2012 EMILIA EARTHQUAKES

The MCS macroseismic survey of the Emilia 2012 earthquakes

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1. Introduction

Most of the inhabitants of northern Italy were woken up during the night of May 20, 2012, by the M_W 6.1 earthquake [QRCMT 2012] that occurred in the eastern Po Plain. The mainshock was preceded a few hours before by a M_W 4.3 shock, and it was followed by a dozen M_L >4 aftershocks in May and June, amongst which 11 had M_L ≥4.5. On May 29, 2012, a second M_W 6.0 mainshock struck roughly the same area [QRCMT 2012], which resulted in further victims, most of whom were caught under the collapse of industrial warehouses. Such earthquakes are an unexpected event in this region, as testified by the lack of local epicenters in the Italian seismic catalog [Rovida et al. 2011: CPTI11 from now] and by the consequent low level of the local seismic classification (seismic zone 3) [DPC 2012].

Apart from the warehouses and hundreds of old, crumbling farmsteads, severe damage was focused on ancient, tall buildings, such as churches, bell towers, castles, towers and palaces. Residential buildings generally suffered only light and/or moderate effects, apart from some exceptional cases. Using the Mercalli–Cancani–Sieberg (MCS) scale [Sieberg 1930], we began a macroseismic survey in the early morning of May 20, 2012, that ultimately included visits to almost 200 localities, 52 of which were carried out before the second mainshock.

2. Hints on the local historical seismicity

According to historical sources, the area hit in 2012 has not been affected by events with epicentral intensity I_O >6 MCS, which, conversely, have fallen at the eastern and western boundaries of this region hit in May 2012 (Figure 1). The strongest event occurred in 1570 (November 17; I_O 7-8 MCS, M_W 5.46), ca. 35 km from the 2012 epicenters, and it is also the only earthquake that has hit some of the villages that were affected by the 2012 sequence. Its mesoseismic area is NW-SE elongated [Postpischl 1985], which parallels the local buried front of the Ferrara thrusts [Pieri and Groppi 1981, Cassano et al. 1986], which are, in turn, the eastern prolongation of the fronts likely to have been activated in the 2012 sequence. As in 2012, the 1570 sequence recorded more mainshocks, which lasted at least until 1572, and many localities were affected by liquefaction phenomena. These occurred mainly around Ferrara, and up to Ficarolo, on the left bank of the Po River [in Galli 2000, see Figure 1].

Prior to 1570, a coeval chronicle [Giacomo da Marano, 15th century] suggested that there was another strong earthquake in Ferrara in the year 1346, when on February 22, "*many houses fell down, palaces, towers…and in the villages, tenements, barns…and other buildings*". However, due to the little information available, this could really have occurred anywhere around Ferrara, and for instance, also in the eastern part of the region that was hit in 2012. The DBMI11 (the Italian macroseismic database) [Locati et al. 2011] reports also two minor earthquakes (I_O 6 MCS) within the 2012 mesoseismic area: one that occurred on December 6, 1986 (M_W 4.35), and the second on May 8, 1987 (M_W 4.56).

On October 15, 1996, at the western boundary of the investigated area, an earthquake with MW 5.41 (CPTI11; I_O 7 MCS) [De Canini et al. 1997] affected mainly Bagnolo in Piano and Correggio, where severe damage was observed to a few ancient buildings, as well as light cracks in many brick and masonry buildings, and also in two reinforced-concrete-frame structures. At that time, the earthquake was associated with the rupture of the left lateral ramp of the Cavone thrust [De Canini et al. 1997]; i.e., the western prolongation of the Mirandola structure. Further north, a similar earthquake in 1806 caused damage in Correggio (7 MCS), and in other localities hit by the 2012 sequence, such as Reggiolo and Carpi (6-7 MCS).

We can conclude that in the period of earthquake completeness for such a class of magnitude [Stucchi and Albini 2000], the epicentral area of the 2012 events has never generated earthquakes with energy comparable to this current sequence. Moreover, it has probably never been affected by damage from external earthquakes, with the exception of those related to the 1570 Ferrara event, in the easternmost

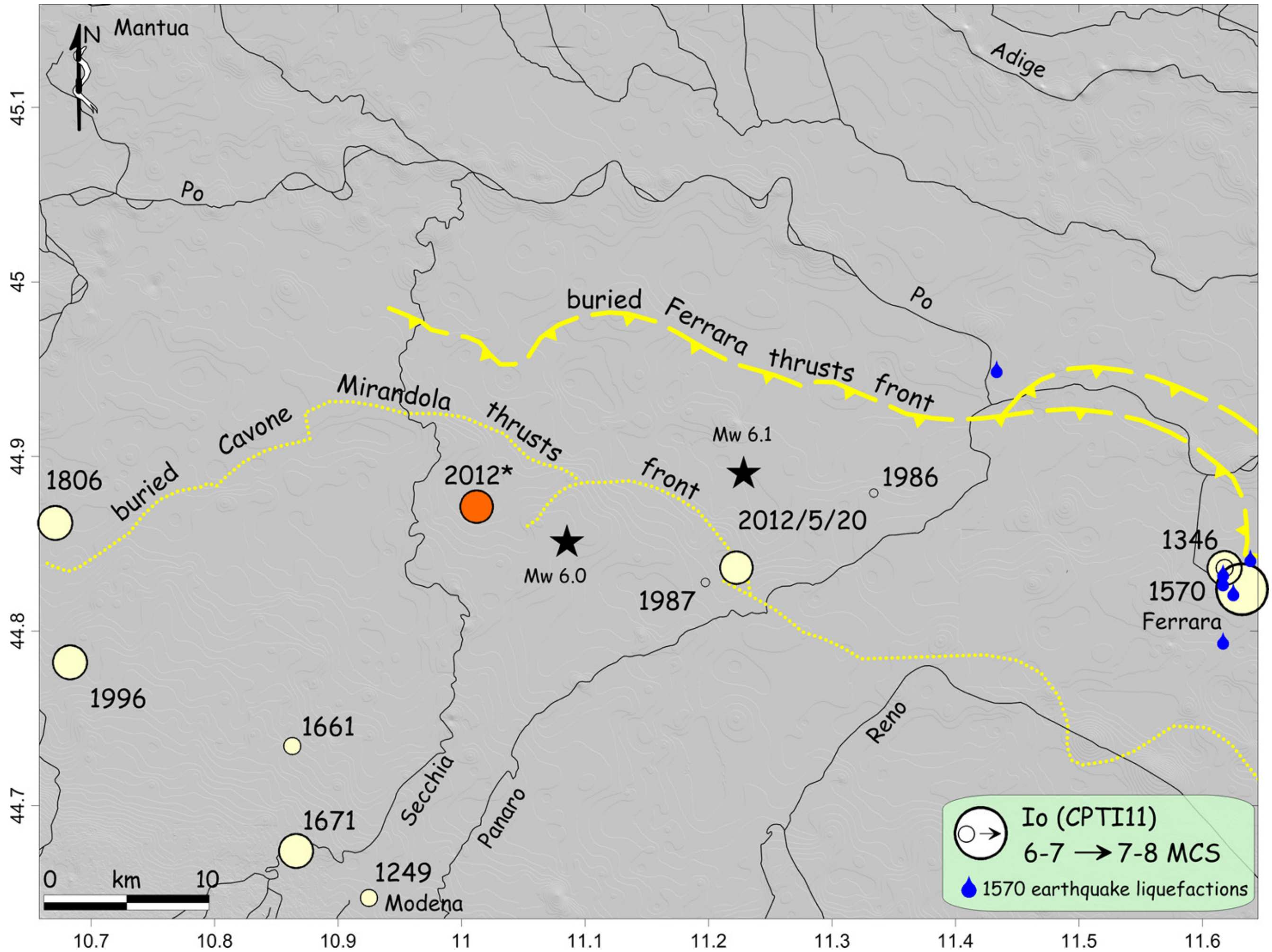

Figure 1. Distribution of the historical epicenters (CPTI11) within the area hit by the 2012 sequence. Stars, instrumental epicenters of May 20 and 29, 2012; orange*, macroseismic epicenter of the cumulated effects of the May 20 and 29, 2012, events; dotted and dashed yellow lines, buried front of the Cavone–Mirandola and Ferrara folds and thrusts. The 1570 earthquake-induced liquefactions are from Galli [2000]. Note the absence of significant historical epicenters in the 2012 seismic sequence area.

portion, and to the 1806 and 1996 events, in the westernmost portion. Therefore, it is likely that the 2012 mainshocks represent the first, and in some places the last, anti-seismic testing for the historical buildings of this region.

3. The 2012 MCS macroseismic survey

Our site intensity (I_S) attribution was achieved by applying the MCS macroseismic scale, i.e., the scale adopted for the whole of the Italian macroseismic database (DBMI11), and not the more recent European macroseismic scale (EMS) [Grünthal 1998]. Indeed, as the MCS scale does not fully account for the vulnerability of each single building, it allows a more expeditious application during surveys, which provides the information that is directly correlated to the damage level. We adopted the methodology proposed by Molin [2003, 2009], who differentiated five damage levels (1-5: light, moderate, severe, destruction, collapse), with the calculation of the percentages of damage as 5%, 25%, 50%, 75% and 100%, which are representative of each MCS degree, as implicitly contained in the original scale [Sieberg 1930; e.g., in Galli et al. 2012].

3.1. The May 20 earthquake survey

We surveyed 52 localities belonging to 30 municipalities in the provinces of Modena, Ferrara and Mantua. This revealed the area of the most severe effects (I_S ≥6 MCS), which was WNW-ESE elongated to the west of the instrumental epicenter, in agreement with the focal mechanism of the mainshock (Figure 2). This area completely matches the hangingwall of the outer Ferrara thrusts front (Figures 1, 2, and the associated focal mechanisms); i.e., the seismogenetic structure responsible for this cluster of the sequence [Galli et al. 2012]. Outside of this area, both to the west and to the east, we observed an intensity increase, in the Moglia, and San Carlo areas, respectively. The maximum intensity (I_{max}) was 7 MCS, which was assigned to Mirandola and San Felice sul Panaro (Figure 2), while I_S 6-7 was evaluated for Finale Emilia, Canaletto, Mortizzuolo and San Carlo, and I_S ≤6 MCS for all of the other localities. The I_O derived through Boxer4 [Gasperini et al. 2010] was 7 MCS, with a much lower equivalent moment magnitude (M_W 5.1) than the instrumental value (M_W 6.11), while the macroseismic epicenter was ca. 5 km south of the instrumental epicenter (Figure 2; Table 1).

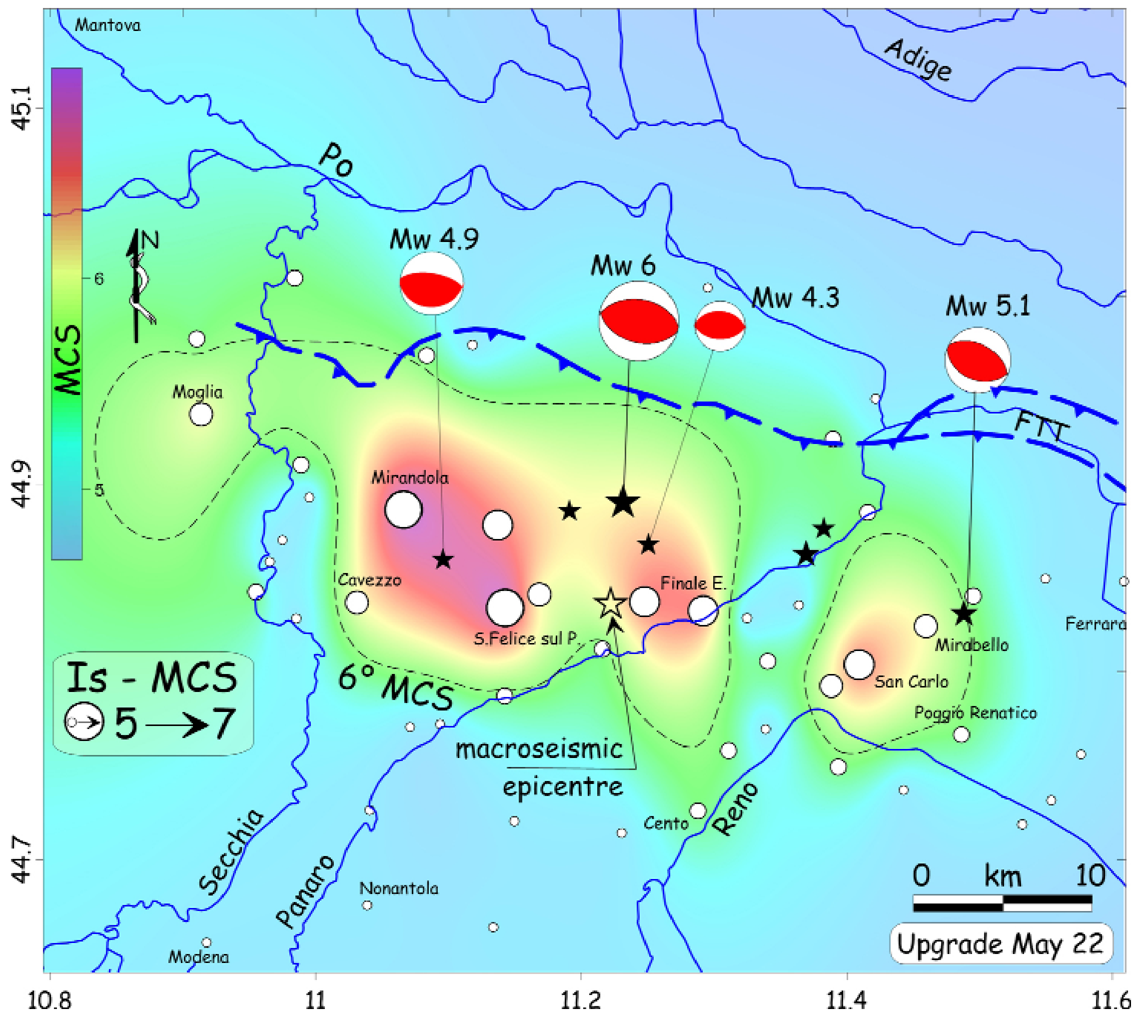

Figure 2. Intensity datapoint distribution of the May 20, 2012, mainshock (white circles, proportional to MCS degrees). The background image indicates the areal shaking in MCS terms. Dashed line, interpolated 6 MCS isoseismal; dashed blue line, buried front of Ferrara thrusts (see Figure 1) to which the focal mechanisms are referred [Time Domain Moment Tensor, TDMT 2012, QRCMT 2012].

Date	Time (GMT)	Instrumental coordinates		Depth (km)	M_L CNT	M_W RCMT	Macroseismic coordinates		I_O (MCS)
		Latitude (°N)	Longitude (°E)				Latitude (°N)	Longitude (°E)	
May 20, 2012	02:03:52.0	44.889	11.228	6.3	5.9	6.11	44.836	11.222	7
May 29, 2012	07:00:03.0	44.851	11.086	10.2	5.8	5.96	44.877	11.004	7

Table 1. Instrumental and macroseismic parameters of the two mainshocks of the Emilia 2012 sequence (INGV source, and the present study). The May 29, 2012, string accounted for the cumulated effects of the sequence. GMT, Greenwich Mean Time; CNT, National Earthquake Center (INGV); RCMT, Regional Centroid Moment Tensor; MCS, Mercalli–Cancani–Sieberg.

Most of the heavy damage, which included total and partial collapses, affected tall historical buildings, such as churches, bell towers, towers, castles (Figure 3), palaces, and ancient farmhouses, as well as many industrial warehouses on the outskirts of Mirandola and Sant'Agostino (Figure 4).

The residential housing estates generally suffered low-grade damage (levels 1-2), both for brick and masonry (reinforced or not) and for reinforced concrete. There was sparse severe damage (level 3) and very rare partial collapse (usually of roof ledges, roofs and loading docks of crumbling houses) or destruction (level 4), as well as diffuse falls of chimneys, tiles and plaster, which occurred almost everywhere within the old downtown areas. This explains why this night earthquake resulted in a limited number of victims (9), almost all of whom were night-shift workers in the industrial warehouses. Severe damage to reinforced-concrete buildings was observed in one case inside Mirandola and in three others on its northern outskirts (light crushing of pillars and cracks on the brick-curtain walls), as in some apartment houses in Cavezzo.

Figure 3. The morning of May 20, 2012. Top: View of the Mirandola Cathedral (15th century). At that time, only a few architectural elements at the top of the façade had fallen down, besides the incipient façade detachment. The church was damaged again, and more seriously, by the May 29, 2012, mainshock. Bottom: Partial collapse of the Estense Castle (15th century) in Finale Emilia.

In some cases, the damage was increased due to the huge liquefaction phenomenon that affected the deposits below the buildings, with the consequent loss of weight-bearing capacity, and differential settling and/or tilting of foundations. Liquefaction occurred extensively in the villages located over the paleo-beds of the main rivers, such as in Sant'Agostino, San Carlo and Mirabello, all of which were founded along the abandoned Reno fluvial ridge. Here, as well as the damage to buildings, the surficial breaks induced by the liquefaction settling processes also affected roads and pipelines. As can be seen from Figure 2, it emerges that the intensity bulge at the eastern side of the mesoseismic area is merely due to these liquefaction effects, and not just to the seismic shaking of buildings.

In the more distant towns of the Po Plain, there was no severe damage, and not even to isolated buildings. In Mantua and Modena the damage was limited to levels 1-2, to only a very few houses, while Ferrara experienced levels 1-2 to several old houses downtown, mostly related to pre-existing cracks. We recorded the fall or rotation of a dozen chimneys, tiles, and sparse architectural elements hanging on the church façades, as well as the partial collapse of a small tower over the Estense Castle.

We did, however, have trouble in evaluation of the I_S in many localities (Appendix 1, Table A1), because of the extreme differences in the damage levels between recent residential housing (usually 1-2 storeys, reinforced brick and masonry villas) and the historical monument buildings. As in the L'Aquila 2009 earthquake (M_W 6.3) [Galli et al. 2009], we chose to take more into account the effects recorded by the buildings inside the old centers, and to exclude entirely the damage to industrial warehouses.

3.2. The May 29, 2012, earthquake survey

We re-started the macroseismic survey on the morning of May 29, 2012, visiting again the villages hit by the May 20, 2012, event, for up to 190 localities belonging to 87 municipalities (Figure 5). We observed an increase of 1-2 MCS degrees in some villages in the western part of the area, with severe damage in Reggiolo (I_S 6-7 MCS), Novi di Modena (I_S 7 MCS), Concordia sulla Secchia (I_S 7 MCS; with some partial collapse and severe damage to the front porches of buildings), Moglia (I_S 7 MCS), and Rovereto ($I_S = I_{max}$ 7-8 MCS; maximum intensity assigned in this earthquake). This last was where various partial collapsing and heavy damage occurred, both in the brick and masonry houses of the old center and in some of the recent reinforced-masonry and reinforced-concrete buildings. In the other localities generally west of Mirandola, the intensity grew by <1 MCS degree. In Mirandola, the May 29, 2012, mainshock and the successive strong aftershock of midday (M_W 5.3) caused the collapse of the 14th century Saint Francis church, which was only slightly damaged by the May 20, 2012, earthquake. Moreover, it caused further collapse of the Cathedral, and various heavy damage to and partial collapse of the old houses downtown, as well as to some reinforced-concrete buildings already damaged on May 20, 2012. In Cavezzo, the increased damage level also yielded a higher intensity (at least I_S 7 MCS), which was mainly justified by the collapse of the *pilotis* of three reinforced-concrete buildings (Figure 6) and by the diffusion of level 3 damage to several brick and masonry houses in the old center.

Southwards, outside the 6 MCS isoseismal shown in Figure 5, both Crevalcore and Cento suffered more effects within their old centers, which now showed diffuse level 2 damage to about a quarter of the buildings, with some heavy damage (level 3) and sparse partial collapse of roof-bearing walls.

In turn, the damage area did not extend substantially northwards, although we assigned I_S 5-6 MCS to several localities near the Po River, and exceptionally also to the north of it (Castelmassa). Heavy damage to isolated monument structures (usually churches or bell towers) and absolutely no damage to residential buildings was observed in many villages, to which we necessarily assigned I_S 5 MCS. However, the intensity datapoints listed in Appendix 1 (Table A1) note these effects in column DJ, where the labels A, B and C indicate heavy damage to and/or collapse of buildings, towers or bell towers, and churches.

Overall, the 6 MCS area extended westwards, to reach a length of 35 km; i.e., 10 km more with respect to the May 20, 2012, event. Also, two extreme intensity bulges were seen to the west and the east: the first was now focused on Reggiolo (it was on Moglia before), while the second was again that occupied by San Carlo and Mirabello. Considering also these areas, the 6 MCS is ca. 55 km elongated WNW-ESE, with a N-S width of 15 km to 20 km. As seen from Figure 5, and assuming a roughly similar vulnerability in all of the surveyed localities, it is probable that the intensity bulges mentioned represent many cases of geological amplification. In one of these, we recognized the strong contribution of the liquefaction phenomenon that occurred extensively all along the paleo-bed of the Reno River, while in the other cases, only future geological analyses will be able to reveal the causes of the seismic shaking increase, hopefully. It is worth noting that also during this shock, several liquefaction phenomena occurred, some in the same places as for the May 20, 2012, event, others in different localities. However, the power of the phenomenon was certainly lower than in the earlier case, and no further damage was reported.

Also for this May 29, 2012, mainshock, our intensity estimates refer mainly to the old center of the surveyed localities, as almost everywhere the earthquake affected these more than the modern outskirts (which were generally affected by sparse 1-2 level damage), apart from some impressive exceptions in Rovereto (collapse of the *pilotis* of new reinforced brick and masonry 3-storey villas) or Fossoli (level 3 damage to the first and second storeys of some reinforced-concrete buildings). In some villages (e.g., Cento, Concordia, Crevalcore, Moglia, Reggiolo, San Giacomo delle Segnate), the damage was diffuse in the porch houses; i.e., the typical buildings of almost all of the main streets of the Po Plain settlements. Here, we often observed level 2 and 3 cracks that affected the columns and/or the pillars of the arches, with consequent damage to the overlying wall of the first/second storey.

Figure 4. Collapse of the Sant'Agostino ceramics warehouse near Sant' Agostino village.

The I_O of the cumulated sequence (mainly from May 20 and 29, 2012) calculated through Boxer4 was again 7 MCS, with an equivalent magnitude always lower (M_W 5.23) with respect to the instrumental one (M_W 6.11 plus M_W 5.96). The final epicentral coordinates (Table 1) identified a point located more than 15 km west of both the instrumental and macroseismic epicenters of May 20, 2012, and 5 km west of the instrumental epicenter of May 29, 2012 (Figure 5). This westward drift of the barycenter of the macroseismic effects with respect to the instrumental ones might roughly indicate the rupture direction along the structures responsible at depth for this sequence; i.e. from east to west.

4. Discussion and conclusions

We applied the MCS scale [Sieberg 1930] for the macroseismic survey of 190 localities in the Provinces of Mantua, Rovigo, Ferrara, Modena and Reggio Emilia, using the methodology proposed by Molin [2009]. On the one hand, the resulting intensity datapoint distribution (IDD) meets the primary purposes of the civil protection intervention (rescue and emergency planning based on real damage, leaving vulnerability out of the consideration), and on the other hand, it can be directly compared to the historical earthquakes contained in the Italian seismic database. We compiled a preliminary IDD also for the May 20, 2012, mainshock, composed of 52 datapoints (Appendix 1, Table A1). The highest IDD (HIDD) for both of the mainshocks

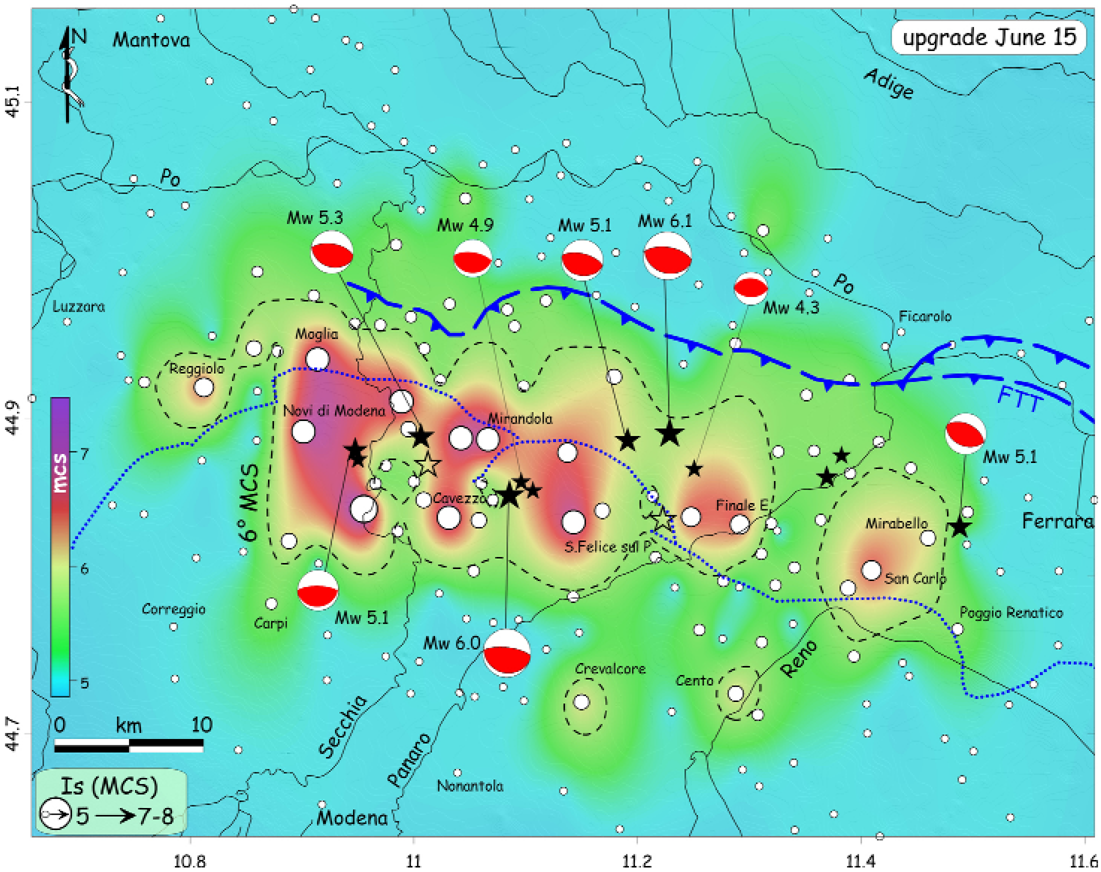

Figure 5. Intensity datapoints distribution of the whole of the 2012 sequence. The color image in the background suggests the areal shaking in terms of the MCS intensity. Black dashed line, the 6 MCS degree isoseismal as interpolated from the intensity data; dashed and dotted blue lines, the Ferrara and Cavone-Mirandola thrust fronts, respectively, i.e., the structures responsible for the whole sequence; black stars, the main events, with their associated focal mechanisms [TDMT 2012, QRCMT 2012]. The two empty stars are the macroseismic epicenters of the May 20, 2012, (east) and of the cumulated May 20 plus 29, 2012, mainshocks (west).

fits with the hangingwall of the two main buried thrust fronts of the region, with the May 20, 2012, HIDD lying entirely south of the outer Ferrara thrust fronts, and the May 29, 2012, HIDD lying south of the Mirandola–Cavone thrust (Figures 1, 5). Therefore, considering the entire extension of the arched, outer Ferrara thrust fronts and the intermediate Cavone–Mirandola buried folds and thrusts (Figure 5), and considering the historical seismicity of the same region (Figure 1), the 2012 sequence partially filled the seismic gap that existed between the earthquakes in the Ferrara area to the east (i.e., 1570) and those around Correggio to the west (i.e., 1806, 1996). This confirms the assumed residual activity of these buried structures [e.g., in Galli 2005, Scrocca et al. 2007].

Figure 6. Cavezzo (I_S 7 MCS). Total collapse of the *pilotis* of a reinforced-concrete building in the old center (photo taken on the morning of May 29, 2012). This building experienced level 2 damage because of the May 20 mainshock, and was not inhabited when it collapsed on May 29.

The equivalent magnitude estimated through Boxer4 [Gasperini et al. 2010] was much lower than the instrumental one (M_W 5.23 vs M_W 6.1). If we had really only considered the damage that affected the ancient houses (excluding all those not only on the recent outskirts, but also the new buildings inside the old centers), our intensities would have been higher by 0.5 to 1.0 degree. Of particular note, this would not be everywhere, as for instance in Cavezzo or Fossoli, it would have been lower, where the damage affects mainly modern, reinforced-concrete buildings. However, this increase is not enough to equal the instrumental magnitude. There is a similar anomaly also when considering the acceleration peaks (e.g., Mirandola, 0.29 g; San Felice sul Panaro, Cento 0.23 g; Moglia, 0.25 g; http://www.protezionecivile.gov.it/jcms/it/attivita_di_monitoraggio_dpc.wp), which would account for much more damage with respect to that which actually occurred (e.g., 9 MCS in Mirandola, by considering the correlations in Faccioli and Cauzzi [2006]). We must conclude that the quality of the ancient brick and masonry houses in Emilia, and the role played by the deep alluvial deposits in filtering the earthquake frequency content, might have concurred in this mitigation of the shaking effects on most of the building typologies (although, unfortunately not for monument buildings), despite the relative high magnitudes and acceleration peaks.

References

Cassano, E., L. Anelli, R. Fichera and V. Cappelli (1986). Pianura Padana. Interpretazione integrata di dati geofisici e geologici, 73° Congresso della Società Geologica Italiana (Roma, 29 sett.-4 ott.), 27 pp.

De Canini, L., G. Di Pasquale, G. Orsini, R. Colozza, P. Galli, A. Marcucci, G. Milana, D. Molin and A. Pugliese (1997). Ricognizione degli effetti del sisma del 15 ottobre 1996 in provincia di Reggio Emilia, Dipartimento dei Servizi Tecnici Nazionali, Servizio Sismico Nazionale, Rapporto Tecnico SSN/RT/97/4, 191 pp.

DPC (2012). Classificazione sismica al 2012. Recepimento da parte delle Regioni e delle Provincie autonome dell'Ordinanza PCM 20 Marzo 2003, n. 3274, Dipartimento della Protezione Civile, http://www.protezionecivile.gov.it/resources/cms/documents/class2012_02prov.pdf (last access July 2012).

Faccioli, E., and C. Cauzzi (2006). Macroseismic intensities for seismic scenarios estimated from instrumentally based correlations, In: Proceedings of the First European Conference on Earthquake Engineering and Seismology (Geneva, 3-8 September 2006), CD-ROM.

Galli, P. (2000). New empirical relationships between magnitude and distance for liquefaction, Tectonophysics, 324, 169-187.

Galli, P. (2005). I terremoti del Gennaio 1117. Ipotesi di un epicentro nel cremonese, Il Quaternario, 18, 87-100.

Galli, P., R. Camassi, R. Azzaro, F. Bernardini, S. Castenetto, D. Molin, E. Peronace, A. Rossi, M. Vecchi and A. Tertulliani (2009). Il terremoto aquilano del 6 aprile 2009: rilievo macrosismico, effetti di superficie ed implicazioni sismotettoniche, Il Quaternario, 22, 235-246.

Galli, P., S. Castenetto and E. Peronace (2012). May 2012 Emilia earthquakes (M_W 6, northern Italy): macroseismic effects distribution and seismotectonic implications, Alpine and Mediterranean Quaternary, 25 (2), 105-123.

Gasperini, P., G. Vannucci, D. Tripone and E. Boschi (2010). The location and sizing of historical earthquakes using the attenuation of macroseismic intensity with distance, B. Seismol. Soc. Am., 100, 2035-2066; doi: 10.1785/0120090330.

Giacomo da Marano (15th century). Cronaca inedita di Ferrara estense dal 1298 al 1412, In: Bollettino statistico del Comune di Ferrara, 56-58, 1929-1931.

Grünthal, G., ed. (1998). European Macroseismic Scale 1998 (EMS-98). European Seismological Commission, subcommission on Engineering Seismology, working Group Macroseismic Scales. Conseil de l'Europe, Cahiers du Centre Européen de Géodynamique et de Séismologie, 15, Luxembourg.

Locati, M., R. Camassi and M. Stucchi (2011). DBMI11, the 2011 version of the Italian Macroseismic Database, Milano/Bologna; http://emidius.mi.ingv.it/DBMI11 (last access July 2012).

Molin, D. (2003). Considerazioni sull'eventuale adozione in Italia della scala macrosismica europea (EMS- 1998), In: GNGTS – Atti del 22° convegno nazionale/06.21, ISBN/ISSN:88-900385-9-4, 11 pp.

Molin, D. (2009). Rilievo macrosismico in emergenza, Rapporto interno Dipartimento della Protezione Civile; Ufficio III Valutazione, prevenzione e mitigazione del rischio sismico, 13 pp.

Pieri, M., and G. Groppi (1981). Subsurface geological structure of the Po Plain (Italy), C.N.R., Progetto Finalizzato Geodinamica, 414, 1-13.

Postpischl, D. (1985). Atlas of isoseismal maps of Italian earthquakes, Bologna, 164 pp.

QRCMT (2012). Quick Regional Centroid Moment Tensor, INGV-Bologna; http://autorcmt.bo.ingv.it/quicks.html (last access July 2012).

Rovida, A., R. Camassi, P. Gasperini and M. Stucchi (2011). CPTI11, versione 2011 del Catalogo Parametrico dei Terremoti Italiani, Milano/Bologna; http://emidius.mi.ingv.it/CPTI (last access July 2012).

Scrocca, D., E. Carminati, C. Doglioni and D. Marcantoni (2007). Slab retreat and active shortening along the central-northern Apennines, In: O. Lacombe, J. Lavè, F. Roure and L. Verges L. (eds.), Thrust belts and foreland basins: From fold kinematics to hydrocarbon systems, Frontiers in Earth Sciences, 471-487.

Sieberg, A. (1930). Geologie der Erdbeben, Handbuch der Geophysik, 4, 552-554.

Stucchi, M., and P. Albini (2000). Quanti terremoti abbiamo perso nell'ultimo millennio?, In: F. Galadini, C. Meletti and A. Rebez (eds.), Le ricerche del GNDT nel campo della pericolosità sismica (1996-1999), CNR-GNDT, 333-343.

TDMT (2012). Time Domain Moment Tensor, INGV-Centro Nazionale Terremoti; http://cnt.rm.ingv.it/tdmt.html (last access July 2012).

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Appendix 1

R	P	Municipality	Locality	Is May 20	Is final	DJ	Long	Lat	pop	blds
LOMBARDIA	MANTOVA	Bagnolo San Vito	Bagnolo San Vito		5.0		10.8744	45.0879	1740	447
		Bagnolo San Vito	San Biagio		5.0		10.8503	45.0977	1521	343
		Borgoforte	Borgoforte		5.0		10.7492	45.0511	977	240
		Borgofranco sul Po	Borgofranco sul Po		5.0		11.2089	45.0464	477	171
		Carbonara di Po	Carbonara di Po		5.0		11.2278	45.0372	847	273
		Felonica	Felonica		5.0		11.3534	44.9790	1162	453
		Gonzaga	Gonzaga		5.0		10.8197	44.9520	4556	1050
		Gonzaga	Zocca		5.5	C	10.8778	44.9423	126	42
		Gonzaga	Bondeno		6.0	C	10.8567	44.9442	872	248
		Magnacavallo	Magnacavallo		5.0		11.1808	45.0046	1149	326
		Mantova	Mantova	5.0	5.0	C	10.7733	45.1526	40398	5073
		Moglia	Moglia	6.0	7.0		10.9139	44.9372	3700	967
		Moglia	Bondanello		5.5	B C	10.9470	44.9595	633	173
		Motteggiana	Motteggiana		5.0		10.7642	45.0294	453	138
		Motteggiana	Villa Saviola		5.0		10.7957	45.0343	515	152
		Ostiglia	Ostiglia		5.0	C	11.1361	45.0740	5808	1557
		Pegognaga	Pegognaga		5.5	A C	10.8597	44.9926	4092	931
		Pegognaga	Galvagnina	5.5	5.5		10.9105	44.9773	108	26
		Pieve di Coriano	Pieve di Coriano		5.0		11.1035	45.0383	672	233
		Poggio Rusco	Poggio Rusco	5.0	5.5	B C	11.1181	44.9740	5476	1332
		Poggio Rusco	Dragoncello		5.0		11.1975	44.9703	178	38
		Poggio Rusco	Avia		5.0		11.1628	44.9775	36	19
		Quingentole	Quingentole		5.5	C	11.0458	45.0388	931	468
		Quistello	Quistello	5.5	5.5	A C	10.9841	45.0096	3710	1014
		Quistello	Zambone		5.5		10.9697	44.9589	39	13
		Quistello	Nuvolato		5.0	C	11.0062	45.0317	259	120
		Revere	Revere		5.0		11.1314	45.0532	2019	576
		Roncoferraro	Roncoferraro		5.0		10.9511	45.1353	2481	626
		Roncoferraro	Barbassolo		5.0		10.9390	45.1390	0	
		Roncoferraro	Barbasso		5.0		10.9073	45.1200	650	177
		Roncoferraro	Cadè		5.0		10.8926	45.1585	135	43
		Roncoferraro	Casale		5.0		10.9750	45.0958	340	122
		Roncoferraro	Governolo		5.0	B C	10.9616	45.0848	1063	320
		Roncoferraro	Nosedole		5.0		10.9831	45.1200	295	89
		Roncoferraro	Villa Garibaldi (Breda)		5.0		10.9119	45.1529	18	5
		San Benedetto Po	San Benedetto Po		5.0		10.9314	45.0482	4973	1907
		San Giacomo delle Segnate	San Giacomo delle Segnate		5.5	A C	11.0318	44.9722	1184	514
		San Giacomo delle Segnate	Malcantone		5.5		10.9975	44.9638	91	29
		San Giorgio di Mantova	Villanova de Bellis		5.0		10.8726	45.1520	468	129
		San Giovanni del Dosso	San Giovanni del Dosso	5.5	5.5	C	11.0837	44.9684	727	228
		Schivenoglia	Schivenoglia		5.0		11.0753	44.9981	1059	372
		Sermide	Sermide	5.0	5.0		11.2954	45.0044	3613	1002
		Sermide	Porcara		5.0		11.2852	44.9588	70	21
		Sermide	Santa Croce		5.0		11.2544	44.9843	318	121
		Sermide	Caposotto		5.0		11.3165	44.9921	412	150
		Serravalle a Po	Serravalle a Po		5.0	A	11.0907	45.0698	653	209
		Serravalle a Po	Libiola		5.0		11.0616	45.0602	806	337
		Sustinente	Sustinente		5.0		11.0167	45.0699	1142	385
		Sustinente	Sacchetta-Ca' Vecchia		5.0	C	10.9913	45.0748	511	184
		Suzzara	Suzzara		5.0	B	10.7395	44.9922	13761	2877
		Villa Poma	Villa Poma		5.0		11.1142	45.0024	1650	465
		Villa Poma	Ghisione		5.0	B	11.1221	45.0140	0	
		Virgilio	Virgilio		5.0		10.8172	45.1130	716	1057
VENETO	ROVIGO	Bergantino	Bergantino		5.0		11.2533	45.0622	2026	645
		Calto	Calto		5.0	C	11.3588	44.9917	755	297
		Castelmassa	Castelmassa		5.5	A C	11.3122	45.0187	3395	928
		Castelnovo Bariano	Castelnovo Bariano		5.0		11.2838	45.0276	1280	430
		Ceneselli	Ceneselli		5.0	C	11.3702	45.0135	976	348
		Ficarolo	Ficarolo		5.0	B C	11.4357	44.9544	2071	532
		Fiesso Umbertiano	Fiesso Umbertiano		5.0	C	11.6039	44.9615	3458	941
		Gaiba	Gaiba		5.0		11.4809	44.9463	796	246
		Melara	Melara		5.0		11.2012	45.0638	1332	557

R	P	Municipality	Locality	Is May 20	Is final	DJ	Long	Lat	pop	blds
		Occhiobello	Occhiobello		5.0		11.5800	44.9208	2004	368
		Stienta	Stienta		5.0		11.5428	44.9410	1647	416
EMILIA ROMAGNA	REGGIO EMILIA	Campagnola Emilia	Campagnola Emilia		5.0		10.7584	44.8392	3928	826
		Correggio	Correggio		5.0		10.7850	44.7679	13480	2333
		Fabbrico	Fabbrico		5.0	C	10.8102	44.8732	4879	802
		Guastalla	Guastalla		5.0		10.6584	44.9122	11087	2339
		Luzzara	Luzzara		5.0		10.6899	44.9608	4090	942
		Luzzara	Villarotta		5.0		10.7446	44.9240	1291	328
		Luzzara	Casoni		5.0	C	10.7380	44.9396	418	150
		Novellara	Novellara		5.0		10.7303	44.8447	9198	1922
		Reggiolo	Reggiolo		6.5		10.8121	44.9194	6243	1284
		Reggiolo	Villanova		5.0		10.8598	44.9167	387	108
		Reggiolo	Brugneto		5.5	C	10.7587	44.9227	781	225
		Rio Saliceto	Rio Saliceto		5.0		10.8054	44.8116	4442	776
		Rolo	Rolo		5.0	C	10.8592	44.8857	3188	779
		San Martino in Rio	San Martino in Rio		5.0		10.7863	44.7353	4963	863
	MODENA	Bastiglia	Bastiglia		5.0		10.9972	44.7259	3005	427
		Bomporto	Bomporto	5.0	5.0		11.0407	44.7265	2265	422
		Bomporto	Sorbara		5.0		11.0047	44.7460	2683	451
		Bomporto	Gorghetto	5.0	5.0		11.0709	44.7706	350	89
		Bomporto	Solara	5.0	5.0	A B	11.0939	44.7722	1096	234
		Campogalliano	Campogalliano		5.0		10.8429	44.6900	5890	793
		Camposanto	Camposanto	5.5	5.5	A B C	11.1422	44.7871	2264	490
		Camposanto	Ca' Bianca	5.5	5.5		11.2160	44.8120	21	11
		Carpi	Carpi Centro		5.5	C	10.8724	44.7825	49658	6631
		Carpi	San Marino		5.0		10.9148	44.8081	1354	291
		Carpi	Migliarina		5.0		10.8471	44.8154	1485	337
		Carpi	Fossoli		6.0		10.8884	44.8222	2756	479
		Cavezzo	Cavezzo	6.0	7.0		11.0310	44.8369	4964	1027
		Cavezzo	Motta	5.0	5.5	B	10.9855	44.8284	19	13
		Cavezzo	La Bottega		6.0		11.0089	44.8481	159	46
		Cavezzo	Disvetro		5.5	C	11.0003	44.8600	128	40
		Concordia sulla Secchia	Concordia sulla Secchia	5.5	7.0		10.9890	44.9103	4414	991
		Concordia sulla Secchia	Fossa		5.5		11.0235	44.9240	1298	388
		Concordia sulla Secchia	Vallalta		5.5	C	11.0094	44.9440	503	137
		Finale Emilia	Finale Emilia	6.5	6.5		11.2917	44.8326	8567	1711
		Finale Emilia	Reno Finalese		5.5	C	11.3197	44.8333	148	57
		Finale Emilia	Canaletto	6.5	6.5		11.2477	44.8373	48	?
		Finale Emilia	Massa Finalese		5.5	C	11.2135	44.8503	4061	934
		Medolla	Medolla		5.5	B C	11.0704	44.8480	4189	999
		Medolla	Villafranca		6.0		11.0578	44.8352	172	66
		Medolla	San Giacomo Roncole		5.5	B C	11.0602	44.8589	72	29
		Mirandola	Mirandola	7.0	7.0		11.0660	44.8864	15414	2814
		Mirandola	Mortizzuolo	6.5	6.5		11.1370	44.8781	729	246
		Mirandola	San Martino Carano		7.0		11.0420	44.8873	168	56
		Mirandola	Quarantoli		5.5	C	11.0982	44.9202	981	302
		Mirandola	Gavello		6.0		11.1793	44.9261	343	110
		Mirandola	San Martino Spino		5.0		11.2409	44.9341	763	214
		Mirandola	Tramuschio		5.5	C	11.0902	44.9580	313	105
		Modena	Modena	5.0	5.0		10.9177	44.6559	156717	13735
		Nonantola	Nonantola	5.0	5.0		11.0389	44.6758	8918	1053
		Novi di Modena	Novi di Modena		7.0		10.9014	44.8915	5330	1273
		Novi di Modena	Rovereto	5.5	7.5		10.9551	44.8425	3207	860
		Ravarino	Ravarino		5.0	B C	11.0985	44.7213	3391	602
		Ravarino	Rami		5.0		11.0801	44.7300	0	
		Ravarino	Casoni		5.0		11.0541	44.7240	335	64
		Ravarino	Stuffione		5.0		11.1185	44.7536	301	90
		San Felice sul Panaro	San Felice sul Panaro	7.0	7.0		11.1425	44.8341	6421	1357
		San Felice sul Panaro	Rivara	6.0	6.0		11.1684	44.8413	755	189
		San Possidonio	San Possidonio	5.0	6.0		10.9953	44.8929	2948	760
		San Possidonio	Forcello	5.0	5.5		10.9751	44.8700	0	
		San Possidonio	Pioppa	5.0	5.5		10.9654	44.8586	81	35
		San Prospero	San Prospero		5.0	B	11.0226	44.7893	1794	375
		San Prospero	San Pietro		5.0	A B	11.0467	44.7730	559	158

R	P	Municipality	Locality	Is May 20	Is final	DJ	Long	Lat	pop	blds
EMILIA ROMAGNA		San Prospero	Staggia		5.5	B C	11.0534	44.8034	298	78
		Soliera	Soliera		5.0		10.9221	44.7343	7586	1166
		Soliera	Sozzigalli		5.0		10.9746	44.7494	761	149
		Soliera	Limidi		5.0		10.9226	44.7628	2253	436
	BOLOGNA	Argelato	Argelato		5.0		11.3404	44.6393	2335	265
		Argelato	Volta Reno		5.0		11.3088	44.6673	306	?
		Baricella	Baricella		5.0		11.5333	44.6473	2944	566
		Bentivoglio	Bentivoglio		5.0		11.4167	44.6353	1069	123
		Castello d'Argile	Castello d'Argile		5.0		11.2940	44.6776	2964	373
		Castello d'Argile	Venezzano		5.0		11.3395	44.6820	1166	149
		Crevalcore	Crevalcore	5.0	6.0		11.1497	44.7205	7570	1430
		Crevalcore	Bolognina		5.0	B	11.1475	44.7644	222	46
		Crevalcore	Palata Pepoli		5.0	B C	11.2332	44.7930	572	116
		Crevalcore	Galeazza		5.5	A C	11.2769	44.7971	150	28
		Galliera	Galliera	5.5	5.5	B C	11.3936	44.7493	483	89
		Galliera	San Venanzio		5.0		11.4369	44.7452	1747	253
		Galliera	San Vincenzo	5.0	5.0		11.4427	44.7370	1632	213
		Malalbergo	Malalbergo	5.0	5.0		11.5320	44.7187	1269	220
		Malalbergo	Altedo		5.0		11.4903	44.6714	3512	696
		Malalbergo	Pegola		5.0		11.5003	44.6891	609	140
		Malalbergo	Ponticelli		5.0		11.4737	44.6972	108	25
		Pieve di Cento	Pieve di Cento		5.5	C	11.3075	44.7123	5946	1011
		San Giorgio di Piano	San Giorgio di Piano		5.0		11.3756	44.6495	4565	589
		San Giovanni in Persiceto	San Giovanni in Persiceto	5.0	5.0		11.1840	44.6400	12974	2017
		San Giovanni in Persiceto	San Matteo della Decima	5.0	5.0		11.2304	44.7142	4585	?
		San Pietro in Casale	San Pietro in Casale		5.0		11.4054	44.7004	6357	843
		San Pietro in Casale	Sant'Alberto		5.0		11.4049	44.7192	135	35
		Sant'Agata Bolognese	Sant'Agata Bolognese	5.0	5.0		11.1339	44.6642	4540	814
	FERRARA	Bondeno	Bondeno	5.5	5.5	B C	11.4157	44.8849	7618	1965
		Bondeno	Santa Bianca		5.5	B C	11.3903	44.8653	185	68
		Bondeno	Ponte Rodoni		5.5	C	11.4442	44.8684	355	109
		Bondeno	Borgo Piva		5.5		11.3576	44.8794	59	20
		Bondeno	Scortichino		5.5		11.3257	44.8788	1487	454
		Bondeno	Burana		5.5	B C	11.3509	44.9145	348	112
		Bondeno	Ponti Spagna	5.5	5.5		11.3895	44.9240	120	36
		Bondeno	Stellata	5.0	5.0	C	11.4214	44.9453	408	143
		Bondeno	Pilastri		5.5	A B C	11.2875	44.9473	751	224
		Cento	Cento	5.5	6.0		11.2880	44.7259	14720	2291
		Cento	Corpo Reno	5.5	5.5	C	11.3110	44.7581	916	161
		Cento	Renazzo		5.0		11.2764	44.7605	3481	770
		Cento	Bevilacqua		5.5	C	11.2551	44.7661	431	135
		Cento	Dodici Morelli		5.0		11.2909	44.7931	1908	491
		Cento	Pilastrello		5.5		11.3233	44.7943	210	70
		Cento	Buonacompra	5.5	5.5	B C	11.3403	44.8056	264	67
		Cento	Alberone		5.5	C	11.3106	44.8141	613	204
		Cento	Reno Centese	5.0	5.0	B	11.3249	44.8287	881	247
		Cento	Casumaro	5.0	5.5	B C	11.3637	44.8355	1957	554
		Ferrara	Ferrara	5.0	5.0		11.6086	44.8481	94307	12731
		Ferrara	Chiesuol del Fosso		5.0		11.5768	44.8034	0	?
		Ferrara	Montalbano	5.0	5.0		11.5762	44.7562	688	198
		Ferrara	Porotto	5.0	5.0	C	11.5494	44.8496	4400	874
		Mirabello	Mirabello	6.0	6.0		11.4595	44.8242	3160	902
		Poggio Renatico	Poggio Renatico	5.5	5.5	A B C	11.4863	44.7666	3958	796
		Poggio Renatico	Gallo	5.0	5.0		11.5537	44.7316	1201	299
		Poggio Renatico	Coronella		5.0		11.5244	44.8029	676	280
		Poggio Renatico	Madonna dei Boschi		5.0		11.4947	44.8200	21	11
		Sant'Agostino	Sant'Agostino	6.0	6.0		11.3883	44.7926	2384	511
		Sant'Agostino	Dosso	5.0	5.0		11.3389	44.7697	1106	240
		Sant'Agostino	San Carlo	6.5	6.5		11.4093	44.8039	1713	434
		Vigarano Mainarda	Vigarano Mainarda	5.5	5.5	B C	11.4951	44.8403	3265	947
		Vigarano Mainarda	Vigarano Pieve		5.0	B C	11.5100	44.8606	1755	443

Table A1. MCS intensities (I_S) evaluated for the May 20, 2012, and the May 29, 2012, (accumulated) Emilia earthquakes. R and P, region and province, respectively. DJ, severe damage to isolated buildings (I_S <6 MCS). Pop, blds, number of inhabitants and buildings, respectively.