. 1 2 3 4 5 6 7 8 9 10 11
2-3 3-4 F 4-5 5-6 6-7 7-8 8-9 9-10 10-11

Terremoto del 24 luglio 1943 01:43:55, VALDOBBIADENE
Studio macrosismico Iaccarino & Mol., 1978 [Np 29, Imax 7]

Epicentro CPTI11 Mw 5.20 ±0.23
macrosismico Mw 5.25 ±0.30
strumentale Mw 5.13 ±0.37

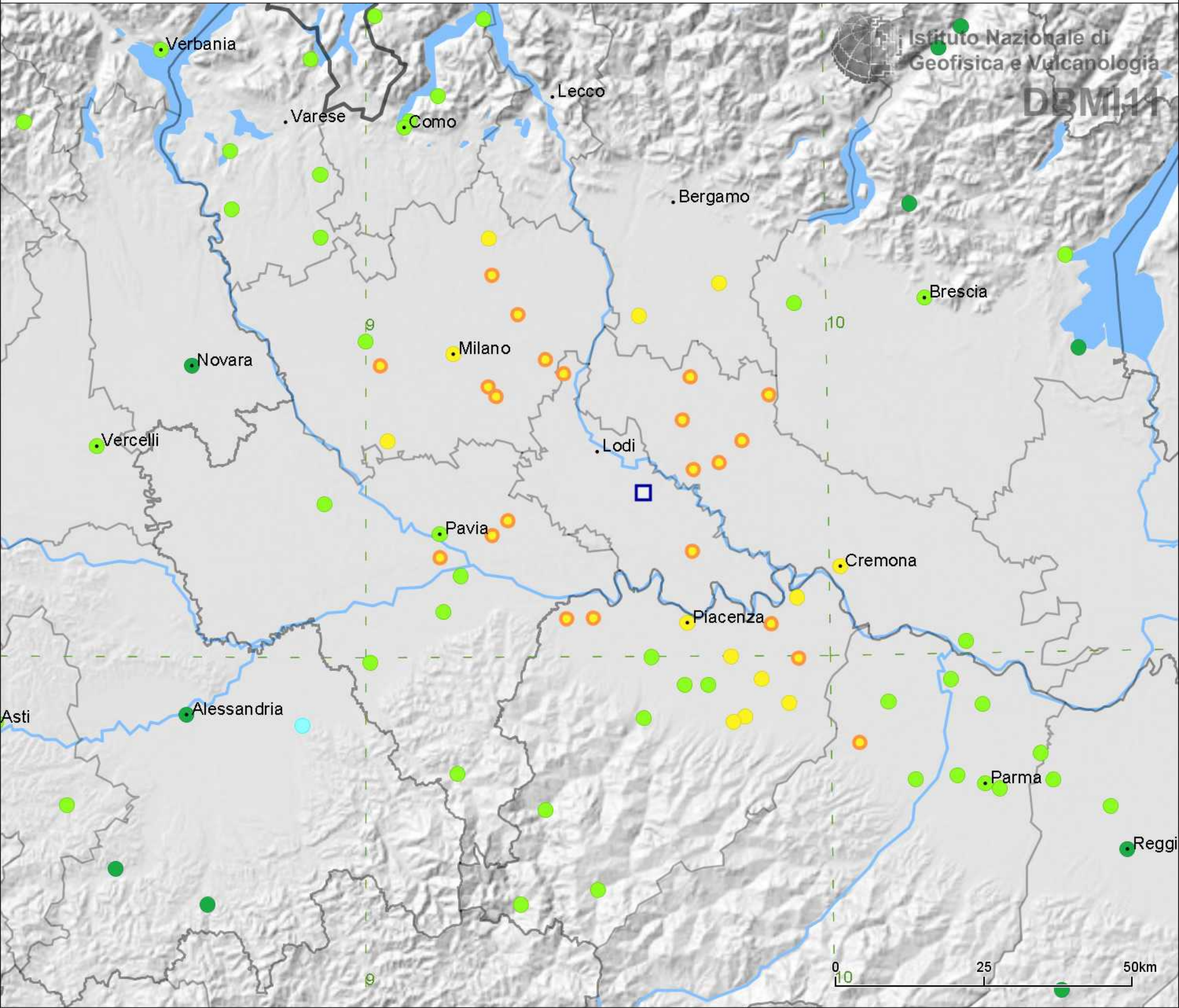


Istituto Nazionale di Geofisica e Vulcanologia | DBMI11

Int.: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11; 2-3, 3-4, F, 4-5, 5-6, 6-7, 7-8, 8-9, 9-10, 10-11

Terremoto del 15 maggio 1951 22:54:--, LODIGIANO
Studio macrosismico St. Geof. Amb., 2002 [Np 154, Imax 6-7]

Epicentro CPTI11 Mw 5.39 ±0.14
macrosismico Mw 5.41 ±0.15
strumentale Mw 5.24 ±0.37

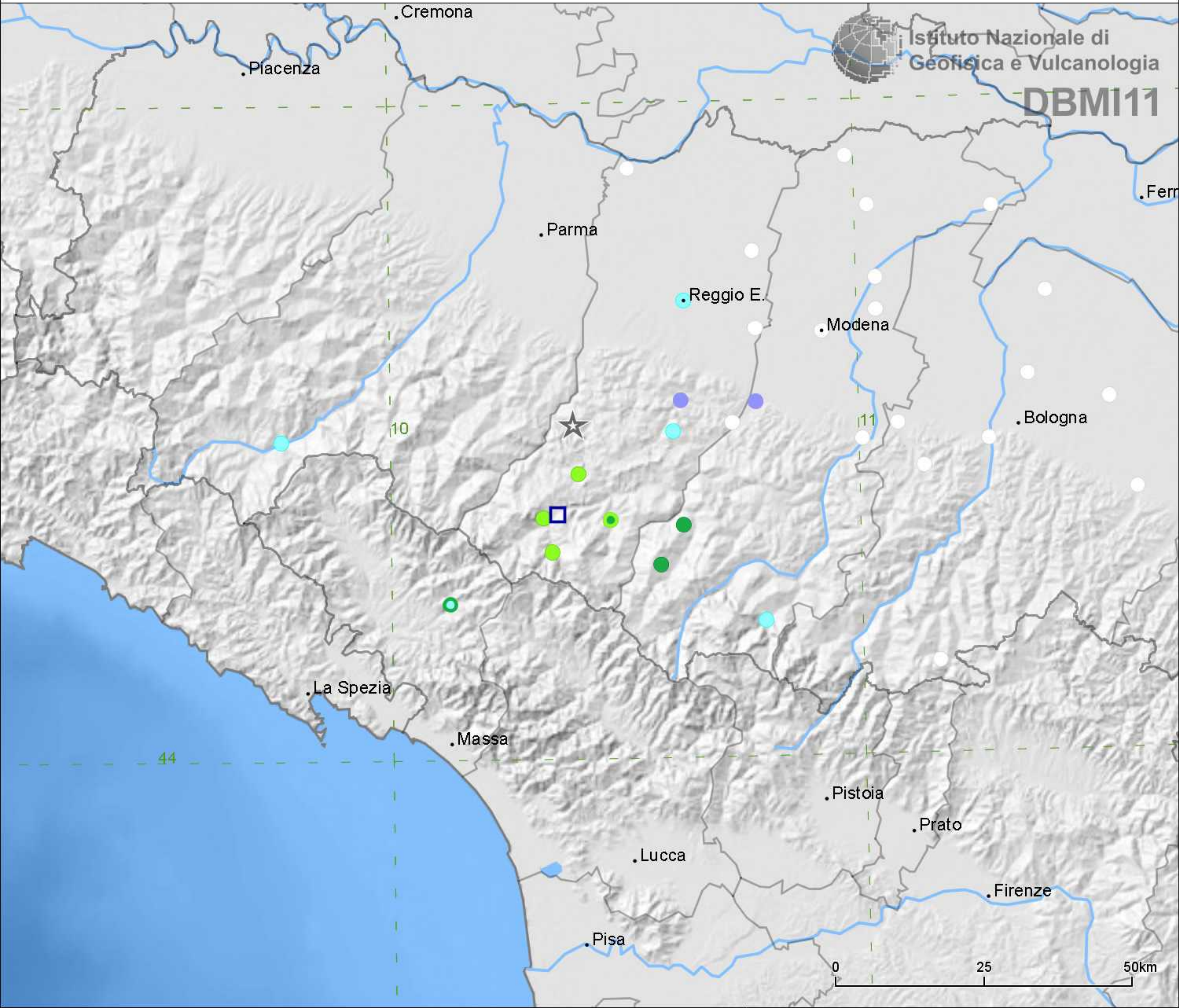


1	2	3	4	5	6	7	8	9	10	11

Int. 2-3 3-4 F 4-5 5-6 6-7 7-8 8-9 9-10 10-11

Terremoto del 9 novembre 1965 15:35:01, ALTA V. SECCHIA
Studio macrosismico Castelli et al., 1996 [Np 32, Imax 5]

Epicentro CPTI11 Mw 4.74 ±0.25
macrosismico Mw 4.36 ±0.54
strumentale Mw 4.85 ±0.29



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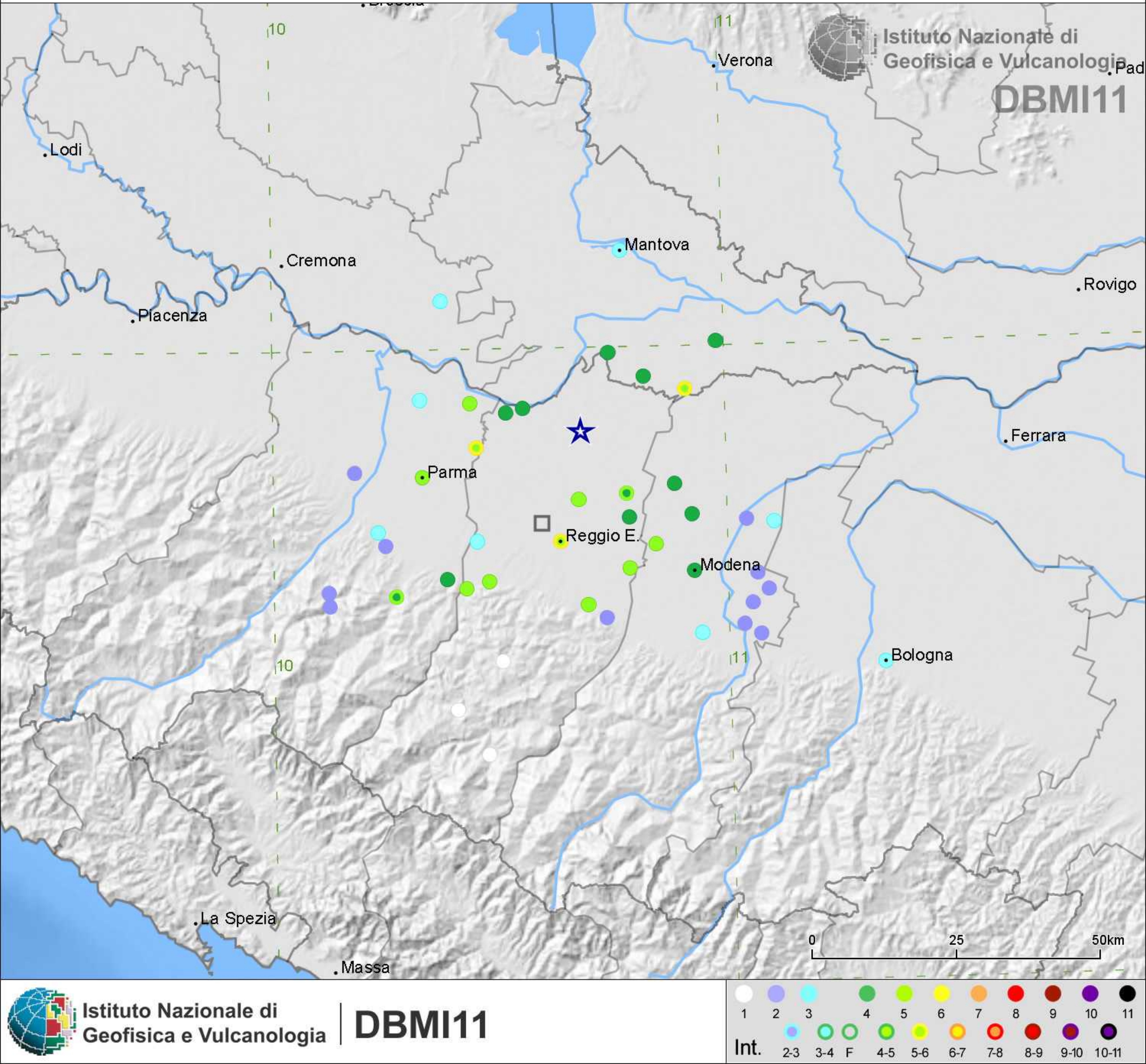
Int. 1 2 3 4 5 6 7 8 9 10 11
2-3 3-4 F 4-5 5-6 6-7 7-8 8-9 9-10 10-11

Terremoto del 3 aprile 1967 16:36:18, Reggiano
Studio macrosismico Guidoboni et al., 2007 [Np 47, Imax 5-6]

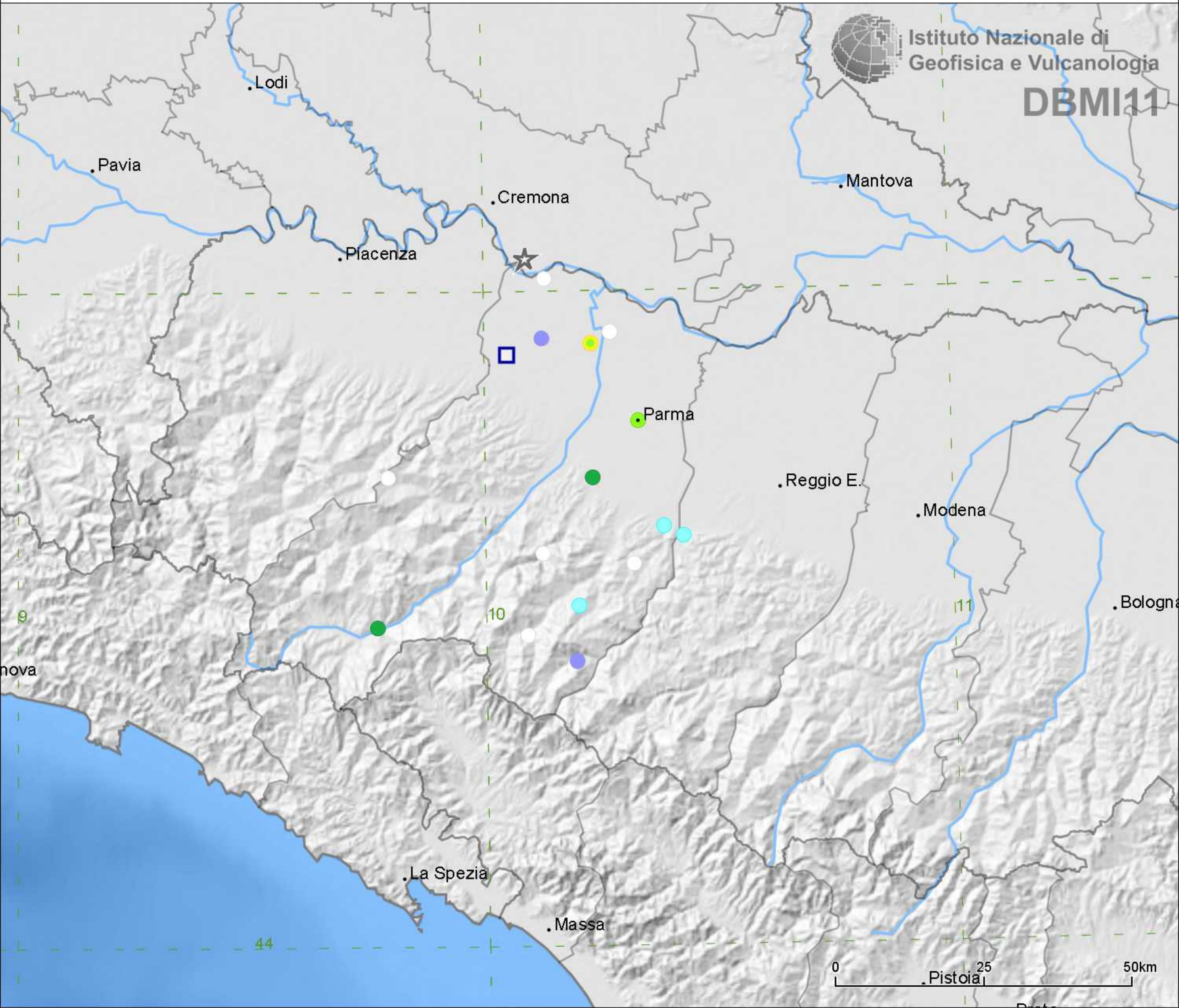
Epicentro CPTI11 ☆ Mw 4.69 ±0.19
macrosismico □ Mw 4.56 ±0.25
strumentale ☆ Mw 4.86 ±0.29

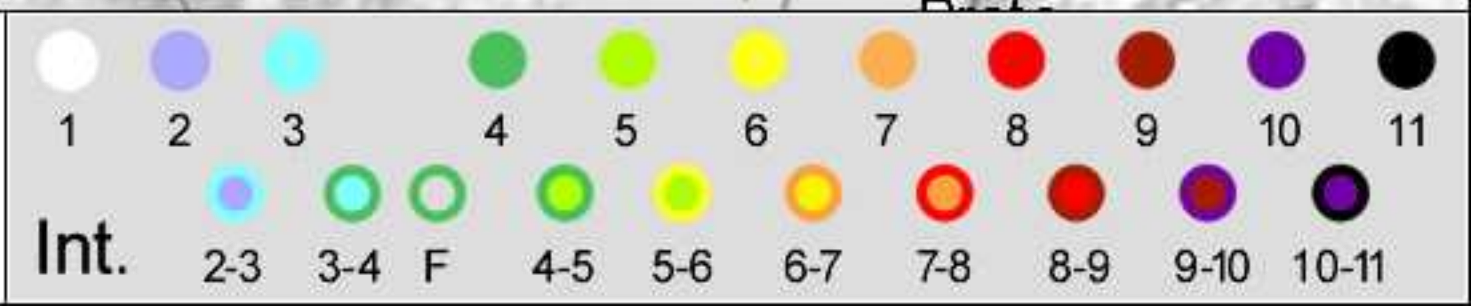


Istituto Nazionale di Geofisica e Vulcanologia | DBMI11

Terremoto del 24 giugno 1969 13:25:22, Parmense
Studio macrosismico Guidoboni et al., 2007 [Np 15, Imax 5-6]

Epicentro CPTI11 Mw 4.62 ±0.23
macrosismico Mw 4.70 ±0.26
strumentale Mw 4.35 ±0.47





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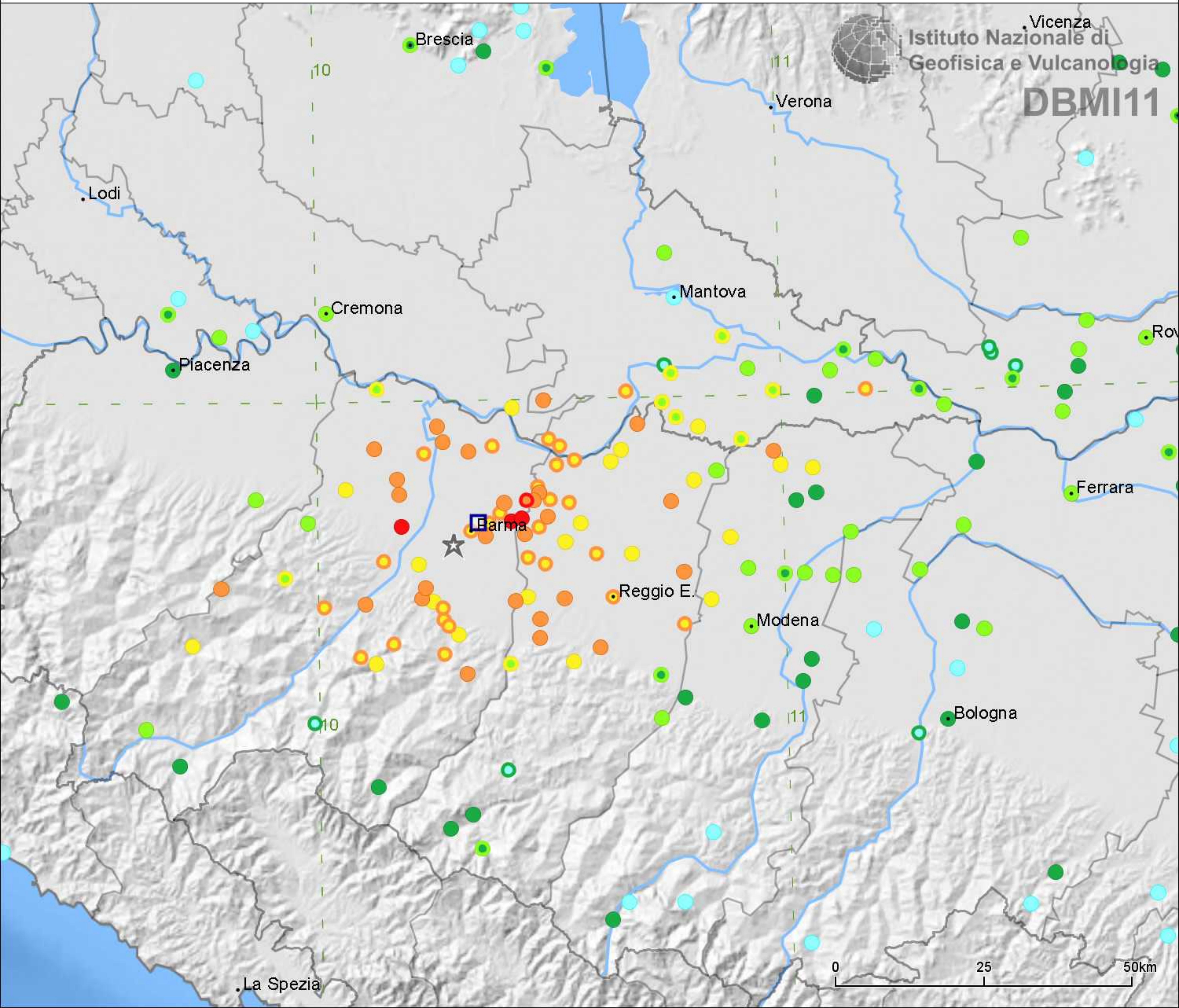
Terremoto del 15 luglio 1971 01:33:23, Parmense
Studio macrosismico Guidoboni et al., 2007 [Np 229, Imax 8]

Epicentro CPTI11 Mw 5.64 ±0.09
macrosismico Mw 5.67 ±0.10
strumentale Mw 5.38 ±0.29



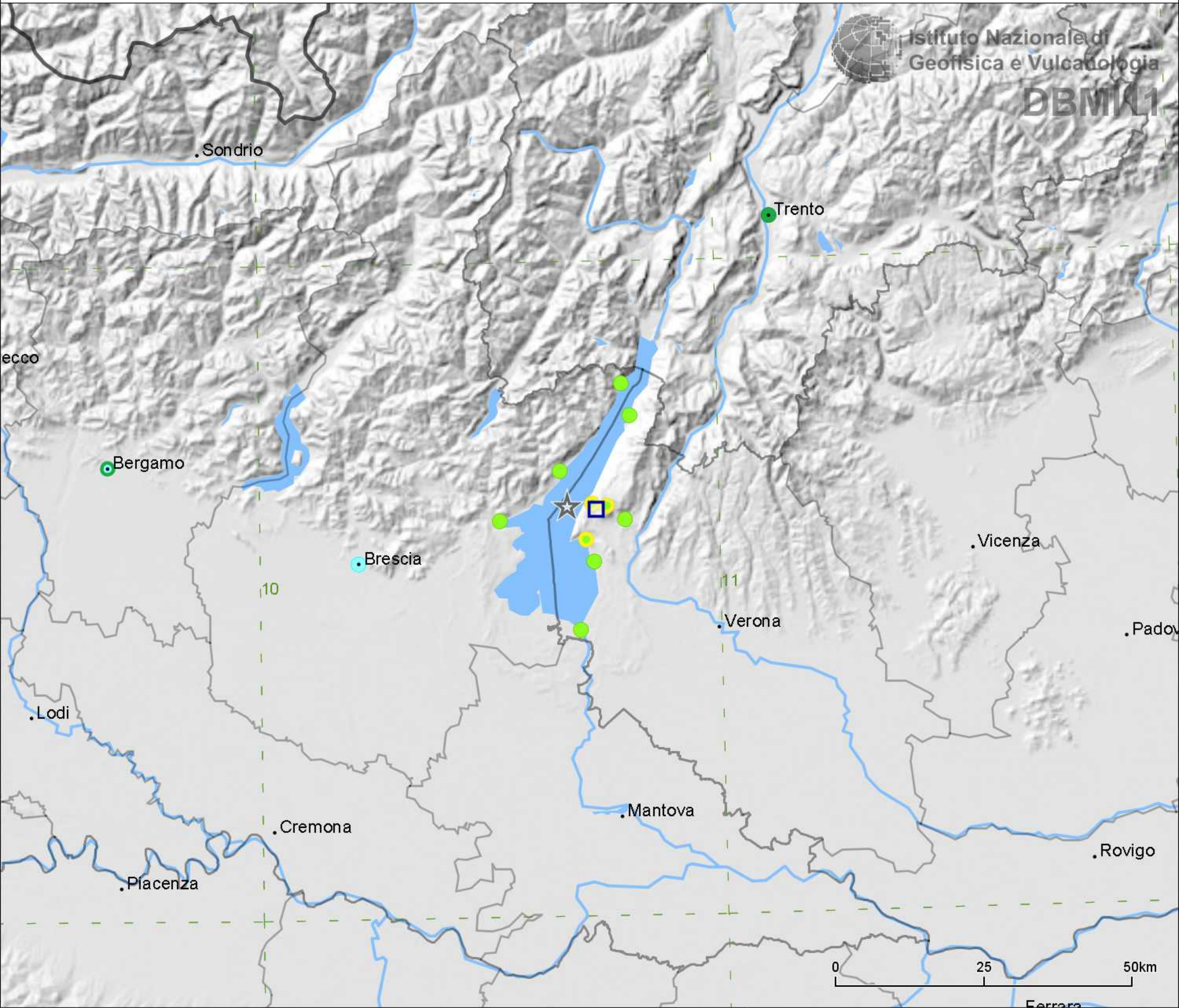
Istituto Nazionale di Geofisica e Vulcanologia | DBMI11

1	2	3	4	5	6	7	8	9	10	11

Int. 2-3 3-4 F 4-5 5-6 6-7 7-8 8-9 9-10 10-11

Terremoto del 11 gennaio 1975 15:54:37, GARDA OR.
Studio macrosismico ENEL, 1985 [Np 13, Imax 5-6]

Epicentro CPTI11 Mw 4.45 ±0.25
macrosismico Mw 4.45 ±0.46
strumentale Mw 4.45 ±0.29



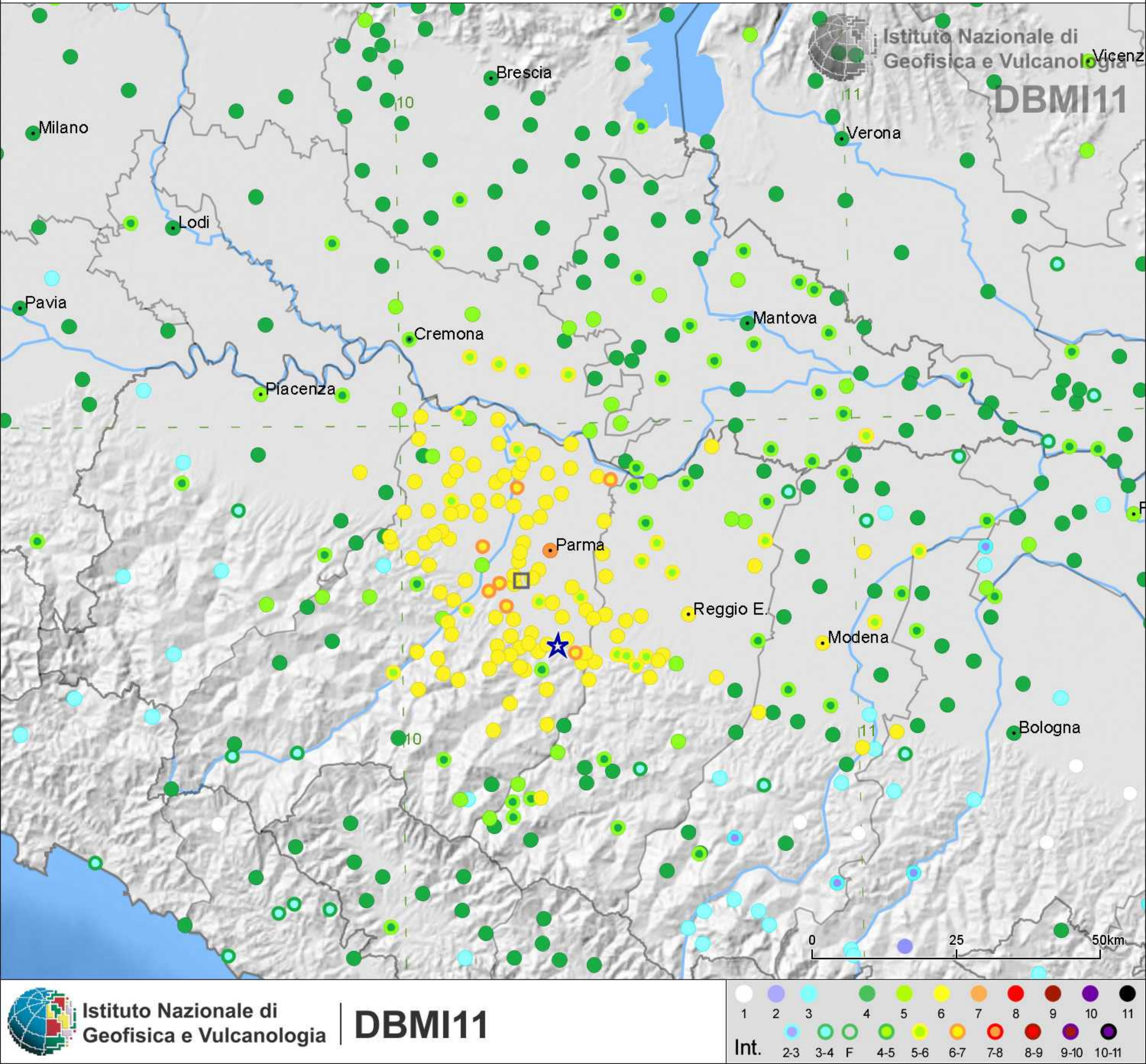
Istituto Nazionale di Geofisica e Vulcanologia | DBMI11

1	2	3	4	5	6	7	8	9	10	11

Int. 2-3 3-4 F 4-5 5-6 6-7 7-8 8-9 9-10 10-11

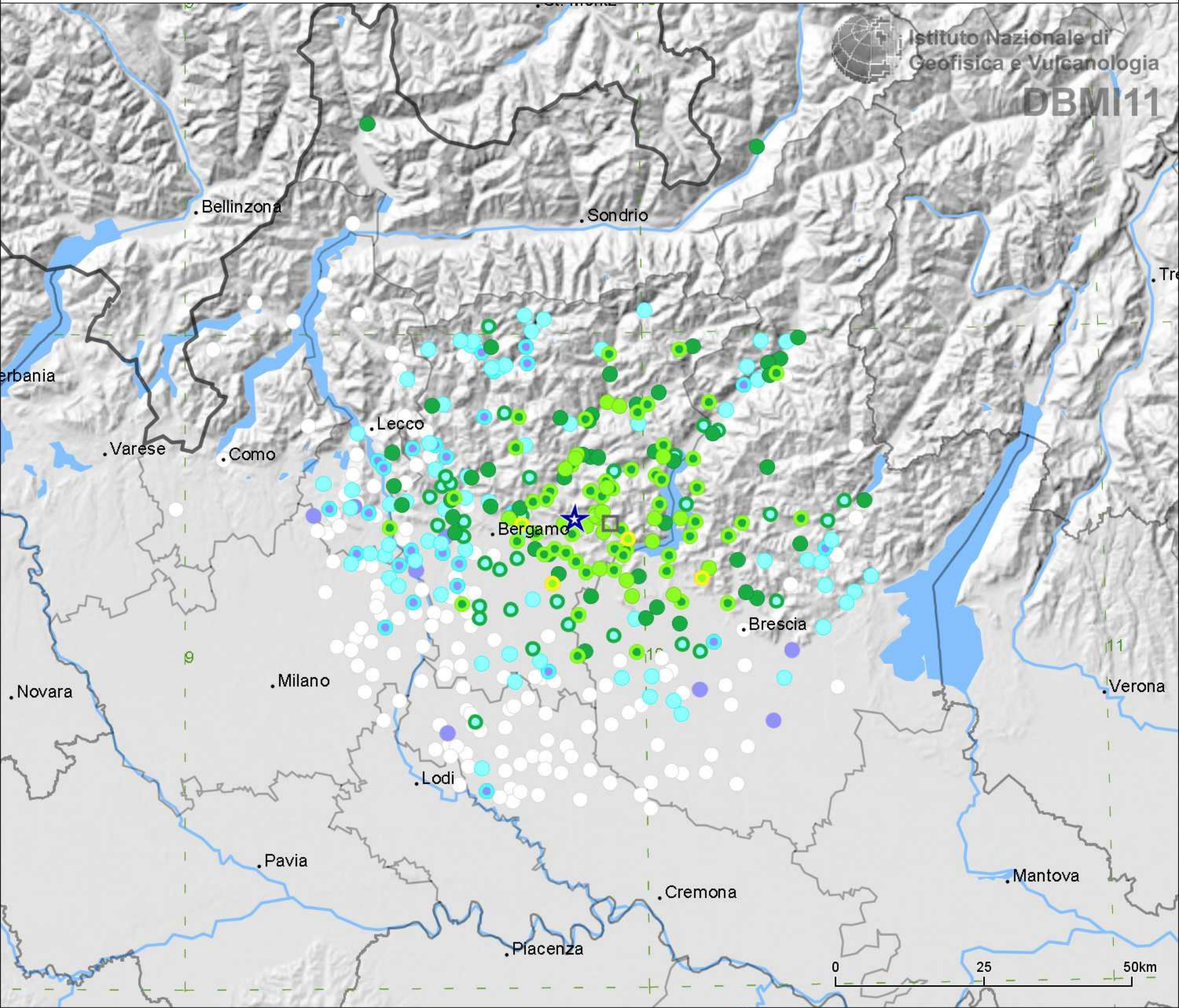
Terremoto del 9 novembre 1983 16:29:52, Parmense
Studio macrosismico Guidoboni et al., 2007 [Np 850, Imax 7]

Epicentro CPTI11 ☆ Mw 5.06 ±0.09
macrosismico □ Mw 5.27 ±0.09
strumentale ☆ Mw 5.06 ±0.09

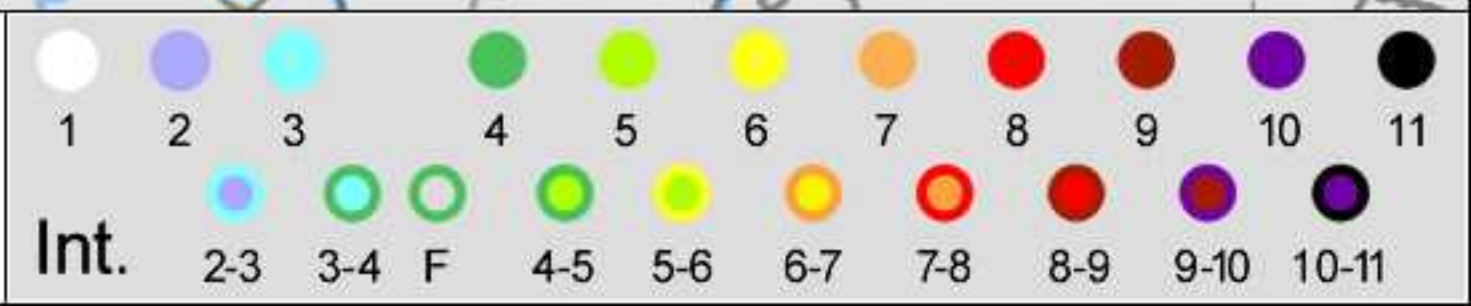


Terremoto del 29 ottobre 1995 13:00:26, BRESCIA-BERGAMO
Studio macrosismico Boll. Macro. ING [Np 408, Imax 5-6]

Epicentro CPTI11 ☆ Mw 4.54 ±0.09
macrosismico □ Mw 4.52 ±0.09
strumentale ☆ Mw 4.65 ±0.22



Istituto Nazionale di Geofisica e Vulcanologia | DBMI11



REVISION OF THE PO PLAIN EARTHQUAKE

CATALOGUE IN PROBABILISTIC TERMS

Report by M. Mucciarelli

Review by G. Woo

Member of the SIGMA Scientific Committee

23 May 2014

Background

This report by Marco Mucciarelli, SIGMA-2014-D1-109 ‘Revision of the Po Plain Earthquake Catalogue in Probabilistic Terms’, is a sequel to his earlier report SIGMA-2012-D1-51 ‘Preliminary Earthquake Recurrence Models with Extensive Use of Site Data.’

In my comments on this earlier report, I stated that I agreed with the author’s conclusions statement that a probabilistic revision of the catalogue would help to refine the MRTs.

The first attempt at a probabilistic version of the catalogue of the Po Plain is presented in this report, and there appears to be a welcome reduction in the uncertainty of estimating MRT for epicentral intensity, which would justify and reward the extensive research efforts made by the author.

Magnitude estimation from intensity data

On page 5 of the report, it is remarked that *‘the only way to solve the uncertainty associated to epicentral intensity (and thus converted magnitude) would be to carry on a reappraisal of the original source behind this single point.’*

Whereas I agree with this, what is open to question is the optimal method for estimating magnitude from historical macroseismic data. I happen also to be a reviewer of the report SIGMA-2014-D1-108 on calibration of macroseismic attenuation models. The methodology for magnitude estimation in this report by Bonnet et al. is to use all intensity data. The well-known problem with reliance on epicentral intensity is the ambiguity in assignment, and discreteness of the intensity scale. Although the author has applied ingenuity and industry to addressing these problematic issues in his report, it is unclear whether this approach for estimating magnitude will be as robust as one based on using more intensity data, e.g. felt area, which is a continuous measure, and is more stable against intensity assignment error.

A benchmark comparison of alternative methods could be made using the instrumental dataset of events for which the magnitude is both measured and inferred via some correlation with macroseismic data: epicentral intensity, felt area, etc..

Ultimately, it may well be the case that some hybrid method suits the Po Plain data best. There are indeed some major old mediaeval events for which only the epicentral intensity is known, and the felt area is very poorly constrained. Conversely, there are other historical events where the felt area is quite well constrained, and would provide a more robust estimate of magnitude than epicentral intensity, which may be poorly estimated if the epicentre happens to be in an area of low population density.

In the production of the final report, it would be instructive if these fundamental methodological issues might be given special priority by the author over refining existing results. In particular, he should take into consideration the work being done in France on magnitude estimation from macroseismic data.

Project SIGMA

Preliminary Review of:

Revision of the Po Plain Earthquake Catalogue in Probabilistic Terms

(Ref : SIGMA-2014-D1-109)

by : Jean B. Savy
May 25, 2014

This is a review of the research work done by Marco Mucciarelli and documented in EDF Ref: SIGMA-2014-D1-109. This work is to be presented at the CS7 of June 4 th to the 6th, 2014, in Cadarache, France.

Purpose and Scope of the study

Comments made at the review of a previous work documented in SIGMA-2012-D1-51 mentioned the fact that the full uncertainty in the intensity data for the Po Plain was not fully expressed as it was using a somewhat deterministic interpretation of the values in the catalog (essentially by using whole values of intensities). In response to this comment, it was decided to explore the possibility of introducing some (epistemic) uncertainty in those values, hence the label “Probabilistic” in the title of the document. The purpose of the study reported in this document (D1-109), was not to start from scratch and revisit the entire set of methods of seismicity characterization via intensity data, this was done extensively in other tasks earlier in SIGMA, but rather the purpose here was to simply explore one possible way of introducing epistemic uncertainty that is inherent in the catalog. The goal of the study is to eventually demonstrate that using a “probabilistic” approach is better from the point of view of characterizing this uncertainty. The authors decided to test the method of collection of information by eliciting the opinion of experts to characterize that uncertainty.

Review approach

The document provided for review appeared to only give a short description of the work performed. The document only gives a short description of the general idea of what is to be done and it provides an example of how to do it, but at this time, it does not appear to be either a mature and complete reporting, or a complete achievement of the goals and full scope of this task. For these reasons, my review concentrated on giving some recommendations and suggestions of what could be done to finish the task.I assumed that performing a full review will be on the agenda of one of the next CS meetings (November 2014?).

Suggestions and recommendations

My suggestions are as follows:

1. From the present document, it appears that the data, in the form of seismicity maps, has not been and will not be modified in any way, and therefore, I do not see the need to put in appendix all the maps if it is only to make the report bigger. Maybe one or two maps as examples would be fine. And if latter on it appears that some actual work is done on the maps it might be useful to append some of them.

2. One important item that seems to be missing in the study is, at least, a quick review of existing literature on studies dealing with characterization of uncertainty in intensity measures, and how to use it in a seismic hazard analysis. Several studies in SIGMA deal specifically with similar issues, and should be consulted.

3. The idea of using a distribution function for the intensity measure is not new, but using expert judgment is more recent, and I support this approach. However I recommend that this be done in a more formal and traceable way than as described in the report. There should definitely be more than one or two experts elicited, and I recommend at least 5. The process of elicitation should be documented completely in the report, in particular with details of questions asked to the experts, how the responses of the experts are used and combined, and how the experts are selected.

4. The goal being to improve on a previous study, I would like to see a convincing measure of improvement. I suggest that a comparison and measure of improvement be done at the level of the calculated hazard itself. Maybe there are some simpler ways to do this.

In conclusion, this is potentially a very important work for seismicity rate determination. A well thought-out process to improve Intensity catalog uncertainty could have a substantial impact on other WPs in SIGMA and I would like to see this task to be a well put together piece of work and a good document, for the benefit of the project.

Respectfully submitted, May 23, 2014

Jean Savy

733 Arimo Avenue, Oakland, CA 94610
(510) 502-3249 * (510) 834-1394 (Fax)
Jean.savy@att.net