Σigma
SeIsmic Ground Motion Assessment

Review of active faulting in the Po Plain

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

Summary

This document is a draft version of Deliverable 1 of Group 1 (tasks 1.3, 1.4) of the Italian SIGMA. The full Deliverable is due by the end of June.

The document describes the input for calculating ground shaking and surface breaking hazard in the Po Plain and around it through a description of three key elements:

1) the seismicity
2) the active faults
3) the seismogenic sources

1) The seismicity is described with reference to very recent releases of datasets maintained by INGV, both for historical and for instrumental earthquakes. A more detailed section describes the relavant seismicity for the three SIGMA test sites (Casaglia, Novellara and Tortona, respectively in the eastern, central-southern and southwestern Po Plain).

2) The active faulting is described with reference to the limited available published material. The final version of the Deliverable will contain original information drawn from subsurface data.

3) The seismogenic sources are described with reference to the material contained in the Italian DISS database, operated and maintained by INGV. Although this section of the document is currently the most complete, some of the seismogenic sources will be improved or slightly modified in preparation for the final version of the Deliverable.

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1. Introduction and structural setting

This report presents an overview of active faulting and active deformation data in the Po Plain taken from published papers, together with a description of the Seismogenic Sources included in the last version of the DISS database (v. 3.1.1) which may be of interest for the characterization of the three sites studied by the project. The geometrical and kinematical characteristics of the seismogenic sources were derived from original and published active tectonic studies and are also freely available in the internet from the DISS home page (http://diss.rm.ingv.it/diss/).

The Po Plain is the foreland area of two opposing verging fold-and-thrust belts: to the north, the S-verging central Southern Alps (SA), which is the conjugate retro-belt with respect to the subduction polarity of the Alpine orogen, and to the south the N-NE-verging Northern Apennines (NA). The outcropping portions of these two chains define the structural and morphological margins of the plain itself, but their outermost thrusts are not confined at the mountain fronts and are today buried by the Plio-Quaternary sediments that fills in the Po Plain (Fig. 1). The two belts developed during the closure of the Mesozoic Tethyan basin realized in the framework of the African and European plates relative convergence from the Cretaceous onward, and were associated with two opposite subduction zones involving both European and African lithosphere (for an in-depth review of the tectonic and geodynamic framework of the Alps and Apennines development and a comparison between the two orogens see Carminati and Doglioni, 2012, and reference therein).

The outermost thrust front of the NA belt buried below the Plio-Quaternary marine and continental deposits infilling the Po Plain basin are organized in three complex system of folds that from west to east are: the Monferrato, the Emilian, and the Ferrara arc (Figs. 1 and 2). The buried compressional structures were extensively studied by seismic exploration lines and deep well logs. These subsurface data show a system of N to NE-verging blind thrusts and folds that controlled the deposition of the syntectonic sedimentary wedges, with the Plio-Quaternary sequence locally up to 7-8 km thick. The fast sedimentation (Bartolini et al., 1996) hid the growing structures, and as a consequence there are few direct surface evidences of the possible ongoing activity of the thrusts. One of the few and most notably exception to this general rule is the San Colombano Hill, that is an outcropping anticline located at the leading edge of the Emilian Arc, involving upper Pliocene and lower Pleistocene sediments and cored by Miocene deposits.

In its turn, the buried outer thrust front of the SA mainly developed during Oligocene to Late Miocene time follows a simpler geometry describing a single wide arc between Milano and the Garda Lake, connected to the east with the NNE-trending Giudicarie thrust system that is considered as a regional transfer zone between the Central and Eastern Southern Alps (e.g. Castellarin and Cantelli, 2000). The S-verging frontal thrust system is characterized by the occurrence of high angle back-thrusts associated at the surface with some of the small topographic highs studied by Desio (1965) (Livio et al., 2009).

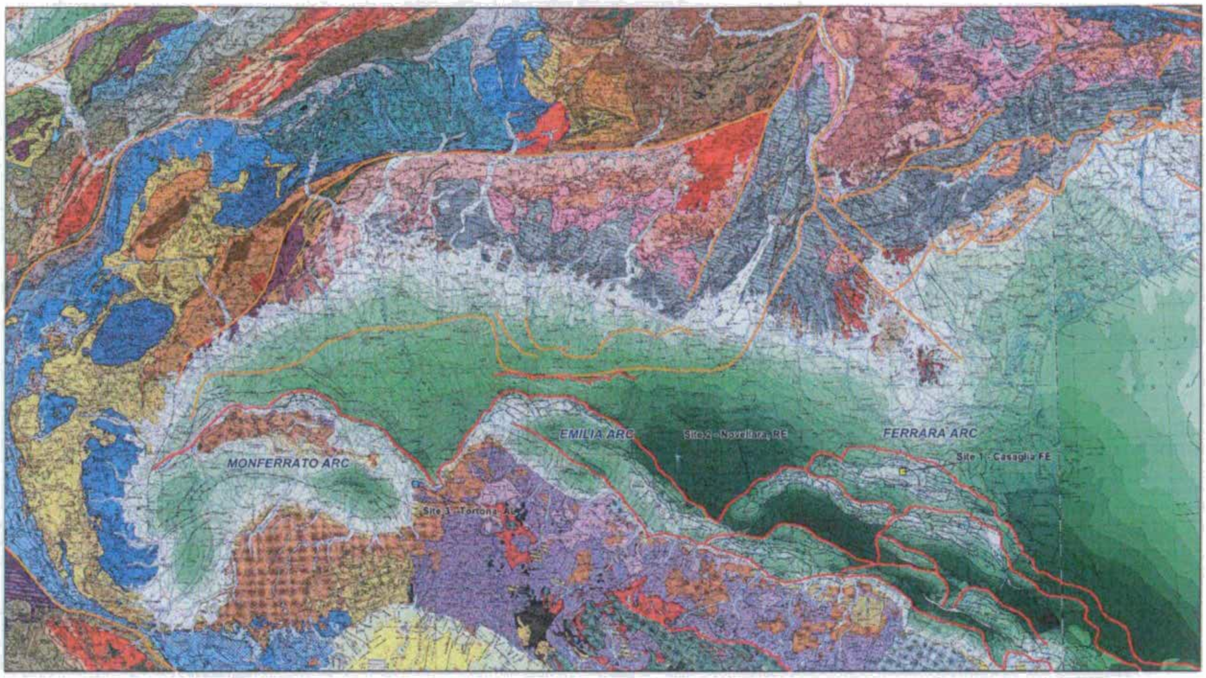


Figure 1.1: Structural Model of Northern Italy (from Bigi et al., 1992) showing the main tectonic elements of the Southern Alps and Northern Apennines chains highlighted in orange and red, respectively. The green colour palette defines the depth of the base of the Plio-Quaternary succession in the plain, which highlight the deformation associated with the outermost thrust fronts of the two chains. Balck lines: traces of the seismic sections of Fantoni and Franciosi (2010), those shown in Figure 2 are numbered 1 to 3.

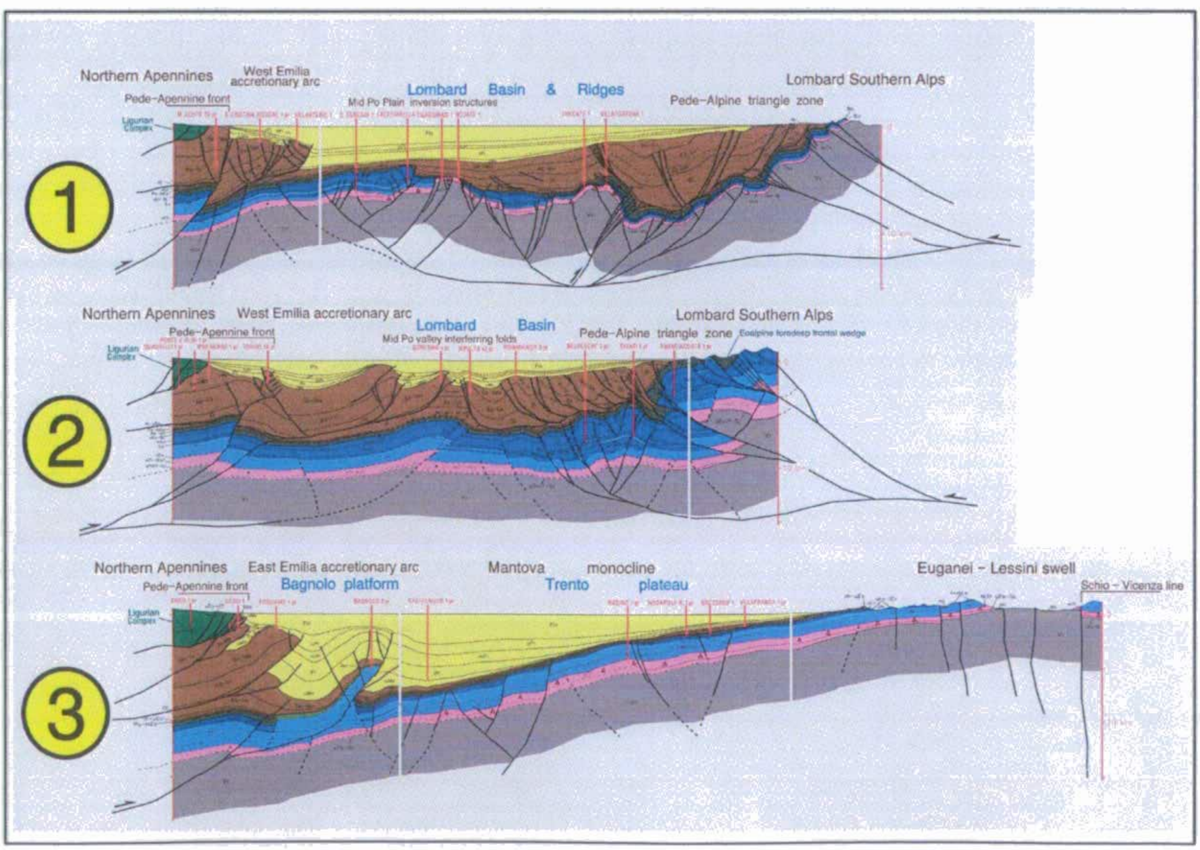


Figure 1.2: N-S trending depth coverted seismic sections showing the geometry of the Northern Apennines and Southern Alps thrust belts (from Fantoni and Franciosi, 2010, modified). The traces of the sections are shown in Figure 1.

2. Active deformation

GPS studies show that plate convergence at the Italian latitude is going on with rates ranging between 3 and 8 mm/yr (e.g. Serpelloni et al., 2007). Crustal deformation analysis of GPS data constrain a weak shortening across the Po Plain, with rates of less than 1 mm/a (Bennet et al., 2012) (Fig. 3). The shortening is accomplished in the frame of a CCW relative rotation of the Adriatic promontory respect to the European plate, with a pole of rotation located near the western Alps. As a consequence the rates of convergence are expected to diminish westward in agreement with the observed lowering of the seismic moment release.

Present-day activity of the frontal thrusts of the NA is testified by historical and instrumental seismicity, the latter characterized by contractional focal mechanisms (e.g. Pondrelli et al., 2006) (Fig.4), and by the influence on the drainage network (Burrato et al., 2003) and faulting and folding of recent sediments. The historical and instrumental Italian seismic catalogues show that the southern Po Plain is affected by low to moderate seismicity, with Mmax up to 5.8 (CPTI11 Catalogue, Rovida et al., 2011; Castello et al., 2006; DISS Working Group, 2010). The borehole breakouts and the focal mechanisms both show Shmax oriented perpendicular to the trend of the buried thrust fronts (Montone et al., 2004; Heidbach et al., 2008) (Fig. 5).

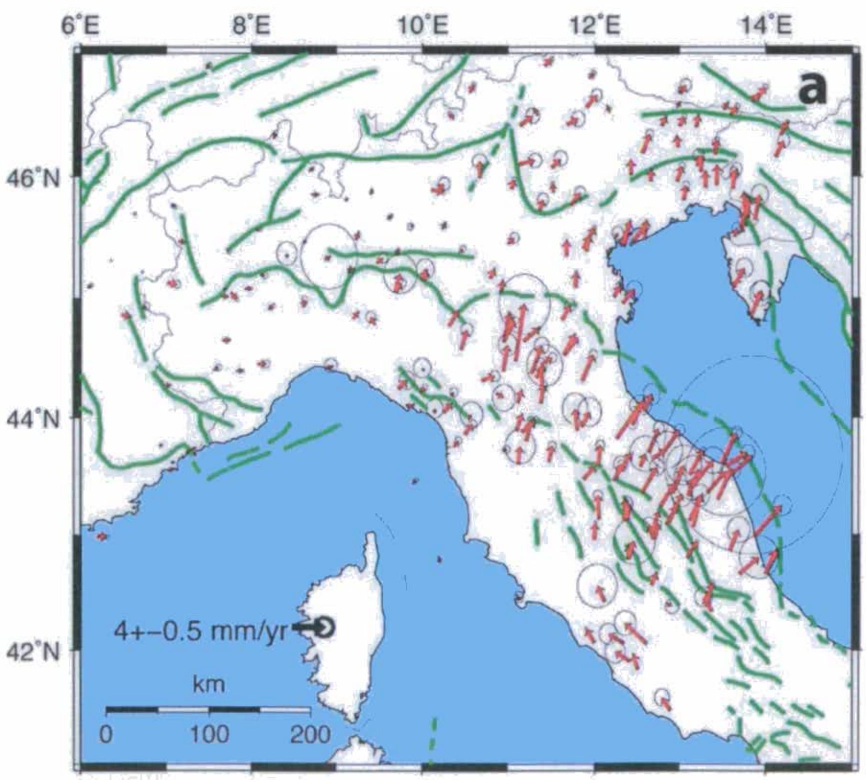


Figure 2.1: GPS horizontal velocity vectors (Bennett et al., 2012). The velocity reference frame is fixed to a stable Eurasia plate.

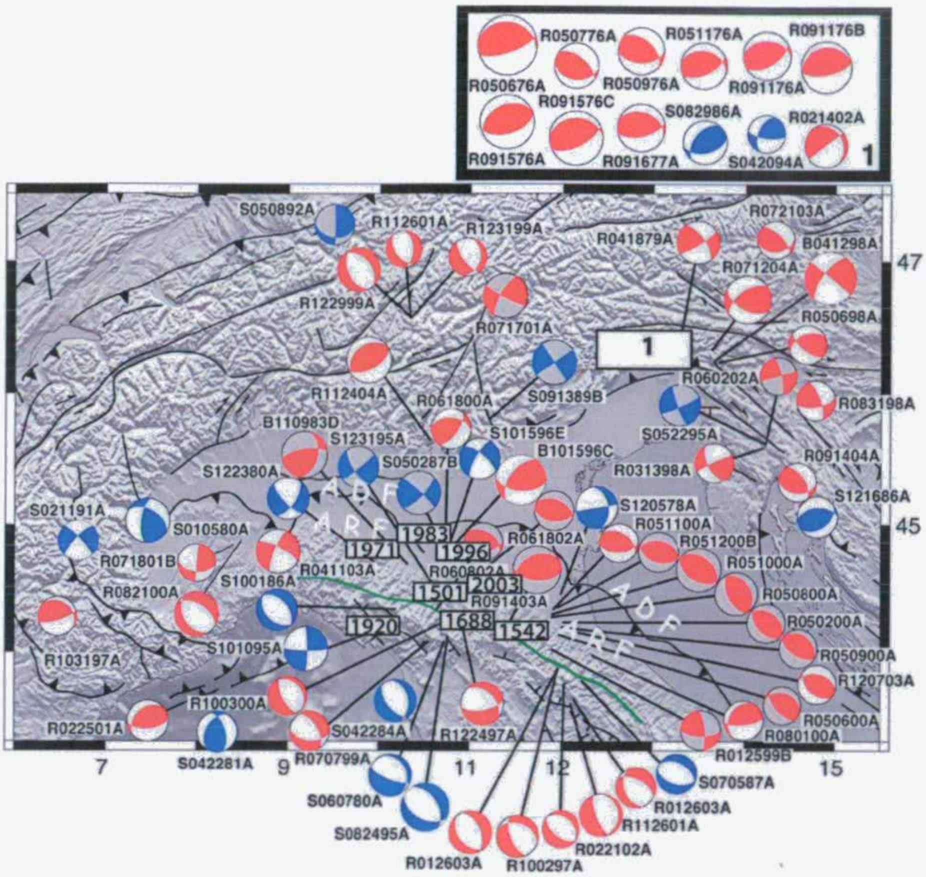


Figure 2.2: Focal mechanisms of the largest instrumental earthquakes recorded in Northern Italy and neighbouring areas (from Bennet at al., 2012). The solutions were taken from the European-Mediterranean RCMT Catalog (http://www.bo.ingv.it/RCMT/; Pondrelli et al., 2011 and references therein). Solutions with the gray background highlights deep earthquakes (hypocenter depth > 20 km).

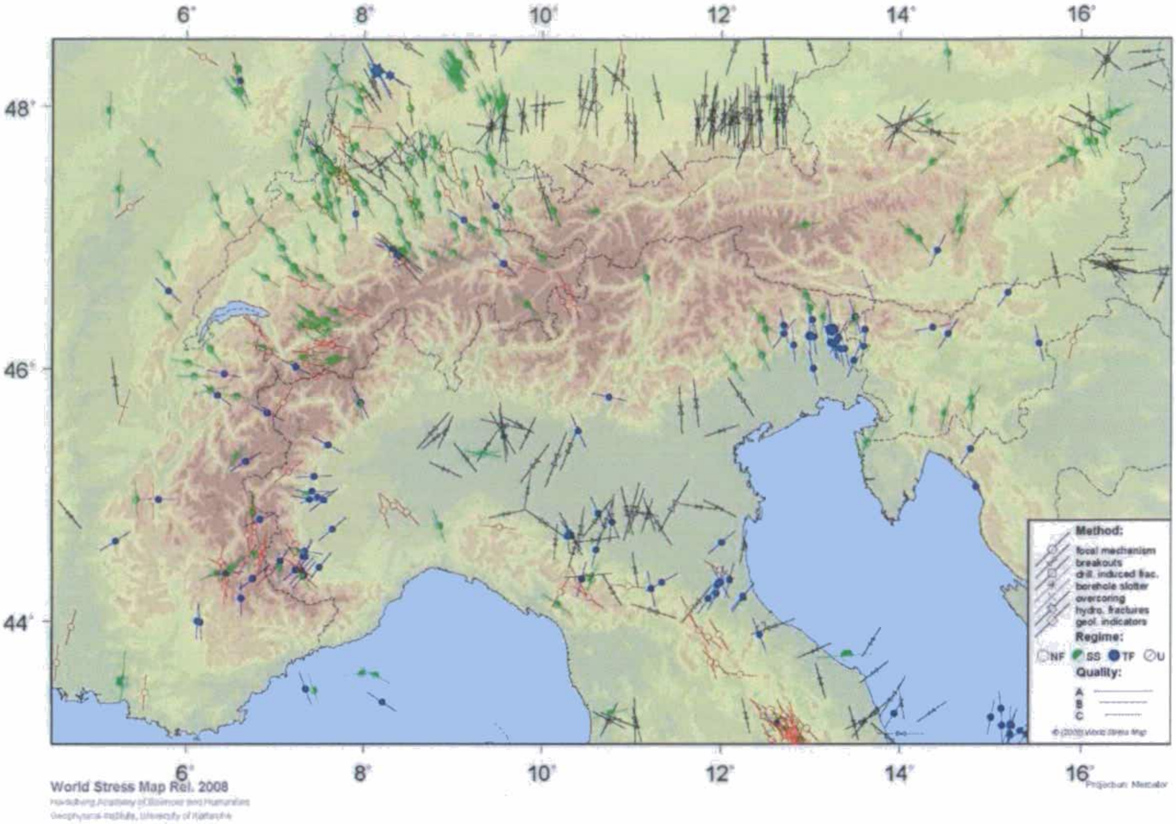


Figure 2.3: Stress map of Northern Italy based on the A–C quality data records from the World Stress Map database release 2008 (Heidbach, O., Tingay, M., Barth, A., Reinecker, J., Kurfeß, D., and Müller, B., The World Stress Map database release 2008 doi:10.1594/GFZ.WSM.Rel2008, 2008).

3. Seismicity

The seismicity of the Po Plain can be described using both historical (Rovida et al. 2011) and instrumental (Pondrelli et al. 2011) seismicity.

The general framework of the historical and seismicity shows that the greatest number of earthquakes, which affected the Po Plain, are concentrated south of the Po river (Rovida et al. 2011, Fig. 3.1). This seismicity testifies the activity of the Northern Apennines compressive structures, both along the pede-apenninic margin and along the buried frontal thrusts inside the Po Plain. In particular the historical and instrumental Italian seismic catalogues show that the southern Po Plain is affected by low to moderate seismicity, with Mmax up to 5.8 [CPTI Working Group, 2004; Castello et al., 2006; DISS Working Group, 2010]. Historical and instrumental seismicity in the Po Plain is sparse but not randomly distributed.

The distribution of low to moderate instrumental earthquakes south oh the Po Plain fits very well with the position and geometries of the three main frontal arcs of the northern Apennines (Ferrana, Emilia, Monferrato arcs) with a higher concentration in the eastern arc. Moreover, deeper earthquakes concentrate along the western portion of the arc, whereas shallower events generally occur along the outer front (Vannoli et al., 2004; Burrato et al., 2004; Meletti et al., 2008; Piccinini et al., 2006). On the contrary, historical and instrumental earthquakes are less numerous north of the Po river and don't follow any particular alignment, showing an apparently random epicentral distribution; with no significant earthquakes west of Milan.

Despite the difficulties in the interpretation of the seismic events distribution, it is possible to identify two main active zones: 1) the areas of the Po Plain comprised between the mountain front and the more external thrust front toward south, related to the Basso Bresciano earthquake of the 1222 (Mw 6.1) and the Valle dell'Oglio earthquake in 1802 (Mw 5.7) ,and 2) a NNE-SSW area linked to the Giudicariensi fault system. Instrumental seismicity show a concentration of events in the piedmont areas of the Garda lake and the Lessini mountains. This seismic release pattern is different from what observed est of the Schio – Vicenza Line, in the eastern sector of the Southern Alps. In these areas the seismicity in mainly concentrated along the mountain thrust fronts and is associated to the important seismicity recorded both in historical and instrumental catalogues in the Friuli and Slovenia regions.

A general observation that can be deduced from the distribution of the seismicity in the Po Plain and surrounding areas is that the number of earthquakes consistently decreases moving from the eastern (Friuli plain) to the west (Piedmont).

The data are in agreement with the general geodynamic setting of the Northern Apennines-Adria-Southern Alps convergent system and with the GPS velocity data. The latter highlight that the Adria plate is moving toward European continent with velocity vectors N-directed and faster in the eastern sectors. The pole of rotation is placed in the Western Alps, where the convergence is absent. For this reason the activity of the compressive structures is higher in the eastern Southern Alps and in the Ferrara arc respect to the western areas of the Southern Alps belts and the Northern Apennines Monferrato arc front.

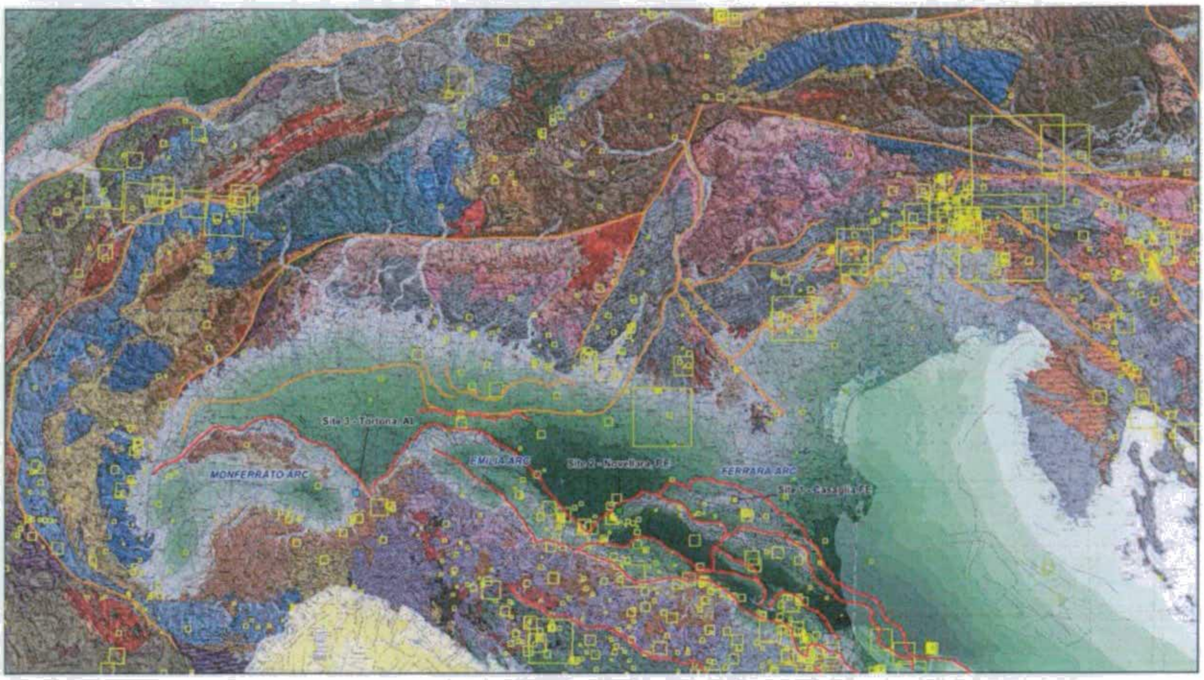


Figure 3.1: Historical seismicity from CPTI11 Catalogue (Rovida et al., 2011) plotted onto the Structural Model of Northern Italy (Bigi et al., 1992). The main tectonic elements of the Southern Alps and Northern Apennines chains are also shown and help discriminating the events generated by the compressive structures of the two chains. Seismic activity decreases westward from the Friuli region, and is almost completely absent in the westernmost Po Plain.

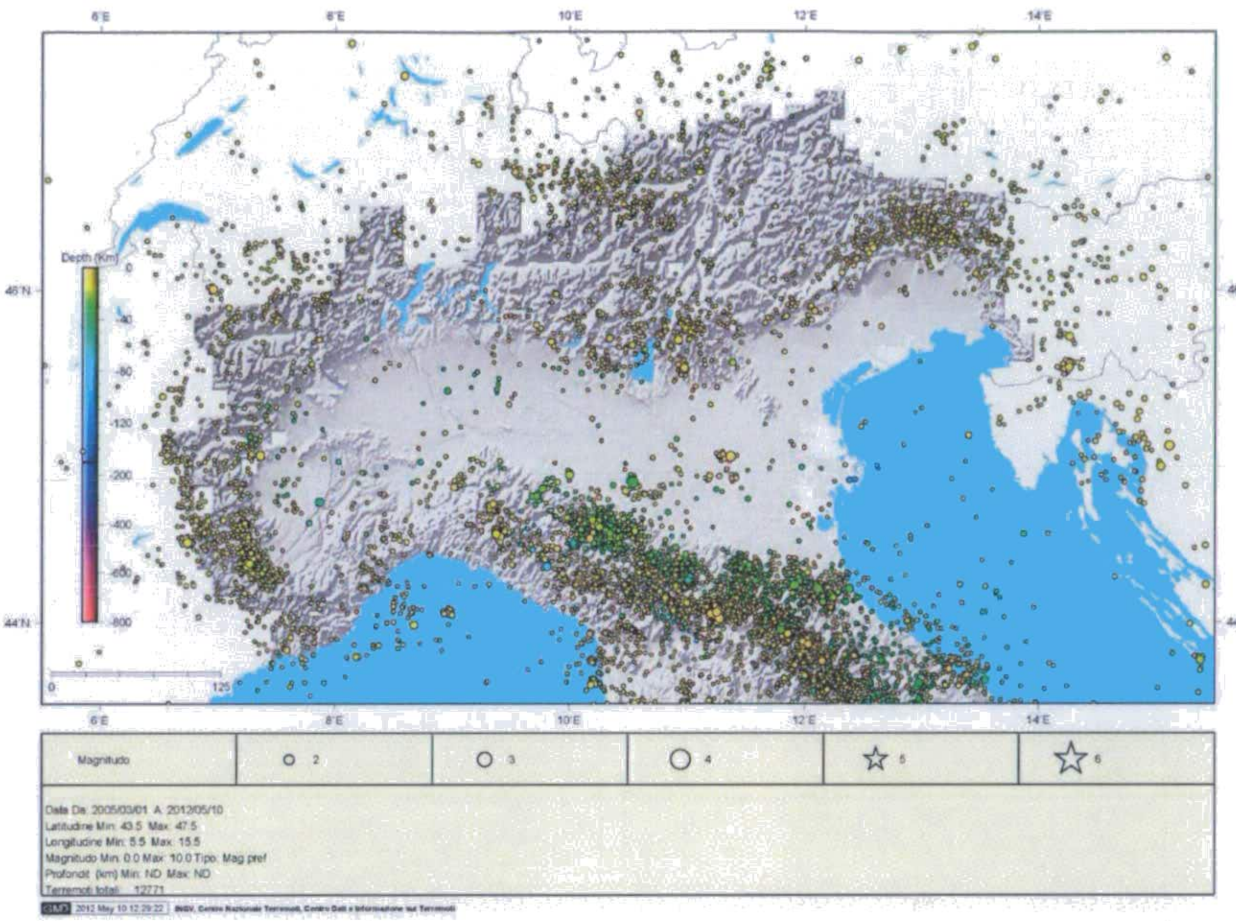


Figure3.2: Instrumental seismicity of Northern Italy and neighbouring regions from ISIDe database (Italian Seismic Instrumental and parametric Data-basE; http://iside.rm.ingv.it/).

3.1 Historical and instrumental seismicity at the SIGMA sites

The three sites chosen for the studies in the SIGMA project (Site 1 – Casaglia, Site 2 – Novellara, Site 3 – Tortona), are located south of the Po river, along the Northern Apennines thrust front. The analysis of the seismic history of the three sites has been made using the Italian Macroseismic Database (Locati et al., 2011) and the Parametric Catalogue of Italian Earthquakes (Rovida et al., 2011) which stores the parameters of the historical earthquakes from the years 1000 A.D.to 2006.

From east to east we find the Casaglia site, that falls in the central and frontal part of the Ferrara arc; the Novellara site, located in the western portion of the Ferrara arc; and the Tortona site, at the western termination of the Emilia arc.

Due to their location, the three sites have undergone a different seismic history. For the city of Ferrara (the nearest to the Casaglia site) the Italian Macroseismic Database (Locati et al., 2011) reports the effects of 125 historical earthquakes, while for the Novellara and Tortona sites only 34 and 25 earthquakes are reported, respectively.

3.1.1 Site 1 – Casaglia

The DBMI11 (Locati et al. 2011) database reported 125 earthquakes. 42 of these events have Mw≥5.5 and 16 have Mw≥6 recorded in the Ferrara – Casaglia site (Figs. 3.3 and 3.4). Some of these events are located at great distance (more than 200 Km) from the Ferrara – Casaglia site, such as the 1915 Avezzano earthquake, the 1980 Irpinia earthquakes or the strong earthquakes of the Friuli – Slovenian region. These events were felt because of their high magnitude and/or their hypocentral depth.

There are 100 historical events within 200 Km from the Ferrara-Casaglia site and are mainly located along the pede-apenninic thrusts or along the extentional faults of the inner Northern Apennines. The strongest earthquake felt in the site is the 1117 "Veronese" Mw=6.69 events, which source is matter of debate (the reader can refer to Chapter 5.5 for further information). Other important earthquakes recorded in this sites were generated by the eastern Southern Alps thrust front (e.g. 1695, Asolano Mw= 6.48; .1873, Bellunese Mw=6.32)

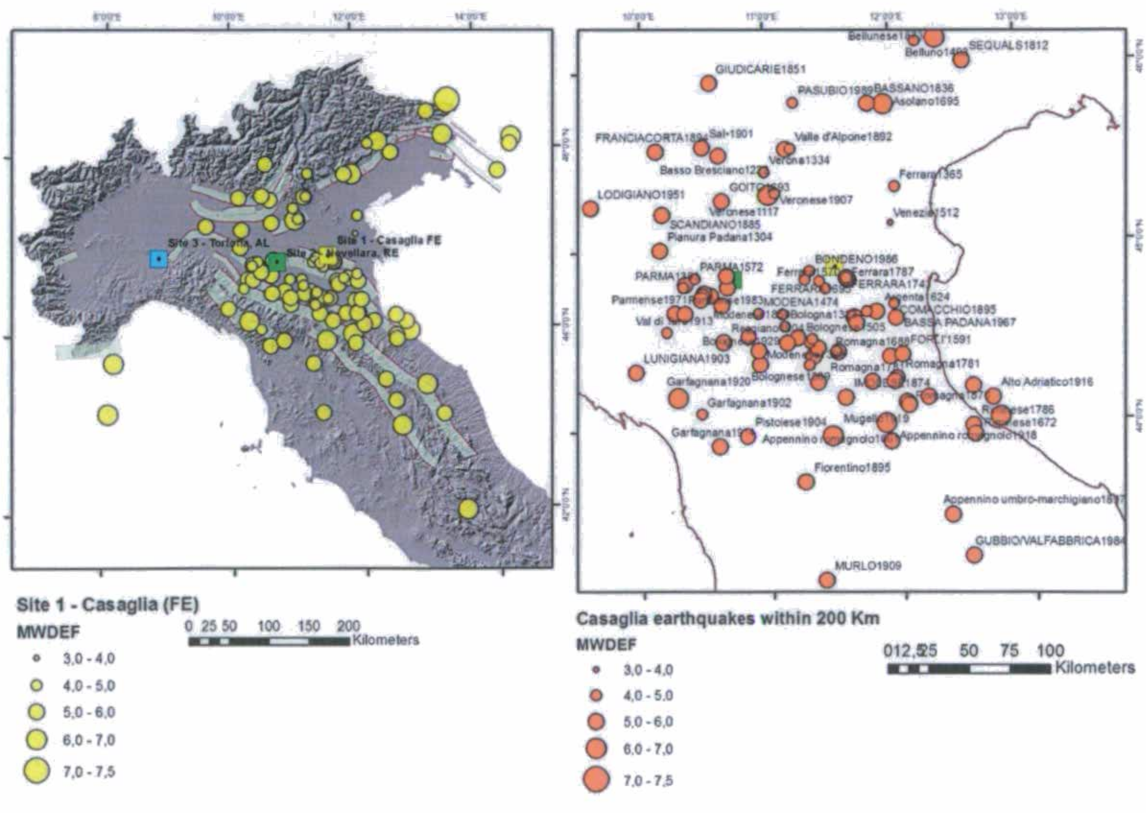


Figure 3.3: Distribution of historical earthquakes with macroseismic effects in the Ferrara-Casaglia site.

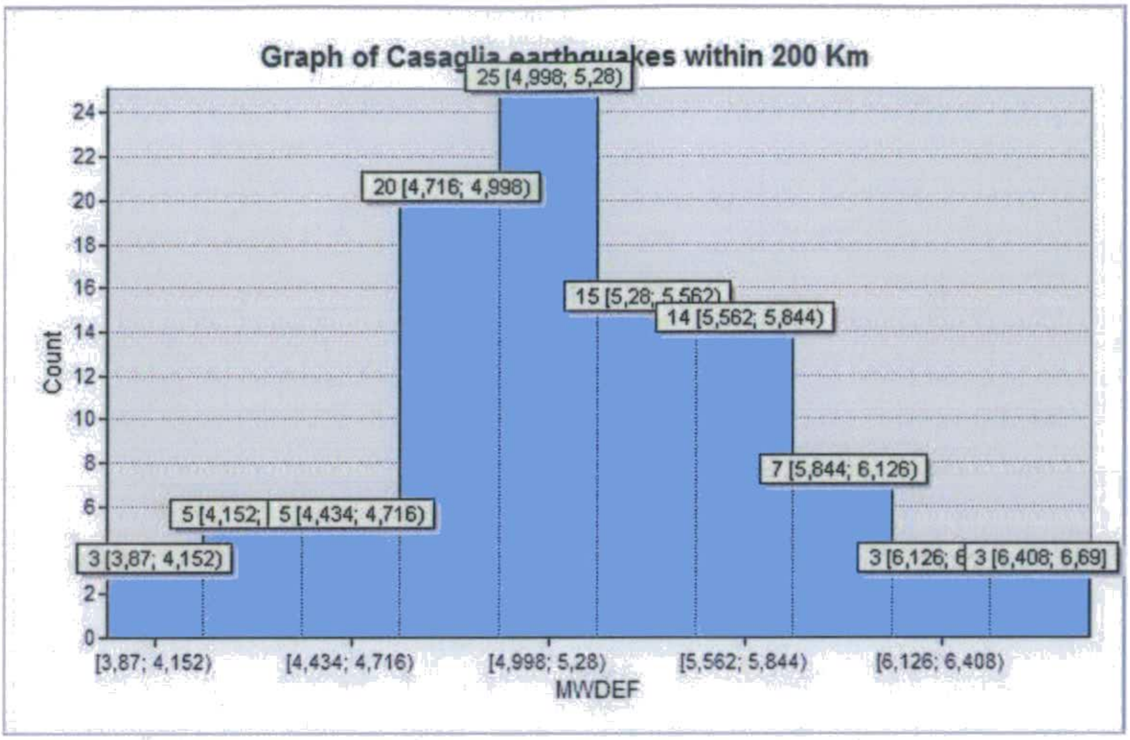


Figure 3.4: Histogram of the frequency magnitude distribution for the historical earthquakes felt in the Ferrara-Casaglia site.

Seismic history of Ferrara							
[44.836, 11.618]							
Id	**Year**	**Locality**	**LatEp**	**LonEp**	**Mw**	**IEp**	**I_{felt}**
10	1117	Veronese	45,309	11,023	6,69	9	5-6
23	1174	Val Padana	44,498	11,340	4,09	5-6	F
33	1222	Basso Bresciano	45,535	10,621	5,84	9	6
37	1234	FERRARA	44,836	11,618	5,14	7	7
58	1285	FERRARA	44,836	11,618	5,14	7	7
68	1304	Pianura Padana	45,010	10,149	5,11	5	5
79	1323	Bologna	44,572	11,133	4,30	5-6	NR
84	1334	Verona	45,438	10,994	4,93	6-7	NR
85	1339	Ferrara	44,836	11,618	4,72	6	6
89	1346	Ferrara	44,836	11,618	4,93	7-8	7-8
90	1348	Carinzia	46,578	13,541	7,02	9-10	5
104	1365	Ferrara	45,337	12,018	4,79	5	5
114	1383	PARMA	44,801	10,329	4,09	5-6	NR
124	1399	Modenese	44,441	10,925	5,14	8	F
127	1403	Belluno	46,146	12,222	4,72	6	NR
133	1409	Ferrara	44,836	11,618	4,72	6	6
135	1410	FERRARA	44,836	11,618	4,93	6-7	6-7
136	1410	Verona	-------	-------	-------	5-6	F

137	1411	Ferrara	44,836	11,618	5,14	7	7
160	1455	Media valle del Reno	-------	-------	-------	7-8	NR
182	1474	MODENA	44,647	10,925	4,30	6	NR
191	1483	FERRARA	44,836	11,618	4,51	5-6	5-6
192	1483	Romagna meridionale	44,156	12,229	5,68	8-9	5
211	1501	Appennino modenese	44,519	10,844	5,98	9	F
218	1504	Bolognese	44,519	10,844	-------	6-7	5
219	1505	Bolognese	44,508	11,231	5,57	8	6
220	1505	Bolognese	44,508	11,231	-------	6-7	5
229	1511	Slovenia	46,198	13,431	6,98	10	6
230	1511	Slovenia	46,198	13,431	-------	6	5-6
233	1512	Venezia	45,137	11,977	3,87	5	4
249	1536	Appennino tosco-emiliano?	44,364	10,933	5,29	6-7	6
261	1547	Reggio Emilia	44,697	10,631	5,14	8	NR
281	1561	Ferrara	44,781	11,454	4,51	6-7	6-7
287	1570	Ferrara	44,824	11,632	5,46	8	8
290	1572	PARMA	44,850	10,422	4,72	7	4
291	1574	FINALE EMILIA	44,833	11,294	4,72	7	F
306	1591	FORLI'	44,400	12,038	5,19	6-7	5
338	1624	Argenta	44,642	11,848	5,47	8-9	6
385	1661	Appennino romagnolo	44,021	11,898	6,09	10	5
386	1666	Bolognese	44,641	11,113	4,30	6	3
394	1672	Riminese	43,941	12,576	5,61	8	5
408	1688	Romagna	44,390	11,942	5,78	9	5
435	1693	GOITO	45,280	10,644	5,22	7	4-5
440	1695	Asolano	45,801	11,949	6,48	10	6-7
441	1695	FERRARA	44,836	11,618	4,51	5-6	5-6
552	1741	FABRIANESE	43,425	13,005	6,21	9	4
559	1743	FERRARA	44,836	11,618	4,93	6-7	6-7
657	1779	Bolognese	44,425	11,527	4,99	6	F
669	1781	Romagna	44,251	11,798	5,94	9-10	4-5
672	1781	Romagna	44,266	11,990	5,58	8	5
705	1786	Riminese	43,991	12,565	5,62	8	3
708	1787	Ferrara	44,836	11,618	4,51	6-7	6-7
709	1787	Ferrara	44,836	11,618	-------	6-7	6-7
738	1796	Emilia orientale	44,615	11,670	5,61	7	7
760	1806	NOVELLARA	44,862	10,671	5,19	7	4
783	1812	SEQUALS	46,028	12,589	5,71	7-8	4-5
784	1813	Romagna centrale	44,249	11,972	5,27	7	4
842	1831	Reggiano	44,752	10,544	5,54	7-8	F
847	1832	Valle del Topino	42,980	12,605	6,33	10	F
853	1832	Reggiano	44,765	10,494	5,53	7-8	5
861	1834	Lunigiana-Parmense	-------	-------	-------	7	3

862	1834	Bolognese	44,480	11,319	4,85	6	3
873	1836	BASSANO	45,807	11,823	5,50	8	3
929	1850	Modenese	44,572	11,133	4,30	6	3
935	1851	GIUDICARIE	45,941	10,559	5,12	6	3
965	1857	PARMENSE	44,749	10,480	5,09	6-7	F
1029	1870	Romagna	44,133	12,062	5,58	8	5
1039	1873	Marche meridionali	43,089	13,244	5,95	9	3-4
1041	1873	Bellunese	46,159	12,383	6,32	9-10	4
1050	1874	IMOLESE	44,168	11,589	5,02	7	NF
1055	1875	Romagna sud-orientale	44,210	12,572	5,93	8	5-6
1083	1878	Bolognese	44,424	11,543	5,06	6	4
1108	1881	Bolognese	44,401	11,348	5,16	7	3
1109	1881	Bolognese	44,401	11,348	-------	5-6	F
1164	1885	SCANDIANO	45,208	10,169	5,19	6	RS
1188	1887	Liguria occidentale	43,715	8,161	6,97	10	3-4
1203	1889	Bolognese	44,355	11,314	4,73	6	3
1227	1891	Valle d'Illasi	45,564	11,165	5,86	9	4
1254	1892	Valle d'Alpone	45,566	11,204	4,91	6-7	3-4
1282	1894	FRANCIACORTA	45,564	10,123	5,07	6	3-4
1290	1895	COMACCHIO	44,685	11,987	4,74	6-7	3
1293	1895	Slovenia	46,131	14,533	6,23	8	5
1294	1895	Fiorentino	43,703	11,264	5,43	8	NF
1343	1897	Slovenia	46,058	14,503	5,25	7-8	NF
1353	1897	Appennino umbro-marchigiano	43,496	12,378	5,13	7-8	NF
1354	1898	Romagna settentrionale	44,645	11,771	4,79	7	4
1357	1898	Valle del Parma	44,655	10,260	5,41	7-8	3
1420	1901	Salò	45,582	10,493	5,70	8	4
1423	1902	Garfagnana	44,093	10,463	4,96	7	3
1444	1903	LUNIGIANA	44,329	9,953	5,25	7-8	2
1451	1904	Reggiano	44,490	10,640	5,05	7	3
1473	1904	Pistoiese	43,964	10,820	5,15	7	NF
1518	1907	Veronese	45,318	11,073	4,91	6	3
1546	1908	Carnia	46,465	13,191	5,38	7-8	2
1562	1909	BASSA PADANA	44,579	11,688	5,53	6-7	6
1573	1909	MURLO	43,150	11,403	5,37	7-8	RS
1609	1911	Romagna meridionale	44,117	12,075	5,28	7	4
1654	1913	Val di Taro	44,551	10,195	4,84	5	3
1672	1914	Garfagnana	43,911	10,598	5,76	7	5
1675	1915	Avezzano	42,014	13,530	7,00	11	2
1698	1915	REGGIO EMILIA	44,732	10,469	5,02	6-7	5
1705	1916	Alto Adriatico	44,141	12,725	5,95	8	4
1724	1916	Alto Adriatico	44,034	12,779	6,14	8	4
1769	1918	Appennino romagnolo	43,917	11,933	5,88	9	3

1778	1919	Mugello	43,957	11,482	6,29	10	3
1803	1920	Garfagnana	44,185	10,278	6,48	10	5
1820	1922	Ferrarese	44,821	11,408	4,34	4-5	4-5
1868	1926	Slovenia	45,761	14,282	5,85	7-8	4-5
1903	1929	Bolognese	44,447	11,385	5,03	7	4
1906	1929	Bolognese	44,447	11,385	-------	6-7	4
1907	1929	Bolognese	44,481	11,150	5,34	7-8	4
1908	1929	Bolognese	44,481	11,150	-------	6-7	3
1913	1929	Bolognese	44,481	11,150	-------	6-7	4-5
2137	1951	LODIGIANO	45,251	9,601	5,39	6-7	4
2290	1963	Mar Ligure	43,150	8,083	6,02	6	3
2339	1967	BASSA PADANA	44,604	11,997	5,24	6	4-5
2426	1971	Parmense	44,814	10,345	5,64	8	5
2594	1980	Irpinia-Basilicata	40,842	15,283	6,89	10	3
2691	1983	Parmense	44,652	10,342	5,06	7	5
2695	1984	GUBBIO/VALFABBRICA	43,262	12,525	5,65	7	NF
2765	1986	BONDENO	44,879	11,334	4,61	6	4
2806	1989	PASUBIO	45,823	11,237	4,88	6-7	4-5
2892	1996	Correggio	44,798	10,678	5,41	7	4-5
3135	2003	Appennino bolognese	44,255	11,380	5,29	7	4

3.1.2 Site 2 – Novellara

The DBMI11 (Locati et al. 2011) database reportes 34 earthquakes. Eight of these events have Mw≥5.5 and three have Mw≥6 recorded in the Novellara site. Some of these events are located at great distance (more than 200 Km) from the Novellara site, such as the strong earthquakes of the Friuli – Slovenian region. These events were felt because of their high magnitude and/or their hypocentral depth. In particular, Fig 3.5 highlights the presence of a cluster of historical seismic events located in a radius of 45 Km from this site, in particular toward SW. This area is located in the western closure of the Ferrara arc, where it came closer to the pedeapenninic thrust front and is characterized also by a high concentration of low to medium events recorded by the instrumental seismicity.

Five of the 34 historical events felt in the Novellara site are events with Mw≥5.5 located within 200 Km from the site. The strongest earthquake felt in the site is the 1919 "Mugello" Mw=6.29 events, which was generated by an extensional seismogenic source of the Northern Apennines (the reader can refer to Chapter 5.5 for further information).

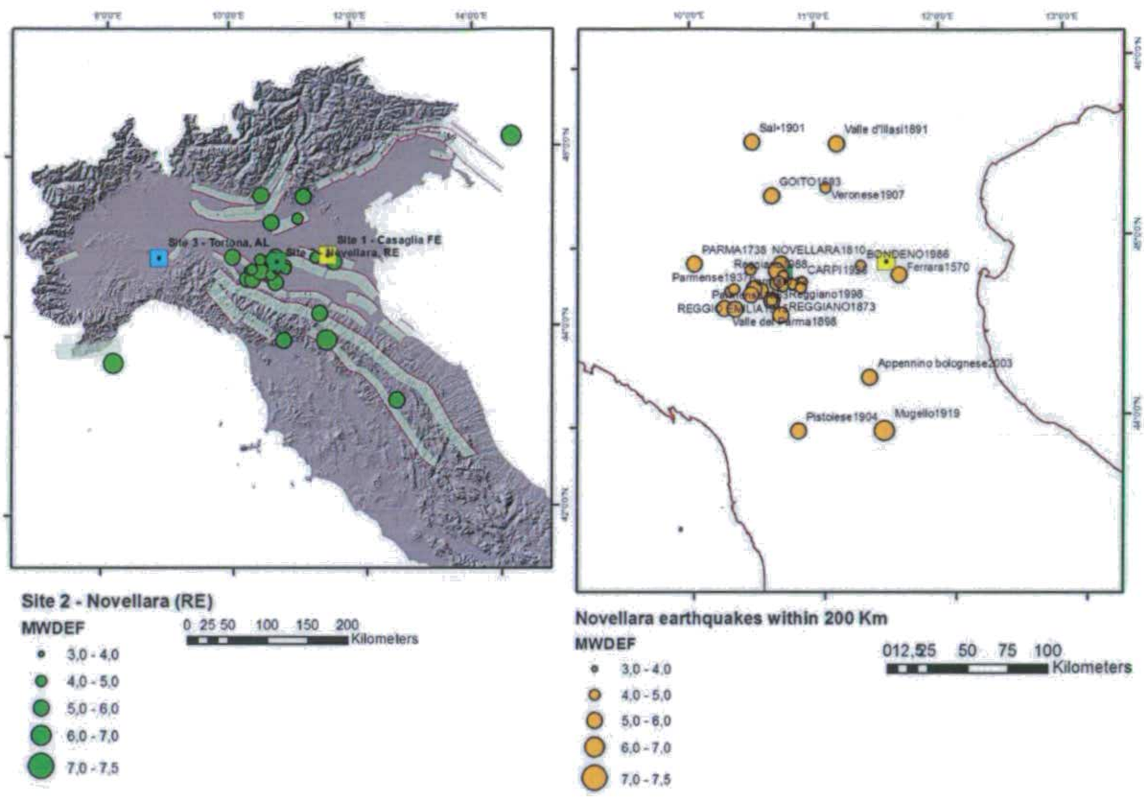


Figure 3.5: Distribution of historical earthquakes with macroseismic effects in the Novellara site.

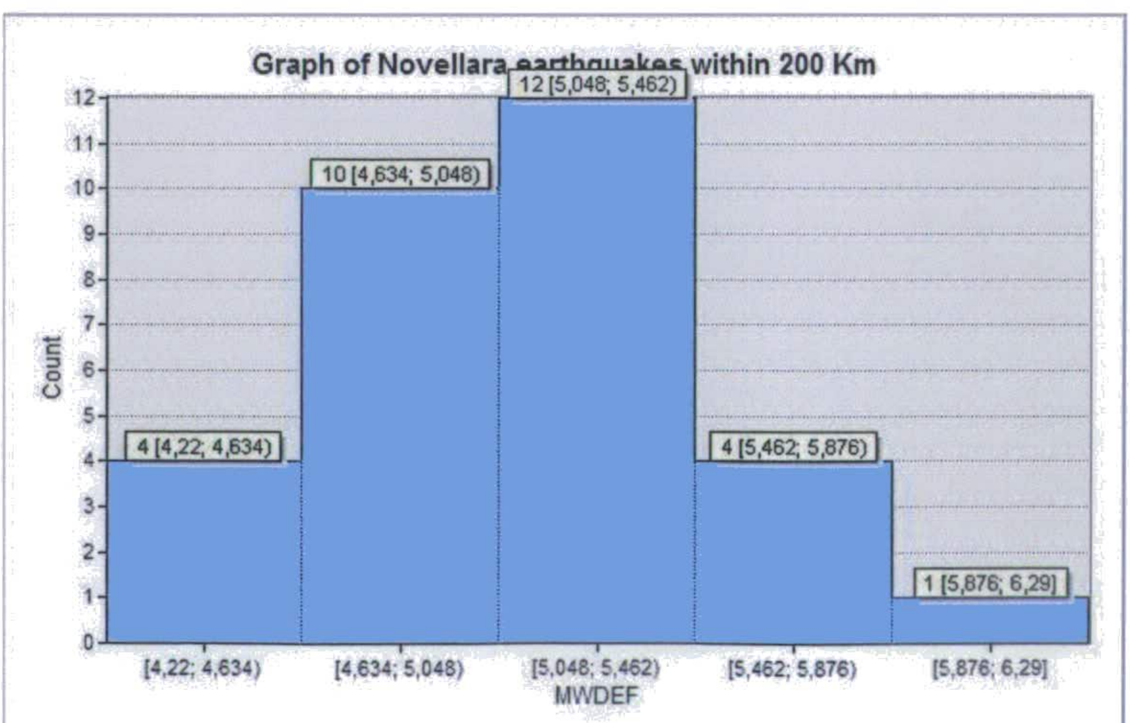


Figure 3.6: Histogram of the frequency magnitude distribution for the historical earthquakes felt in the Novellara site.

Seismic history of Novellara
[44.845, 10.731]

Id	Year	Locality	LatEp	LonEp	Mw	IEp	I_{felt}
261	1547	Reggio Emilia	44,697	10,631	5,14	8	6
287	1570	Ferrara	44,824	11,632	5,46	8	F
305	1591	REGGIO EMILIA	44,697	10,631	4,72	6	NR
435	1693	GOITO	45,280	10,644	5,22	7	5
532	1732	Parma	44,871	10,468	4,65	6-7	3
545	1738	PARMA	44,906	10,028	5,14	7	5-6
760	1806	NOVELLARA	44,862	10,671	5,19	7	7
777	1810	NOVELLARA	44,898	10,712	5,29	7	7
842	1831	Reggiano	44,752	10,544	5,54	7-8	7
853	1832	Reggiano	44,765	10,494	5,53	7-8	6
1040	1873	REGGIANO	44,612	10,701	5,09	6-7	F
1185	1886	COLLECCHIO	44,750	10,306	4,70	6	4
1188	1887	Liguria occidentale	43,715	8,161	6,97	10	F
1227	1891	Valle d'Illasi	45,564	11,165	5,86	9	4
1293	1895	Slovenia	46,131	14,533	6,23	8	F
1357	1898	Valle del Parma	44,655	10,260	5,41	7-8	3-4
1420	1901	Salò	45,582	10,493	5,70	8	4
1473	1904	Pistoiese	43,964	10,820	5,15	7	NF
1518	1907	Veronese	45,318	11,073	4,91	6	3
1698	1915	REGGIO EMILIA	44,732	10,469	5,02	6-7	4
1778	1919	Mugello	43,957	11,482	6,29	10	3
1892	1928	CARPI	44,797	10,872	4,78	7	4
2016	1937	Parmense	44,764	10,338	4,65	7	NF
2158	1953	Reggiano	44,787	10,795	4,77	6	4
2427	1971	Correggio	44,764	10,862	4,23	5-6	3-4
2691	1983	Parmense	44,652	10,342	5,06	7	5
2695	1984	GUBBIO/VALFABBRICA	43,262	12,525	5,65	7	NF
2765	1986	BONDENO	44,879	11,334	4,61	6	NF
2771	1987	Reggiano	44,801	10,694	4,74	6	6
2787	1988	Reggiano	44,833	10,724	4,66	6-7	5-6
2892	1996	Correggio	44,798	10,678	5,41	7	6
2900	1997	Reggiano	44,801	10,693	4,22	5-6	5-6
2978	1998	Reggiano	44,777	10,723	4,34	5-6	5-6
3135	2003	Appennino bolognese	44,255	11,380	5,29	7	4

3.1.3 Site 3 - Tortona

The DBMI11 (Locati et al. 2011) database reported 25 earthquakes. Seven of these events have Mw≥5.5 and 3 have Mw≥6 recorded in the Tortona site. (Figs. 3.7 and 3.8) Some of these events are located at great distance (more than 200 Km) from the Novellara site, such as the 1915 Avezzano earthquake or the strong earthquakes of the Friuli – Slovenian region. These events were felt because of their high magnitude and/or their hypocentral depth.

21 of the 25 historical events felt at the Tortona site are located within 200 Km from the site itself and four of these events have Mw≥5.5.

The strongest of the events within 200 Km from the site is the Mw=6.97 1887 Liguria earthquake

3.2 Deeper seismicity

The Po Plain and its surroundings are the locus of infrequent, instrumentally recorded, relatively deep earthquakes (h>15 km) occurring below the basal decollement of the Northern Apennines and Southern Alps (Figure 3.9). There is also limited historical evidence suggesting that these events may attain a magnitude larger than 5.0. These deeper seismogenic sources may be either related to the ongoing subduction of the Adria Plate beneath the Northern Apennines, or to inherited lineraments corresponding to the boundaries of paleogeographic domains.

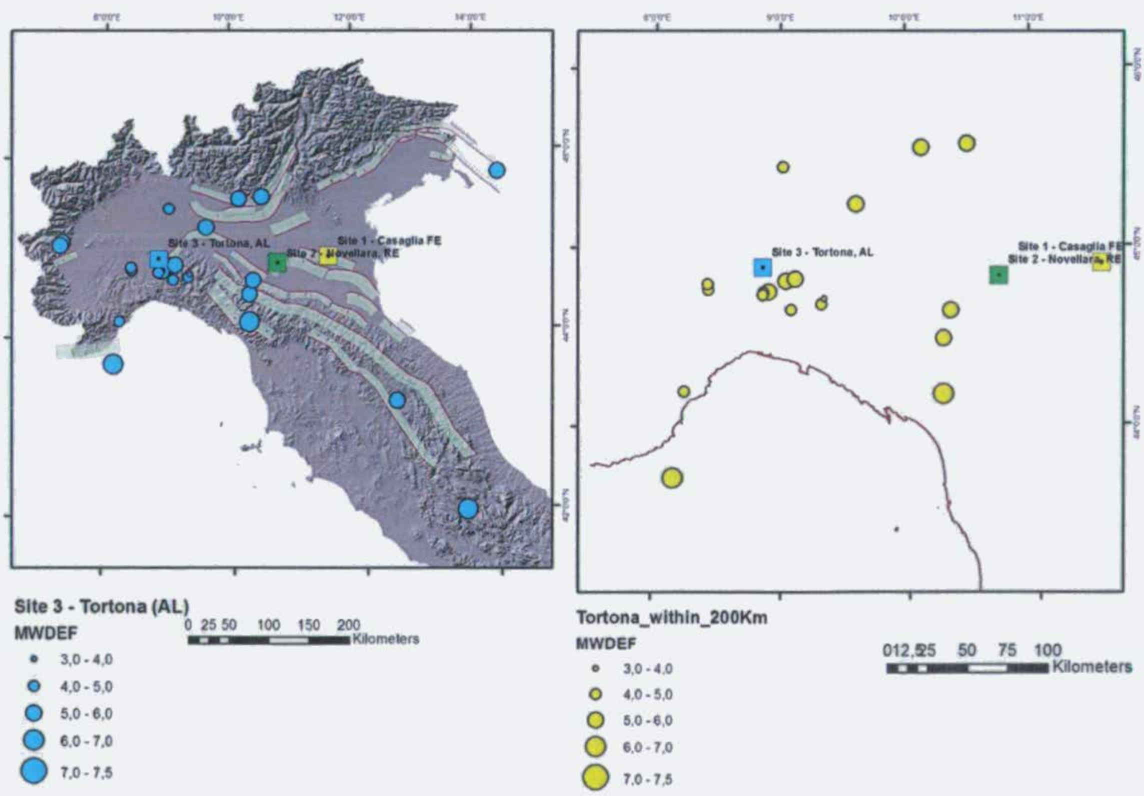


Figure 3.7: Distribution of historical earthquakes with macroseismic effects in the Tortona site.

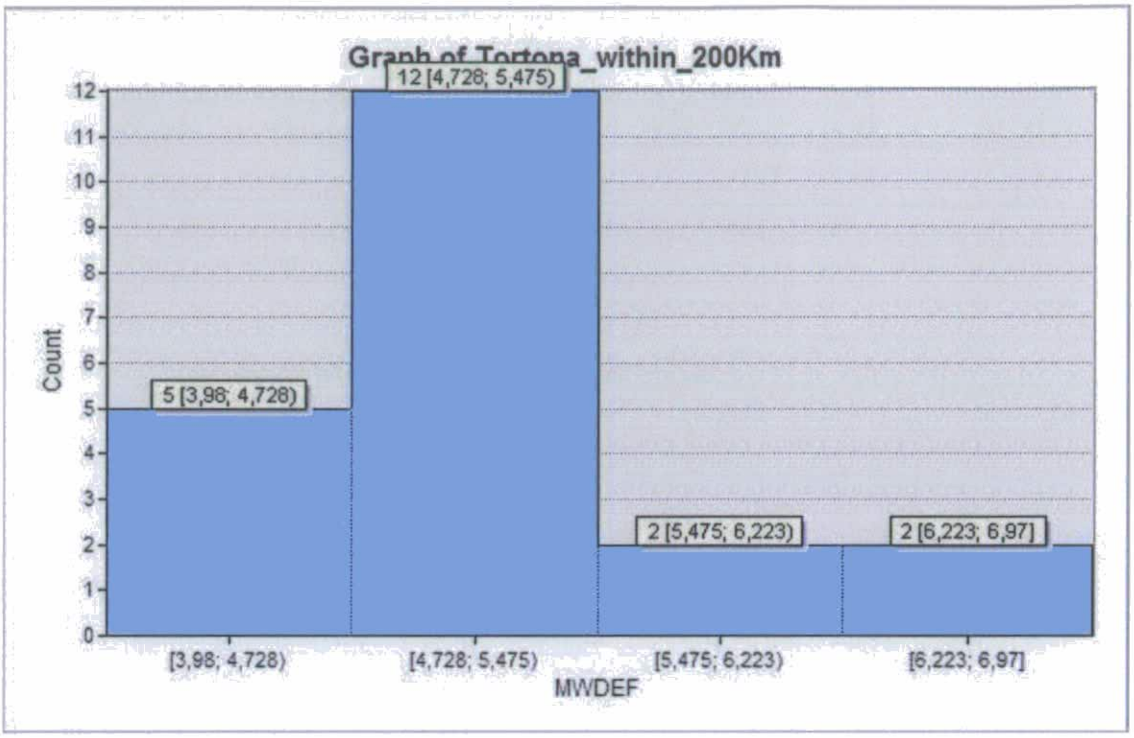


Figure 3.8: Histogram of the frequency magnitude distribution for the historical earthquakes felt in the Tortona site.

Seismic history of Tortona							
[44.897, 8.864]							
Id	**Year**	**Locality**	**LatEp**	**LonEp**	**Mw**	**IEp**	**I_{felt}**
255	1541	VALLE SCRIVIA	44,761	8,909	5,24	7	6
599	1759	PAVIA					5
829	1828	Valle Staffora	44,821	9,047	5,76	8	7
1044	1873	LIGURIA ORIENTALE	44,497	10,283	5,43	6-7	3
1129	1882	Val Borbera	44,660	9,085	4,99	6	4
1182	1886	VAL DI SUSA	45,036	7,306	5,25	7	3
1188	1887	Liguria occidentale	43,715	8,161	6,97		6
1282	1894	FRANCIACORTA	45,564	10,123	5,07	6	3-4
1420	1901	Salò	45,582	10,493	5,70	8	5
1655	1913	NOVI LIGURE	44,744	8,863	4,70	5	5
1669	1914	TAVERNETTE	45,067	7,336	5,41	7	3-4
1675	1915	Avezzano	42,014	13,530	7,00	11	2
1756	1918	Milanese	45,458	9,021	4,80	4-5	2
1803	1920	Garfagnana	44,185	10,278	6,48	10	4
1868	1926	Slovenia	45,761	14,282	5,85	7-8	2
2079	1945	VARZI	44,831	9,116	5,05	6	4-5
2137	1951	LODIGIANO	45,251	9,601	5,39	6-7	3

2691	1983	Parmense	44,652	10,342	5,06	6-7	3-4
2695	1984	GUBBIO/VALFABBRICA	43,262	12,525	5,65	7	NF
2851	1993	Finale Ligure	44,199	8,245	4,51	5	NF
3045	2000	Monferrato	44,769	8,432	4,86	6	4
3068	2001	Monferrato	44,801	8,427	4,17	5-6	NF
3129	2003	S. Agata Fossili	44,758	8,868	4,85	6	5
3160	2005	Valle del Trebbia	44,690	9,326	4,05	5	NF
3161	2005	Valle del Trebbia	44,724	9,348	3,98	5	NF

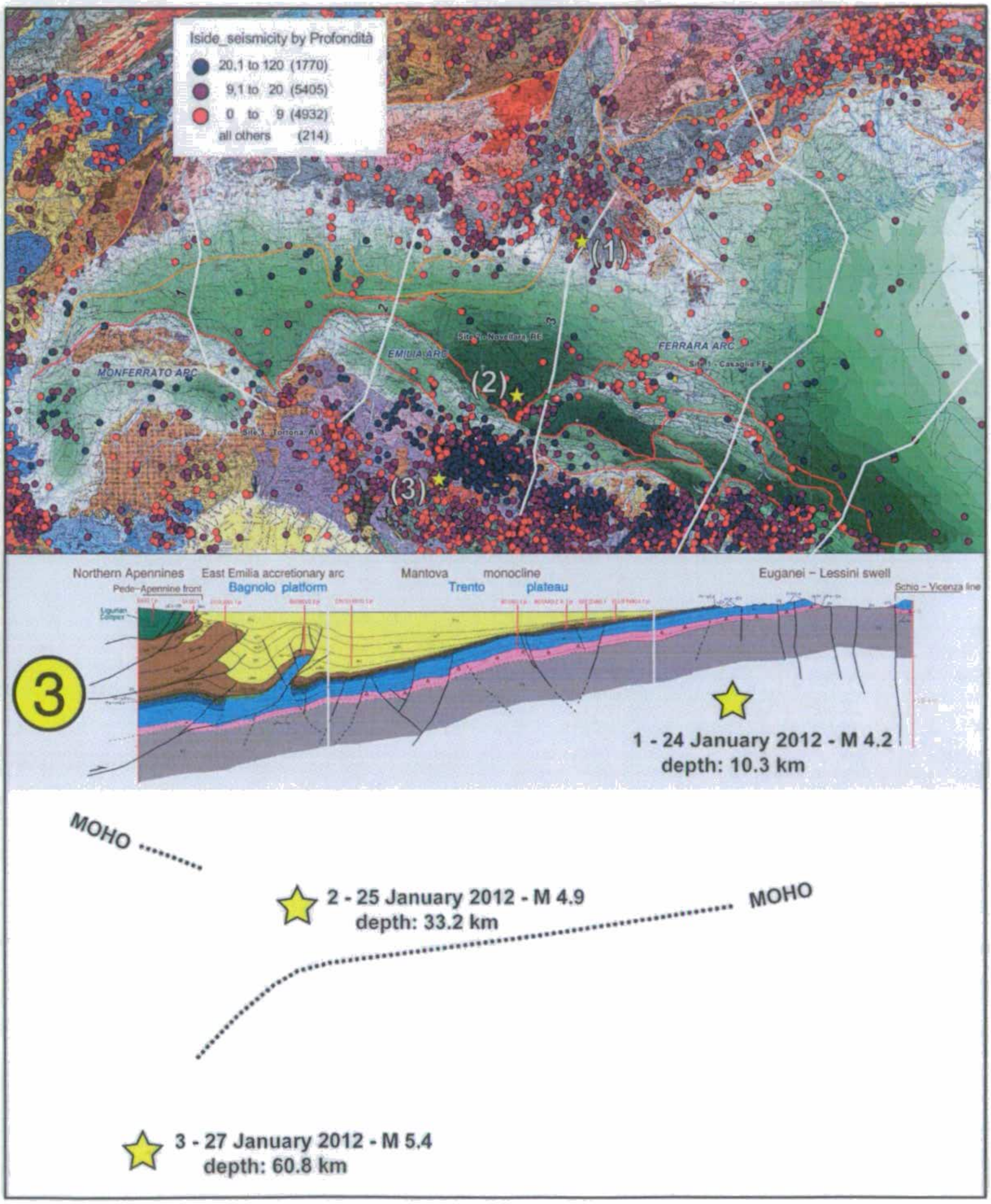


Figure 3.9: Instrumental seismicity from ISIDe database (Italian Seismic Instrumental and parametric Data-basE; http://iside.rm.ingv.it/) color-coded for hypocentral depth. The section below (Section 3 of Fantoni and Franciosi, 2010) shows the relationships among the three seismic events of January 2012 and the known crustal structures of the Northern Apennines and of the Lessini Mts. The latter is not deformed by the thrusts of the Southern Alps, but is characterized by the structures of the Schio-Vicenza trascurrent fault system. The Moho depth is also shown for reference (from Map of the European Moho, compiled by P. Dèzes and P.A. Ziegler, 2001 - http://comp1.geol.unibas.ch/).

4. Review of active faulting studies in the Po Plain

Although it is placed in the context of an active convergence between two opposite verging orogens (the Northern Apennines and the Southern Alps), the Po Plain appears as a geomorfological flat area. In fact, the subsidence rates induced in the whole Po Plain by the tectonic load of the two chains, and, as a consequence, the sedimentation rates in the basins, are higher than the uplift rates along the active thrust-related folds. For this reason, the main active tectonic structures are buried under the clastic sedimentary bodies of the plain and the evidences of surface faulting are rare or absent. The few exceptions are represented by the Trino Vercellese and San Colombano anticlines and by some isolated reliefs in the plain south of Brescia (Desio, 1965). Therefore, the main active structural elements (reverse fault, thrust and related folds), were mapped using numerous indirect geophysical dataset collected for oil exploration since the '60s (e.g. Pieri and Groppi, 1981; Cassano et al., 1986) and, more recently, using satellite geodesic techniques (e.g. Bennett et al. 2012).

In this chapter we review the main scientific works on active faulting in the Po Plain area. These scientific papers use different approaches to identify the evidence of active deformation: the geomorphological analysis of fluvial terraces or of river drainage anomalies, the field mapping of surface structures and the interpretation of indirect geophysical datasets.

Desio, 1965
This investigator identified isolated hills, underlain by Quaternary marine and fluvial deposits (Castenedolo, Ciliverghe and Capriano del Colle hills), whose presence cannot be explained by glacial or fluvioglacial morphogenic processes. These hills were in fact interpreted as the culmination of growing anticlines associated with underlying thrusts.

Castaldini and Panizza, 1988
This paper addresses a number of selected indicators of recent deformation in unconsolidated Quaternary deposits and around the Po Plain, and specifically along the Appeninnes and Alps foothills. Some of the indicators are ascribed to genuine tectonic activity whereas others are seen as the result of other, non-tectonic surface processes. Perhaps the most interesting of the investigated indicators is the sharp eastward turn of the Mincio R. to the northwest of Mantova, in the central Po Plain (Fig. 4.1). Three explanations are proposed for the nearly 90° deflection of the river from its natural NNW-SSE to N-S trend, two of which involve the action of a large buried fault whereas the last one invokes differential compaction of loose fluvial deposits due significant lateral facies changes. The authors of the paper also discuss the methods and the observations that may help discriminating between tectonic and non-tectonic, warning that such discrimination is not always immune from mistakes and misinterprations.

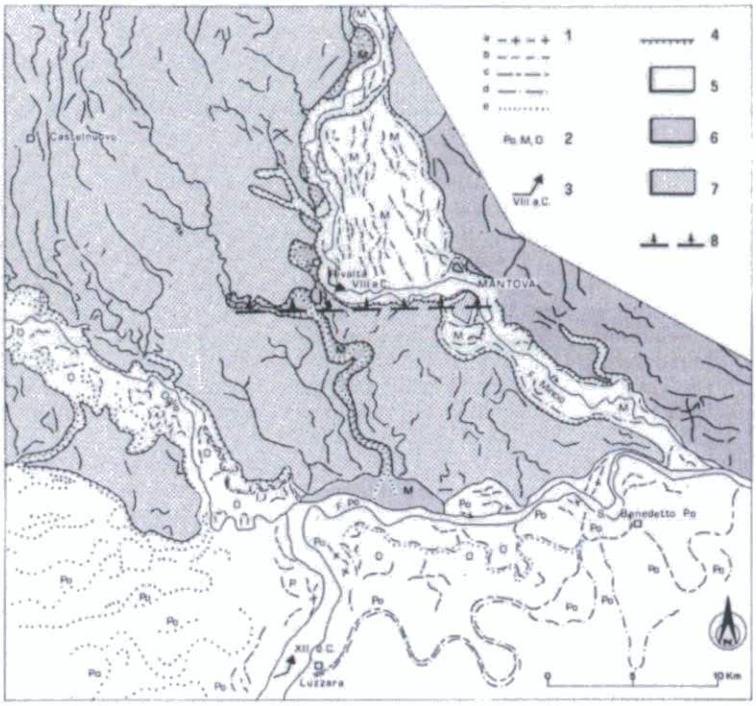


Fig. 9 - Schizzo geomorfologico dell'area di Mantova (da Panizza & *alii*, 1988 a, modificato): 1)Paleoalveo a) età moderna, b) età basso medioevale, c) età alto medioevale, d) di età romana e a luoghi del ferro, e) età del bronzo; 2) Sigle dei paleoalvei: Po = Po, M = Mincio, O = Oglio; 3) Principali deviazioni fluviali con indicazione dell'età; 4) Scarpata; 5) Depositi alluvionali abbandonati dai corsi d'acqua o dai paleoalvei che li attraversano e quindi ad essi coevi; 6) Depositi alluvionali sub-boreali (recenti nelle vicinanze degli alvei attuali) del Mincio, Tartaro ed Adige con paleoalvei coevi; 7) Depositi fluvioglaciali di pertinenza gardesana con tracce di canali proglaciali; 8) Asse di deformazione ritenuto attivo (frecce verso la zona più abbassata).

Figure 4.1: Geomorphological scheme of the Mantova area showing a sharp diversion of Mincio River resulting from uplift of an E-W ridge. Paleobeds of Mincio R. are shown as "M" (from Castaldini and Panizza, 1988).

Castaldini and Panizza, 1991

This paper illustrates the inventory of active faults located in the sectors of Northern Italy between the Po and Piave rivers and the Como lake (Fig. 4.2) and which pertain to the interval ranging from the Middle Pleistocene up to the Holocene (0,7 Myr to the Present). The Authors analyzed the distribution a features of the faults inventoried and presented a "Degree of activity map" in which it is possible to observe that the major elements in the eastern area showed a Class II degree of activity (average slip rate from 0,1 to 0,1 mm/yr). In the Garda sector, the faults identified were found to have both Class II and Class II degrees of activity (average slip rate of less than 0,1 mm/yr). In both sectors, average slip rates greater than 1 mm/yr (Class I) was observed locally. The Authors concluded that the isolated relief in the upper part of the Brescia plain are not part of the southern alps active sectors and that the activity in the area north of the Garda lake has been underestimated. Moreover the authors considered the Holocene tectonic activit in the Adda river basin to be more widespread than has been indicated.

Benedetti et al., 2003

These investigators presented geomorphic evidence for an emergent active thrust along the northwestern Apennine front about 50 km south of Milano. Fieldwork combined with SPOT image analysis attests to the presence of a35-km-long, en echelon, cumulative fault scarp, that cuts E-W across Quaternary surface deposits from Casteggio to Sarmato. The scarp offsets vertically alluvial fans and terraces emplaced by tributaries of the Po River that flow northward from the Apennines; to the northeast, the buried, east dipping Pavia lateral ramp bounds the San Colombano anticline. Total station profiles leveled perpendicular to the Stradella thrust show variable cumulative surface throws ranging from 2 to 25 m. Scarp degradation analysis indicates fairly recent offset of the terrace surfaces (10–100 kyr) suggesting a minimum uplift rate of 0.3 mm/yr.

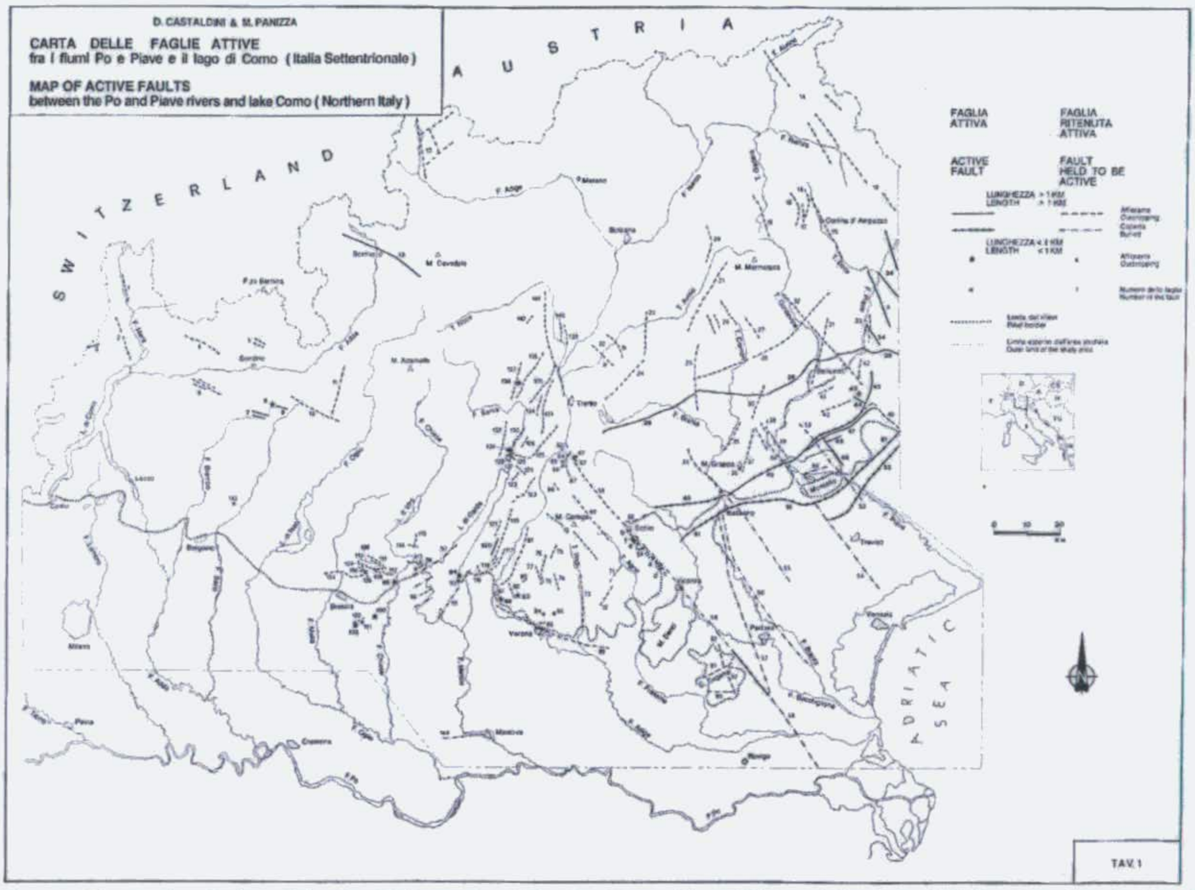


Figure 4.2: Active faults of the Po Plain north of the Po River (Castaldini and Panizza, 1991). Note that in the plain there are few evidence of active faulting due to the blind geometry of the outer Southern Alps thrust fronts, whereas most of the evidence concentrate at or near the mountan front.

Burrato et al., 2003

These investigators analyzed in detail the fluvial system of the Po Plain and identified several areas where significant drainage anomalies (e.g., river diversions and shifts in channel patterns) with wave-length comparable to that of tectonic structures of crustal significance are suggestive of the presence of active blind thrust or reverse faults. As second step of their approach the authors compared the position of the drainage anomalies with the location of known buried anticlines, to corroborate the hypothesis of the tectonic nature of the anomalies. Following the observation that some of the anomalies are associated also with historical earthquakes, they proposed that these blind thrusts may be potential sources of rather infrequent large earthquakes beneath the Po Plain. Among all the anomalies, they identified one related to the seismogenic source responsible for the 12 May 1802 earthquake (Me 5.7), which struck the Oglio River Valley near Soncino (Cremona) and proposed that this earthquake was generated by an east-west trending, north-dipping, blind thrust fault that roots into the Alpine system. Moreovere, also the Secchio and Panaro rivers exhibit significant anomalies in their trend as they cross an anticline reported in the official geological map. The Authors interpreted the fluvial anomaly as having tectonic origin.

Sileo et al., 2007

These investigators studied a sector of the Insubria area, near the city of Como, in which several evidences of active tectonics were recognized. The active faulting influenced the deposition of quaternary glacial fluvio-glacial sediments and the development of the drainage pattern. The activity of these faults produced topographic reliefs of 100 – 200 m higher respect to the surrounding areas. The Authors suggested that these active structures have deformation rates values lower than what observed in the eastern sectors of the Giudicarie-Lessini Mts area.

Scrocca et al., 2007

The Quaternary evolution of one of the active thrust-relat-ed folds recognised in the Po Plain subsurface (the Mirandola anticline) has been investigated in detail by backstripping high-resolution stratigraphic data. The Author's results showed decreasing relative uplift rates during the Quaternary. However, tectonic relative uplift rate of about 0.16 mm/a can still be recognised during the last 125 ka. Horizontal shortening faster than 1 mm/a should be expected in agreement with available GPS data.

Furthermore, the SW-ward (or W-ward) increasing dip of the foreland monocline in the Po Plain and in the central-northern Adriatic and the asymmetric distribution of the Quaternary to Recent subsidence indicate a still active flexural re-treat of the subducting lithosphere in these domains.

Stramondo et al., 2007

These investigators studied the surface deformations affecting the southeastern sector of the Po Plain sedimentary basin, in particular the area of Bologna. To this aim an advanced DInSAR technique, referred to as DInSAR–SBAS (Small BAseline Subset), has been applied. The surface displacements detected by DInSAR SBAS from 1992 to 2000 are between 10 mm/year in the historical part of Bologna town, and up to 59 mm/year in the NE industrial and agricultural areas. Former measurements from optical levelling referred to 1897 show 2–3 mm/year vertical movements. This trend of displacement increased in the second half of the 20th century and the subsidence rate reached 60 mm/year. We compared the more recent levelling campaigns (in 1992 and late 1999) and DInSAR results from 1992 to 1999. The standard deviation of the difference between leveling data, projected onto the satellite Line Of Sight, and DInSAR results is 2 mm/year. This highlights a good agreement between the measurements provided by two different techniques. The explanation of soil movements based on interferometric results, ground data and geological observations, allowed confirming the anthropogenic cause (surface effect due to the overexploitation of the aquifers) and highlights a natural, tectonic, subsidence.

Picotti and Pazzaglia, 2008

These investigators integrated existing and new geologic data, particularly on the origin, growth, and activity of the mountain front at Bologna, Italy, into a new model that explains Apennine orogenesis in the context of a slab rollback - upper plate retreat process. The authors interpreted the

Bologna mountain front as an actively growing structure driving rock uplift ≈1 mm/year, cored by a midcrustal flat-ramp structure that accommodates ongoing shortening driven by Adria subduction at a rate of ≈2.5 mm/year. In the Author's interpretation the Po Plain around Bologna is a subsiding sag basin, superposed on top of the former proforeland basin, where shallow thrust-cored folds appear to be mostly inactive since the middle Pleistocene.

Livio et al., 2009 a,b

The same structural culmination studied by Desio (1965) were the object of two works of Livio et al (2009 a, b) that analysed the subsurface geological structures using seismic reflection profiles. The fault systems of Capriano del Colle and Castenedolo comprise the eastern termination of a fold and thrust beld located at the outermost buried structural front of the Southern Alps.

The Capriano del Colle fault system is represented by a south verging thrust and an associated high angle backthrust located in correspondence of the Capriano del Colle and Castenedolo hills. Both the thrusts appear as "blind fault" in the seismic cross sections and do not offset the plio-pleistocene sedimentary sequence, but their propagation toward the surface is expressed by the association of secondary folds and fault planes. The frontal south verging thrust shows a cumulate.ive displacement of 1200 m, while the backthrust has a total displacement of 5700 m.

The cumulative slip rates decrease in the last 1.6 Ma from 3.45 mm/yr in the interval 1.6-1.2 Myr to 2.75 mm/yr between 1.2 and 0.89 Myr and 0.47 mm/yr from 0.89 mm/yr to the present, with greater deformation rates on the backthrust respect to the frontal thrust. The suface expression of this backthrust is represented by the Capriano del Colle and Castenedolo hills and by the drainage anomalies in the Mella river in this sector. The data presented by the Authors allows to estimates a maxima magnitude for the Capriano del Colle and Castenedolo structures in the range of Mw=5.9 – 6.5

Toscani et al., 2009

These investigators used geological, structural and morphotectonic data to draw a N-S-striking section between Bologna and Ferrara, aimed at analyzing whether and how the deformation is partitioned among the frontal thrusts of the Northern Apennines and identifying the potential sources of damaging earthquakes. The Authors pointed out active anticlines based on the correspondence among drainage anomalies, historical seismicity and buried ramps. They also analyzed the evolution of the Plio-Quaternary deformation by modeling in a sandbox the geometry, kinematics and growth patterns of the thrust fronts.

Their results (i) confirm that some of the main Quaternary thrusts are still active and (ii) highlight the partitioning of deformation in the overlap zones. The extent and location of some of the active thrusts are compatible with the location and size of the main historical earthquakes (11 April 1688, Bagnacavallo earthquake, Mw 5.9; 3 March 1624, Mw5.4; 22 October 1796, Mw 5.6; 13 January 1909, Mw5.5; and 30 December 1967, Mw5.4; 17 November 1570, Mw5.5 Ferrara earthquake) and, on this base, the Authors hypnotized that these thrusts may correspond to their causative seismogenic faults.

Wegmann and Pazzaglia, 2009

These investigators summarized a new fluvial terrace chronostratigraphy of the Bidente and Musone Rivers (respectively in the Emilian Apennines and in the Marche Apennines) cast within a broader European framework, which forms the basis of a terrace genesis and river incision model for the northern Apennines.

These and all Po-Adriatic draining rivers are proximal to a base level defined by mean sea level and have little room for increasing their longitudinal profile concavities through incision, particularly in their lower reaches despite periodic glacio-eustatic drawdowns. In the Author's interpretation, the observed incision is best explained by rock uplift associated with active local fault or fold growth embedded in the actively thickening and uplifting Apennine foreland.

Boccaletti et al., 2011

These investigators presented a comprehensive study of the recent and active tectonics of the external part of the Northern Apennines (Italy) by using morphotectonic, geological–structural, and stratigraphic analysis, compared with the current seismicity of the region. Geological data and interpreted seismic sections indicate a roughly N–S Quaternary deformation direction, with rates 2.5 mm/year. The shortening decreased since the Plio-cene, when our data indicate compression in a NNW–SSE direction and rates up to 7 mm/year. The trend and kinematics of the structures affecting the Apennines–Po Plain margin and the Po Plain subsoil fit well the pattern of the current seismicity of the area, as well as recent GPS and geodetic levelling data, pointing to a current activity of these thrust systems controlled by an overall compressive stress field.

5. Seismogenic sources in the Po Plain

In this chapter we review the seismogenic sources of the DISS database affecting the Po Plain and nearby regions. A seismogenic source model includes explicit three-dimensional faults deemed capable of generating ground motions of engineering significance within a specified time frame of interest (HullerHaller & Basili, 2011). The seismological and geometrical parameters of each seismogenic source are presently stored in the Database of Individual Seismogenic Sources (DISS) in its version 3.1.1 that was build and is updated and maintained by the INGV DISS Working Group and that will be use as a reference for this chapter.

The DISS is a repository of geologic, tectonic, and active fault data for the Italian and neighboring territories; it highlights the results of several decades of research work, with special emphasis on data and conceptual achievements of the past 20 years (Basili et al. 2008; DISS Working Group, 2009).

The most obvious use of DISS data is in the prediction of the geological effects of a significant earthquake. DISS data may be used to predict the approximate location of surface ruptures, either from direct reports taken in the literature or by extrapolation of the fault geometry; to anticipate the pattern of expected ground subsidence or uplift and of the ensuing landscape and drainage modifications; and to predict the scenario of earthquake-induced tsunamis.

The most recent seismic zonation for the Italian territory (published by Meletti et al., 2008, but prepared in 2003) relied on DISS data and eventually led to the national seismic hazard map of Italy (MPS Working Group, 2004) and has been used in several other hazard applications. Some of these applications are:

(a) Conventional time-independent probabilistic seismic hazard assessment (SHA) . (Meletti et al., 2008) .);

(b) Non-conventional time-independent probabilistic SHA analyses. (Calvi and Stucchi, 2006);

(c) Time-independent probabilistic SHA in terms of displacement spectra (Faccioli and Rovelli, 2006; Faccioli et al., 2004).);

(d) Probabilistic SHA analyses that include time-dependency. (Pace et al., 2006; Slejko and Valensise, 2006);

(e) Deterministic SHA for specific areas, settlements, or major infrastructures (earthquake scenarios) (Faccioli and Vanini, 2004; Mucciarelli and Tiberi, 2007; Franceschina et al., 2006).

(f) Stochastic finite-fault modeling to quantify near field and the directivity effects (Zonno and Carvalho, 2006).

(g) Mid and short-term earthquake predictions based on real-time analyses of seismic moment release (AMR-type techniques) (Barba and Grondin, 2004).

Currently, the model contains 98 seismogenic sources located in Italy and neighboring countries (Figure 1A). Overall, the DISS incorporated information from about 2,500 publications, which are cited in comments.

As the database name suggests, DISS initially contained a seismogenic source model of individual fault ruptures. These were mainly the preferred fault representations of the sources of known past earthquakes, that is, historical earthquakes associated with faults recognized by geological and geophysical methods (see chapter 5.1).

However, most faults in and near Italy are blind or inaccessible; for example, numerous known faults are located offshore, buried faults are prevalent in the River Po alluvial plains (from Torino to Venezia), and lower crust fault sources have revealed themselves in several recent damaging earthquakes. Recognizing these inherent difficulties in identifying fault segments in the Italian geologic/geomorphic record, there has been the need to add a new category, currently named

"Composite Seismogenic Sources," in DISS3 (http://diss.rm.ingv.it/diss/) to extend the completeness of the model (for other detail see chapter 5.1)).

A minimum magnitude of M 5.5 is required for a source to be included in the database. Earthquakes of magnitude 5.5 and larger indeed provide evidence for the highest hierarchy level of active crustal deformation, reducing and summarizing the geological complexity created by the interplay of secondary tectonic processes, local stress fields and strictly surficial processes. They also justify and explain the evolution of the youngest geological deposits and processes and of landscape features at the scale of large crustal faults (10 –50 km).

5.1. Conceptual framework: types of seismogenic sources

DISS' main cataloguing element is the Seismogenic Source. In Version 3.1.1 the Seismogenic Sources are distinct in three main categories based on their attributes, their expected use, the nature and reliability of data used to define them:

1) Individual Seismogenic Sources
2) Composite Seismogenic Sources
3) Debated Sources

The ***Individual Seismogenic Sources*** (ISSs, Fig. 5.1) are defined by geological and geophysical data and are characterized by a full set of geometric (strike, dip, length, width and depth), kinematic (rake), and seismological parameters (single event displacement, magnitude, slip rate, recurrence interval). Each parameter is then rated for accuracy.

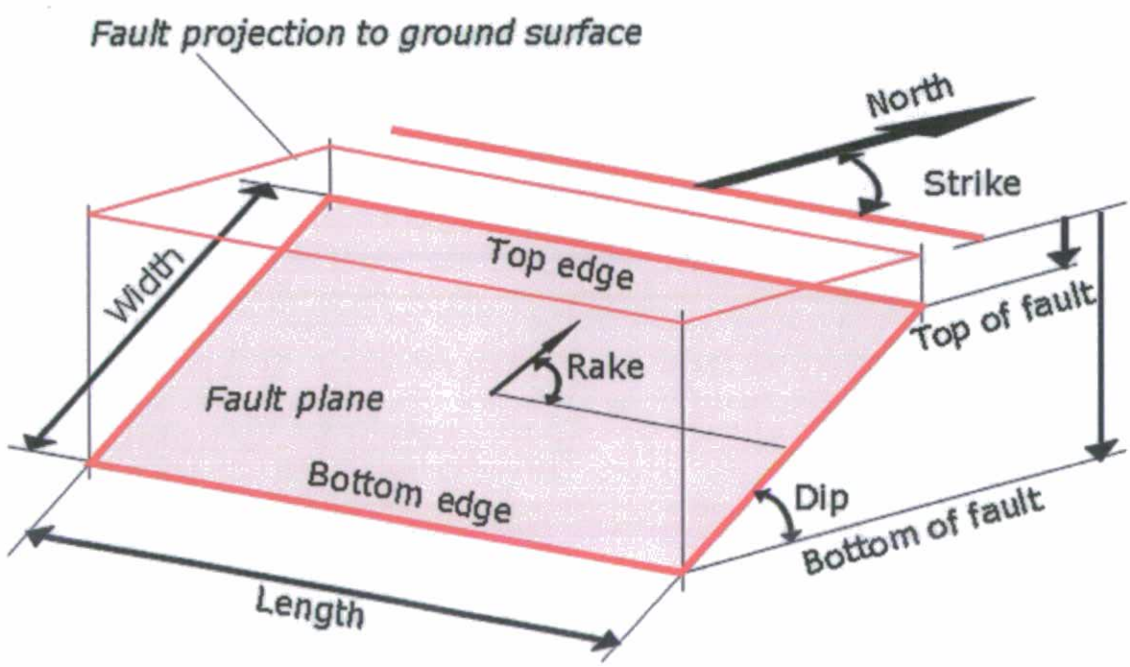


Figure 5.1: Geometric parameters of an Individual Seismogenic Source.

Individual Seismogenic Sources are assumed to exhibit strictly-periodic recurrence with respect to rupture length/width, slip per event, and expected magnitude. They are compared to worldwide databases for internal consistency in terms of length, width, single event displacement and magnitude, and can be augmented by fault scarp or fold axis data when available (usually structural features with documented Late Pleistocene - Holocene activity).

This category is intended to supply the most accurate information available for the best identified sources, but the completeness of the sources themselves cannot be guaranteed. Individual Seismogenic Sources can hence be used for calculating earthquake and tsunami scenarios and for tectonic and geodynamic investigations, but are not meant to comprise a complete input dataset for probabilistic assessment of seismic hazard.

Similarly to the other categories of DISS sources, each Individual Seismogenic Source is identified by the code CCIS###, where:

- CC is the two-letter ISO 3166-1 code for names of officially recognized countries;
- IS identifies specifically the Individual Seismogenic Sources;
- ### is an ordinal between 1 and 999 (including leading zeroes).

The ***Composite Seismogenic Sources*** (CSSs, Fig. 5.2) are based on geological and geophysical data and are characterized by geometric (strike, dip, width, depth) and kinematic (rake) parameters.

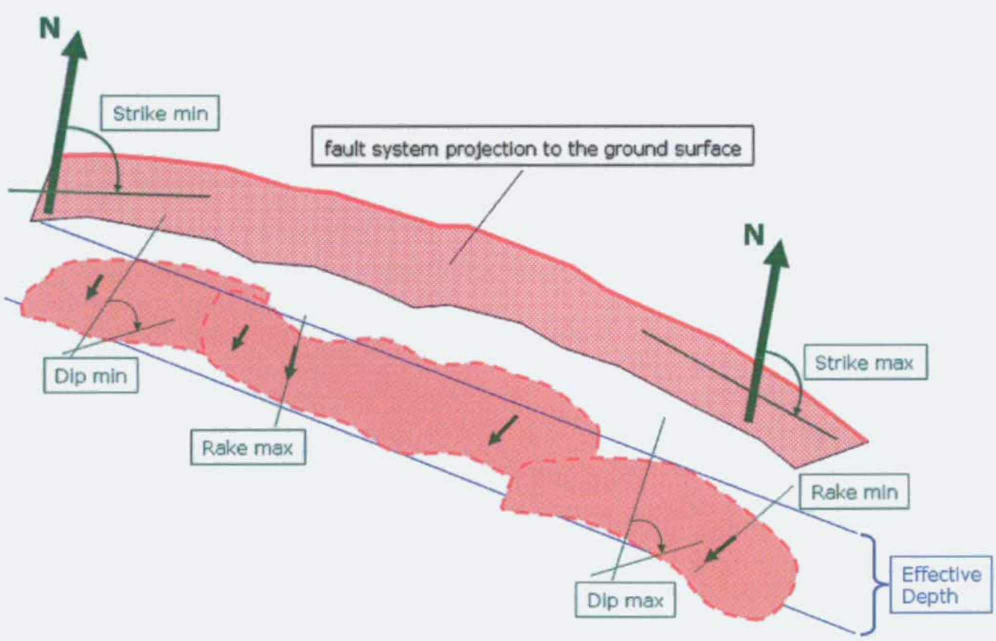


Figure 5.2: Geometric parameters of a Composit Seismogenic Source

A Composite Seismogenic Source is essentially an inferred structure based on regional surface and subsurface geological data that are exploited well beyond the simple identification of active faults or youthful tectonic features. The length of the expected earthquake ruptures, however, is poorly defined or unknown; hence a typical Composite Seismogenic Source spans an unspecified number of Individual Sources. As a result, sources of this category are not assumed to be capable of a specific-size earthquake, but their seismic potential can be estimated from existing earthquake catalogues. Their description can be augmented by fault scarp or fold axis data when available (usually structural features with documented Late Pleistocene - Holocene activity).

As opposed to the Individual Seismogenic Sources, this category of sources was conceived to achieve completeness of the record of potential earthquake sources, although this may imply a smaller accuracy in their description. In conjunction with seismicity and modern strain data, Composite Seismogenic Sources can thus contribute to the development of regional probabilistic seismic hazard assessment and for investigating large-scale geodynamic processes.

Similarly to the other categories of DISS sources, each Composite Seismogenic Source is identified by the code CCCS###, where:

- CC is the two-letter ISO 3166-1 code for names of officially recognized countries;
- CS identifies specifically the Composite Seismogenic Sources;
- ### is an ordinal between 1 and 999 (including leading zeroes).

The ***Debated Seismogenic Sources*** (DSSs). The compilers of the DISS database guarantee the existence of all listed seismogenic sources, both Individual and Composite, and strive to describe them with the best possible accuracy. Nevertheless, they are well aware that the literature contains hypotheses and descriptions concerning a significantly larger number of potential seismogenic sources than those currently listed in the database. In contrast with the aleatoric uncertainty normally associated with the inherent variability in the parameters of the expected earthquake rupture, the uncertainty associated with the mere existence of a large fault is epistemic. This uncertainty may become crucial in deterministic seismic hazard assessment, or even in a probabilistic approach dominated by large potential earthquake sources; yet it is very difficult to assess and may vary substantially depending on the region and on different investigators. No matter how careful the work is, this type of uncertainty is generally not properly conveyed to the potential end-users of a seismogenic source database (e.g. Woo, 2005).

The compilers of DISS addressed this major source of uncertainty in seismic hazard assessment practice by identifying and describing a number of "Debated Seismogenic Sources" (DSSs); these are active faults that have been proposed in the literature as potential seismogenic sources but were not considered reliable enough to be included in the database. They may include:

- faults for which only minimal surface evidence is supplied in the literature;
- faults based on inherently ambiguous geological evidence;
- faults for which the literature offers highly contrasting views;
- faults that occur in low or very low seismicity areas;
- faults whose characteristics are in open contrast with those of nearby, better known and established seismogenic sources, or that violate established tectonic and seismological evidence.

Similarly to the other categories of DISS sources, each Debated Seismogenic Source is identified by the code CCDS###, where:

- CC is the two-letter ISO 3166-1 code for names of officially recognized countries;
- DS identifies specifically the Debated Seismogenic Sources;
- ### is an ordinal between 1 and 999 (including leading zeroes).

5.2 Characterizing seismogenic sources parameters

The parameters of the seismogenic sources are derived from geological consideration, subsurface data analysis and from the historical (Rovida et al., 2011) and instrumental catalogues (Pondrelli et al. 2011) that allow to constraint the expected magnitude and behavior of a given structure.

Geologic data used to characterize the occurrences of rupturing events on seismogenic sources come from several subdisciplines including paleoseismology, geomorphology, and other geologic studies, which address the timing of the fault's most recent earthquakes and displacement history. All of these types of investigations report observations and interpretations at one or more point locations along the fault.

5.2.1 Seismogenic Source Geometry

A seismogenic source is a generalized, three dimensional representation of a dipping surface in the earth's crust where fault slip occurs and where most of the seismic energy is released during an earthquake. Seismogenic sources are idealized as a uniformly dipping surface constrained between two parallel lines that define the top edge and bottom edge of the source. The locations of seismogenic sources are defined by pairs of latitude/longitude geographic coordinates in decimal degrees with positive values for north/east and negative values for south/west. Conventionally, the seismogenic source model adopts the right hand rule (Aki and Richards, 1980) for representing the geometry of faults. The entire fault surface is defined by pairs of latitude/longitude coordinates corresponding to the top and bottom of the fault vertically projected to the ground surface and corresponding depths.

Additional characteristics such as length, strike, and width (as defined in structural geology textbooks) can be determined from the idealized geometry of the seismogenic source. Length is measured along strike. Width is the distance between the two horizontal lines that constrain the dipping surface measured along dip. For vertical sources, the width equals the absolute value of the difference between upper and lower edges of seismogenic sources. Finally, rake is commonly used to define the sense of slip on the source.

All of the above geometric parameters are required to characterize a seismogenic source; however, some parameters may be unknown or more appropriately unconstrained. Characteristics such as dip at depth, bottom of rupture, and, in the case of blind faults, the top of rupture, are known only under the most favorable circumstances. Source specific data may come from seismic reflection profiles or possibly from an aftershock study, but generally these parameters are, at best, loosely constrained. Thus, these critical parameters are typically assigned values based on regional or worldwide comparisons.

5.2.2 Seismogenic Source Magnitude

The earthquake magnitude for each source is measured using the moment magnitude scale (M_w) and represents the size of the largest earthquake that a seismogenic source can generate.due to the extreme difficulty in positively identifying individual ruptures, especially for composite seismogenic sources, maximum magnitude is assigned using data independent from the mapped object. The maximum magnitude is constrained by the largest historical earthquake that can be associated with that source or the largest fault segment that composes the source; as such, the largest potential earthquake will not necessarily rupture the entire source. This bears important consequences in applications that require individual fault ructures; the DISS composite sources must be split into sections of appropriate dimension consistent with the assigned earthquake magnitude.

The seismogenic sources may release earthquakes of smaller size than the maximum magnitude reported an expected maximum.

5.2.3 Seismogenic Source Behavior

Predicted probabilistic ground motions from seismogenic sources are based on magnitude rate distributions that reflect the recurrent production of earthquakes of certain sizes. Most probabilistic seismic hazard assessments are typically based on slip rate or less frequently, on the number of earthquakes during a specified interval of time, or recurrence rate. Slip rate is the amount of slip as a function of geologic time; seismogenic source models provide a range of variability in rake parallel slip rates, in mm/year.

Analyses of field observations provide estimates of single event slip, cumulative (multi event) slip, or both at a given location, which carry considerable and usually unrecognized uncertainty. In most studies, slip is typically observed (and thus, reported) as vertical or horizontal components of displacement because the dip and/or the rake of the fault at depth are poorly constrained by field studies. In addition, reported slip not only includes the sum of individual seismic events but also any aseismic slip on the fault (e.g., pre and/or post seismic slip and aseismic slip at the surface). These components of slip are not distinguishable in the geologic record and may be defined only under the most favorable conditions in conjunction with well studied modern earthquakes. Therefore, reported slip at a site includes considerable uncertainty due to inability to differ entiate the different sources of slip. However, mapping of off-set features in the days and months following historical events highlights an additional source of uncertainty due to the variability in the amount of displacement along strike, where ends of the surface rupture undergo less slip than the center of the rupture. In standard practice, data from one or a limited number of point observations commonly are accepted as representing some presumed average displacement along strike for the time frame under consideration.

Likewise, the time component of slip rate also is associated with large uncertainties. Geologic and paleoseismologic field data may span considerably different time frames. The historical record reaches back a few hundred years worldwide and on the millennial scale locally. Some paleoseismology studies address time frames that extend the record to tens of thousands of years through radiometric, luminescence, or other forms of dating.

Some geologic studies may address fault behavior on the scale of millions of years. Few (if any) faults have regularly repeating earthquakes with similar amounts of slip. Although some faults do show regularity or only modest variability in the timing of repeating earthquakes, other faults seem to have short bursts of activity (temporal cluster) following extremely long periods of inactivity, which appears to be especially true in stable continental regions (e.g., Crone et al. 1997).

These complications make it very difficult to access the "mean" behavior of a source from geologic data alone, much less the behavior to be expected in the next few decades.

Characterizing a seismogenic source becomes more challeng ing as time from the earthquake rupture increases. Therefore, assigned values for seismogenic sources in seismic hazard analysis inevitably have large intrinsic uncertainties.

5.3 Update of DISS sources for this report

The tables of the composite seismogenic sources, as designed in DISS 3.1.1, show the slip rate values as a range between a maximum and a minimum value calculated on the base of geological and geodynamic considerations and, where possible, on the base of the historical and instrumental seismicity.

Recently availability of oil exploration data, published in the Videpi project (acronym for "Visibilità dei dati afferenti all'attività di esplorazione petrolifera in Italia" http://unmig.sviluppoeconomico.gov.it/videpi/)http://unmig.sviluppoeconomico.gov.it/videpi/) by the Ministry of Economic Development, and other database of local institution (Regione Emilia Romagna and Regione Lombardia with ENI; R.E.R and ENI-AGIP, 1998, R.L. and ENI-AGIP 2002), allowed to study the buried structures of the Po Plain using new subsurface data.

The results of these studies are the object of INGV internal report, congress contribution and abstract (Maesano et al. 2011) and of scientific papers in preparation (Maesano et al., in preparation).

These results are used here to update the data relative to some DISS seismogenic sources that includes the compressive structures investigated by the Authors (Fig. 5.3).

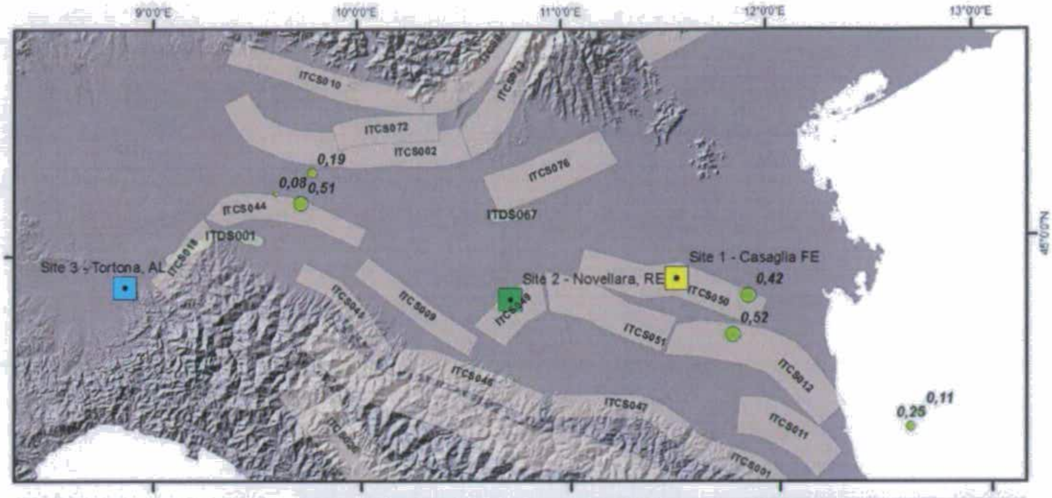
For the investigated structures it was possible to calculate the slip rate value in a portion of the fault using three dimensional modeling of the available data. The slip rate values were obtained from the restoration of the deformation (both due to differential sediment compaction and to faulting and/or folding of the horizons) observed on the geological horizon on the hangingwall and footwall of the structures.

The restoration process consider the structural styles observed in the fold and fault system and different algorithm were use on the base of the geological contest (fault propagation folds, fault parallel flow, trishear).

The slip values were calculated for the same structure, restoring geological horizon of different ages. Using these data it is possible to evaluate te variability of deformation rate during the Plio-Pleistocene.

These values do not reflect the deformation of the whole seismogenic sources and are valid only of the part of the fault considered in the three dimensional models, but they represent a contribution to the definition of the slip rates along the fault and to the reconstruction of the geological history of the sismogenic sources.

In particular, the seismogenic souces that can be updated using these new slip rate values are referred to the Northern Apennines buried thrust front, in the Emilia Arc and Ferrara Arc (ITCS044 Portalbera - Cremona, ITCS012 Malalbergo - Ravenna; ITCS050 Poggio Rusco - Migliarino).



ID	Dip par.	Lat	Lon	Age of marker	Age intervals	Authors	Year
ITCS044	0,03	45,2145	9,5983	Upper Pleistocene	0,00 - 0,45	Maesano et al.	2010
ITCS044	0,06	45,2145	9,5983	Middle Pleistocene	0,45 - 0,65	Maesano et al.	2010
ITCS044	0,09	45,2145	9,5983	Middle Pleistocene	0,65 - 0,85	Maesano et al.	2010
ITCS044	0.10	45.2145	9.5983	Lower Pleistocene	0.85 - 1.80	Maesano et al.	2010
ITCS044	0.71	45,2145	9,5983	Pliocene	1.80 - 5,30	Maesano et al.	2010
ITCS044	0,51	45.2017	9,7300	Pleistocene	0.00 - 1,80	Maesano et al.	2011
ITCS044	0,56	45,2017	9,7300	Lower Pleistocene	1,80 - 2,60	Maesano et al.	2011
ITCS044	0,25	45,2017	9,7300	Upper Pliocene	2,60 - 3,60	Maesano et al.	2011
ITCS012	0,52	44,5495	11,6931	Pleistocene	0,00 - 1,80	Maesano et al.	2011
ITCS012	0,41	44,5495	11,6931	Up.Pliocene - Low.Pleistoc.	1,80 - 3,60	Maesano et al.	2011
ITCS050	0,42	44,7404	11,7610	Pleistocene	0,00 - 1.80	Maesano et al.	2011

Figure 5.3: Distribution of slip rates (Maesano et al. in preparation.). The dataset includes point outside the seismogenic sources of the DISS database. The slip values immediately south of ITCS002 sources is referred to an external front of the Northern Apennines Emilia arc and is not related to the Southern Alps frontal thrusts. The two value offshore of Rimini are related to structural culmination that are not identified as seismogenic sources as difined in the present version of DISS

5.4 Criteria for the selection of the seismogenic sources of interest

The critera used to discriminate the seismogenic sources that will be described in the following sections are based on the available data on the three localities on which the SIGMA project mainly focuses. The three sites are placed in 3 different sector of the Apennines thrust front:

Site 1 – Casaglia (FE) is located in the Ferrara arc, in correspondence of a well known structural culmination and to an individual seismogenic sources of the DISS (Mirandola).

Site 2 – Novellara (RE) is located in zone of transition between the Ferrara and Emilia arc, in a sector where the thrust front is less propagated toward the external foreland areas.

Site 3 – Tortona (AL) is located in the western part of the Emilia arc.

The analysis of historical and instrumental seismicity shows that the localities inside the Po Plain also felt the effects of earthquakes with epicenter located outside the geographic and geological context of the Po Plain.

The tectonic contest in which the earthquakes with macroseismic effect in the three sites are generated can be distinguished in: i) compressive tectonic of the northern Apennines fronts, ii) compressive tectonics of the Western southern alps, iii) compressive and strike slip tectonics of the

Eastern southern Alps and Dinarides and, iv) extentional tectonics of the northern and central Apennines crest and Tyrrhenian limb.

The seismogenic sources described identified inside the Po Plain and describe in DISS are mainly referred to compressive structures pertaining the three structural arcs of the Apennines front observed at regional scale.

The seismogenic sources that will be described in the following section (Fig. 5.4) have been chosen using a buffer of 120 Km around the sites of the SIGMA project (Casaglia, Novellara, Tortona) with the aim to include all the principal earthquakes felt in each site. Moreover DISS compilers consider also the eastern seismogenic sources of the southern alps and dinarides that are outside the 120 Km buffer for the Casaglia sites but that are responsible of earthquakes with important macroseismc effects (up to Is=5) in the Ferrara area, and also, with less important effects, on the other sites.

As imaged by Figure 5.5, there are also earthquakes that were felt in the sites of interest despite their great epicentral distance (e.i. Avezzano, 1915; Irpirna, 1980). This fact can be explained with the great magnitude of these events or with their great hypocentral depth. In this case the macroseismic effect for these seismic events are negligible at the study sites and, for this reason, their relative seismogenic sources are not considered in this report.

Figure 5.4 shows the distribution of the seismogenic sources described in the following section and their identificative code in DISS.

The description of the seismogenic sources follows the subdivision of the main geo-tectonic features in the area:

- Western Alps sources
- Northern Apennines compressive sources
- Western Southern Alps Sources
- Eastern Southern Alps and Dinarides Sources
- Northern Apennines extentional sources

The description will be guided by the Composite Seismogenic Sources that allow to depict a general seismotectonic framework of the structures and, where available, the description will be completed with the associated Individual Seismogenic sources. A complete list of Individual, Composite and Debated seismogenic sources is provided in Tables 5.1, 5.2 and 5.3.

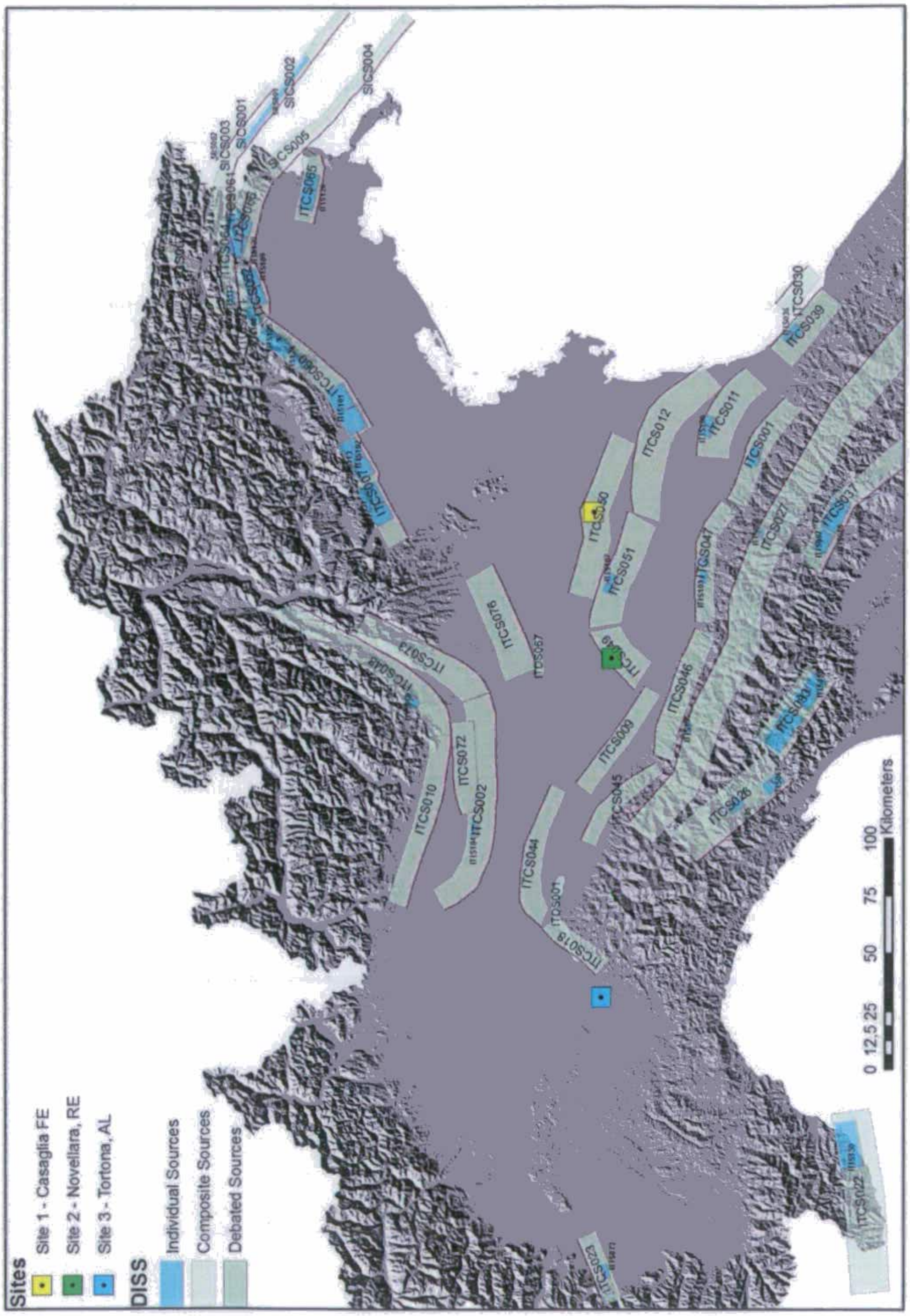


Figure 5.4: Composite, Individual and Debated seismogenic sources (DISS v.3.1.1) described in this report .

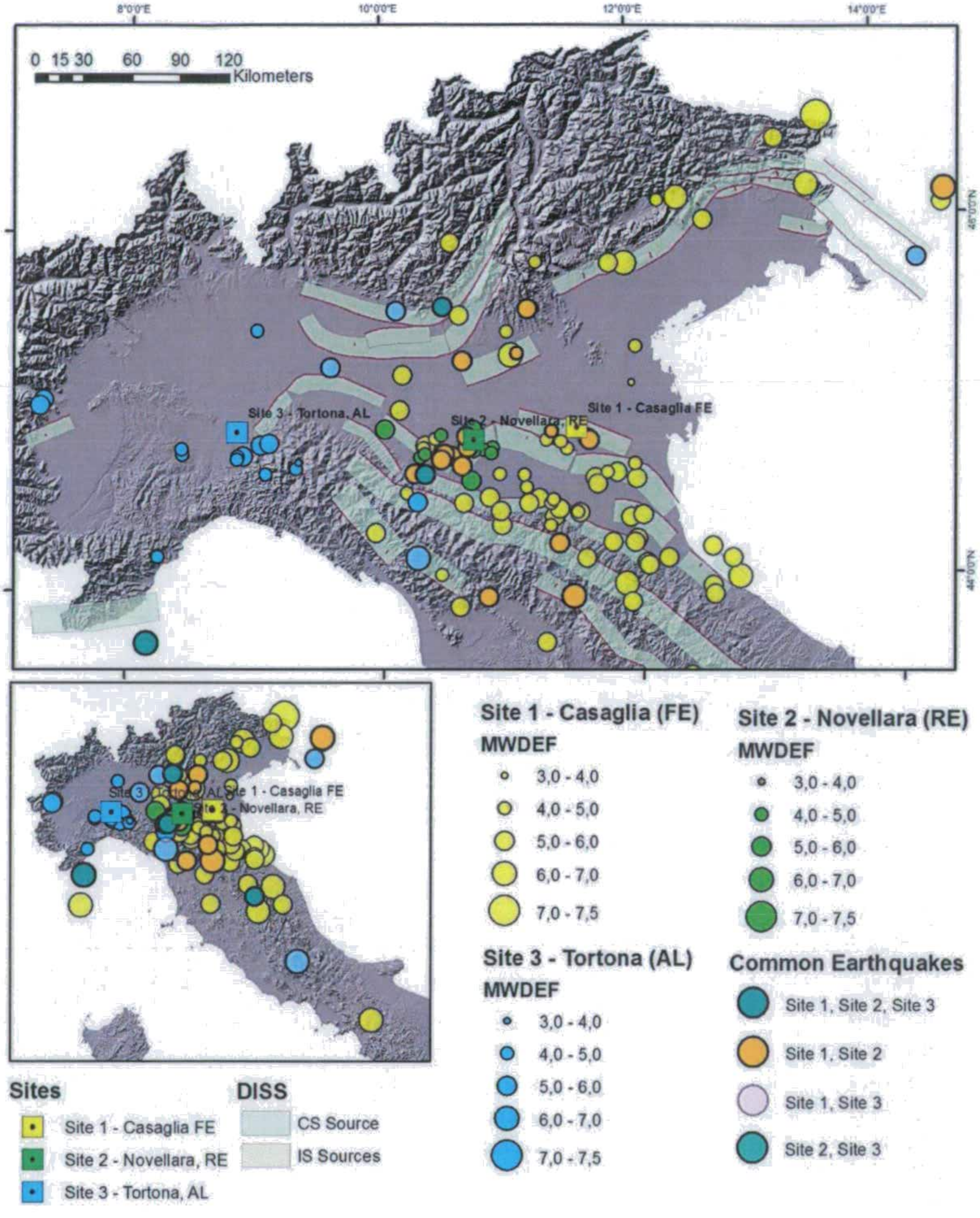


Figure 5.5: Historical earthquakes: epicentral location of events with effects on the three sites of investigation of the SIGMA project. Data from CPTI11 and DBMI11 databases.

DISS COMPOSITE SOURCES		
IDSOURCE	*SOURCENAME*	*Max M*
ITCS022	Imperia	6,3
ITCS023	Western Piemonte	5,7
ITCS027	Bore-Montefeltro-Fabriano-Laga	6,2
ITCS018	Rivanazzano-Stradella	5,5
ITCS044	Portalbera-Cremona	5,5
ITCS009	Busseto-Cavriago	5,6
ITCS045	San Giorgio Piacentino-Fornovo di Taro	5,5
ITCS046	Langhirano-Sassuolo	5,9
ITCS049	Reggio Emilia-Rolo	5,5
ITCS051	Novi-Poggio Renatico	5,9
ITCS012	Malalbergo-Ravenna	5,6
ITCS050	Poggio Rusco-Migliarino	5,5
ITCS047	Castelvetro di Modena-Castel San Pietro Terme	5,6
ITCS001	Castel San Pietro Terme-Meldola	5,8
ITCS011	Mordano-Guarniera	5,9
ITCS039	Riminese onshore	5,7
ITCS030	Riminese offshore	5,9
ITCS002	Western S-Alps external thrust	6,1
ITCS072	Capriano-Castenedolo back-thrust	6,1
ITCS010	Western S-Alps internal thrust	5,5
ITCS048	Giudicarie	5,7
ITCS073	Monte Baldo	5,5
ITCS076	Adige Plain	6,7
ITCS007	Thiene-Cornuda	6,6
ITCS060	Montebelluna-Montereale	6,5
ITCS071	Andreis-Forgaria nel Friuli	5,9
ITCS062	Maniago-Sequals	6,5
ITCS064	Tramonti-Montemaggiore	6,2
SICS003	Polovnik	5,5
ITCS067	But-Chiarso	5,8
ITCS066	Gemona-Tarcento	6,5
ITCS061	Trasaghis-Taipana	6,1
ITCS065	Medea	6,4
SICS001	Bovec-Tolminka Springs	5,8
SICS002	Tolmin-Idrija	6,8
SICS005	Cividale-Nova Gorica	5,5
SICS004	Branik-Ilirska Bistrica	5,5
ITCS026	Lunigiana	6,0
ITCS083	Garfagnana	6,4
ITCS037	Mugello-Citta' di Castello-Leonessa	6,2

Table 5.1: List of the Composite seismogenic sources described in paragraph 5.5. Max M is the maxima magnitude expected of the sources, the values derives from the maximum earthquake magnitude, from the greatest associated individual source or from the geometry (width) of the sources.

DISS INDIVIDUAL SOURCES			
Source ID	***Source Name***	***Latest EQ***	***MaxM***
ITIS033	Rimini offshore South	16 Aug 1916	5,6
ITIS034	Rimini offshore North	17 May 1916	5,7
ITIS035	Rimini	25 Dec 1786	5,6
ITIS036	Val Marecchia	17 Mar 1875	5,7
ITIS050	Garfagnana North	07 Sep 1920	6,4
ITIS051	Garfagnana South	Unknown	6,1
ITIS058	Loiano	14 Sep 2003	5,3
ITIS067	Aulla	05 May 1481	5,8
ITIS069	Sal_	30 Oct 1901	5,7
ITIS073	Pinerolo	16 Apr 1808	5,6
ITIS085	Pontremoli	14 Feb 1834	5,7
ITIS086	Mugello East	29 Jun 1919	6,2
ITIS087	Mugello West	13 Jun 1542	5,9
ITIS090	Ferrara	17 Nov 1570	5,5
ITIS091	Casalecchio di Reno	03 Jan 1505	5,5
ITIS093	Faenza	04 Apr 1781	5,8
ITIS100	Bagnacavallo	11 Apr 1688	5,9
ITIS101	Montello	Unknown	6,5
ITIS102	Bassano-Cornuda	25 Feb 1695	6,6
ITIS103	Crespellano	20 Apr 1929	5,6
ITIS104	Romanengo	12 May 1802	5,7
ITIS107	Mirandola	Unknown	5,9
ITIS108	Maniago	10 Jul 1776	5,9
ITIS109	Sequals	Unknown	6,5
ITIS112	Tramonti	07 Jun 1794	5,8
ITIS113	Monte Grappa	12 Jun 1836	5,5
ITIS119	Tarcento	11 Sep 1976	5,7
ITIS120	Gemona South	06 May 1976	6,5
ITIS121	Montenars	15 Sep 1976 (1/2)	6,0
ITIS122	Gemona East	15 Sep 1976 (2/2)	6,1
ITIS124	Cansiglio	18 Oct 1936	6,1
ITIS125	Polcenigo-Montereale	29 Jun 1873	6,4
ITIS126	Medea	Unknown	6,4
ITIS127	Thiene-Bassano	Unknown	6,6
ITIS130	Imperia	23 Feb 1887	6,3
ITIS135	Neviano degli Arduini	23 Dec 2008	5,4
SIIS001	Idrija	26 Mar 1511	6,8
SIIS002	Bovec-Krn	12 Apr 1998	5,7

Table 5.2: List of the Individual sources described in paragraph 5.5. Maxima magnitude are related to the associated earthquakes or from the geometry (width) of the sources.

DISS Debated seismogenic sources	
IDSOURCE	***SOURCENAME***
ITDS001	Broni-Stradella
ITDS067	Mantova Lakes

Table 5.3: List of the Debated sources described in paragraph 5.5.

5.5 Description of the seismogenic sources

Legend of the codes used in the tables of source parameters. Every parameter of each Individual Seismogenic Source or Composite Seismogenic Source is qualified according to the type of analyses that were doneused to determine it. The qualifiers are defined as follows:

- Literature Data (LD): data taken from studies published in scientific journals, Master or Ph D theses, and technical reports of research projects or internal reports of major research institutions or universities.
- Original Data (OD): unpublished original measurements and interpretations for the purposes of this Database.
- Empirical Relationship (ER): values derived from empirical relations such as those of moment magnitude vs. fault size (Wells and Coppersmith, 1994) or vs. seismic moment (Kanamori and Anderson, 1975; Hanks and Kanamori, 1979).
- Analytical Relationship (AR): values derived from simple equations relating the geometric properties of a rectangular fault plane or the equation relating seismic moment with rigidity, fault area, and average displacement.
- Expert Judgment (EJ): assignments made by the compiler on the basis tectonic information or established knowledge at a scale broader than that of the seismogenic source under consideration.

5.5.1 Seismogenic sources of the Western Alps

The western Alpine Arc is a rather complex structure which was initiated during convergence and collision more than 35 Myr ago, when the Adriatic micro-plate, moving northwards with respect to the European foreland, caused sinistral transpression in the Western Alps The complexity of this sector and the relationship with the adjacent structures are confirmed by the geophysical data, which highlight a sharp change of the stress regime between the chain, undergoing an extensional-to-transtensive regime, and the westernmost Po Plain, where a transpressive regime is present (Perrone et al., 2011). For the Alps, compression is observed at the borders of the belt, in particular at the border of the Po plain, with a globally E-W direction, and along with the Provence and Ligurian area with a N-S direction to the east and NE-SW to the west (Delacou et al., 2008).

ITCS 022 – Imperia

Code			ITCS022
Name			Imperia
Compiled By			Fracassi, U., and S. Mariano
Latest Update			03/08/2006
	Parameter	Qual.	Evidence
Min Depth (km)	3	LD	Based on instrumental seismicity data.
Max Depth (km)	10	LD	Based on instrumental seismicity data.
Strike (deg)	250 - 270	OD	Based on regional geological data.
Dip (deg)	25 - 35	EJ	Inferred from regional geological data.
Rake (deg)	80 - 100	EJ	Inferred from regional geological data.
Slip Rate (mm/y)	0.1 - 1	EJ	Unknown, values assumed from geodynamic constraints.
Max Magnitude (Mw)	6.3	OD	Derived from maximum magnitude of associated individual source(s).

This composite source straddles the region across the Italy – France border on the Ligurian seaboard. It belongs to the S-verging, Imperia reverse fault system in western Liguria.

Historical and instrumental catalogues (Boschi et al., 2000; Gruppo di Lavoro CPTI, 2004; Pondrelli et al., 2006; Guidoboni et al., 2007) show a number of intermediate (4.5 < Mw 5.0) to damaging earthquakes surrounding the area, but also the key damaging events of (from west to east): 29 December 1854 (Mw 5.8), 26 May 1831 (Mw 5.5), 23 February 1818 (Mw 5.5) and the destructive 23 February 1887 (Mw 6.3, Liguria occidentale) earthquakes. The latter event was accompanied by a sizeable tsunami.

The tectonic activity of this region is still not clearly documented but a plausible interpretation is that it is a large, S-verging reverse fault system. Various evidence suggest that the area is undergoing N-S to NW-SE trending compression, including earthquake focal mechanisms all along the onshore/offshore front (see: Bethoux et al., 1992; Courboulex et al., 1998).

A segment of this source has been associated with the 1887 earthquake. For an in-depth analysis of seismogenesis in this region, the reader can refer to the individual source.

The strike of the source was based on that of the mapped regional structures (N250°-270°). The dip was based on subsurface data and geometrical considerations (25°-35°). The rake is assumed to represent pure thrusting, based on geological observations (80-100). The minimum and maximum depth were based on subsurface data and on geometrical considerations concerning the thrust geometry (3.0 and 10.0 km, respectively). The slip rate was inferred from geological observations in adjacent structures that share the same tectonic environment with the Imperia source (0.1 – 1.0 mm/y). The maximum magnitude was taken from that of the largest individual source associated (Mw 6.3).

Associated Individual Seismogenic Source(s)

ITIS130 Imperia

Code	ITIS130
Name	Imperia

Compiled By	Valensise, G.		
Latest Update	21/05/2009		
	Parameter	Qual.	Evidence
Location (Lat/Lon)	43.925 / 8.07147	LD	Primarily based on the location of the associated historical earthquake.
Length (km)	20.3	ER	Calculated using the relationships from Wells and Coppersmith (1994).
Width (km)	10.6	ER	Calculated using the relationships from Wells and Coppersmith (1994).
Min Depth (km)	3	EJ	Inferred from regional crustal structure and seismicity.
Max Depth (km)	8.3	EJ	Inferred from regional crustal structure and seismicity.
Strike (deg)	259	EJ	Inferred from regional stress field derived from focal mechanisms.
Dip (deg)	30	EJ	Inferred from regional stress field derived from focal mechanisms.
Rake (deg)	90	EJ	Inferred from regional stress field derived from focal mechanisms.
Slip Per Event (m)	0.53	ER	Calculated from Mo using the relationship from Hanks and Kanamori (1979).
Slip Rate (mm/y)	0.1 - 0.5	EJ	Unknown, values assumed from geodynamic constraints.
Recurrence (y)	1060 - 5300	EJ	Inferred from slip rate and average displacement.
Magnitude (Mw)	6.3	LD	Value adopted from the historical earthquake catalogue CPTI04.

In the past, the 1887 earthquake has been believed to have occurred 10-20 km off the coast of Imperia. The Catalogue of Strong Earthquakes in Italy (Boschi et al., 1997) and the Parametrical Catalogue of Italian Earthquakes (Gruppo di Lavoro CPTI, 1999) first locate the event beneath the coast a few km E of Imperia. This is partially due to the fact that higher intensities in fact concentrate in a relatively small area around Imperia, and partially to the fact that the automatic location procedure used in both catalogues tends to force offshore earthquakes towards inland. An inland source is also suggested by the comparison of the size and intensity level of the highest degree isoseismal (intensity IX) with the size of lower degree isoseismals. An offshore source would require a larger magnitude than that calculated for CPTI (Me 6.3), which in turn should be reflected in a larger propagation of the intermediate level intensities. An offshore source would also require that all intensity IX data points be interpreted as site amplification effects, which is unlikely given their number and diversity of the associated site conditions.

Little is known about the kinematics of this source, except for the substantial dip-slip component required by the occurrence of a sizeable tsunami. Eva and Rabinovich (1997) model the tsunami data with a normal fault located offshore but do not discuss the reasons for this choice. The regional stress field that can be inferred from background seismicity is purely compressional with a largest principal stress oriented N-S to NW-SE (e.g. the 21 April 1995, Ventimiglia earthquake). A similar trend is also suggested by the general plate motions in this reach of the Alps/Apennines system.

Evidence for cumulative tectonic deformation is also very limited. No evident uplift is reported along the coast. Given the magnitude of the 1887 earthquake, however, and the fact that similar events must be rare (recurrence interval > 1,000 y), the inferable rate of coseismic uplift would be extremely low and possibly unresolvable.

OPEN QUESTIONS

1) All the hypotheses made about the essential parameters of this source remain essentially unwarranted. Is the source really inland? Is the causative fault of the 1887 earthquake purely reverse?

2) Is there any geological evidence of sustained activity along this fault?

3) Does the fault terminate against one of the many roughly N-S transverse features that cut the western Ligurian coast at nearly right angles?

4) Does this source coincide with an especially strong fault zone (asperity), or are similar events likely to occur all along western Liguria and across the border with France?

5.5.2 Seismogenic sources of the southwestern Alps

The Lombardian plain is a region characterized by crustal strain rate from low to moderate and therefore presents a lower number of significant seismic events (CPTI Working Group 2004). These types of seismic energy release, together with the scarce evidences of seismic structures, make the evaluation of the seismic hazard of the region poorly constrained. Though the Italian seismic catalogues can be considered complete fot the last 700-1000 years for the higher magnitude events, the low deformation rates of this region allow to suppose a recurrence time of more than 1000 years for the single structures. As a consequence, the seismic catalogues can be considered as constraint for all the seismic sources of this area, but only for the ones with a significant seismic activity in the historical period included in the catalogues.

The seismic activity of this area is due to blind faults for which it is impossible – or highly difficult - to perform paleoseismic analyses.

ITCS002 Western S-Alps external thrust

Code	**ITCS002**		
Name	Western S-Alps external thrust		
Compiled By	Burrato, P.		
Latest Update	19/04/2010		
	Parameter	**Qual.**	**Evidence**
Min Depth (km)	2	OD	Based on geological and geophysical data from various authors.
Max Depth (km)	9	OD	Based on geological and geophysical data from various authors.
Strike (deg)	230 - 340	OD	Based on geological data from various authors.
Dip (deg)	25 - 40	OD	Based on geological data from various authors.
Rake (deg)	80 - 100	EJ	Inferred from geological data.
Slip Rate (mm/y)	0.1 - 0.5	EJ	Derived from geological data concerning adjacent structures.
Max Magnitude (Mw)	6.1	OD	Based on the strongest earthquake occurred in the region.

This composite source straddles the region between the cities of Milano (to the west) and Brescia (to the east) and belongs to the Southern Alpine Lombardian thrust system. This front is a S-verging external arc, the southernmost compressional fault system of the Alps.

Current catalogues (Boschi et al., 2000; Gruppo di Lavoro CPTI, 2004; Pondrelli et al., 2006; Guidoboni et al., 2007) show a sparse distribution of minor seismicity in this region, but for one key earthquake that has occurred on 12 May 1802 (Mw 5.9) in the Oglio R. valley (Brega et al., 1985; Burrato et al., 2003; Albini and Rovida, 2010). One more destructive earthquake (Mw 6.1) that has occurred on 25 December 1222 (Magri and Molin, 1986; Guidoboni and Comastri, 2005) can be associated with this source or to a N-verging backthrust.

This Source is a S-verging blind thrust fault, as indicated by subsurface data (Cassano et al., 1986; Pieri and Groppi, 1981), whose surface expression remains unclear or feeble. A segment of this Source has been associated to the 1802 earthquake. For an in-depth analysis of seismogenesis in this region, the reader can refer to the individual source.

The strike was taken from the general orientation of mapped tectonic structures (N230°-340°). The dip was taken from subsurface evidence of the thrust plane (25°-40°). The rake was assumed to represent pure thrusting, based on general geodynamic considerations (80°-100°). The minimum and maximum depth were based on subsurface geology and on the uncertainty concerning the depth at which active thrusting is rooted (3.0 and 9.0 km, respectively). The slip rate was inferred from regional geodynamic data (0.1 – 0.5 mm/y). Maximum magnitude was taken from that of the largest individual source associated.

Associated Individual Seismogenic Source(s)

ITIS104 Romanengo

Code	**ITIS104**
Name	Romanengo
Compiled By	Burrato, P.
Latest Update	19/04/2010

	Parameter	Qual.	Evidence
Location (Lat/Lon)	45.3889 / 9.7934	OD	Based on macroseismic, geological and geomorphological data.
Length (km)	6.5	OD	Based on geological and geomorphological observations.
Width (km)	4.7	OD	Based on geological and geomorphological observations.
Min Depth (km)	2.5	OD	Based on geological and geomorphological observations.
Max Depth (km)	5.8	AR	Derived from dip, width and min depth, constrained by subsurface geology.
Strike (deg)	275	OD	Based on geological and geomorphological observations.
Dip (deg)	45	OD	Based on geological and geomorphological observations.
Rake (deg)	90	EJ	Inferred from geological data, constrained by orientation of T axes.
Slip Per Event (m)	0.5	ER	Calculated from Mo using the relationship from Hanks and Kanamori (1979).
Slip Rate (mm/y)	0.1 - 0.5	EJ	Unknown, values assumed from geodynamic constraints.
Recurrence (y)	1000 – 5000	AR	Calculated from slip rate and average displacement.
Magnitude (Mw)	5.7	LD	Value adopted from the historical earthquake catalogue CPTI04.

Associated earthquake		
Latest Eq	12 May 1802	CPTI04.
Penultimate Eq	Unknown	See "Commentary" for information.
Elapsed Time	198	As of year 2000 (assigned datum).

The occurrence of the Mw 5.7 1802 earthquake sheds light on the activity and seismogenic potential of the Southern Alps thrust fronts buried in the Po Plain to the south-west of the Garda Lake. This portion of the plain is characterized by a low seismic release if compared to areas located more to the east and north-east that were hit by important historical events like the Mw 6.5 1117 Veronese, the Mw 6.1 1222 Basso Bresciano and the Mw 5.7 1901 Salò earthquakes. The location and geometry of the 1802 seismogenic source is based on geomorphological observations provided by several investigators, on the analysis of the subsurface data provided by the oil industry (e.g. Cassano et al., 1986; Pieri and Groppi, 1981) and on the study of the intensity macroseismic field that constrain the position of the thrust activated during the earthquake.

The 1802 seismogenic source has the following geometrical characteristics:

- the strike is chosen according with the general orientation of mapped buried tectonic structures (N275°);

- the fault dips 45° towards the North, in agreement with subsurface evidence and based on the characteristic distance between the synclinal and anticlinal axes;

- the rake is assumed to be 90° (pure thrusting) based on strike and on general geodynamic considerations;

- the down-dip width (4.7 km) is based on the characteristic distance between the synclinal and anticlinal axes and on the assumptions made concerning the minimum and maximum faulting depth;
- the minimum and maximum depth (2.5 and 5.8 km respectively) are constrained by subsurface geology, by the symmetry of the anticline and by the general aspect-ratio of the anticline-syncline pair;
- the length (6.5 km) is scaled using empirical relationships with the Mw of the associated earthquake.

Current catalogues (CPTI04, 2004) report a large event in 1802 (Mw 5.7) that falls in the upper Oglio River valley. This is the only event that can be associated with the source. Calculations made with the Boxer method proposed by Gasperini et al. (1999) obtained a source slightly smaller than that proposed on the basis of geological and geomorphological observations alone, and located few km to the north. However the strike of the two sources is the same, and is in agreement with that of the local tectonic structures.

This source belongs to the Lombardian thrust system, the southernmost compressional front of the Alps.

Boschi et al. [1997] report that the water flow of the Oglio River in the Soncino area stopped for a while after the earthquake. This account is consistent with sudden coseismic uplift of the anticline and subsidence of the syncline driven by the blind thrust fault.

The Romanengo Source is developed in the subsurface, but has no clear geomorphic expression. To the south of the source, the presence of the Casalmorano paleo-channel south of the diversion of the Oglio River may be the geomorphic evidence of the long-term deformation produced by the outermost Southalpine thrust.

OPEN QUESTIONS

1) What is the average return time of the Romanengo Source? Current catalogues (CPTI04, 2004) which cover a time span of about 2,000 years, report only a large event in 1802 that could be associated with the Romanengo Source.

2) What is the seismic behaviour of the Romanengo Source? Does it rupture only with events in the magnitude range 5.5-6.0, or it can generate also larger rather infrequent events?

3) The occurrence of the 1802 earthquake highlight the activity and seismogenic potential of the Southern Alps thrust system, can nearby individual thrusts generate similarly large events in the future?

ITCS072 Capriano - Castenedolo backthrust

Code	**ITCS072**		
Name	Capriano-Castenedolo back-thrust		
Compiled By	Burrato, P.		
Latest Update	19/04/2010		
	Parameter	**Qual.**	**Evidence**
Min Depth (km)	1	LD	Based on geological data from Livio et al. (2009).
Max Depth (km)	7	LD	Based on geological data from Livio et al. (2009).
Strike (deg)	70 - 100	LD	Based on geological data from Livio et al. (2009).
Dip (deg)	30 - 45	LD	Based on geological data from Livio et al. (2009).
Rake (deg)	80 - 100	EJ	Inferred from geological data.
Slip Rate (mm/y)	0.1 - 0.5	EJ	Derived from geological data concerning adjacent structures.
Max Magnitude (Mw)	6.1	LD	Based on data from Livio et al. (2009).

This composite source is a N-verging backthrust of the southernmost and most external, S-verging thrust front of the Southern Alpine Lombardian thrust system. This source straddles a region located south-west of the Garda Lake, where early works by Desio (1965) identified isolated hills in the plain that were interpreted as anticlines related to buried compressional structures (Castenedolo, Ciliverghe and Capriano del Colle hills).

Current catalogues (Boschi et al., 2000; Gruppo di Lavoro CPTI, 2004; Pondrelli et al., 2006; Guidoboni et al., 2007) show a sparse distribution of minor seismicity in this region, but for one key earthquake that has occurred on 12 May 1802 (Mw 5.9) in the Oglio R. valley (Brega et al., 1985; Burrato et al., 2003; Albini and Rovida, 2010) along the western segment of the S-verging thrust front. One more destructive earthquake (Mw 6.1) that has occurred on 25 December 1222 (Magri and Molin, 1986; Guidoboni and Comastri, 2005; Livio et al., 2009) could be associated with this source or to the S-verging thrust.

A quarry at Capriano del Colle provided a surface exposure of secondary structures related to the backthrust with evidence of coseismic surface faulting and liquefaction near the core of an active mid-Pleistocene to Holocene anticline (Livio et al., 2009).

The strike was taken from the general orientation of mapped tectonic structures (N70°-100°). The dip was taken from subsurface evidence of the thrust plane (30°-45°). The rake was assumed to represent pure thrusting, based on general geodynamic considerations (80°-100°). The minimum and maximum depth were based on subsurface geology and on the uncertainty concerning the depth at which active thrusting is rooted (1.0 and 7.0 km, respectively). The slip rate was inferred from regional geodynamic data (0.1 – 0.5 mm/y).

ITCS010 Western S-Alps internal thrust

Code	**ITCS010**		
Name	Western S-Alps internal thrust		
Compiled By	Burrato, P.		
Latest Update	19/04/2010		
	Parameter	**Qual.**	**Evidence**
Min Depth (km)	5	OD	Based on geological data from various authors.
Max Depth (km)	10	OD	Based on geological data from various authors.
Strike (deg)	265 - 295	OD	Based on geological data from various authors.
Dip (deg)	25 - 45	OD	Based on geological data from various authors.
Rake (deg)	80 - 100	EJ	Inferred from geological data.
Slip Rate (mm/y)	0.1 - 0.5	EJ	Derived from geological data concerning adjacent structures.
Max Magnitude (Mw)	5.5	EJ	Assigned on the basis of conservative criteria.

This composite source straddles the region west of the Garda Lake between the cities of Brescia (to the east) and Bergamo (to the west) and belongs to an internal thrust front of the Southern Alpine Giudicarie thrust system. This front locally is a S-verging internal arc, a ramp of the southernmost compressional fault systems of the Alps.

Historical and instrumental catalogues (Boschi et al., 2000; Gruppo di Lavoro CPTI, 2004; Pondrelli et al., 2006; Guidoboni et al., 2007) show only a scattered distribution of intermediate seismicity along-strike of the thrust front. In particular the historical catalogues list events having magnitude in the range of Mw 4.6 to 5.0, which may have been generated by seismogenic sources belonging to this composite source.

However, a key earthquake to understand the seismic potential of the structures belonging to the Giudicarie thrust system has occurred on 30 October 1901 (Mw 5.7, Salò) east of this composite souce and along the NE-trending segment of the front. It was followed, about one century later and virtually in the same area, by a further event on 24 November 2004 (Mw 5.2). One more destructive earthquake has occurred to the east of this source on 3 January 1117 (Mw 6.6, Veronese) (Magri and Molin, 1986; Guidoboni and Comastri, 2005).

This Source is a S-verging blind thrust fault, thought to be an active ramp of the Giudicarie fault system. The overall role and geometry of this source is based on regional geological and subsurface geophysical data (cf. Cavallin et al., 1988; Castaldini and Panizza, 1991).

The strike was taken from the general orientation of mapped tectonic structures (N265°-N295°). The dip was inferred from regional geological consideration concerning the thrust plane (25°-45°). The rake was assumed to represent pure thrusting, based on general geodynamic considerations (80°-100°). The minimum and maximum depth were based on subsurface geology and on the uncertainty concerning the depth at which active thrusting is rooted (5.0 and 10.0 km, respectively). The slip rate was inferred from regional geodynamic data (0.1 – 0.5 mm/y). The maximum magnitude was conservatively inferred from regional seismological considerations (Mw 5.5).

ITCS048 Giudicarie

Code	**ITCS048**		
Name	Giudicarie		
Compiled By	Burrato, P.		
Latest Update	19/04/2010		
	Parameter	**Qual.**	**Evidence**
Min Depth (km)	5	OD	Based on geological and seismological data.
Max Depth (km)	10	OD	Based on geological and seismological data.
Strike (deg)	205 - 265	OD	Based on geological and seismological data.
Dip (deg)	25 - 45	OD	Based on geological and seismological data.
Rake (deg)	70 - 100	EJ	Inferred from geological and seismological data.
Slip Rate (mm/y)	0.1 - 0.5	EJ	Derived from geological data concerning adjacent structures.
Max Magnitude (Mw)	5.7	OD	Derived from maximum magnitude of associated individual source(s).

This composite source straddles the region between the cities of Salò (to the southwest) and Trento (to the northeast) and belongs to the Southern Alpine Giudicarie thrust system. This front is a S-to SE-verging external arc, a ramp of the southernmost compressional fault system of the Alps.

Historical and instrumental catalogues (Boschi et al., 2000; Gruppo di Lavoro CPTI, 2004; Pondrelli et al., 2006; Guidoboni et al., 2007) show a scattered but significant distribution of intermediate seismicity (Mw ca. 4) along-strike in the central sector of this region, up to the high Sarca R. valley. Moreover, a key earthquake has occurred on 30 October 1901 (Mw 5.7, Salò), followed, about one century later and virtually in the same area, by a further event on 24 November 2004 (Mw 5.2). One more destructive earthquake has occurred to the southeast of this source on 3 January 1117 (Mw 6.6, Veronese) (Magri and Molin, 1986; Guidoboni and Comastri, 2005).

This Source is a SE-verging blind thrust fault, thought to be an active ramp of the Giudicarie fault system. The overall role and geometry of this source is based on regional geological data (cf. Cavallin et al., 1988; Castaldini and Panizza, 1991).

A segment of this Source has been associated with the 1901 Salò earthquake. For an in-depth analysis of seismogenesis in this region, the reader can refer to the individual source.

The strike was taken from the general orientation of mapped tectonic structures and augmented by instrumental parameters of the 2004 Salò earthquakes (N205°-N265°). The dip was inferred from regional geological consideration concerning the thrust plane (25°-45°). The rake was assumed to represent pure thrusting, based on general geodynamic considerations (70°-100°). The minimum and maximum depth were based on subsurface geology, focal depth of the 2004 Salò earthquake and on the uncertainty concerning the depth at which active thrusting is rooted (5.0 and 10.0 km, respectively). The slip rate was inferred from regional geodynamic data (0.1 – 0.5 mm/y). Maximum magnitude was taken from that of the largest individual source associated (Mw 5.7).

Associated Individual Seismogenic Source(s)

ITIS069 Salò

Code	**ITIS069**

Name	Salò		
Compiled By	Burrato, P., and P. Vannoli		
Latest Update	02/12/2005		
	Parameter	**Qual.**	**Evidence**
Location (Lat/Lon)	45.634 / 10.5135	OD	Based on macroseismic, geological and geomorphological data.
Length (km)	7	ER	Calculated using the relationships from Wells and Coppersmith (1994).
Width (km)	5	ER	Calculated using the relationships from Wells and Coppersmith (1994).
Min Depth (km)	6.5	OD	Based on geological and geomorphological observations.
Max Depth (km)	9	AR	Derived from dip, width and min depth, constrained by subsurface geology.
Strike (deg)	231	OD	Based on geological and seismological data.
Dip (deg)	30	OD	Based on geological and seismological data.
Rake (deg)	90	OD	Based on regional geological data.
Slip Per Event (m)	0.35	ER	Calculated from Mo using the relationship from Hanks and Kanamori (1979).
Slip Rate (mm/y)	0.1 - 0.5	EJ	Unknown, values assumed from geodynamic constraints.
Recurrence (y)	700 - 3500	AR	Calculated from slip rate and average displacement.
Magnitude (Mw)	5.7	LD	Value adopted from the historical earthquake catalogue CPTI04.

Associated earthquake		
Latest Eq	30 Oct 1901	CPTI04.
Penultimate Eq	Unknown	See "Commentary" for information.
Elapsed Time	99	As of year 2000 (assigned datum).

The Salò Source is included in the Database as a 7 km-long, N231-striking, NW-dipping blind thrust fault. DISS compilers propose that this source is on a deep ramp of the Giudicarie fault system.

The geometry and kinematics of the source were chosen following regional geological and geodynamic considerations.

This source is associated to the 30 October 1901, M 5.7 Salò earthquake. A recent M 5.2 thrust faulting earthquake, occurred on 24 November 2004 few km north of the Salò Source. The focal solution of this event further constrained the parameters of the 1901 earthquake seismogenic source.

The depth of the Salò Source, besides being constrained by the hypocentral depth of the 2004 earthquake (8 km of depth), was chosen following an analysis of the felt reports of the 1901 earthquake. This was characterised by a wide damage area, with maximum intensities of VIII MCS at the town of Salò, typical of deep focus eartquakes. With this geometrical configuration the Salò thrust fault would connect with the shallow thrusts of the Monte Baldo ridge.

West of the Salò Source, the lateral continuity of the active thrust front can be inferred from geomorphic and seismological evidences: 1) south of Brescia, in the epicentral area of the 1222 M 6.2 earthquake, the LGM aggradation surface is deformed and the Castenedolo and Ciliverghe hills may represent the surfacem expression of a shallow thrust ramp; 2) more westward, the Orzinuovi Source, responsible for the M 5.6, 12 May 1802 earthquake, controls locally the drainage pattern (Burrato et al. [2003]).

OPEN QUESTIONS

1) What are the structural relationships between the Salò Source and the more surficial thrust ramps emerging along the Monte Baldo ridge?

2) Is the deep portion of the Monte Baldo thrust seismogenic as well (as already proposed by Galadini et al. [2001])?

3) How does this thrust front continue towards the SW? Is it connected with the structures responsible for the recent uplift of the Castenedolo and Ciliverghe hills south of Brescia?

ITCS073 Monte Baldo

Code	**ITCS073**		
Name	Monte Baldo		
Compiled By	Burrato, P.		
Latest Update	19/04/2010		
	Parameter	**Qual.**	**Evidence**
Min Depth (km)	3	OD	Based on geological data from various authors.
Max Depth (km)	9	OD	Based on geological data from various authors.
Strike (deg)	200 - 250	OD	Based on geological data from various authors.
Dip (deg)	25 - 45	OD	Based on geological data from various authors.
Rake (deg)	70 - 100	EJ	Inferred from geological data.
Slip Rate (mm/y)	0.1 - 0.5	EJ	Derived from geological data concerning adjacent structures.
Max Magnitude (Mw)	5.5	OD	Assigned on the basis of conservative criteria.

This composite source straddles the region east of the Garda Lake and belongs to the most external thrust front of the Southern Alpine Giudicarie thrust system. This front is a S-to SE-verging external arc, a ramp of the southernmost compressional fault system of the Alps.

Historical and instrumental catalogues (Boschi et al., 2000; Gruppo di Lavoro CPTI, 2004; Pondrelli et al., 2006; Guidoboni et al., 2007) show a scattered but significant distribution of intermediate seismicity along-strike in the central and northern sector of this region, along the Monte Baldo ridge. In particular the historical catalogues list 9 events occurred during the XIX and XX century having magnitude in the range of Mw 4.6 to 5.2, which may have been generated by seismogenic sources belonging to this composite source.

This Source is a SE-verging blind thrust fault, thought to be an active ramp of the Giudicarie fault system. The overall role and geometry of this source is based on regional geological data (cf. Cavallin et al., 1988; Castaldini and Panizza, 1991).

The strike was taken from the general orientation of mapped tectonic structures (N200°-N250°). The dip was inferred from regional geological consideration concerning the thrust plane (25°-45°). The rake was assumed to represent pure thrusting, based on general geodynamic considerations (70°-100°). The minimum and maximum depth were based on subsurface geology and on the uncertainty concerning the depth at which active thrusting is rooted (3.0 and 9.0 km, respectively). The slip rate was inferred from regional geodynamic data (0.1 – 0.5 mm/y). The maximum magnitude was conservatively inferred from regional seismological considerations (Mw 5.5).

ITCS076 Adige Plain

Code	**ITCS076**		
Name	Adige Plain		
Compiled By	Burrato, P.		
Latest Update	20/04/2010		
	Parameter	**Qual.**	**Evidence**
Min Depth (km)	2	OD	Based on geological and geomorphological data.
Max Depth (km)	10	OD	Based on geological and geomorphological data.
Strike (deg)	240 - 260	OD	Based on geological and geomorphological data.
Dip (deg)	20 - 40	OD	Based on geological and geomorphological data.
Rake (deg)	80 - 100	EJ	Inferred from geological data.
Slip Rate (mm/y)	0.1 - 0.5	EJ	Derived from geological data concerning adjacent structures.
Max Magnitude (Mw)	6.7	OD	Based on the strongest earthquake occurred in the region.

This composite source is located in the Adige Plain south of the city of Verona. It is interpreted to belongs to the most external thrust front of the Southern Alpine Giudicarie thrust system, and it is buried in the plain. However, this source does not follow any previously mapped structural trend, and as such is an hypothesis based on the occurrence of the 3 January 1117 Veronese earthquake.

Historical and instrumental catalogues (Boschi et al., 2000; Gruppo di Lavoro CPTI, 2004; Pondrelli et al., 2006; Guidoboni et al., 2007) show that this area is characterized by a scattered distribution of low magnitude events, apart from the 1117 key earthquake (Guidoboni et al., 2005).

The source of the 1117 earthquake was hypothesized to be either a segment of the Eastern Southalpine Chain in the Veneto plain, east of the Lessini Mts. (Thiene segment, Galadini et al., 2005) or on a blind thrust of the Northern Apennines chain near Cremona (Galli, 2005).

The most updated macroseismic intensity field of this event clearly show that the most damaged area was in the Adige plain south of the town of Verona (Guidoboni et al., 2005). This is considered a clear indication that the seismogenic source of the 1117 earthquake must be located in that area and can not be elsewhere. However, this hypothesis is in contrast with the lack of any geophysical and/or geological evidence of the presence of compressional structures buried in the plain south of Verona. As a matter of fact, all the geophysical and structural studies published so far show that the epicentral area of the 1117 earthquake is an undeformed, or slightly deformed, S-dipping monocline in the foreland of both Southalpine and Northern Apennines chains.

In this framework, the location and geometry of this composite source is based on a detailed study of the morphology and drainage pattern of the portion of the Adige plain coincident with the macroseismic epicentral area of the 1117 earthquake. This study (Burrato, P. and G. Valensise, in preparation) highlighted the occurence of drainage and topographic anomalies compatible with the presence of a buried thrust inducing vertical relative motions. The best fitting thrust fault derived from modeling of the anomalies happens to coincide with a buried structure seen in seismic exploration lines. This Source is a SE-verging blind thrust fault, thought to be an active ramp of the Giudicarie fault system.

The strike was taken from modeling of the topographic and drainage anomalies, however it is in agreement with the general orientation of mapped tectonic structures (N240°-N260°). The dip was also inferred from the modeling and agrees with regional geological consideration concerning the thrust plane (20°-40°). The rake was assumed to represent pure thrusting, based on general geodynamic considerations (80°-100°). The minimum and maximum depth were based on the modeling, on subsurface geology and on the uncertainty concerning the depth at which active thrusting is rooted (2.0 and 10.0 km, respectively). The slip rate was inferred from regional geodynamic data (0.1 – 0.5 mm/y). Maximum magnitude was taken from that of the largest earthquake occurred within this source.

Associated Debated Seismogenic Source(s)

ITDS067 Mantova lakes

The existence of an active fault was first proposed by Baraldi et al. (1980). De Martini et al. (1998) and Burrato et al. (2003) constrained the geometry of the hypothesized seismogenic source using geomorphological evidence and geodetic data.

5.5.3 Seismogenic sources of the southeastern Alps and Dinarides

The Eastern Southern Alps and Northern Dinarides have long been known as being characterized by a compressional stress field due to the convergence between the Adriatic and the European plates. This area has intermediate to strong earthquakes that have caused severe damage even in the recent past (e.g., 6 May 1976, Friuli, Mw 6.4; 12 April 1998, Bovec-Krn, Mw 5.7); local geological studies have already addressed several active faults (e.g. Aoudia et al., 2000; Benedetti et al., 2000; Zanferrari et al., 2003;Fitzko et al., 2005). Recent studies have brought together an internally consistent regional seismotectonic picture of low-angle north-dipping thrusts at the Southern Alps piedmont and high-angle dextral strike slip faults in the Northern Dinarides with interspersed seismically quiescent faults (Galadini et al., 2005; Burrato et al., 2008).

The domain of active strike-slip deformation in NW and W Slovenia is positioned between the S vergent thrust domain in the Friuli area of NE Italy and SW thrusting domain of the Dinarides. Earthquake and geology data in NE Italy indicate that the prevailing mechanism of deformation is thrusting on E-W oriented planes whereas dextral-reverse and purely dextral strike-slip displacements on NNW-SSE oriented planes occur further E and SE. The prevailing fault orientation in the Dinarides is in the orogen-parallel NW-SE direction. Earthquakes and geologic data along these faults exhibit thrust focal mechanisms in the southern and central parts of the Dinarides, and dextral-reverse mechanisms in the northern Dinarides.

The Friuli area marks the inception of a very complex fault system, both along-strike and in depth, called to explain several destructive earthquakes, remarkably concentrated in the border region between Italy and Slovenia, including the well known 1976 Friuli seismic sequence. Fault(s) size, quantity of seismic moment, complex inherited geology and unclear (and contrasting?) geometries all conjure toward one of the key areas subject to assess seismogenic faulting.

ITCS007 Thiene Cornuda

Code	**ITCS007**		
Name	Thiene-Cornuda		
Compiled By	Burrato, P.		
Latest Update	03/08/2006		
	Parameter	**Qual.**	**Evidence**
Min Depth (km)	0.5	LD	Based on geological data from Galadini et al. (2005).
Max Depth (km)	6.5	LD	Based on geological data from Galadini et al. (2005).
Strike (deg)	235 – 275	LD	Based on geological data from Galadini et al. (2005).
Dip (deg)	30 – 40	LD	Based on geological data from Galadini et al. (2005).
Rake (deg)	80 - 100	LD	Based on geological and geodetic data.
Slip Rate (mm/y)	0.1 – 1	EJ	Unknown, values assumed from geodynamic constraints.
Max Magnitude (Mw)	6.6	OD	Derived from maximum magnitude of associated individual source(s).

This composite source straddles the region across the Veneto southwestern foothills and belongs to the overall thrust system that borders the Veneto-Friuli plain in north-eastern Italy. This front is a S- to SE-verging fault system of the eastern Southalpine Chain and is thought to accommodate the ~N-S convergence between Africa (the Adriatic microplate here) and Europe.

Historical and instrumental catalogues (Boschi et al., 2000; Gruppo di Lavoro CPTI, 2004; Pondrelli et al., 2006; Guidoboni et al., 2007) show scattered, intermediate seismicity (ca. Mw 4) just north of this region. A key, destructive earthquake has occurred in the eastern sector on 25 February 1695 (Mw 6.7) in the Asolano area, while another damaging event hit just west, on 12 June 1836 (Mw 5.5) in Bassano.

The overall role and geometry of this source is based on the thrust system studied by Castaldini and Panizza (1991). The activity of the thrust has been shown by uplifted terraces, abandoned river valleys, and tectonically subsiding areas studied by Galadini et al. (2005). This sector of the north-eastern South Alpine chain is characterised by large magnitude earthquakes (Mw 6+, such as the 1695 event) that are generated by segments of the frontal, S- to SE-verging thrust, while smaller (Mw 5+), yet potentially destructive events, can be generated by secondary structures, such as the Monte Grappa back-thrust.

This source is dissected at its center by transverse structures that act as a segment boundary between the southwestern and northeastern invidual portions of the thrust.

Some segments of this source have been associated with the key earthquakes that have affected this region. For an in-depth analysis of seismogenesis in this region, the reader can refer to the associated individual sources.

The strike was taken from the general orientation of mapped tectonic structures (N240°-245°). The dip was inferred from regional geological considerations concerning the thrust plane (30°-40°). The rake was assumed to represent pure thrusting, based on general geodynamic considerations (80-100). The minimum depth was based on the surface expression of tectonic warping (data by Galadini et al., 2005), while maximum depth was inferred by geometrical considerations concerning the depth at which active thrusting is rooted (0.5 and 6.5 km, respectively). The slip rate was inferred from regional geodynamic data (0.1 – 1.0 mm/y). The maximum magnitude was taken from that of the largest individual source associated (Mw 6.6).

Associated Individual Seismogenic Source(s)

ITIS147 Thiene Bassano

Code	**ITIS127**		
Name	Thiene-Bassano		
Compiled By	Burrato, P., and F. Galadini		
Latest Update	23/11/2005		
	Parameter	**Qual.**	**Evidence**
Location (Lat/Lon)	45.7543 / 11.6163	LD	Based on geological data from Galadini et al. (2005).
Length (km)	18	EJ	Inferred from geological data constrained by seismological considerations.
Width (km)	9.5	EJ	Inferred from geological data constrained by seismological considerations.
Min Depth (km)	1	LD	Based on geological data from Galadini et al. (2005).
Max Depth (km)	5.8	LD	Based on geological data from Galadini et al. (2005).
Strike (deg)	244	LD	Based on geological data from Galadini et al. (2005).
Dip (deg)	30	LD	Based on geological data from Galadini et al. (2005).
Rake (deg)	80	LD	Based on geological and geodetic data.
Slip Per Event (m)	1.5	ER	Calculated from Mo using the relationship from Hanks and Kanamori (1979).
Slip Rate (mm/y)	0.1 - 1	LD	Based on geological observations.
Recurrence (y)	1500 - 15000	EJ	Inferred from slip rate and average displacement.
Magnitude (Mw)	6.6	ER	Calculated using the relationships from Wells and Coppersmith (1994).

The geometry and strike of the Thiene-Bassano Source have been constrained following the work of Galadini et al., 2005. The source have been modified, scaling the dimensions proposed by these authors, with the average seismological stress drop of the Friuli 1976 seismic sequence, assumed to be characteristic in this region for thrust faulting earthquakes, constrained by empirical relationship between magnitude and rupture area (Poli et al., 2006). The Thiene-Bassano Source is a segment of a thrust fault system, that borders the Venetian and Friuli plain for more than 100 km (Aviano line, according to Castaldini and Panizza, 1991). The activity of this thrust front is testified by uplifted terraces, abandoned river valleys, tectonically subsiding areas, and small scarps deforming recent depositional surfaces (Galadini et al., 2005). The Thiene-Bassano Source is separated from the neighbouring source to the east by transverse structures that act as segment boundaries. The assumed rake of this source (reverse with a small lateral component) derives from geodynamic considerations.

OPEN QUESTIONS

1) What are the relationships among the Thiene-Bassano Source and the neighbouring seismogenic sources? Can they rupture in sequence like the 1976 Friuli earthquakes?

2) Can also the transverse structures that segment the Aviano line, defining the boundaries of the main seismogenic sources, be associated with significant seismicity?

ITIS102 Bassano – Cornuda

Code	**ITIS102**

Name	Bassano-Cornuda		
Compiled By	Burrato, P., and F. Galadini		
Latest Update	23/11/2005		
	Parameter	**Qual.**	**Evidence**
Location (Lat/Lon)	45.8226 / 11.8701	LD	Based on geological data from Galadini et al. (2005).
Length (km)	18	EJ	Inferred from geological data constrained by seismological considerations.
Width (km)	9.5	EJ	Inferred from geological data constrained by seismological considerations.
Min Depth (km)	1	LD	Based on geological data from Galadini et al. (2005).
Max Depth (km)	6.4	LD	Based on geological data from Galadini et al. (2005).
Strike (deg)	240	LD	Based on geological data from Galadini et al. (2005).
Dip (deg)	35	LD	Based on geological data from Galadini et al. (2005).
Rake (deg)	80	LD	Based on geological and geodetic data.
Slip Per Event (m)	1.5	ER	Calculated from Mo using the relationship from Hanks and Kanamori (1979).
Slip Rate (mm/y)	0.7 - 0.87	LD	Based on geological observations.
Recurrence (y)	1724 - 2143	EJ	Inferred from slip rate and average displacement.
Magnitude (Mw)	6.6	LD	Value adopted from the historical earthquake catalogue CPTI04.

	Associated earthquake	
Latest Eq	25 Feb 1695	CPTI04.
Penultimate Eq	Unknown	See "Commentary" for information.
Elapsed Time	305	As of year 2000 (assigned datum).

The Bassano-Cornuda Source is included in the Database as a 18 km-long, N240-striking, NW- dipping fault. The geometry and strike of the source have been constrained following the work of Galadini et al., 2005. The source have been modified, scaling the dimensions proposed by these authors with the average seismological stress drop of the Friuli 1976 seismic sequence, assumed to be characteristic in this region for thrust faulting earthquakes, constrained by empirical relationship between magnitude and rupture area (Poli et al., 2006). DISS compilers propose that the Bassano-Cornuda thrust is the causative source of the Mw 6.6 1695 earthquake. The Bassano-Cornuda Source has a right en-echelon relationship with the adjoining Montello Source to the east, while it is in strike with the Thiene-Bassano Source to the west. The Monte Grappa Source, associated with the M 5.3 1836 earthquake, is instead a N-verging back-thrust of the larger Bassano-Cornuda Source. The assumed rake of this source (reverse with a small lateral component) derives from geodynamic considerations.

OPEN QUESTIONS

1) What are the relationships among the Bassano-Cornuda Source and the neighbouring seismogenic sources? Can they rupture in sequence like the 1976 Friuli earthquakes?

2) Can also the transverse structures that segment the Aviano Line, defining the boundaries of the main seismogenic sources, be associated with significant seismicity?

3) Can other backthrust of this large S-verging thrust generate eartquakes like the 1836?

ITIS113 Monte Grappa

Code	**ITIS113**		
Name	Monte Grappa		
Compiled By	Burrato, P., and F. Galadini		
Latest Update	23/11/2005		
	Parameter	**Qual.**	**Evidence**
Location (Lat/Lon)	45.8244 / 11.8346	OD	Based on geological data constrained by macroseismic field.
Length (km)	5	EJ	Inferred from geological data constrained by seismological considerations.
Width (km)	3.9	EJ	Inferred from geological data constrained by seismological considerations.
Min Depth (km)	0.5	EJ	Inferred from geological and geomorphological observations.
Max Depth (km)	2.7	EJ	Inferred from geological and geomorphological observations.
Strike (deg)	60	LD	Based on geological data.
Dip (deg)	35	EJ	Inferred from geological and geomorphological observations.
Rake (deg)	80	LD	Based on geological and geodetic data.
Slip Per Event (m)	0.4	ER	Calculated from Mo using the relationship from Hanks and Kanamori (1979).
Slip Rate (mm/y)	0.1 - 1	EJ	Unknown, values assumed from geodynamic constraints.
Recurrence (y)	400 - 4000	EJ	Inferred from slip rate and average displacement.
Magnitude (Mw)	5.5	LD	Value adopted from the historical earthquake catalogue CPTI04.

		Associated earthquake
Latest Eq	12 Jun 1836	CPTI04.
Penultimate Eq	Unknown	See "Commentary" for information.
Elapsed Time	164	As of year 2000 (assigned datum).

The DISS compilers propose that the Monte Grappa Source is a back-thrust of the larger Bassano-Cornuda Source. Its position was constrained by the distribution of the highest intensity data points of the associated historical earthquake. DISS compilers therefore suggest that in this sector of the South-Alpine chain, large magnitude earthquakes (M 6+) are generated by the frontal thrusts, while smaller (M 5+) but nonless potentially destructive earthquakes, may be generated by secondary structures. The source dimensions have been scaled with the average seismological stress drop of the Friuli 1976 seismic sequence, assumed to be characteristic in this region for thrust faulting earthquakes, constrained by empirical relationship between magnitude and rupture area (Poli et al., 2006). The assumed rake of this source (reverse with a small lateral component) derives from geodynamic considerations.

OPEN QUESTIONS

Is the Monte Grappa Source the evidence of the existence of other sources of similar intermediate magnitude earthquakes elsewhere along the Southalpine thrust front?

ITCS060 Montebelluna – Montereale

Code	**ITCS060**		
Name	Montebelluna-Montereale		
Compiled By	Burrato, P.		
Latest Update	30/08/2007		
	Parameter	**Qual.**	**Evidence**
Min Depth (km)	1	LD	Based on geological data from Galadini et al. (2005).
Max Depth (km)	9	LD	Based on geological data from Galadini et al. (2005).
Strike (deg)	210 - 245	LD	Based on geological data from Galadini et al. (2005).
Dip (deg)	30 - 50	LD	Based on geological data from Galadini et al. (2005).
Rake (deg)	60 - 100	LD	Based on geological and geodetic data.
Slip Rate (mm/y)	0.31 - 1.56	OD	Based on long-term geological markers.
Max Magnitude (Mw)	6.5	OD	Derived from maximum magnitude of associated individual source(s).

Associated Active Faults or Folds

#	Type	Name	Reference
124	Fold	Montello	Ferrarese et al. [1998]; Benedetti et al. [2000]

This composite source straddles the region across the Veneto-Friuli foothills midway between the cities of Belluno (to the northwest) and Pordenone (to the southeast). This source belongs to the overall thrust system of the eastern Southalpine Chain that borders the Veneto-Friuli plain in north-eastern Italy.

Historical and instrumental catalogues (Boschi et al., 2000; Gruppo di Lavoro CPTI, 2004; Pondrelli et al., 2006; Guidoboni et al., 2007) show intermediate (4.5 < Mw < 5.0) seismicity all over the area. Damaging and destructive events have concentrated on the eastern sector of the source. The 25 October 1812 (Mw 5.7, Sequals) earthquake hit the Friuli plain toward Pordenone; the 18 October 1936 (Mw 6.1) hit the foothills in Bosco Cansiglio, while the 29 June 1873 (Mw 6.3) has occurred in the Bellunese area.

The south-western sector of this source is characterized by the Montello–Conegliano Thrust, the most remarkable structure of the eastern Southalpine Chain, whose geometry and evolution has been studied by several authors (e.g. Ferrarese et al., 1998; Benedetti et al., 2000; Fantoni et al., 2001). Surface geological and structural data show that the Montello–Conegliano Thrust is a continuous fault that gives way to the east to the Cansiglio Thrust (Galadini et al., 2005).

Two segments of this source have been associated with the key earthquakes of this area. For an in-depth analysis of seismogenic processes in this region, the reader may refer to the relevant individual sources.

The strike of this source was taken parallel to the axis of the outcropping Montello and Cansiglio anticlines (to the southeast and NE-ward, respectively) (N210°-245°). The dip was obtained from the geological section published by Galadini et al. (2005) (30°-50°). The rake was assumed to represent oblique thrusting, based on geological observations (60-100). The minimum and maximum depth were based on tectonic and geometrical considerations concerning the thrust geometry (1.0 and 9.0 km, respectively). The slip rate was based on geological observations (0.31 – 1.56 mm/y). The maximum magnitude was taken from that of the largest individual source associated (Mw 6.5).

Associated Individual Seismogenic Source(s)

ITIS101 Montello

Code	**ITIS101**		
Name	Montello		
Compiled By	Burrato, P., and F. Galadini		
Latest Update	23/08/2007		
	Parameter	**Qual.**	**Evidence**
Location (Lat/Lon)	45.8575 / 12.1515	LD	Based on geological data from Galadini et al. (2005).
Length (km)	22	EJ	Inferred from geologic-geomorphological data constrained by seismic profiles.
Width (km)	11.2	EJ	Inferred from geologic-geomorphological data constrained by seismic profiles.
Min Depth (km)	1	LD	Based on geological data from Galadini et al. (2005).
Max Depth (km)	8.2	LD	Based on geological data from Galadini et al. (2005).
Strike (deg)	242	LD	Based on geological data from Galadini et al. (2005).
Dip (deg)	40	LD	Based on geological data from Galadini et al. (2005).
Rake (deg)	80	LD	Based on geological and geodetic data.
Slip Per Event (m)	0.8	ER	Calculated from Mo using the relationship from Hanks and Kanamori (1979).
Slip Rate (mm/y)	0.47 - 1.56	LD	Based on geological observations.
Recurrence (y)	513 - 1702	EJ	Inferred from slip rate and average displacement.
Magnitude (Mw)	6.5	ER	Calculated using the relationships from Wells and Coppersmith (1994).

The Montello–Conegliano Thrust is the most remarkable structure of the Eastern Southalpine Chain, as a result of the conspicuous morphological evidence of the Montello anticline. Many papers dealt with its geometry and evolution (e.g. Ferrarese et al., 1998; Benedetti et al., 2000; Fantoni et al., 2001). Surface geological and structural data show that the Montello–Conegliano Thrust is a continuous fault that dies out to the east where it is overridden by the Cansiglio Thrust (Galadini et al., 2005). The presence of several orders of Middle and Upper Pleistocene warped river terraces (e.g. Benedetti et al., 2000) in the western sector strongly suggests that the Montello–Conegliano anticline is active and driven by the underlying thrust. The interpretation of the structure reported in DISS considers only the western and central portion of the Montello–Conegliano Thrust (Montello Source). The geometry of Montello Source was based on modeling surface geological and subsurface geophysical data. The length of the source was constrained using: 1— the south-western periclinal termination of the anticline that suggests the location of the western tip of the blind thrust; and 2—the extension of the outcrops of the Neogene sequence that locally are the oldest exposed rocks, and that provide a hint to the location of the maximum tectonic uplift. Further indications of the fault dimensions are given by a series of seismic reflection profiles orthogonal to the structure interpreted by Galadini et al. (2005). This geophysical dataset shows that the fault width and the displacement along the Montello–Conegliano Thrust decrease progressively toward the east and that close to its eastern termination the structure is overridden by the Cansiglio Thrust. The eastward decrease of displacement matches the asymmetric shape of the anticline (higher to the west) and the exposure of the oldest fold core rocks. East of the Piave River, the anticline becomes gentler and symmetric, until it is overridden by the Cansiglio Thrust. The strike of the Montello Source was taken parallel to the axis of the outcropping Montello anticline (Benedetti et al., 2000) and its dip was obtained from the geological section published by Galadini et al. (2005). Based on the anticline width projected onto the thrust plane, constrained using the seismic lines, the Montello Source was confined at depth between 1 and 8.2 km. The overall geometry, location and kinematics was further constrained by geodetic observations of vertical relative movements analysed by De Martini et al. (1998) and Burrato et al. (2008). In contrast to the segmentation scheme of the Montello-Conegliano thrust adopted in DISS, Galadini et al. (2005) considered the whole thrust as a single, 30-km-long, seismogenic source rooted at about 12 km depth, and capable of generating earthquakes of magnitude up to 6.7. In spite of the spectacular geomorphic and geologic evidence of activity of the Montello-Conegliano Thrust, there is only little evidence on how much contractional strain is released through discrete events (i.e. earthquakes) and how much goes aseismic. Benedetti et al. (2000) hypothesized that the western part of the thrust (Montello) may have slipped three times in the past 2000 years (during the Mw 5.8 778 A.D., Mw 5.4 1268 and Mw 5.0 1859 earthquakes), yielding a mean recurrence time of about 500 years. Whereas, the eastern part of the thrust (Conegliano) would be silent. The Italian seismic catalogues have very poor-quality and incomplete data for these events associated with the Montello thrust, leaving room for different interpretations, as for example the possibility that these earthquakes were generated by nearby secondary structures. In this latter case, the whole Montello–Conegliano Thrust would represent a major "silent" structure, with a recurrence interval longer than 700 years, because none of the historical earthquakes reported in the Italian Catalogues of seismicity for the past seven centuries can be convincingly referred to the Montello Source.

OPEN QUESTIONS

The open issues regarding the Montello Source refer to the segmentation scheme applied to the Montello–Conegliano Thrust, and to its seismic history.

1) Is the Montello–Conegliano Thrust unsegmented, as it was proposed by Galadini et al. (2005), and as such may represent the source of very large future earthquakes?

2) Is it possible to associate to the Montello-Conegliano Thrust any of the earthquakes suggested by Benedetti et al. (2000), or is it a seismic gap?

3) If the three earthquakes (778 A.D., 1268 and 1859) were really generated by the Montello Source, does this mean that its seismic behavior is characterized by smaller and more frequent earthquakes than expected (from its dimensions), each one rupturing a small portion of the entire structure?

ITIS124 Cansiglio

Code	**ITIS124**		
Name	Cansiglio		
Compiled By	Burrato, P., and F. Galadini		
Latest Update	23/11/2005		
	Parameter	**Qual.**	**Evidence**
Location (Lat/Lon)	46.0286 / 12.4257	OD	Based on geological and seismological data.
Length (km)	10	EJ	Inferred from geological data constrained by seismological considerations.
Width (km)	6.4	EJ	Inferred from geological data constrained by seismological considerations.
Min Depth (km)	1.5	OD	Derived from dip, width and max depth.
Max Depth	6.4	LD	Based on geological and seismological data from

(km)			various authors.
Strike (deg)	214	LD	Based on geological and seismological data from various authors.
Dip (deg)	50	LD	Based on geological and seismological data from various authors.
Rake (deg)	60	LD	Based on geological and geodetic data.
Slip Per Event (m)	0.75	ER	Calculated from Mo using the relationship from Hanks and Kanamori (1979).
Slip Rate (mm/y)	0.52 - 0.65	LD	Based on geological observations.
Recurrence (y)	1154 - 1442	EJ	Inferred from slip rate and average displacement.
Magnitude (Mw)	6.1	LD	Value adopted from the historical earthquake catalogue CPTI04.

1.1.1.1.1. Associated earthquake

Latest Eq	18 Oct 1936	CPTI04.
Penultimate Eq	Unknown	See "Commentary" for information.
Elapsed Time	64	As of year 2000 (assigned datum).

The geometry of the Cansiglio source has been constrained based on several papers dealing with the Cansiglio 1936 earthquake. The source dimensions have been scaled using the measured average seismological stress drop of the Friuli 1976 seismic sequence, constrained by empirical relationship between magnitude and rupture area. - the length (10 km) is based on scaling with width, constrained by empirical relationship between magnitude and rupture area; - the down-dip width (6.4 km) is based on the assumptions made concerning the minimum and maximum faulting depth, constrained by empirical relationship of rupture area with respect to the magnitude; - the strike (N214) is chosen according with the general orientation of mapped tectonic structures; - the fault dips 50° towards the northwest; - the rake is assumed to be 60° (reverse faulting with left-lateral component) based on strike and on general geodynamic considerations; - the minimum and maximum depth (1.5 and 6.4 km respectively) are constrained by subsurface geology and lack of evidence of coseismic surface faulting; The 18 October 1936 earthquake is the only event reported in the current catalogues (CPTI, 2004) that can be associated with the Cansiglio Source based on damage distribution. The area that experienced the strongest effects is found just south of the Cansiglio and in the Alpago valley. These are the same zones that suffered the strongest effects during the 1873 Me=6.3 Bellunese earthquake.

OPEN QUESTIONS

1) What are the relationships between the Cansiglio Source and the Polcenigo-Montereale Source?
2) What are the slip rate and the average return time of the Cansiglio Source?

ITIS125 Polcenigo – Montereale

Code	**ITIS125**		
Name	Polcenigo-Montereale		
Compiled By	Burrato, P., and F. Galadini		
Latest Update	23/11/2005		
	Parameter	**Qual.**	**Evidence**

Location (Lat/Lon)	46.1246 / 12.5461	OD	Based on geological data constrained by macroseismic field.
Length (km)	15	EJ	Inferred from geological data constrained by seismological considerations.
Width (km)	8.5	EJ	Inferred from geological data constrained by seismological considerations.
Min Depth (km)	2	LD	Based on geological data from Galadini et al. (2005).
Max Depth (km)	7.5	LD	Based on geological data from Galadini et al. (2005).
Strike (deg)	220	LD	Based on geological data from Galadini et al. (2005).
Dip (deg)	40	LD	Based on geological data from Galadini et al. (2005).
Rake (deg)	80	LD	Based on geological and geodetic data.
Slip Per Event (m)	1	ER	Calculated from Mo using the relationship from Hanks and Kanamori (1979).
Slip Rate (mm/y)	0.31 - 0.78	LD	Based on geological observations.
Recurrence (y)	1282 – 3226	EJ	Inferred from slip rate and average displacement.
Magnitude (Mw)	6.4	LD	Value adopted from the historical earthquake catalogue CPTI04.

1.1.1.1.2. Associated earthquake

Latest Eq	29 Jun 1873	CPTI04.
Penultimate Eq	Unknown	See "Commentary" for information.
Elapsed Time	127	As of year 2000 (assigned datum).

The Polcenigo-Montereale Source is included in DISS as a 15 km-long, N220-striking, NW-dipping fault. The geometry and strike of the source have been constrained following the work of Galadini et al., 2005. The source have been modified, scaling the dimensions proposed by these authors with the average seismological stress drop of the Friuli 1976 seismic sequence, assumed to be characteristic in this region for thrust faulting earthquakes, constrained by empirical relationship between magnitude and rupture area (Poli et al., 2006). The rake is assumed to be 80° (reverse faulting) based on strike and on general geodynamic considerations; The minimum and maximum depth (2.0 and 7.5 km respectively) are constrained by subsurface geology and by the lack of evidence of coseismic surface faulting; The 29 June 1873 earthquake is the only event reported in the current catalogues (CPTI, 1999) that can be associated with the Polcenigo-Montereale Source based on damage distribution. The area that experienced the strongest effects is found in the Alpago valley and also just south of the Cansiglio. This mesoseismic zone is very similar to that of the 1936 Cansiglio earthquake.

OPEN QUESTIONS

1) What are the relationships between the Polcenigo-Montereale Source and the Cansiglio Source?
2) What are the slip rate and the average return time of the Alpago Source?

ITCS071 - Andreis-Forgaria nel Friuli

Code	**ITCS071**
Name	Andreis-Forgaria nel Friuli

Compiled By	Burrato, P.		
Latest Update	18/09/2007		
	Parameter	**Qual.**	**Evidence**
Min Depth (km)	0.5	OD	Based on geological data from various authors.
Max Depth (km)	4	OD	Based on geological data from various authors.
Strike (deg)	230 - 265	OD	Based on geological data from various authors.
Dip (deg)	30 - 40	OD	Based on geological data from various authors.
Rake (deg)	80 - 100	OD	Based on geological and geodetic data.
Slip Rate (mm/y)	0.1 - 0.34	OD	Based on long-term geological markers.
Max Magnitude (Mw)	5.9	OD	Derived from maximum magnitude of associated individual source(s).

This composite source straddles the region across the Friuli foothills. It belongs to the overall thrust system of the eastern Southalpine Chain that borders the Veneto-Friuli plain in north-eastern Italy and continues onto the Italy-Slovenia border.

Historical and instrumental catalogues (Boschi et al., 2000; Gruppo di Lavoro CPTI, 2004; Pondrelli et al., 2006; Guidoboni et al., 2007) show a remarkable concentration of damaging and destructive earthquakes over the entire region and adjoining Composite Sources. In particular, the area was affected by the 10 July 1776 (Mw 5.8, Tramonti) event to the west, and by the 25 January 1348 (Mw 7.0, Carnia) earthquake.

This source marks the inception of the very complex fault system of the Friuli foothill called to explain several destructive earthquakes, remarkably concentrated in the border region between Italy and Slovenia, including the well known 1976 Friuli seismic sequence. Fault(s) size, quantity of seismic moment, complex inherited geology and unclear (and contrasting?) geometries all conjure toward one of the key areas subject to assess seismogenic faulting.

A segment of this source has been associated with the 1776 earthquake. For an in-depth analysis of seismogenesis in this region, the reader can refer to the individual source.

The strike of this source was based on that of the mapped structures and on the data by Galadini et al. (2005) (N230°-265°). The dip was inferred from geological considerations (30°-40°). The rake was assumed to represent pure thrusting, based on geological observations (80-100). The minimum and maximum depth were based on tectonic and geometrical considerations concerning the thrust geometry (0.5 and 4.0 km, respectively). The slip rate was based on geological observations (0.1 – 0.34 mm/y). The maximum magnitude was taken from that of the largest individual source associated (Mw 5.9).

Associated Individual Seismogenic Source(s)

ITIS108 Maniago

Code	**ITIS108**		
Name	Maniago		
Compiled By	Burrato, P., and F. Galadini		
Latest Update	23/11/2005		
	Parameter	**Qual.**	**Evidence**
Location	46.2114 /	OD	Based on geological data constrained by macroseismic

(Lat/Lon)	12.6952		field.
Length (km)	8	EJ	Inferred from geological data constrained by seismological considerations.
Width (km)	5.5	EJ	Inferred from geological data constrained by seismological considerations.
Min Depth (km)	0.5	EJ	Inferred from geological and geomorphological observations.
Max Depth (km)	3.3	EJ	Inferred from geological and geomorphological observations.
Strike (deg)	237	LD	Based on geological data.
Dip (deg)	30	EJ	Inferred from geological and geomorphological observations.
Rake (deg)	90	LD	Based on geological and geodetic data.
Slip Per Event (m)	0.66	ER	Calculated from Mo using the relationship from Hanks and Kanamori (1979).
Slip Rate (mm/y)	0.1 - 0.34	LD	Based on geological observations.
Recurrence (y)	1941 - 6600	EJ	Inferred from slip rate and average displacement.
Magnitude (Mw)	5.9	LD	Value adopted from the historical earthquake catalogue CPTI04.

1.1.1.1.3. Associated earthquake

Latest Eq	10 Jul 1776	CPTI04.
Penultimate Eq	Unknown	See "Commentary" for information.
Elapsed Time	224	As of year 2000 (assigned datum).

The DISS compilers propose the existence of the Maniago Source on the basis of structural observations and on the occurrence of the 1776 Tramonti earthquake, close to the western termination of the Arba-Ragogna thrust. The pattern of the macroseismic intensity data points of this earthquake is very localised, and points to a causative source very close to the macroseismic epicenter.

The Arba-Ragogna thrust can be segmented on the basis of difference in the hanging wall structural elevations (between western and eastern sectors), and of slight different orientations of the structural grain.

The eastern, larger segment of the Arba-Ragna thrust hosts the Sequals Source, that is not associated to any historical/instrumental earthquake. As such this source represent a potential seismic gap for a M 6+ earthquake.

Galadini et al. (2005) proposed a single seismogenic structure occuring along the Arba-Ragogna thrust, but they were not analysing earthquakes with a magnitude lower than 6.

The Maniago and Sequals sources follow a trend that is more easterly than the sources located to the west along the Aviano line. Moving eastwards from this area on, the structural configuration seems to be more complicated, since seismicity is more widespread diffused and more thrust fronts seems to be active contemporary. In fact, north of the Maniago and Sequals sources one can find the Tramonti Source, that falls along the EW-trending Periadriatic thrust, and is associated with the Me 5.8, 1794 Tramonti earthquake. According to Galadini et al. (2005), the Periadriatic thrust is active till Kobarid in Slovenia, where interacts with the NW-SE trending, right-lateral structures of the Idrija fault system.

OPEN QUESTIONS

It is possible to assume that the segment boundary between the Maniago and Sequals sources is permanent? Or the Arba-Ragogna thrust can host larger magnitude, more infrequent earthquakes (as suggested by Galadini et al., 2005)?

ITCS062 - Maniago-Sequals

Code	**ITCS062**		
Name	Maniago-Sequals		
Compiled By	Burrato, P.		
Latest Update	30/08/2007		
	Parameter	**Qual.**	**Evidence**
Min Depth (km)	1	LD	Based on geological data from various authors.
Max Depth (km)	7	LD	Based on geological data from various authors.
Strike (deg)	245 - 275	LD	Based on geological data from Galadini et al. (2005).
Dip (deg)	30 - 40	LD	Based on geological data from various authors.
Rake (deg)	80 - 100	LD	Based on geological and geodetic data.
Slip Rate (mm/y)	0.1 - 0.34	OD	Based on long-term geological markers.
Max Magnitude (Mw)	6.5	OD	Derived from maximum magnitude of associated individual source(s).

This composite source straddles the region across the Friuli foothills. It belongs to the overall thrust system of the eastern Southalpine Chain that borders the Veneto-Friuli plain in north-eastern Italy and continues onto the Italy-Slovenia border.

Historical and instrumental catalogues (Boschi et al., 2000; Gruppo di Lavoro CPTI, 2004; Pondrelli et al., 2006; Guidoboni et al., 2007) show a remarkable concentration of damaging and destructive earthquakes over the entire region and adjoining Composite Sources. In particular, the area was affected by the 10 July 1776 (Mw 5.8, Tramonti) event to the west, and by the 25 January 1348 (Mw 7.0, Carnia) earthquake.

This sector of the Arba-Ragogna thrust hosts the Sequals source (ITIS109), a seismogenic fault segment not associated to any historical/or instrumental earthquake. As such, the Maniago-Sequals Composite Source includes a potential seismic gap for a M 6+ earthquake.

The strike of this source was based on that of the mapped structures and on the data by Galadini et al. (2005) (N245°-275°). The dip was inferred from geological considerations (30°-40°). The rake was assumed to represent pure thrusting, based on geological observations (80-100). The minimum and maximum depth were based on tectonic and geometrical considerations concerning the thrust geometry (1.0 and 7.0 km, respectively). The slip rate was based on geological observations (0.1 – 0.34 mm/y). The maximum magnitude was taken from that of the largest individual source associated (Mw 6.5).

Associated Individual Seismogenic Source(s)

ITIS109 – Sequals

Code	**ITIS109**		
Name	Sequals		
Compiled By	Burrato, P., and F. Galadini		
Latest Update	23/11/2005		
	Parameter	**Qual.**	**Evidence**

Location (Lat/Lon)	46.2037 / 12.8581	EJ	Inferred from geological data from Galadini et al. (2005).
Length (km)	16.5	EJ	Inferred from geological data constrained by seismological considerations.
Width (km)	9	EJ	Inferred from geological data constrained by seismological considerations.
Min Depth (km)	1	LD	Based on geological data from Galadini et al. (2005).
Max Depth (km)	6.8	LD	Based on geological data from Galadini et al. (2005).
Strike (deg)	254	LD	Based on geological data from Galadini et al. (2005).
Dip (deg)	40	LD	Based on geological data from Galadini et al. (2005).
Rake (deg)	90	LD	Based on geological and geodetic data.
Slip Per Event (m)	1.3	ER	Calculated from Mo using the relationship from Hanks and Kanamori (1979).
Slip Rate (mm/y)	0.1 - 0.26	LD	Based on geological observations.
Recurrence (y)	5000 - 13000	EJ	Inferred from slip rate and average displacement.
Magnitude (Mw)	6.5	ER	Calculated using the relationships from Wells and Coppersmith (1994).

The DISS compilers propose the existence of the Sequals Source following the structural and geomorphological observations of Galadini et al. (2005).

Galadini et al. (2005) proposed a single seismogenic structure occuring along the Arba-Ragogna thrust, but they were not analysing earthquakes with a magnitude lower than 6.

The Maniago and Sequals sources follow a trend that is more easterly than the sources located to the west along the Aviano Line. Moving eastwards from this area on, the structural configuration seems to be more complicated, since seismicity is more widespread diffused and more thrust fronts seems to be active contemporary. In fact, north of the Maniago and Sequals sources is present the Tramonti Source, that falls along the EW-trending Periadriatic thrust, and is associated with the Me 5.8, 1794 Tramonti earthquake. According to Galadini et al. (2005), the Periadriatic thrust is active till Kobarid in Slovenia, where interacts with the NW-SE trending, right-lateral structures of the Idrija fault system.

OPEN QUESTIONS

It is possible to assume that the segment boundary between the Maniago and Sequals sources is permanent? Or the Arba-Ragogna thrust can host larger magnitude, more infrequent earthquakes (as suggested by Galadini et al., 2005)?

ITCS064 - Tramonti-Montemaggiore

Code	**ITCS064**		
Name	Tramonti-Montemaggiore		
Compiled By	Burrato, P., and V. Kastelic		
Latest Update	30/08/2007		
	Parameter	**Qual.**	**Evidence**
Min Depth (km)	1	EJ	Inferred from geological and geomorphological observations.
Max Depth (km)	5.5	EJ	Inferred from geological and geomorphological observations.

Strike (deg)	250 - 285	EJ	Inferred from geological and geomorphological observations.
Dip (deg)	30 - 45	EJ	Inferred from geological and geomorphological observations.
Rake (deg)	80 - 100	EJ	Inferred from geological and geodetic data.
Slip Rate (mm/y)	0.1 - 1	EJ	Unknown, values assumed from geodynamic constraints.
Max Magnitude (Mw)	6.2	EJ	Assumed from regional seismological data.

This composite source straddles the region across the higher Friuli foothills. It belongs to the overall thrust system of the eastern Southalpine Chain that borders the Veneto-Friuli plain in north-eastern Italy and continues onto the Italy-Slovenia border

Historical and instrumental catalogues (Boschi et al., 2000; Gruppo di Lavoro CPTI, 2004; Pondrelli et al., 2006; Guidoboni et al., 2007) show a remarkable concentration of damaging and destructive earthquakes over the entire region. In particular, the area was affected by the 7 June 1794 (Mw 5.8, Tramonti) event to the west, the 16 September 1977 (Mw 5.7, Trasaghis) one to the east, and by the 25 January 1348 (Mw 7.0, Carnia) earthquake to the south.

The strike of this source was based on that of the mapped structures (N250°-285°). The dip was inferred from geological considerations (30°-45°). The rake was assumed to represent pure thrusting, based on geological observations (80-100). The minimum and maximum depth were based on tectonic and geometrical considerations concerning the thrust geometry (1.0 and 5.5 km, respectively). The slip rate was inferred from regional geodynamic data (0.1 – 1.0 mm/y). The maximum magnitude was assumed from seismological data (Mw 6.2).

Associated Individual Seismogenic Source(s)

ITIS112 – Tramonti

Code	**ITIS112**		
Name	Tramonti		
Compiled By	Burrato, P., and F. Galadini		
Latest Update	23/11/2005		
	Parameter	**Qual.**	**Evidence**
Location (Lat/Lon)	46.2908 / 12.8046	OD	Based on geological data constrained by macroseismic field.
Length (km)	6	EJ	Inferred from geological data constrained by seismological considerations.
Width (km)	4.5	EJ	Inferred from geological data constrained by seismological considerations.
Min Depth (km)	1	EJ	Inferred from geological and geomorphological observations.
Max Depth (km)	3.6	EJ	Inferred from geological and geomorphological observations.
Strike (deg)	268	LD	Based on geological data.
Dip (deg)	35	EJ	Inferred from geological and geomorphological

			observations.
Rake (deg)	90	LD	Based on geological and geodetic data.
Slip Per Event (m)	0.66	ER	Calculated from Mo using the relationship from Hanks and Kanamori (1979).
Slip Rate (mm/y)	0.1 - 1	EJ	Unknown, values assumed from geodynamic constraints.
Recurrence (y)	660 - 6600	EJ	Inferred from slip rate and average displacement.
Magnitude (Mw)	5.8	LD	Value adopted from the historical earthquake catalogue CPTI04.

1.1.1.1.4. Associated earthquake

Latest Eq	07 Jun 1794	CPTI04.
Penultimate Eq	Unknown	See "Commentary" for information.
Elapsed Time	206	As of year 2000 (assigned datum).

The DISS compilers propose the existence of the Tramonti Source on the basis of the analysis of the distribution of the intensity data points of the 1794, M 5.8 earthquake. This source is a segment of the E-W trending Periadriatic thrust, that continues eastwards up to Kobarid in Slovenia, where it meets the NW-SE trending structures of the Idrija fault system. The central and eastern portion of the Periadriatic thrust are not associated to any historical/instrumental earthquakes. South of the Tramonti Source, the Arba-Ragogna thrust runs along the foothills of the uplifted chain. This thrust is segmented into two sources, of which only the westernmost is associated to an historical earthquake.

OPEN QUESTIONS

1) Is the Periadriatic thrust seismogenic all along its length?

2) Can it generate large magnitude earthquake (M 6+), or it is segmented in small sources like the Tramonti Source?

ITCS067 But – Chiarso

Code	**ITCS067**		
Name	But-Chiarso		
Compiled By	Burrato, P.		
Latest Update	24/09/2007		
	Parameter	**Qual.**	**Evidence**
Min Depth (km)	1	EJ	Inferred from regional tectonic considerations.
Max Depth (km)	9	EJ	Inferred from regional tectonic considerations.
Strike (deg)	190 - 235	EJ	Inferred from geological data.
Dip (deg)	60 - 90	EJ	Inferred from geological data.
Rake (deg)	0 - 50	EJ	Inferred from geological data.
Slip Rate (mm/y)	0.1 - 1	EJ	Unknown, values assumed from geodynamic constraints.
Max Magnitude (Mw)	5.8	LD	Derived from the largest associated historical earthquake (CPTI04).

This composite source straddles the middle Tagliamento Valley north of the epicenters of the 1976, Friuli earthquakes and belongs to the high angle But–Chiarsò oblique to left-lateral strike-slip system. This fault system is located to the north of thrust system of the eastern Southalpine Chain that borders the Veneto-Friuli plain in north-eastern Italy and continues onto the Italy-Slovenia border.

The middle Tagliamento Valley area is dominated by strike–slip seismicity, and P-axes parallel to those of the thrust faulting zones located more to the south. This evidence confirms that the seismotectonic of the area is driven by the Adria–Europe relative motion.

Historical and instrumental catalogues (Boschi et al., 2000; Gruppo di Lavoro CPTI, 2004; Pondrelli et al., 2006; Guidoboni et al., 2007) show few moderate earthquakes that hit the middle Tagliamento Valley. The four most important events are: the Mw 5.8, 1700 Raveo, the Mw 5.7, 1788, Tolmezzo, the Mw 5.5, 1924, Carnia and the Mw 5.8, 1928 Carnia earthquakes. Of these events, the 1928 earthquake, showing a transcurrent fault plane solution with two conjugate dextral WNW–ESE and sinistral NE–SW high angle planes, helps defining the seismotectonics of the area. In fact, both these solutions are consistent with the structural setting of the area, characterized by the presence of high angle left-lateral faults, such as the But–Chiarsò Fault System, and dextral WNW–ESE subvertical strike–slip faults.

The strike of this source was taken from the general orientation of mapped tectonic structures (N190°-N235°). The dip was inferred from regional geological considerations concerning the strike-slip system (60°-90°). The rake was assumed to represent left-lateral to oblique component of motion, based on general geodynamic considerations (0-50). The minimum and maximum depths were inferred by geometrical considerations concerning the depth at which active faulting is rooted (1.0 and 9.0 km, respectively). The slip rate was inferred from regional geodynamic data (0.1 – 1.0 mm/y). The maximum magnitude was assumed from regional seismological data (Mw 5.8).

ITCS066 Gemona-Tarcento

Code	**ITCS066**		
Name	Gemona-Tarcento		
Compiled By	Burrato, P.		
Latest Update	30/08/2007		
	Parameter	**Qual.**	**Evidence**
Min Depth (km)	2	LD	Based on geological and seismological data from various authors.
Max Depth (km)	8	LD	Based on geological and seismological data from various authors.
Strike (deg)	270 - 300	LD	Based on geological and seismological data from various authors.
Dip (deg)	30 - 40	LD	Based on geological and seismological data from various authors.
Rake (deg)	90 - 110	LD	Based on geological and geodetic data.
Slip Rate (mm/y)	0.1 - 1.15	EJ	Unknown, values assumed from geodynamic constraints.
Max Magnitude (Mw)	6.5	OD	Derived from maximum magnitude of associated individual source(s).

This composite source straddles the region across the Friuli foothills. It belongs to the overall thrust system of the eastern Southalpine Chain that borders the Veneto-Friuli plain in north-eastern Italy and continues onto the Italy-Slovenia border.

Historical and instrumental catalogues (Boschi et al., 2000; Gruppo di Lavoro CPTI, 2004; Pondrelli et al., 2006; Guidoboni et al., 2007) show a remarkable concentration of damaging and destructive earthquakes over the entire region and in the adjacent Composite Sources. In particular, the area was affected by the 26 March 1511 (Mw 6.5, Slovenia) earthquake and by the well known 6 May 1976 (Mw 6.4) and 15 Sep 1976 (Mw 5.9) Friuli earthquakes. In addition, a closely-spaced intermediate (4.5 < Mw < 5.0) seismicity can be found in the eastern sector of the Source.

A segment of this source has been associated with oneevent of the 1976 sequence. For an in-depth analysis of seismogenesis in this region, the reader can refer to the individual source.

The strike of this source was based on that of the mapped structures and on data by from Talamo et al. (1978) and Pondrelli et al. (2001) (N270°-300°). The dip was based on the geometry of the blind thrusts from subsuirface data (30°-40°). The rake represents oblique thrusting, based on seismological observations and on data by Pondrelli et al. (2001) (90-110). The minimum and maximum depth were based on tectonic and geometrical considerations concerning the thrust geometry (2.0 and 8.0 km, respectively). The slip rate was based on geological observations (0.1 – 1.15 mm/y). The maximum magnitude was taken from that of the largest individual source associated (Mw 6.5).

Associated Individual Seismogenic Source(s)

ITIS120 Gemona South

Code	**ITIS120**
Name	Gemona South

Compiled By	Burrato, P., and F. Galadini		
Latest Update	23/11/2005		
	Parameter	**Qual.**	**Evidence**
Location (Lat/Lon)	46.2507 / 13.1447	LD	Based on geological and seismological data.
Length (km)	16	EJ	Inferred from geological data constrained by seismological considerations.
Width (km)	9	EJ	Inferred from geological data constrained by seismological considerations.
Min Depth (km)	2	LD	Based on geological and seismological data from various authors.
Max Depth (km)	6.5	LD	Based on geological and seismological data from various authors.
Strike (deg)	290	LD	Based on geological and seismological data from various authors.
Dip (deg)	30	LD	Based on geological and seismological data from various authors.
Rake (deg)	105	LD	Based on geological and geodetic data.
Slip Per Event (m)	1.32	ER	Calculated from Mo using the relationship from Hanks and Kanamori (1979).
Slip Rate (mm/y)	0.1 - 1.15	OD	Derived from geodetic measurements.
Recurrence (y)	1148 - 13200	EJ	Inferred from slip rate and average displacement.
Magnitude (Mw)	6.5	LD	Value adopted from the historical earthquake catalogue CPTI04.

1.1.1.1.5. Associated earthquake

Latest Eq	06 May 1976	CPTI04.
Penultimate Eq	Unknown	See "Commentary" for information.
Elapsed Time	24	As of year 2000 (assigned datum).

The Gemona South Source is the causative fault of the 6 May 1976 earthquake.

The geometry of the Gemona South Source have been constrained following the work of several papers, dealing with the Friuli 1976 seismic sequence. The source dimensions have been scaled using the measured average seismological stress drop of the Friuli 1976 seismic sequence, constrained by empirical relationship between magnitude and rupture area . .

- - the strike is chosen according with the general orientation of mapped tectonic structures and with the mean orientation of the nodal planes of the focal mechanisms of the 6 May 1976 earthquake (from Pondrelli et al., 2001); the position of the fault is constrained by the epicentral location of the main shock (following Slejko et al. 1989, and Aoudia et al., 2000), and by modelling of repeated levelling measurements (Talamo et al., 1978);
- the fault dips 30° towards the north in agreement with the geometry of the blind thrusts imaged in the seismic profiles, with the preferred nodal plane of the focal mechanisms of the 6 May 1976 earthquake, and with the spatial distribution of the aftershocks;
- the rake (105) follows seismological observations (focal mechanisms from Pondrelli et al., 2001);

- the down-dip width (9 km) is based on the thickness of the seismogenic layer derived from the distribution of the 1976 earthquake aftershocks (Finetti et al., 1976), and on empirical relationships of rupture area with respect to the magnitude;
- the minimum and maximum depths (2.0 and 6.5 km respectively) follow the observations of Cipar (1980), the aftershocks distribution, and general subsurface geological observations;
- the length (16 km) is based on scaling with width and on geological and seismological observations.

The DISS compilers propose that the causative faults of the main shock and of the stronger aftershocks of the 1976 Friuli seismic sequence (6 May, 11 September, 15 September, h 03:15 and 09:21 GMT) are WNW-striking, S-verging blind-thrusts, belonging to the Eastern Southern Alps chain (ITIS120 Gemona South, ITIS119 Tarcento, ITIS122 Gemona East). The location of the hypocentre of the aftershocks shows that the second and stronger shock of September 15 was generated by a structure deeper than the others (Gemona East Source), located north of the Gemona South Source.

The elevation changes derived from repeated levelling along the IGM geodetic Line 36 (Talamo et al., 1978; Pondrelli et al., 2001;) show two possible distinct components of uplift: a regional part due to the uplift of the Alps, and a coseismic part due to the whole 1976-1977 Friuli sequence. The area affected by coseismic uplift along the profile falls between the towns of Tricesimo and Venzone, for a total length of about 20 km. The extent of the uplifted region seems to be larger than that expected to be associated with the 6 May 1976 main-shock alone. Therefore it is possible to hypothesise that the geodetic signal is the sum of coseismic deformation induced by the main shock and by the strongest aftershocks.

The epicentral locations proposed by Lyon-Caen (1980), Barbano et al. (1985), Slejko et al. (1989) and Aoudia et al. (2000) seem to be in a better agreement with the area of greatest coseismic deformation, as it is shown in the IGM geodetic Line 36, and with the area that experienced the greatest damage.

The 6 May 1976 earthquake seems to have nucleated on the lower-eastern corner of the fault plane and propagated westward with a pure reverse movement. The position of the maximum damage area slightly shifted westward with respect to the epicentral location appears to be in agreement with this hypothesis.

If the "fault scarps" described by Bosi et al (1976) are the real surface expression of the fault plane, they should be located at the intersection between the prolongation of the fault plane and the surface; instead these features are located directly above the plane itself. Besides the ruptures follow the roughly E-W trend of the axis of the major folds and fall near the hinge of the coseismic uplift shown in the geodetic line. On the basis of these considerations the ruptures could be interpreted as due to landslides, or to be the expression of extrados deformation (i.e.: associated with bending at the top of a rising anticline).

The Gemona South Source falls in the area where the Alpine structures meet the Dinaric structures. Some investigators propose an horse-tail splay geometry to link this source with the Dinaric fault system, while according to other workers it would belong to the Alpine system because of its strike.

OPEN QUESTIONS

1) What are the relationships between the Gemona South Source and the strike-slip Idrija fault system?

2) How are the sources of the 1976 mainshocks linked with the trascurrent systems outcropping in the Slovenia region?

3) Were the ruptures described by Bosi et al. (1976) evidence of genuine coseismic surface faulting? Or are they the evidence of landslides and or fractures triggered by the earthquake?

ITIS119 – Tarcento

Code	**ITIS119**		
Name	Tarcento		
Compiled By	Burrato, P., and F. Galadini		
Latest Update	23/11/2005		
	Parameter	**Qual.**	**Evidence**

Location (Lat/Lon)	46.2392 / 13.2634	OD	Based on geological, seismological and macroseismic data.
Length (km)	6	EJ	Inferred from geological data constrained by seismological considerations.
Width (km)	4.5	EJ	Inferred from geological data constrained by seismological considerations.
Min Depth (km)	2	LD	Based on geological and seismological data from various authors.
Max Depth (km)	4.3	LD	Based on geological and seismological data from various authors.
Strike (deg)	277	LD	Based on geological and seismological data from various authors.
Dip (deg)	30	LD	Based on geological and seismological data from various authors.
Rake (deg)	90	LD	Based on geological and geodetic data.
Slip Per Event (m)	0.46	ER	Calculated from Mo using the relationship from Hanks and Kanamori (1979).
Slip Rate (mm/y)	0.1 - 0.58	OD	Derived from geodetic measurements.
Recurrence (y)	793 - 4600	EJ	Inferred from slip rate and average displacement.
Magnitude (Mw)	5.7	LD	Value adopted from the historical earthquake catalogue CPTI04.

1.1.1.1.6. Associated earthquake

Latest Eq	11 Sep 1976	CPTI04.
Penultimate Eq	Unknown	See "Commentary" for information.
Elapsed Time	24	As of year 2000 (assigned datum).

The Tarcento Source is the causative fault of the 11 September 1976 earthquake. The geometry of the Tarcento source have been constrained following the work of several papers, dealing with the Friuli 1976 seismic sequence. The source dimensions have been scaled using the measured average seismological stress drop of the Friuli 1976 seismic sequence, constrained by empirical relationship between magnitude and rupture area.

- the strike is chosen according with the general orientation of mapped tectonic structures and with the mean orientation of the nodal planes of the focal mechanisms of the 6 May 1976 earthquake (from Pondrelli et al., 2001); the position of the fault is constrained by the epicentral location of the main shock (following Slejko et al. 1989, and Aoudia et al., 2000), and by modelling of repeated levelling measurements (Talamo et al., 1978);
- the fault dips 30° towards the north in agreement with the geometry of the blind thrusts imaged in the seismic profiles, with the preferred nodal plane of the focal mechanisms of the 6 May 1976 earthquake, and with the spatial distribution of the aftershocks;
- the rake (90) follows seismological observations of Pondrelli et al. 2001 (focal mechanisms);
- the down-dip width (4.5 km) is based on the thickness of the seismogenic layer derived from the distribution of the 1976 Earthquake aftershocks (Finetti et al., 1976), and on empirical relationships of rupture area with respect to the magnitude;
- the minimum and maximum depths (2.0 and 4.3 km respectively) follow the observations of Cipar (1980), the aftershocks distribution, and general subsurface geological observations;

- the length (6 km) is based on scaling with width and on geological and seismological observations. See ITIS120 Gemona South commentary for further information.

OPEN QUESTIONS

How are the sources of the 1976 mainshocks linked with the trascurrent systems outcropping in the Slovenia region?

ITCS061 Trasaghis – Taipana

Code	**ITCS061**		
Name	Trasaghis-Taipana		
Compiled By	Burrato, P.		
Latest Update	30/08/2007		
	Parameter	**Qual.**	**Evidence**
Min Depth (km)	6	LD	Based on geological and seismological data from various authors.
Max Depth (km)	11	LD	Based on geological and seismological data from various authors.
Strike (deg)	270 - 285	LD	Based on geological and seismological data from various authors.
Dip (deg)	30 - 40	LD	Based on geological and seismological data from various authors.
Rake (deg)	90 - 110	LD	Based on geological and geodetic data.
Slip Rate (mm/y)	0.1 - 0.61	OD	Calculated from geodetic and geodynamic data.
Max Magnitude (Mw)	6.1	LD	Derived from the largest associated historical earthquake (CPTI04).

This composite source straddles the region across the Friuli foothills. It belongs to the overall thrust system of the eastern Southalpine Chain that borders the Veneto-Friuli plain in north-eastern Italy and continues onto the Italy-Slovenia border.

Historical and instrumental catalogues (Boschi et al., 2000; Gruppo di Lavoro CPTI, 2004; Pondrelli et al., 2006; Guidoboni et al., 2007) show a remarkable concentration of damaging and destructive earthquakes over the entire region. In particular, the area was affected by the 26 March 1511 (Mw 6.5, Slovenia) earthquake and by the well known 6 May 1976 (Mw 6.4) and 15 September 1976 (Mw 5.9) Friuli earthquakes. In addition, a closely-spaced intermediate (4.5 < Mw < 5.0) seismicity can be found in the eastern sector of the Source.

The strike of this source was based on that of the mapped structures and on data by from Talamo et al. (1978) and Pondrelli et al. (2001) (N270°-285°). The dip was based on the geometry of the blind thrusts from subsuirface data (30°-40°). The rake represents oblique thrusting, based on seismological observations and on data by Pondrelli et al. (2001) (90-110). The minimum and maximum depth were based on tectonic and geometrical considerations concerning the thrust geometry (6.0 and 11.0 km, respectively). The slip rate was based on geological observations (0.1 – 0.61 mm/y). The maximum magnitude was taken from that of the largest individual source associated (Mw 6.1).

Associated Individual Seismogenic Source(s)

ITIS122 Gemona East

Code	**ITIS122**
Name	Gemona East
Compiled By	Burrato, P., and F. Galadini
Latest Update	23/11/2005

	Parameter	Qual.	Evidence
Location (Lat/Lon)	46.2754 / 13.2009	OD	Based on geological and seismological data.
Length (km)	10	EJ	Inferred from geological data constrained by seismological considerations.
Width (km)	6.4	EJ	Inferred from geological data constrained by seismological considerations.
Min Depth (km)	6.5	LD	Based on geological and seismological data from various authors.
Max Depth (km)	10.2	LD	Based on geological and seismological data from various authors.
Strike (deg)	276	LD	Based on geological and seismological data from various authors.
Dip (deg)	35	LD	Based on geological and seismological data from various authors.
Rake (deg)	110	LD	Based on geological and geodetic data.
Slip Per Event (m)	0.75	ER	Calculated from Mo using the relationship from Hanks and Kanamori (1979).
Slip Rate (mm/y)	0.1 - 0.61	OD	Derived from geodetic measurements.
Recurrence (y)	1230 - 7500	EJ	Inferred from slip rate and average displacement.
Magnitude (Mw)	6.1	LD	Value adopted from the historical earthquake catalogue CPTI04.

1.1.1.1.7. Associated earthquake

Latest Eq	15 Sep 1976 (2/2)	Second shock at 9:21:18 GMT; Amato et al. (1976).
Penultimate Eq	Unknown	See "Commentary" for information.
Elapsed Time	24	As of year 2000 (assigned datum).

The Gemona East Source is the causative fault of the 15 September 1976, 09:21 earthquake.

The geometry of the Gemona East Source have been constrained following the work of several papers, dealing with the Friuli 1976 seismic sequence. The source dimensions have been scaled using the measured average seismological stress drop of the Friuli 1976 seismic sequence, constrained by empirical relationship between magnitude and rupture area.

- the WNW strike is chosen according with the general orientation of mapped tectonic structures and with the mean orientation of the nodal planes of the focal mechanisms (see Figure "Summary of mechanisms for 1976 sequence" from Pondrelli et al., 2001); the position of the fault is constrained by the epicentral location and by modelling of repeated levelling measurements (Talamo et al., 1978);
- the fault dips 35 towards the north in agreement with the geometry of the blind thrusts imaged in the seismic profiles, with the preferred nodal plane of the focal mechanisms, and with the spatial distribution of the aftershocks;
- the rake (110) follows seismological observations (focal mechanisms) (see Figure "Summary of mechanisms for 1976 sequence" from Pondrelli et al., 2001);

- the down-dip width (6.4 km) is based on the thickness of the seismogenic layer derived from the distribution of the 1976 earthquake aftershocks (Finetti et al., 1976), and on empirical relationships of rupture area with respect to magnitude;
- the minimum and maximum depths (6.5 and 10.2 km respectively) follow the observations of Cipar (1980), the aftershocks distribution, and general subsurface geological observations;
- the length (10.0 km) is based on scaling with width and on geological and seismological observations.
  See ITIS120 Gemona South commentary for further information.

OPEN QUESTIONS

1) What are the relationships between the Gemona East Source and the Gemona South and Montenars sources?

2) What are its relationships with the strike-slip Idrija fault system?

3) How are the sources of the 1976 mainshocks linked with the trascurrent systems outcropping in the Slovenia region?

ITCS065 Medea

Code	**ITCS065**		
Name	Medea		
Compiled By	Burrato, P.		
Latest Update	03/08/2006		
	Parameter	**Qual.**	**Evidence**
Min Depth (km)	0.5	LD	Based on geological data from Galadini et al. (2005).
Max Depth (km)	7	LD	Based on geological data from Galadini et al. (2005).
Strike (deg)	255 - 300	LD	Based on geological data from Galadini et al. (2005).
Dip (deg)	40 - 50	LD	Based on geological data from Galadini et al. (2005).
Rake (deg)	110 - 130	LD	Based on geological and geodetic data.
Slip Rate (mm/y)	0.1 - 1	EJ	Unknown, values assumed from geodynamic constraints.
Max Magnitude (Mw)	6.4	OD	Derived from maximum magnitude of associated individual source(s).

This composite source straddles the region to the southeast of the Friuli foothills, toward the Italy-Slovenia border. It is the southernmost expression of the overall thrust system of the eastern Southalpine Chain that borders the Veneto-Friuli plain in north-eastern Italy and that continues onto the Italy-Slovenia border.

Historical and instrumental catalogues (Boschi et al., 2000; Gruppo di Lavoro CPTI, 2004; Pondrelli et al., 2006; Guidoboni et al., 2007) show a sparse intermediate (4.5 < Mw 5.0) seismicity in this region, with the notable exception of the 23 April 1279 (Mw 5.4) earthquake.

Among the active thrusts that deform the central Friuli plain south of the city of Udine, this source is the only one considered capable of releasing large earthquakes due to its deeper rooting (Galadini et al., 2005).

A segment of this source has been recognized based on its seismogenic potential. For an in-depth analysis of seismogenesis in this region, the reader can refer to the related individual source.

The strike of this source was based on that of the mapped structures and on data by the work of Galadini et al. (2005) (N255°-300°). The dip was based on subsuirface data (40°-50°). Rake is is assumed to represents oblique thrusting, based on seismological observations (110-130). The minimum and maximum depth were based on tectonic and geometrical considerations concerning the thrust geometry (0.5 and 7.0 km, respectively). The slip rate was based on geological observations (0.1 – 0.28 mm/y). The maximum magnitude was taken from that of the largest individual source associated (Mw 6.4).

Associated Individual Seismogenic Source(s)

ITIS126 Medea

Code	**ITIS126**
Name	Medea
Compiled By	Burrato, P., and F. Galadini
Latest Update	23/11/2005

	Parameter	Qual.	Evidence
Location (Lat/Lon)	45.967 / 13.3798	LD	Based on geological data from Galadini et al. (2005).
Length (km)	16	EJ	Inferred from geological data constrained by seismological considerations.
Width (km)	9	EJ	Inferred from geological data constrained by seismological considerations.
Min Depth (km)	0.5	LD	Based on geological data from Galadini et al. (2005).
Max Depth (km)	6.9	LD	Based on geological data from Galadini et al. (2005).
Strike (deg)	285	LD	Based on geological data from Galadini et al. (2005).
Dip (deg)	45	LD	Based on geological data from Galadini et al. (2005).
Rake (deg)	120	LD	Based on geological and geodetic data.
Slip Per Event (m)	1	ER	Calculated from Mo using the relationship from Hanks and Kanamori (1979).
Slip Rate (mm/y)	0.1 - 0.28	LD	Based on geological observations.
Recurrence (y)	3571 - 10000	EJ	Inferred from slip rate and average displacement.
Magnitude (Mw)	6.4	ER	Calculated using the relationships from Wells and Coppersmith (1994).

The geometry and strike of the Medea Source have been constrained following the work of Galadini et al., 2005. The source have been modified, scaling the dimensions proposed by these authors, with the average seismological stress drop of the Friuli 1976 seismic sequence, assumed to be characteristic in this region for thrust faulting earthquakes, constrained by empirical relationship between magnitude and rupture area (Poli et al., 2006).

The Medea Source is one of the thrusts that deform the central Friuli plain south of Udine (Udine-Buttrio and Pozzuolo thrusts). Hovever it is the only considered able to generate large earthquakes due to its deeper detachment (Galadini et al., 2005).

The activity of this thrust is testified by the deformation of the aggrading surface of the LGM. It was described at depth thanks to the available seismic exploration lines.

The seismogenic potential of the buried thrusts of the Friuli plain, seems to be controlled by the presence of the older Dinaric thrusts, that limit the depth of the detachment of the westernmost structures.

The evidence of activity of the thrusts present in the subsurface of the Friuli plain is in contrast with the lack of historical and instrumental seismicity of this area.

OPEN QUESTIONS

There are fundamental questions regarding the seismogenic potential of the Medea Source.

1) Can the Medea Source generate M 6+ eartquakes? Or the seismic activity of this sector is concentrated along the thrusts of the 1976 seismic sequence and further north?

2) Can also the Udine-Buttrio and Pozzuolo thrusts generate small/intermediate, although locally damaging due to the shallow hypocenter, earthquakes?

SICS003 Polovnik

Code	**SICS003**
Name	Polovnik
Compiled By	Kastelic, V., and P. Burrato
Latest Update	29/04/2009

	Parameter	Qual.	Evidence
Min Depth (km)	1	EJ	Inferred from geological and geomorphological observations.
Max Depth (km)	7	EJ	Inferred from geological and geomorphological observations.
Strike (deg)	275 - 310	OD	Based on geological and geomorphological observations.
Dip (deg)	45 - 70	OD	Based on geological and geomorphological observations.
Rake (deg)	120 - 145	OD	Based on geological and geodetic data.
Slip Rate (mm/y)	0.1 - 1	EJ	Unknown, values assumed from geodynamic constraints.
Max Magnitude (Mw)	5.5	EJ	Assumed from regional seismological data.

The Polovnik source lies in the zone of interaction between NW-SE oriented trace of the Idrija Fault and E-W oriented Gemona – Kobarid thrust system. This area in fact is characterised by the gradual change in the strike as well as the dip and rake of the structures accomodating the different kinematics between activey deforming thrust belt to the E and strike-slip zone to the SE.

The depth interval of the sesimogenic source can be set as from 1-7 km based on data of local and regional geologic setting. The average strike of the source was based on geologic maps (Buser, 1986) and field and geomorphological observations. Average dip and rake of the source was infered from published work on local geologic conditions (Buser, 1986; Kastelic et al., 2008) and field observations. Values of minimum and maximum slip rates were set to values of 0.1 to 0.5 mm/yr respectively, based on considering measured horizontal velocity vectors obtained from GPS measurements (Grenerczy et al., 2005) and considering geometrical characteristics of the source. Maximum magnitude of the source was assigned as MW = 5.5 taking into consideration regional geologic conditions and seismologic data.

SICS001 - Bovec-Tolminka Springs

Code	**SICS001**		
Name	Bovec-Tolminka Springs		
Compiled By	Kastelic, V., and P. Burrato		
Latest Update	29/04/2009		
	Parameter	**Qual.**	**Evidence**
Min Depth (km)	1	EJ	Inferred from geological observations and earthquake data.
Max Depth (km)	10	EJ	Inferred from geological observations and earthquake data.
Strike (deg)	300 - 320	OD	Based on field work, structural and geomorphologic observations.
Dip (deg)	70 - 85	OD	Based on field work structural and geomorphologic observations.
Rake (deg)	160 - 180	OD	Based on interpretation of microkinematic field data and seismological data.
Slip Rate (mm/y)	0.1 - 0.5	EJ	Calculated from geodetic and geodynamic data.
Max Magnitude (Mw)	5.8	LD	Derived from the largest instrumentally registrated earthquake.

The Bovec-Tolminka Springs source lies on the NW-SE trending, dextral strike-slip Ravne Fault that runs through the eastern part of the Southern Alps. The surface trace of the Ravne Fault can be observed in the field and on satellite and digital topographic imagery over a distance of approximately 30 km and along its trace exhibits segmented geometry in a form of right stepping segments.

The depth interval of the sesimogenic source is set from 1-10 km based on data of local and regional geologic setting. The average strike and dip of the source was based on the base of field measurements of the geometrical characteristics of the fault traces (Kastelic et al., 2008) and characteristics obtained on spatial distribution of the latest seismic events and their focal mechanism solutions (Bajc et al., 2001; Kastelic, 2008). Average rake of the source was determined by using measured data on microkinematic indicators present within the fault zone combained with focal mechanism solutions.

Values of minimum and maximum slip rates were set to values of 0.1 to 0.5 mm/yr respectively, based on considering measured horizontal velocity vectors obtained from GPS measurements (Grenerczy et al., 2005) and considering geometrical characteristics of the source. Maximum magnitude of the source was assigned as MW = 5.7 after the April 12th 1998 earthquake, that is strongest earthquake reported for the Ravne Fault.

Associated Individual Seismogenic Source(s)

SIIS002 - Bovec-Krn

Code	**SIIS002**
Name	Bovec-Krn
Compiled By	Kastelic, V., and P. Burrato
Latest Update	29/04/2009

	Parameter	Qual.	Evidence
Location (Lat/Lon)	46.2948 / 13.662	LD	Primarily based on instrumental earthquake location.
Length (km)	13	OD	Based on various geological and seismological data.
Width (km)	6.3	LD	Based on various geological and seismological data by Bajc et al. (2001).
Min Depth (km)	3	LD	Based on various geological and seismological data by Bajc et al. (2001).
Max Depth (km)	9.2	LD	Based on various geological and seismological data by Bajc et al. (2001).
Strike (deg)	315	OD	Based on various geological and seismological data.
Dip (deg)	82	LD	Based on various geological and seismological data by Bajc et al. (2001).
Rake (deg)	171	LD	Based on various geological and seismological data by Bajc et al. (2001).
Slip Per Event (m)	0.18	LD	Based on seismological data by Bajc et al. (2001).
Slip Rate (mm/y)	0.1 - 0.5	LD	Values assumed from geodetic measurements.
Recurrence (y)	360 - 1800	EJ	Inferred from slip rate and average displacement.
Magnitude (Mw)	5.7	LD	Based on seismological data.

1.1.1.1.8. Associated earthquake

Latest Eq	12 Apr 1998	INGV-CNT Seismic Bulletin.
Penultimate Eq	Unknown	See "Commentary" for information.
Elapsed Time	2	As of year 2000 (assigned datum).

The Bovec-Krn Source belongs to the NW-SE trending, dextral strike-slip Ravne Fault.

The DISS compilers defined its surface trace as the course of the actual fault plane, which is visible in some parts, whereas in other parts, it is indicated at the surface by increased fracturing and erosional incision as a consequence of deeper fault-movements. At the NW end of the surface trace, there are several parallel NW-SE oriented rock-walls a few tens of meters in length and height that could be products of surface rupturing, but any more tangible evidence for surface fault activity is absent. At the SE end of the fault trace towards the Cerkno area, the surface expression of the fault trace is progressively less visible and eventually dies out. The fault is best exposed in its central part around the Tolminka Springs basin over a length of approximately 11 km from the Èez Potoèe pass in the NW to the Tolminske Ravne in the SE. Over its total course, the fault cuts through very diverse topography with relief in excess of 1400 m from lower elevations at 450 m to high mountainous terrain up to 1860 m elevation, including the Krn mountain chain. Ravne Fault along its trace exhibits segmented geometry. Four segments of different length and with slightly different orientation can be distinguished. In the current regional stress field the fault system is dextral, as evidenced by earthquake focal mechanisms, but fault architecture, kinematic indicators, and the degree of rock damage within the fault zone strongly suggest the existence of earlier kinematic phases. The first stage of activity, connected to Eocene thrusting, produced hangingwall uplift on a NW-SE trending, towards NE dipping fault system. Subsequently, the fault zone was disintegrated and displaced by E-W trending thrusts and reverse faults, connected to N-S compression during the Miocene, which resulted in N-S offsets of a few hundreds of meters between the neighbouring fault traces. During the Miocene-Pliocene transition, as a cause in the change of regional tectonics, the NW-SE oriented faults, due to their prefered orientation, were reactivated in dextral strike-slip mode. Previously dismembered fault trace started acting as a segmented, right-stepping fault array in the overall transpressional tectonic setting, associated with formation of small-scale transtensional basins in the overstep zones.

The Bovec-Krn Source is located at the NW strand of the fault trace from the NE outskirts of the Bovec Basin as the NW limit to the Tolminka Springs basin at its SE termination. Both source boundaries are geologically conditioned and represent at its NW end an area where the NW-SE oriented fault trace fades out and interacts with E-W oriented thrust faults that streach to this part of the Julian Alps from the west. The SE boundary of the source is represented by a local transtensional basin of Tolminka Springs formed in the over-stepping zone of two segments of the Ravne Fault. The geometry and dimensions of the proposed source is based on seismological work of Bajc et al. (2001) and geological and seismological data by Kastelic et al. (2008). Slip rates for the source are obtained by taking into consideration data on horizontal velocity obtained by GPS measurements (Grenerczy et al., 2005) and local geological considerations.

On 12th April 1998 a Mw 5.7 earthquake occured along the Ravne Fault. The 1998 earthquake sequence is distributed in a NW-SE direction. The seismic cluster stretches from Planina Golobar in the NW end to Tolminka Springs basin in the SE end of Ravne Fault trace where the seismic activity ceased. The location of the main shock is situated 4.5 km off the NW end of the cluster. Fault plane solution for the main event gives a dextral strike-slip kinematics on a subvertical, slightly towards NE inclined fault plane. On 12th July 2004 just 1.1 km to the WNW off the location of the 1998 main shock, a M 5.2 event took place. The entire seismic sequence, because of its lesser magnitude, also covers less area around the fault compared to the 1998 sequence. The spatial distribution of aftershocks is not as homogeneous in direction as for the 1998 cluster. Two branches of aftershocks can be observed; one line continues in a NW-SE direction rupturing the same area as the 1998 aftershocks, while the other line branches off in an E-W direction from Planina Predolina towards the village of Èezsoèa. Focal mechanism of the main event gives a dextral strike slip with a minor reverse component displacement on a medium, towards SW dipping fault plane. The brench of the aftershocks continuing in the NW direction exhibit dextral strike-slip kinematics, while events located to the east of the main event all give reverse displacements on E-W oriented planes. Such characteristics speak of contemporary activity both on NW-SE oriented strike-slip aw well as on E-W oriented thrust/reverse faults present in the region.

OPEN QUESTIONS

1) What is the average return time of the Bovec-Krn Source? How is partitioned the slip budget among the different strike-slip strands in Slovenia?

2) What are the relationships between the Bovec-Krn Source and the sources of the 1976 Friuli seismic sequence?

SICS002 - Tolmin-Idrija

Code	**SICS002**		
Name	Tolmin-Idrija		
Compiled By	Kastelic, V., and P. Burrato		
Latest Update	29/04/2009		
	Parameter	**Qual.**	**Evidence**
Min Depth (km)	1	EJ	Inferred from geologic and regional structural setting.
Max Depth (km)	14	EJ	Inferred from geologic and regional structural setting.
Strike (deg)	290 - 330	LD	Based on geologic and geomorphological maps and data.
Dip (deg)	70 - 85	EJ	Inferred from geological and geomorphological observations.
Rake (deg)	160 - 180	EJ	Inferred from geological and geodetic data.
Slip Rate (mm/y)	0.1 - 0.5	EJ	Calculated from geodetic and geodynamic data.
Max Magnitude (Mw)	6.8	OD	Derived from maximum magnitude of associated individual source(s).

The Idrija Fault is responsible for the strongest event recorded in the region that occured on March 26th 1511, as well as an M 5.8 event of January 1st 1926. The Ravne Fault, that lies just 8 km to the north and exhibits same geometrical and mechanical characteristics as the Idtija Fault has hosted moderate sized earthquakes in 1998 and 2004 with magnitude values of 5.7 and 5.2 respectivately. Approximately 30 km to the E from the Tolmin - Idrija source lies the source of the 1976 Gemona earthquake that occured on E – W oriented thrust plane.

The Tolmin - Idrija source lies on the NW-SE trending, dextral strike-slip Idrija Fault that in its NW part runs through the eastern part of the Southern Alps, while at its SE end extends to the unit of Dinarides. The source extends for 80 km along the strike of the Idrija fault system, that exhibits right-stepping segmentation along its trace. The northwestern boundary of the source is in the area of interaction between the E-W trending Gemona-Kobarid thrust with the NW-SE oriented strand of the Idrija Fault System. The activity of the south-eastern part of the source is testified by moderate historical and instrumental seismicity. The Mw 5.8 1926 Cerknica earthquake is located in the area of a segment over-step zone.

The depth interval of the sesimogenic source can be set from 1-14 km based on data of local and regional geologic setting. The average strike of the source was obtained on the base of published geologic maps (Buser, 1986) and field and geomorphological observations. Average dip and rake of the source was infered from published work on local geologic conditions (Buser, 1986; Cunningham et al., 2006) and geomorphological data. Values of minimum and maximum slip rates were set to values of 0.1 to 0.5 mm/yr respectively, based on considering measured horizontal velocity vectors obtained from GPS measurements (Grenerczy et al., 2005) and considering geometrical characteristics of the source. Maximum magnitude of the source was assigned as MW = 6.8 after the March 26th 1511 earthquake, that is strongest earthquake reported for the Idrija Fault as well as the region of eastern Southern Alps and northern Dinarides.

Associated Individual Seismogenic Source(s)

SIIS001 – Idrija

Code	**SIIS001**		
Name	Idrija		
Compiled By	Kastelic, V., and P. Burrato		
Latest Update	29/04/2009		
	Parameter	**Qual.**	**Evidence**
Location (Lat/Lon)	46.084 / 13.8853	LD	Inferred from geological data and seismological consideration.
Length (km)	50	LD	Based on seismological data from Fitzko et al. (2005).
Width (km)	12.6	LD	Based on seismological data from Fitzko et al. (2005).
Min Depth (km)	1	LD	Based on geological data from Fitzko et al. (2005).
Max Depth (km)	13.4	AR	Derived from dip, width and min depth.
Strike (deg)	310	LD	Based on geological fault trace.
Dip (deg)	80	LD	Based on geological data used by Fitzko et al. (2005).
Rake (deg)	176	LD	Based on geological and seismological data used by Fitzko et al. (2005).
Slip Per Event (m)	1	ER	Calculated from Mo using the relationship from Hanks and Kanamori (1979).
Slip Rate (mm/y)	0.1 - 0.5	LD	Values assumed from geodetic measurements.
Recurrence (y)	2000 - 10000	EJ	Inferred from slip rate and average displacement.
Magnitude (Mw)	6.8	LD	Value adopted from the work of Fitzko et al. (2005).

1.1.1.1.9. Associated earthquake

Latest Eq	26 Mar 1511	CPTI04.
Penultimate Eq	Unknown	See "Commentary" for information.
Elapsed Time	489	As of year 2000 (assigned datum).

The Idrija Source is responsible for the 26 March 1511 earthquake that is the largest seismic ever recorded in Slovenia. The location and geometry of the source follow that of the Idrija Fault Zone, one of the best expressed NW-SE trending strike-slip fault system of Western Slovenia. This fault system lays about 8 km to the south of the Ravne Fault zone, responsible for the Mw 5.8 1998 Krn Mts. earthquake.

The DISS compilers propose for the Idrija Source the following geometrical and kinematic characteristics:

- the length is based on scaling with width, constrained by geomorphological observations and empirical relationship between magnitude and rupture area.
- the down-dip width is based on the assumptions made concerning the minimum and maximum faulting depth, constrained by empirical relationship of rupture area with respect to the magnitude;
- the strike is chosen according with the general orientation of mapped tectonic structures belonging to the Dinaric system;
- the fault dips towards the northeast;

- the rake is assumed to be 176 (pure dextral strike-slip) based on strike and on general geodynamic considerations;
- the minimum and maximum depth (1.0 and 13.4 km respectively) are constrained by subsurface geology and by the lack of evidence of coseismic surface faulting;

The Idrija Source is located more to the NW along the Idrija Fault System with respect to the model source proposed by Fitzko et al. (2005). The northwestern boundary of the source can be interpret as the area of interaction between the E-W trending Gemona-Kobarid thrust with the NW-SE oriented strand of the Idrija Fault System. The activity of the south-eastern segment of the Idrija Fault System is testified by moderate historical and instrumental seismicity. The Mw 5.8 1926 Cerknica earthquake is located in this area and could be associated to the rupture of one of the segments of the fault zone.

The 26 March 1511 earthquake is the only event reported in the current catalogues (CPTI, 2004) that can be associated with the Idrija Source based on damage distribution.

The area of the strongest effects of this event falls in the Tagliamento valley (very close to the macroseismic epicentre of the 1976 Friuli seismic sequence) and in western Slovenia. Ribaric (1979) explained this double macroseismic epicenter with the occurrence of two or more major shocks occurring on the thrusts of the Eastern Southern Alps chain and on the Idrija strike-slip system. However more recent studies by Fitzko et al. (2005) showed that the macroseismic field can be more fittingly explained by a large rupture along the Idrija Fault Zone.

This source belongs to the Dinaric fault system, which is characterised by NW-SE orientations and right-lateral reverse movements.

Despite the large magnitude there is no evidence of coseismic surface ruptures along the surface trace of the Idrija Fault.

GPS studies show that in the Friuli region the S-verging thrusts accommodate about 2 mm/yr of regional shortening. About the same budget of movement is accommodated by the right-lateral faults of the Slovenia region. The three most prominent fault zones accomodating the active deformation are the Rasa, the Idrija and the Ravne fault systems, from S to N respectively.

OPEN QUESTIONS

1) What is the average return time of the Idrija Source? Current catalogues (CPTI, 2004), which cover reliably a time span of less than 1,000 years, report only the event in 1511 that can be associated with it.

2) Is the equivalent Magnitude of the 1511 earthquake over-estimated?

3) How can be explained the presence of two zones with the strongest effect in western Slovenjia and in the Tagliamento valley?

4) What are the relationships between the Idrija Source and the sources of the 1976 Friuli seismic sequence?

5) Is the Idrija Fault system characterised mainly by strike-slip movements? Or is it rather an oblique fault?

SICS005 Cividale – Nova Gorica

Code	**SICS005**		
Name	Cividale-Nova Gorica		
Compiled By	Kastelic, V., and P. Burrato		
Latest Update	29/04/2009		
	Parameter	**Qual.**	**Evidence**
Min Depth (km)	1	EJ	Inferred from geologic and regional structural setting.
Max Depth (km)	9	EJ	Inferred from geologic and regional structural setting.
Strike (deg)	300 - 335	OD	Based on geologic and geomorphological field data.
Dip (deg)	40 - 85	OD	Based on geologic and structural field data and geomorphological observations.
Rake (deg)	120 - 180	OD	Based on interpretation of microkinematic field data and seismological data.
Slip Rate (mm/y)	0.1 - 0.5	EJ	Calculated from geodetic and geodynamic data.
Max Magnitude (Mw)	5.5	EJ	Assumed from regional seismological data.

The Cividale – Nova Gorica source lies on NW part of the NNW-SSE trending, dextral strike-slip Raša Fault that runs through the northern parts of the Dinaride structural unit. The source extends for 30 km along the strike of the fault system. At the NW the source extends to the valley of the Soca river, where more to the east a E – W trending Gemona – Tarcento source begins. To the SE the source borders the NW-SE oriented Branik-Ilirska Bistrica source, that covers the SE end of the Raša Fault.

The depth interval of the sesimogenic source can be set from 1-9 km based on data of local and regional geologic setting. The average strike of the source was obtained on the base of published geologic maps (Buser, 1973) and field and geomorphological observations. Average dip and rake of the source was infered from published work on local geologic conditions (Buser, 1973; Gregoric, 2005) and field observations. Values of minimum and maximum slip rates were set to values of 0.1 to 0.5 mm/yr respectively, based on considering measured horizontal velocity vectors obtained from GPS measurements (Grenerczy et al., 2005) and considering geometrical characteristics of the source. Maximum magnitude of the source was assigned as MW = 5.5 taking into consideration regional geologic conditions and seismologic data.

SICS004 - Branik-Ilirska Bistrica

Code	**SICS004**		
Name	Branik-Ilirska Bistrica		
Compiled By	Kastelic, V., and P. Burrato		
Latest Update	29/04/2009		
	Parameter	**Qual.**	**Evidence**
Min Depth (km)	1	EJ	Inferred from geologic and regional structural setting.
Max Depth (km)	12	EJ	Inferred from geologic and regional structural setting.
Strike (deg)	300 - 325	LD	Based on geologic and geomorphological maps and data.
Dip (deg)	70 - 85	LD	Based on geologic, structural and seismological data.
Rake (deg)	160 - 180	EJ	Inferred from geological and seismological data.
Slip Rate (mm/y)	0.1 - 0.5	EJ	Calculated from geodetic and geodynamic data.
Max Magnitude (Mw)	5.5	EJ	Assumed from regional seismological data.

The Branik – Ilirska Bistrica source lies on the SE part of the Raša Fault. At its NW end the source reaches the area of the regional change in the strike style, where the dominating orientation of NW-SE direction becomes more oblique and oriented in E-W sense. The same kind of trend is also observable in the direction of lithological and stratigraphic units in the area, where the Paleocene-Eocene limestones and Eocene flysch units change their regional space position from NW-SE direction at the SE end to E-W oriented exposures at the NW end of the source boundary. According to historical and instrumental eathhquake data seismicity is mainly distributed at the SE part of the source around the Ilirska Bistrica area with seismic deformation releasing in predominantly dextral strike-slip kinematics (Pondrelli et al., 2006).

The depth interval of the sesimogenic source can be set from 1-12 km based on data of local and regional geologic setting. The average strike of the source was based on geologic maps (Buser, 1973) and field and geomorphological observations. Average dip and rake of the source was infered from published work on local geologic conditions (Buser, 1973). Values of minimum and maximum slip rates were set to values of 0.1 to 0.5 mm/yr respectively, based on considering measured horizontal velocity vectors obtained from GPS measurements (Grenerczy et al., 2005) and considering geometrical characteristics of the source. Maximum magnitude of the source was assigned as MW = 5.5 taking into consideration regional geologic conditions and seismologic data.

5.5.4 Seismogenic sources of the northern Apennines (compressional)

The seismicity of the outer northern Apennines arc has always appeared rather scattered and apparently random.

The area is characterized by reverse faulting at widely different depths. A careful reassessment of the typical depth of instrumental earthquakes and an "educated guess" of the depth of the main historical events allowed to match the location of the main earthquakes with geologically documented parts of the same major thrust belt. In particular, deeper earthquakes concentrate along the western portion of the arc, whereas shallower events generally occur along the outer front (Vannoli et al. , 2004; Burrato et al . ,2004; Meletti et al., 2008; Piccinini et al., 2006).

ITCS 023 - Western Piemonte

Code	ITCS023		
Name	Western Piemonte		
Compiled By	Burrato, P.		
Latest Update	03/08/2006		
	Parameter	**Qual.**	**Evidence**
Min Depth (km)	1	OD	Based on inference from intensity data of the 1808 earthquakes.
Max Depth (km)	7	OD	Based on the maximum depth of the individual seismogenic sources.
Strike (deg)	60 - 80	OD	Based on regional geological data.
Dip (deg)	40 - 50	EJ	Inferred from regional geological data.
Rake (deg)	130 - 155	EJ	Inferred from geological data, constrained by orientation of T axes.
Slip Rate (mm/y)	0.1 - 1	EJ	Unknown, values assumed from geodynamic constraints.
Max Magnitude (Mw)	5.7	OD	Derived from maximum magnitude of associated individual source(s).

This composite source belongs to the Monferrato Arc of the Northern Apennines outermost thrust fronts. It includes the blind thrusts forming the western portion of the Monferrato Arc.

Historical and instrumental catalogues (Boschi et al., 2000; Gruppo di Lavoro CPTI, 2004; Pondrelli et al., 2006; Guidoboni et al., 2007) show few moderate earthquakes that hit the Monferrato Arc. The largest events occurred south-west of Torino at the Alps foothills on 2 and 16 April 1808 (Mw 5.7 and 5.6, respectively).

The strike of this source was taken from the general orientation of mapped tectonic structures (N60°-80°). The dip was inferred from regional geological considerations concerning the thrust plane (40°-50°). The rake was assumed to represent thrusting with right-lateral component of motion, based on general geodynamic considerations (130-155). The minimum and maximum depths were inferred by geometrical considerations concerning the depth at which active thrusting is rooted (1.0 and 7.0 km, respectively). The slip rate was inferred from regional geodynamic data (0.1 – 1.0 mm/y). The maximum magnitude was taken from that of the largest historical earthquake occurred in the region (Mw 5.7).

Associated Individual Seismogenic Source(s)

ITIS071 Torre Pellice

Code	ITIS071
Name	Torre Pellice
Compiled By	Burrato, P.
Latest Update	15/06/2006

	Parameter	Qual.	Evidence
Location (Lat/Lon)	44.8414 / 7.26313	OD	Primarily based on the location of the associated historical earthquake.
Length (km)	7	ER	Calculated using the relationships from Wells and Coppersmith (1994).
Width (km)	5	ER	Calculated using the relationships from Wells and Coppersmith (1994).
Min Depth (km)	3	OD	Based on inference from intensity data.
Max Depth (km)	6.5	OD	Based the Min depth, and geometrical calculations.
Strike (deg)	62	EJ	Inferred from regional geological data.
Dip (deg)	45	EJ	Inferred from regional geological data.
Rake (deg)	135	EJ	Inferred from geological data, constrained by orientation of T axes.
Slip Per Event (m)	0.4	ER	Calculated from Mo using the relationship from Hanks and Kanamori (1979).
Slip Rate (mm/y)	0.1 - 1	EJ	Unknown, values assumed from geodynamic constraints.
Recurrence (y)	400 - 4000	EJ	Inferred from slip rate and average displacement.
Magnitude (Mw)	5.7	LD	Value adopted from the historical earthquake catalogue CPTI04.

	Associated earthquake	
Latest Eq	02 Apr 1808	CPTI04.
Penultimate Eq	Unknown	See "Commentary" for information.
Elapsed Time	192	As of year 2000 (assigned datum).

The Torre Pellice Source is associated to the 2 April 1808, M 5.7, earthquake, that is the largest event occurred in historical/instrumental time in this portion of the western Alps foothills. The location and geometry of the source have been inferred using the damage pattern of the associated historical earthquake, constrained by geological data. Diss compilers propose that the seismogenic source is part of the western termination of the Monferrato-Collina Torinese arc, and is characterised by right-lateral transpressive movement.

The present-day tectonic activity of the western Alps is highlighted by moderate seismicity, and few geological/geomorphological observations of recent deformation. Instrumentally recorded extensional earthquakes are mostly concentrated along the crest of the chain, down to a depth of 15 km, while deeper compressional events occur at the transition with the Po Plain and along the Ivrea body. The extensional events follow two subparallel trends, the Piemontais arc to the east and the Brianconais arc to the west. The epicentral area of the 1808 earthquake falls within the Piemontais arc, close to its northern termination.

The 1808 earthquake occurred at the transition between the extensional and compressional zones, as defined by Delacou et al. 2004. No focal mechanism is available for this event, while Delacou et al. (2004) present 2 focal mechanisms of two small, shallow earthquakes (M max 1.6) occurred near the epicenter of the historical event, both characterised by normal faulting solutions and nodal planes oriented NS to NE-SE. This shallow seismicity can be interpreted either as secondary faulting occuring in the extrados of a deeper reverse structure, or as the expression of a truly active extension.

The main shock of the 1808 earthquake was followed by a strong aftershock few hours later, and by another M 5+ earthquake 14 days later (M 5.6, 16 April 1808), which epicenter is located about 6 km east of that of the mainshock.

The two M 5+ earthquakes were felt and produced damages over a wide area, along the western Alps eastern margin, but also across the mountain chain itself. This suggest the probable activation of relatively deep sources.

Due to the low strain rates envisioned by GPS studies, it is expect long return times for earthquakes similar to the 1808 event. The historical catalogue reports very few events occuring along the eastern foothills of the western Alps. Low slip rates and long recurrence times, imply that the geological/geomorphological evidence of the seismogenic sources of damaging M 5+ earthquakes are very difficult to detect in this area.

ITIS073 Pinerolo

Code	**ITIS073**		
Name	Pinerolo		
Compiled By	Burrato, P.		
Latest Update	15/06/2006		
	Parameter	**Qual.**	**Evidence**
Location (Lat/Lon)	44.8688 / 7.36305	OD	Primarily based on the location of the associated historical earthquake.
Length (km)	6	ER	Calculated using the relationships from Wells and Coppersmith (1994).
Width (km)	4.5	ER	Calculated using the relationships from Wells and Coppersmith (1994).
Min Depth (km)	3	OD	Based on inference from intensity data.
Max Depth (km)	6.2	OD	Based the Min depth, and geometrical calculations.
Strike (deg)	76	EJ	Inferred from regional geological data.
Dip (deg)	45	EJ	Inferred from regional geological data.
Rake (deg)	150	EJ	Inferred from geological data, constrained by orientation of T axes.
Slip Per Event (m)	0.4	ER	Calculated from Mo using the relationship from Hanks and Kanamori (1979).
Slip Rate (mm/y)	0.1 - 1	EJ	Unknown, values assumed from geodynamic constraints.
Recurrence (y)	400 - 4000	EJ	Inferred from slip rate and average displacement.
Magnitude (Mw)	5.6	LD	Value adopted from the historical earthquake catalogue CPTI04.

Associated earthquake		
Latest Eq	16 Apr 1808	CPTI04.
Penultimate Eq	Unknown	See "Commentary" for information.
Elapsed Time	192	As of year 2000 (assigned datum).

The Pinerolo Source is associated with the 16 April 1808, M 5.6, earthquake, that is one of the largest event occurred in historical/instrumental time in this portion of the western Alps foothills. This earthquake occurred 14 days after the mainshock of the M 5.7 1808 sequence, and struck few kilometres west of its epicentral area.

The location and geometry of the source have been inferred using the damage pattern of the associated historical earthquake, constrained by geological data. DISS compilers propose that the seismogenic source is part of the western termination of the Monferrato-Collina Torinese arc, and is characterised by right-lateral transpressive movement.

OPEN QUESTIONS

1) There exists a fundamental question concerning the geometry and the faulting mechanism of this source, since there are very few geological and seismological data that can be used to constrain these parameters.

2) Another question regards the possible existence of nearby sources, and their geometry and location eastward of this source along the Collina Torinese thrust.

ITCS027 Bore-Montefeltro-Fabriano-Laga

Code	**ITCS027**		
Name	Bore-Montefeltro-Fabriano-Laga		
Compiled By	Burrato, P., and S. Mariano		
Latest Update	24/09/2007		
	Parameter	**Qual.**	**Evidence**
Min Depth (km)	12	OD	Based on structural geology and geodynamic constraints.
Max Depth (km)	22	OD	Based on structural geology and geodynamic constraints.
Strike (deg)	90 - 160	OD	Based on geological constraints and structural geology.
Dip (deg)	20 - 55	OD	Based on geological constraints and structural geology.
Rake (deg)	70 - 110	EJ	Inferred from geological data.
Slip Rate (mm/y)	0.1 - 1	EJ	Unknown, values assumed from geodynamic constraints.
Max Magnitude (Mw)	6.2	OD	Derived from maximum magnitude of associated individual source(s).

This is the more internal compressive seismogenic sources of the northern and central Apennines. The structures pertaining to this source are recognized along the whole apenninic ridge from the Laga mountains to the Emilian Apennines.

The DISS dataset propose that the Northern Apennines seismogenic area is located between 12 and 21 km on a ramp of a major thrust emerging along the Adriatic coastline. This regional thrust is well imaged in the CROP03 seismic reflection profile (Barchi et al., 1998; Finetti et al., 2001; Lavecchia et al., 2004), and has been interpreted: 1) as a major lithospheric structure, cutting the whole crust from the metamorphic basement up to the higher levels (Barchi et al., 1998; Lavecchia et al., 2003, 2004); or 2) or as one of the leading elements of the accretionary prism of the Apennine belt (Bally et al. 1986; Doglioni et al. 1994). In this last case the earthquakes generate at the interface where the sedimentary cover is delaminated from the metamorphic basement.

The geometry of this seismogenic area is constrained by the individual sources contained within: the strike ranges between 88° (Loiano source) and 160° (Camerino and Sarnano sources), and the dip of the area ranges between 20° and 54° toward the SW. The rake is assumed to be of pure thrusting (90°) based on general geodynamic consideration.

The individual seismogenic sources contained within this source from north to south are: 1) Neviano degli Aduini; 2) Loiano; 3) Cagli; 4) Fabriano; 5) Camerino; and 6) Sarnano.

These sources were identified analysing the macroseismic fields of their associated earthquakes, and using the interpretation of deep reflection profiles.

The main differences in the interpretation of the structural style of this region concern the position of the basal decollement level of the thrusting, and the presence or not of secondary decollement levels. Some researchers (Bally et al., 1986; Doglioni et al., 1994) indicate the bottom of the Triassic evaporites as the basal decollement level, and propose that a thin-skinned tectonic has characterized the Paleogene-Neogene evolution of the belt. Other researchers (Barchi et al., 1998; Finetti et al., 2001; Lavecchia et al., 2003) consider that also the upper portion of the magnetic basement was involved in thrusting, and propose a thick-shinned structural style. In general there is a good agreement among the researches (e.g.: Coward et al., 1999; Barchi et al., 1998; Calamita et al., 1994) about the presence of two main decollement levels inside the accretionary prism, the lower coinciding with the bottom of the Triassic evaporites, on which the major thrust ramps originate, and the shallower coinciding with the Marne a Fucoidi or Scaglia Cinerea formation, on which minor thrusts sheet detach.

The deformation style is characterized by two main structural levels: 1) a lower level consisting of deep and broad anticlines deforming the Mesozoic-Paleogene carbonate succession, produced by thrust faults detaching on the Triassic evaporites; and 2) a shallow level made up of small and tight anticlines, found in the axial zones of the major anticlines, and developed in the Neogene foredeep sediments. These last structures show a more complex structural pattern with respect the deeper ones.

Other geometrical features of this region are: 1) the occurrence of complex thrust trajectories, due to the presence of several potential detachment levels in the sedimentary multilayer; 2) decreasing upward wavelength of the anticlines; and 3) disharmony between different structural levels.

The Northern Apennines composite source it is located to the west of the Pesaro-Senigallia and Southern Marche seismogenic areas, that are associated with shallower seismicity. This set of structures can be interpret as the same leading lithospheric thrust recognized along the central Apennines, which activation in different time and at different depths produces damaging earthquakes along two parallel strips.

OPEN QUESTIONS

1) Are the Northern Apennines characterized by active subduction or present deformation is taken up by major lithospheric thrusts?

2) Are the deep seismogenic sources segments of the basal decollement of the accretionary prism, or rather are they portions of the most external lithospheric thrust?

3) If subduction is active in the Northern Apennines, is the magnetic basement involved in thrusting? So, the structural style in this region is thin- or thick-skinned?

4) How is it possible to explain the upper crustal seismicity of this region, (with hypocenter depths ranging between 15 and 21 km), in a thin-skinned tectonic context?

5) Is the Northern Apennines seismogenic area a deep segment of a major regional thrust? If so, is this thrust laterally continuous from the Southern Marche to the Po Plain?

6) Is the Northern Apennines upper crustal seismicity related with the easternmost shallower seismicity found along the Adriatic coast line? If so, does the shallower and deeper seismicity occur at different depth on the same thrust fault?

Associated Individual Seismogenic Source(s)

ITIS135 Neviano degli Aduini

Code	**ITIS135**			
Name	Neviano degli Arduini			
Compiled By	Vannoli, P.			
Latest Update	26/04/2010			
	Parameter		**Qual.**	**Evidence**
Location (Lat/Lon)	44.5467 10.3338	/	OD	Based on INGV-CNT Seismic Bulletin.

Length (km)	4.9	ER	Calculated using the relationships from Wells and Coppersmith (1994).
Width (km)	3.9	ER	Calculated using the relationships from Wells and Coppersmith (1994).
Min Depth (km)	18.5	AR	Derived from dip, width and max depth.
Max Depth (km)	21.7	LD	Based on seismological data.
Strike (deg)	98	LD	Based on RCMT focal mechanism.
Dip (deg)	55	LD	Based on RCMT focal mechanism.
Rake (deg)	79	LD	Based on RCMT focal mechanism.
Slip Per Event (m)	0.3	OD	Based on seismological data.
Slip Rate (mm/y)	0.1 - 0.5	EJ	Unknown, values assumed from geodynamic constraints.
Recurrence (y)	600 - 3000	EJ	Inferred from slip rate and average displacement.
Magnitude (Mw)	5.4	LD	Based on seismological data.

Associated earthquake		
Latest Eq	23 Dec 2008	INGV-CNT Seismic Bulletin.
Penultimate Eq	Unknown	See "Commentary" for information.
Elapsed Time	-8	As of year 2000 (assigned datum).

The Neviano degli Ardiuni Source is included in the Database as a 4,9 km-long, N98-striking, S-dipping blind thrust fault. The strike, dip and rake of the fault was chosen following the focal solution of the 23 December 2008, Mw 5.4 earthquake contained in the Centroid Moment Tensor Catalog, available at the web site http://www.bo.ingv.it/RCMT/searchRCMT.html.

The main shock occured at 23 km of depth, and the most of the shocks are located below 20 km depth (data from ISIDE, Italian Seismic Bulletin, Istituto Nazionale di Geofisica e Vulcanologia, available online at http://iside.rm.ingv.it/iside/standard/index.jsp). The earthquake was felt over a wide area due to its depth.

OPEN QUESTIONS

1) What are the structural relationships between the Neviano degli Ardiuni Source and the more surficial thrust ramps emerging along the foothills of the northern Apennines?

2) Is the Neviano degli Ardiuni Source in a structural position similar to that of the Loiano Source responsible for the 14 September 2003 earthquake, located near Bologna, about 80 km South-Eastern?

3) Is the Neviano degli Ardiuni Source in a structural position similar to that of the sources responsible for the deep thrust faulting earthquakes of the Marche region (more to the SE)?

ITIS058 Loiano

Code	**ITIS058**		
Name	Loiano		
Compiled By	Vannoli, P., and P. Burrato		
Latest Update	31/08/2006		
	Parameter	**Qual.**	**Evidence**
Location (Lat/Lon)	44.2479 / 11.3972	LD	Based on data from Piccinini et al. (2006).
Length (km)	4	ER	Calculated using the relationships from Wells and Coppersmith (1994).
Width (km)	3.4	ER	Calculated using the relationships from Wells and Coppersmith (1994).
Min Depth (km)	16.4	AR	Derived from dip, width and max depth.
Max Depth (km)	19.1	LD	Based on seismological data.
Strike (deg)	94	LD	Based on data by Pondrelli et al. (2006).
Dip (deg)	53	LD	Based on data by Pondrelli et al. (2006).
Rake (deg)	107	LD	Based on data by Pondrelli et al. (2006).
Slip Per Event (m)	0.3	OD	Based on seismological data.
Slip Rate (mm/y)	0.1 - 1	EJ	Unknown, values assumed from geodynamic constraints.
Recurrence (y)	300 - 3000	EJ	Inferred from slip rate and average displacement.
Magnitude (Mw)	5.3	LD	Based on seismological data.

1.1.1.1.10. Associated earthquake

Latest Eq	14 Sep 2003	INGV-CNT Seismic Bulletin.
Penultimate Eq	Unknown	See "Commentary" for information.
Elapsed Time	-3	As of year 2000 (assigned datum).

The Loiano Source is included in the Database as a 4 km-long, N94-striking, SE-dipping blind thrust fault. The strike, dip and rake of the fault was chosen following the focal solution of the 14 September 2003, Mw 5.3 earthquake contained in the Italian CMT catalogue (Pondrelli et al. [2006]).

The main shock occured at 20 km of depth, and the aftershocks were confined between 15 and 22 km of depth, and showed a very sharp NE-SW alignment. Almost all of the aftershocks were located E of the main shock.

Piccinini et al [2006] analysing the 2003 seismic sequence, on the basis of the depth distribution of the hypocenters of the aftershocks, suggested that the main shock occurred on a NW-dipping back-thrust of the northern Apennines chain.

Conversely, the DISS dataset suggests that the main shock (occurred on a SE-dipping plane) triggered an aftershock sequence along a deep, subvertical fault corresponding with the Prato-Sillaro Line (Auct.).

The issue of the seismogenic potential of the inherited transversal structures follows this hypothesis.

The earthquake, besides being felt over a wide area, did not produce any damage due to its depth.

OPEN QUESTIONS

1) What are the structural relationships between the Loiano Source and the more superficial thrust ramps emerging along the foothills of the northern Apennines?

2) Is the Loiano Source in a structural position similar to that of the sources responsible for the deep thrust faulting earthquakes of the Marche region (more to the SE)?

3) What is the seismic potential of the old, inherited transverse structure? Do they host only small magnitude sequences? Do they act only as segment boundaries for the larger thrust ramps?

ITCS018 Rivanazzano Stradella

Code	**ITCS018**
Name	Rivanazzano-Stradella
Compiled By	Burrato, P., and S. Mariano
Latest Update	07/09/2007

	Parameter	**Qual.**	**Evidence**
Min Depth (km)	2	OD	Based on geological data from various authors.
Max Depth (km)	8	OD	Based on geological data from various authors.
Strike (deg)	30 - 50	OD	Based on geological data from various authors.
Dip (deg)	20 - 45	OD	Based on geological data from various authors.
Rake (deg)	60 - 90	EJ	Inferred from geological data.
Slip Rate (mm/y)	0.1 - 0.5	EJ	Derived from geological data concerning adjacent structures.
Max Magnitude (Mw)	5.5	EJ	Assumed from regional seismological data.

This is the composite seismogenic source closer to the Tortona site and straddles the region from to the southwest of the city of Pavia (to the north) and Northern Apennines foothills between the Emilia and Piemonte regions. It belongs to the Northern Apennines outer thrust front. This front is a NW-verging fault system at the north-western tip of the Northern Apennines chain, well into the Po Plain. It marks the northerly termination of damaging seismogenesis in the Apennines.

Historical and instrumental catalogues (Boschi et al., 2000; Gruppo di Lavoro CPTI, 2004; Pondrelli et al., 2006; Guidoboni et al., 2007) show a lack of significant seismicity in this region, with the notable exception of the 9 October 1928 (Mw 5.7) earthquake that hit the Valle dello Staffora area, to the southwestern border of the Source.

This source (together with the ITCS044 and ITCS009) represents the hypothesized westerly active arc where the Southern Alpine thrust and the Apennines come closer and may account for the intermediate seismicity of the region and its seismogenic potential.

The strike of the source was based on that of the mapped regional structures (N30°-50°). The dip was based on geological observations and geometrical considerations (20°-45°). The rake was assumed to represent oblique thrusting, based on geological observations (60-90). The minimum and maximum depth were based on tectonic and geometrical considerations concerning the thrust geometry (2.0 and 8.0 km, respectively). The slip rate was inferred from geological observations in adjacent structures that share the same tectonic environment with the Rivanazzano-Stradella Source (0.1 – 0.5 mm/y). The maximum magnitude was assumed from regional seismicity (Mw 5.5).

ITCS044- Portalbera – Cremona

Code	ITCS044
Name	Portalbera-Cremona
Compiled By	Burrato, P., and S. Mariano
Latest Update	06/09/2007

	Parameter	Qual.	Evidence
Min Depth (km)	2	OD	Based on geological data from various authors.
Max Depth (km)	7	OD	Based on geological data from various authors.
Strike (deg)	30 - 115	OD	Based on geological data from various authors.
Dip (deg)	20 - 40	OD	Based on geological data from various authors.
Rake (deg)	80 - 100	EJ	Inferred from geological data.
Slip Rate (mm/y)	0.1 - 0.5	EJ	Derived from geological data concerning adjacent structures.
Max Magnitude (Mw)	5.5	EJ	Assumed from regional seismological data.

Associated Active Faults or Folds

#	Type	Name	Reference
125	Fold	San Colombano	Toscani et al. [2006]

ITCS044 Portalbera - Cremona Updates

Site of measurement		Age		Slip rate component	Reference	
Lat	**Lon**	**Age of marker**	**Age intervals (Myr)**	**Dip parallel (mm/yr)**	**Authors**	**Year**
45,2145	9,5983	Upper Pleistocene	0,00 - 0,45	0,03	Maesano et al.	2010
45,2145	9,5983	Middle Pleistocene	0,45 - 0,65	0,06	Maesano et al.	2010
45,2145	9,5983	Middle Pleistocene	0,65 - 0,85	0,09	Maesano et al.	2010
45,2145	9,5983	Lower Pleistocene	0,85 - 1,80	0,10	Maesano et al.	2010
45,2145	9,5983	Pliocene	1,80 - 5,30	0,71	Maesano et al.	2010
45,2017	9,7300	Pleistocene	0,00 - 1,80	0,51	Maesano et al.	2011
45,2017	9,7300	Lower Pleistocene	1,80 - 2,60	0,56	Maesano et al.	2011
45,2017	9,7300	Upper Pliocene	2,60 - 3,60	0,25	Maesano et al.	2011

This composite source straddles the region from the cities of Pavia (to the west) to Cremona (to the east), between the Ticino and Adda R. valleys, and belongs to the Northern Apennines outer thrust front. This front is a N- to NE-verging fault system at the north-western tip of the Northern Apennines chain, well into the Po Plain. It marks the northerly termination of damaging seismogenesis in the Apennines.

Historical and instrumental catalogues (Boschi et al., 2000; Gruppo di Lavoro CPTI, 2004; Pondrelli et al., 2006; Guidoboni et al., 2007) show a sparse intermediate (4.5 < Mw 5.0) seismicity in this region, with the exception of the 28 July 1276 (Mw 5.1) earthquake and the 15 May 1951 (Mw 5.2) event that hit the Lodigiano area.

This source (together with the ITCS018 and ITCS009) represents the hypothesized active arc where the Southern Alpine thrust and the Apennines come closer, and may account for the intermediate seismicity of the region and its seismogenic potential.

The strike of this source was based on that of the mapped regional structures (N30°-115°). The dip was based on geological observations and geometrical considerations (20°-40°). The rake was assumed to represent pure thrusting, based on geological observations (80-100). The minimum and maximum depth were based on tectonic and geometrical considerations concerning the thrust geometry (2.0 and 7.0 km, respectively). The slip rate was inferred from geological observations in adjacent structures that share the same tectonic environment with the Portalbera-Cremona source (0.1 – 0.5 mm/y). The maximum magnitude was assumed from regional seismicity (Mw 5.5).

The update values for this sources derive from two areas in which three dimensional modeling and restoration were performed. The first site is located west of Piacenza and show slow deformation rates during Pleistocene, probably due to the position of the studied site tha lies closer to a fault tip. The second model show the deformation of the main fault of the ITCS044 Seismogenic source in its central part. The differential slip rate values show a decreasing activity of the thrust from Pliocene to Pleistocene, with Pleistocene average slip rates of 0,51 mm/yr. In the western sector it was possible to calculate slip rates also for intra-pleistocenic horizons which show slip rates of 0,03 mm/yr in the last 0,45 Myr and a cumulative slip rate for Pleistocene of 0,08 mm/yr

ITCS009 Busseto Cavriago

Code	**ITCS009**		
Name	Busseto-Cavriago		
Compiled By	Burrato, P., and S. Mariano		
Latest Update	07/09/2007		
	Parameter	**Qual.**	**Evidence**
Min Depth (km)	2	OD	Based on geological data from various authors.
Max Depth (km)	8	OD	Based on geological data from various authors.
Strike (deg)	120 - 140	OD	Based on geological data from various authors.
Dip (deg)	20 - 40	OD	Based on geological data from various authors.
Rake (deg)	90 - 120	EJ	Inferred from geological data.
Slip Rate (mm/y)	0.1 - 0.5	EJ	Derived from geological data concerning adjacent structures.
Max Magnitude (Mw)	5.6	LD	Derived from the strongest earthquake occurred in the region.

This composite source straddles the region from the cities of Reggio Emilia (to the southeast) toward Parma and continuing NW-ward, and belongs to the Northern Apennines outer thrust front. This front is a NE-verging fault system at the north-western tip of the Northern Apennines chain, between the Emilia foothills and the the Po Plain. The outer thrust front this Source belongs to marks the northerly termination of damaging seismogenesis in the Apennines.

Historical and instrumental catalogues (Boschi et al., 2000; Gruppo di Lavoro CPTI, 2004; Pondrelli et al., 2006; Guidoboni et al., 2007) show a number of damaging earthquakes all over the area; from northwest to southeast, they are: the 5 November 1738 (Mw 5.4, Parma), 11 June 1438 (Mw 5.6, Parmense), 15 July 1971 (Mw 5.6, Parmense), 13 March 1832 (Mw 5.6, Reggiano), and 11 September 1831 (Mw 5.5, Reggiano) earthquakes. Finally, a sparse intermediate (4.5 < Mw 5.0) seismicity can be found in the whole region, including a sequence that has occurred from late 1991 to early 1992.

This source (together with the ITCS044 and ITCS018) represents the active arc where the Southern Alpine thrust and the Apennines come closer and may account for the intermediate to damaging seismicity of the region. In particular, the 1831 and 1832 earthquakes are interestingly very close both in space and time, as it is not seldom observed in the seismic history of Italy and in its complex patterns concerning possible fault interaction. These two events may well have been caused by two adjacent segments (to date unknown) of this Composite Source, although this could be influenced by the junction with the Romagnan outer thrust to the southeast.

The strike of this source was based on that of the mapped regional structures (N120°-140°). The dip was based on geological observations and geometrical considerations (20°-40°). The rake to represents pure to oblique thrusting, based on geological observations (90-120). The minimum and maximum depth were based on tectonic and geometrical considerations concerning the thrust geometry (2.0 and 8.0 km, respectively). The slip rate was inferred from geological observations in adjacent structures that share the same tectonic environment with the Busseto-Cavriago Source (0.1 – 0.5 mm/y). The maximum magnitude was taken from the largest damaging earthquake occurred within this area (Mw 5.6).

ITCS045 San Giorgio Piacentino - Fornovo di Taro

Code	**ITCS045**		
Name	San Giorgio Piacentino-Fornovo di Taro		
Compiled By	Burrato, P., and S. Mariano		
Latest Update	12/09/2007		
	Parameter	**Qual.**	**Evidence**
Min Depth (km)	2	OD	Based on geological data from various authors.
Max Depth (km)	10	OD	Based on geological data from various authors.
Strike (deg)	110 - 150	OD	Based on geological data from various authors.
Dip (deg)	20 - 40	OD	Based on geological data from various authors.
Rake (deg)	80 - 100	EJ	Inferred from regional geological data.
Slip Rate (mm/y)	0.1 - 0.5	EJ	Derived from geological data concerning adjacent structures.
Max Magnitude (Mw)	5.5	EJ	Assumed from regional seismological data.

This composite source straddles the region to the northwest of the Taro R. valley, and lies at the passage between the Pedeapenninic Thrust Front (to the southeast) and the Northern Apennines outer thrust front (to the north and northwest). It is a NE-verging fault system, in part made of small arcs, on the higher Emilia-Romagna foothills of the Northern Apennines chain.

Historical and instrumental catalogues (Boschi et al., 2000; Gruppo di Lavoro CPTI, 2004; Pondrelli et al., 2006; Guidoboni et al., 2007) show a lack of significant seismicity in this region, except for a few intermediate (4.5 < Mw 5.0) earthquakes to the west and east of the area.

This source represents the hypothesized westerly termination of the active Pedeapenninic Thrust Front where it gives way to the outer arc of the Northern Apennines, and may account for the intermediate seismicity of the region and its seismogenic potential.

The strike of this source was based on that of the mapped regional structures (N110°-150°). The dip was based on geological observations and geometrical considerations (20°-40°). The rake represents pure thrusting, based on geological observations (80-100). The minimum and maximum depth were based on geological observations and on geometrical considerations concerning the thrust geometry (2.0 and 10.0 km, respectively). The slip rate was inferred from geological observations in adjacent structures that share the same tectonic environment with the San Giorgio Piacentino-Fornovo di Taro source (0.1 – 0.5 mm/y). The maximum magnitude was assumed from regional seismicity (Mw 5.5).

ITCS046 Langhirano-Sassuolo

Code	**ITCS046**		
Name	Langhirano-Sassuolo		
Compiled By	Burrato, P., and S. Mariano		
Latest Update	12/09/2007		
	Parameter	**Qual.**	**Evidence**
Min Depth (km)	2	OD	Based on geological data from various authors.
Max Depth (km)	8	OD	Based on geological data from various authors.
Strike (deg)	95 - 120	OD	Based on geological data from various authors.
Dip (deg)	20 - 40	OD	Based on geological data from various authors.
Rake (deg)	80 - 100	EJ	Inferred from regional geological data.
Slip Rate (mm/y)	0.1 - 0.5	EJ	Derived from geological data concerning adjacent structures.
Max Magnitude (Mw)	5.9	OD	Based on the strongest earthquake occurred in the region.

This composite source straddles the region across the upper Secchia R. and Enza R. valleys, and belongs to the Pedeapenninic Thrust Front. It is a NE-verging fault system, in part made of small arcs, on the higher Emilia-Romagna foothills of the Northern Apennines chain.

Historical and instrumental catalogues (Boschi et al., 2000; Gruppo di Lavoro CPTI, 2004; Pondrelli et al., 2006; Guidoboni et al., 2007) show a sparse concentration of both intermediate (4.5 < Mw 5.0) and damaging seismicity all along the region. The key earthquakes have occurred on 5 May 1501 (Mw 5.8, Appennino Modenese), and on 9 Sep 1818 (Mw 5.6, Langhirano), in the eastern and western sectors of the area, respectively. Just north of the region, a strong event took place in 91 B.C. (Mw 5.7, Modena-Reggio Emilia) but its location can be considered uncertain, due to its age.

This area may hold a seismogenic potential based on subsurface data (Pieri and Groppi, 1981; Cassano et al., 1986), evidence of drainage anomalies (Amorosi et al., 1996), and structural analysis (Castellarin et al., 1985) that suggest the current tectonic activity of the Pedeapenninic Thrust Front in this region.

The strike of the Source was based on that of the mapped regional structures (N95°-120°). The dip was based on subsurface data and on geometrical considerations (20°-40°). The rake represents pure thrusting, based on geological observations (80-100). The minimum and maximum depth were based on geological observations and on geometrical considerations concerning the thrust geometry (2.0 and 8.0 km, respectively). The slip rate was inferred from geological observations in adjacent structures that share the same tectonic environment with the Langhirano-Sassuolo source (0.1 – 0.5 mm/y). The maximum magnitude was taken from the largest damaging earthquake occurred within the area (Mw 5.9).

ITCS049 Reggio Emilia – Rolo

Code	**ITCS049**		
Name	Reggio Emilia-Rolo		
Compiled By	Burrato, P., and S. Mariano		
Latest Update	30/08/2007		
	Parameter	**Qual.**	**Evidence**
Min Depth (km)	3	OD	Based on structural and seismological data from various authors.
Max Depth (km)	10	OD	Based on structural and seismological data from various authors.
Strike (deg)	35 - 65	OD	Based on structural and seismological data from various authors.
Dip (deg)	30 - 50	OD	Based on structural and seismological data from various authors.
Rake (deg)	60 - 90	OD	Based on structural and seismological data from various authors.
Slip Rate (mm/y)	0.1 - 0.5	EJ	Derived from geological data concerning adjacent structures.
Max Magnitude (Mw)	5.5	EJ	Assumed from regional seismological data.

This composite source straddles the region to the northeast of the city of Reggio Emilia and belongs to the Ferrara Arc thrust front. This fault system is the NW- to N-verging external arc at the north-eastern tip of the Northern Apennines chain, well into the Po Plain, and marks the northeastern most advanced thrust with damaging seismogenic potential in the Apennines.

Historical and instrumental catalogues (Boschi et al., 2000; Gruppo di Lavoro CPTI, 2004; Pondrelli et al., 2006; Guidoboni et al., 2007) show a number of intermediate to damaging earthquakes that have affected the area; to the southwest, they are the 11 September 1831 (Mw 5.5, Reggiano), and 10 February 1547 (Mw 5.2, Reggio Emilia) earthquakes; to the south, the 20 June 1671 (Mw 5.3, Rubiera) event; to the north, the 12 February 1806 (Mw 5.3) and 25 Dec 1810 (Mw 5.3, Novellara) earthquakes, while the 15 October 1996 (Mw 5.4) has hit the southwestern sector of the source. Finally, a sparse intermediate (4.5 < Mw 5.0) seismicity can be found in the whole region.

This source is the left ramp of the blind Romagnan Apennines outer thrust and may account for the intermediate to damaging seismicity of the region. In particular, the 1806 and 1810 earthquakes are interestingly very close both in space and time, as it is not seldom observed in the seismic history of Italy and in its complex patterns concerning possible fault interaction. These two events may well have been caused by two adjacent segments (to date unknown) of this source.

To the southwest, this source gives way to the Northern Apennines outer thrust.

The strike of this source was based on that of the mapped regional structures (N35°-65°). The dip was based on geological observations and geometrical considerations (30°-50°). The rake was represents oblique thrusting, based on geological observations (60-90). The minimum and maximum depth were based on tectonic and geometrical considerations concerning the thrust geometry (3.0 and 10.0 km, respectively). The slip rate was inferred from geological observations in adjacent structures that share the same tectonic environment with the Reggio Emilia-Rolo source (0.1 – 0.5 mm/y). The maximum magnitude was based on regional seimicity data (Mw 5.5).

ITCS051 Novi-Poggio Renatico

Code	**ITCS051**		
Name	Novi-Poggio Renatico		
Compiled By	Burrato, P., and S. Mariano		
Latest Update	30/08/2007		
	Parameter	**Qual.**	**Evidence**
Min Depth (km)	3	OD	Based on geological data from various authors.
Max Depth (km)	10	OD	Based on macroseismic and geological data from various authors.
Strike (deg)	95 - 125	OD	Based on geological data from various authors.
Dip (deg)	25 - 45	OD	Based on geological data from various authors.
Rake (deg)	80 - 100	OD	Based on geological data from various authors.
Slip Rate (mm/y)	0.25 - 0.5	OD	Based on geological data from Scrocca et al. (2007).
Max Magnitude (Mw)	5.9	OD	Derived from maximum magnitude of associated individual source(s).

Associated Active Faults or Folds

#	**Type**	**Name**	**Reference**
78	Fault	Mirandola	Castaldini et al. [1979]
79	Fault	Canalazzo di Finale Emilia	Castaldini et al. [1979]
80	Fault	Concordia	Castaldini et al. [1979]

This composite source straddles the region across the lower Reno R. and Secchia R. valleys and belongs to the Ferrara Arc thrust front. This fault system is the NE-verging external arc at the north-eastern tip of the Northern Apennines chain, well into the Po Plain, and marks the northeastern most advanced thrust with damaging seismogenic potential in the Apennines.

Historical and instrumental catalogues (Boschi et al., 2000; Gruppo di Lavoro CPTI, 2004; Pondrelli et al., 2006; Guidoboni et al., 2007) show a sparse intermediate (4.5 < Mw < 5.0) seismicity in the region, with the notable exception of the 22 Feb 1346 (Mw 5.8) Ferrara earthquake in the northwestern sector of the area.

This source is the main portion of the blind Romagnan Apennines outer thrust and may account for the damaging seismicity of the region. In fact, subsurface data (e.g., Cassano et al., 1986) show well developed buried anticlines, including the Mirandola one. Also, there are well known drainage anomalies in this area (eg., Castaldini et al., 1979), for which Burrato et al. (2003) hypothesize a tectonic origin. The latter authors propose that segments of the blind thrusts imaged by the subsurface data may be potential sources of infrequent Mw 5.5+ earthquakes in this area.

A segment of this source has been recognized based on its seismogenic potential. For an in-depth analysis of seismogenesis in this region, the reader can refer to the relative individual source.

The strike of this source was based on that of the mapped regional structures (N95°-125°). The dip was based on geological observations and geometrical considerations (25°-45°). The rake represents pure to oblique thrusting, based on geological observations (80-120°). The minimum and maximum depth were based on tectonic and geometrical considerations concerning the thrust geometry (3.0 and 10.0 km, respectively). The slip rate was based on geological observations (0.25 – 0.5 mm/y). The maximum magnitude was taken from that of the largest individual source associated (Mw 5.9).

Associated Individual Seismogenic Source(s)

ITIS107 Mirandola

Code	**ITIS107**		
Name	Mirandola		
Compiled By	Burrato, P., E. Carminati, C. Doglioni and D. Scrocca		
Latest Update	19/09/2007		
	Parameter	**Qual.**	**Evidence**
Location (Lat/Lon)	44.8396 / 11.1351	OD	Based on geological and geomorphological observations.
Length (km)	8.7	OD	Based on geological and geomorphological observations.
Width (km)	5.8	OD	Based on geological and geomorphological observations.
Min Depth (km)	3.9	LD	Based on geological and seismological data.
Max Depth (km)	7.6	LD	Based on geological and seismological data.
Strike (deg)	113	OD	Based on geological and geomorphological observations.
Dip (deg)	40	LD	Based on surface displacement modeling constrained by subsurface data.
Rake (deg)	90	EJ	Inferred from geological data, constrained by orientation of T axes.
Slip Per Event (m)	0.45	ER	Calculated from Mo using the relationship from Hanks and Kanamori (1979).
Slip Rate (mm/y)	0.25 - 0.5	OD	Based on growth strata analysis.
Recurrence (y)	900 - 1800	EJ	Inferred from slip rate and average displacement.
Magnitude (Mw)	5.9	ER	Inferred from slip rate and average displacement.

Associated earthquake		
Latest Eq	Unknown	See "Commentary" for information.
Penultimate Eq	Unknown	See "Commentary" for information.
Elapsed Time	-9999	See "Commentary" for information.

Associated Active Faults or Folds

#	Type	Name	Reference
78	Fault	Mirandola	Castaldini et al. [1979]
79	Fault	Canalazzo di	Castaldini et al. [1979]

		Finale Emilia	
80	Fault	Concordia	Castaldini et al. [1979]

DISS proposes the existence of the Mirandola Source based on the evidence of the recent tectonic activity of the buried Ferrara Arc, highlighted by the control exerted on the evolution of the drainage network and by the geometry of syntectonic growth strata.

In the area located between the Pede-Apenninic Thrust front and the buried external fronts of the Northern Apennines an active compressional tectonic regime is documented by borehole breakout data with N-S oriented maximum horizontal stress, focal mechanism and GPS data.

The Pede-Apenninic Thrust Front is traditionally considered an active out-of-sequence thrust of the Northern Apennines belt, with a continuous trace along the Apennines foot-hills defined by geologic and geomorphic evidence of activity (e.g., Boccaletti et al., 2004). However, recent papers proposed that the geomorphic feature of the pede-Apennines foot-hills is not the expression of a continuos shallow thrust fault (Picotti and Pazzaglia, 2008). According to this view, most of the regional deformation would be taken by a deep, blind thrust ramp responsible of the large scale geomorphology of the Northern Apennines foot-hills.

The ongoing activity of the more external Northern Apennines thrust fronts buried in the plain is still a matter of debate, probable due to the unfavorable balance between tectonic activity (expressed as vertical deformation due to growing anticlines) and the rates of sedimentation. As a consequence, only high resolution geophysical and geological subsurface data are able to show the most recent growth of the buried structures.

Besides, in the Po Plain differential compaction of unconsolidated sediments mimicks the vertical tectonic movements induced by thrust activity (i.e. the relative sinclinal subsidence and anticlinal uplift).

The geometry of the Mirandola Source and its kinematics were characterized by a combined study that used the modeling of drainage anomalies and the backstripping of high-resolution stratigraphic data (Ciucci et al., 2002; Burrato et al., 2003; Scrocca et al., 2007). In particular, activity of the Mirandola Source was responsible for attraction in the sincline and diversion around the anticline of the Secchia and Panaro rivers, whose paleo-courses show consistent evolution with migration towards areas of relative subsidence. The use of high resolution stratigraphic data highlighted the geometry of growth strata in sintectonic strata, and allowed to calculate the relative uplift rates of the growing anticline during the late Quaternary, obtaining 0.16 mm/a of relative uplift rate for the last 125 ka.

The DISS compilers propose the following geometrical parameters for the source: the strike (N113°) is chosen according to the local strike of the buried Ferrara Arc; the fault dips 40° towards the South, according to subsurface seismic profiling; the rake is assumed to be 90° (pure thrusting), based on geodynamic considerations constrained by modeling of the drainage anomalies; the down-dip width is obtained by seismic profiles and is also constrained by modeling of the drainage anomalies; the minimum and maximum depth (3.9 and 7.6 km respectively) are constrained by subsurface geology; the length (8.7 km) is obtained by modeling of the drainage anomalies.

The Mirandola Source is not associated to any historical and/or instrumental earthquake, and as such it may represents a seismic gap. Given its dimension this source is able to generate earthquakes of Mw 5.9. The low slip rate suggests long recurrence interval for the potential earthquake.

OPEN QUESTIONS

1) Considering that the Mirandola Source is not associated with any earthquake, is it possible that the current Italian seismic catalogue missed an earthquake generated by this source?

2) What is the recurrence interval for the earthquakes generated by the Mirandola Source?

ITCS012 Malalbergo-Ravenna

Code	**ITCS012**		
Name	Malalbergo-Ravenna		
Compiled By	Burrato, P.		
Latest Update	31/08/2007		
	Parameter	**Qual.**	**Evidence**
Min Depth (km)	2	LD	Based on data of instrumental seismicity.
Max Depth (km)	8	LD	Based on data of instrumental seismicity.
Strike (deg)	85 – 150	OD	Based on consideration on regional geological data.
Dip (deg)	20 – 40	OD	Based on consideration on regional geological data.
Rake (deg)	80 – 120	OD	Based on geological data, constrained by orientation of T axes.
Slip Rate (mm/y)	0.1 - 0.5	EJ	Derived from geological data concerning adjacent structures.
Max Magnitude (Mw)	5.6	OD	Based on the strongest earthquake occurred in the region.

ITCS012 Malalbergo - Ravenna
Updates

Site of measurement		Age		Slip rate component	Reference	
Lat	**Lon**	**Age of marker**	**Age intervals (Myr)**	**Dip parallel (mm/yr)**	**Authors**	**Year**
44,5495	11,6931	Pleistocene	0,00 - 1,80	0,52	Maesano et al.	2011
44,5495	11,6931	Up.Pliocene - Low.Pleistoc.	1,80 - 3,60	0,41 minimum	Maesano et al.	2011

This composite source straddles the region across the lower Reno R. valley down to the city of Ravenna (to the southeast) and belongs to the Ferrara Arc thrust front. This fault system is the N- to NE-verging external arc at the north-eastern tip of the Northern Apennines chain, well into the Po Plain, and marks the northeastern most advanced thrust with damaging seismogenic potential in the Apennines.

Historical and instrumental catalogues (Boschi et al., 2000; Gruppo di Lavoro CPTI, 2004; Pondrelli et al., 2006; Guidoboni et al., 2007) show a number of intermediate to damaging earthquakes that have affected the area; to the southeast (although of uncertain location, due to their age), there is the 725 A.D. (Mw 5.6, Classe-Ravenna) earthquake; in the center of the region, the 18 March 1624 (Mw 5.4, Argenta) and 30 December 1967 (Mw 5.4, Bassa Padana) events; W-ward, the 22 October 1796 (Mw 5.6, Bassa Padana) and 13 January 1909 (Mw 5.5, Bassa Padana) earthquakes.

This source is a forwarding and shallower arc than the rest of the Romagnan Apennines outer thrust it is part of, and it includes the right ramp of the front. It may account for the intermediate to damaging seismicity of the region.

The strike of this source was based on that of the mapped regional structures (N85°-150°). The dip was based on geological observations and geometrical considerations (20°-40°). The rake represents pure to oblique thrusting, based on geological observations (80-120). The minimum and maximum depth were based on tectonic and geometrical considerations concerning the thrust geometry (2.0 and 8.0 km, respectively). The slip rate was inferred from geological observations in adjacent structures that share the same tectonic environment with the Malalbergo-Ravenna source (0.1 – 0.5 mm/y). The maximum magnitude was taken from the largest damaging earthquake occurred within the area (Mw 5.6).

A ramp anticline related to the activity of the fault segments of this seismogenic sources was restored by Maesano et al (in preparation) and the observed deformation can be explained with a movement of 0,52 mm/yr during the Pleistocene. A minimum value of 0,41 mm/yr was found for the Upper Pliocene interval but this datum is considered as a minimum value because of the erosional surfaces observed along the anticlinal axis.

ITCS050 Poggio Rusco – Migliarino

Code	**ITCS050**		
Name	Poggio Rusco-Migliarino		
Compiled By	Burrato, P., and S. Mariano		
Latest Update	07/09/2007		
	Parameter	**Qual.**	**Evidence**
Min Depth (km)	1	OD	Based on geological data from various authors.
Max Depth (km)	8	OD	Based on geological data from various authors.
Strike (deg)	85 - 115	OD	Based on geological data from various authors.
Dip (deg)	25 - 55	OD	Based on geological data from various authors.
Rake (deg)	80 - 100	OD	Based on geological data from various authors.
Slip Rate (mm/y)	0.1 - 0.5	EJ	Derived from geological data concerning adjacent structures.
Max Magnitude (Mw)	5.5	OD	Based on the strongest earthquake occurred in the region.

ITCS050 Poggio Rusco - Migliarino Updates

Site of measurement		**Age**		**Slip rate component**	**Reference**	
Lat	**Lon**	**Age of marker**	**Age intervals (Myr)**	**Dip parallel (mm/yr)**	**Authors**	**Year**
44,7404	11,7610	Pleistocene	0,00 - 1,80	0,42	Maesano et al.	2011

This composite source straddles the region across the lower Po River valley and forms the external Ferrara Arc thrust front. This fault system is the NE-verging external arc at the north-eastern tip of the Northern Apennines chain, well into the Po Plain, and marks the northeastern most advanced thrust with damaging seismogenic potential in the Apennines.

Historical and instrumental catalogues (Boschi et al., 2000; Gruppo di Lavoro CPTI, 2004; Pondrelli et al., 2006; Guidoboni et al., 2007) show a sparse intermediate (4.5 < Mw 5.0) seismicity in the region, with the notable exception of the 22 February 1346 (Mw 5.8, Ferrara) earthquake at the westerrn tip of the area, and the 17 November 1570 (Mw 5.5) event in the city of Ferrara.

This source is a rather shallow, long outer thrust thought to account for the damaging seismicity of the region. This area holds a seismogenic potential based on subsurface data (Pieri and Groppi, 1981; Boccaletti and Martelli, 2004) and on evidence of active deformation at the surface (Burrato et al. 2003) that suggest the tectonic activity of the Ferrara Arc.

A segment of this arc has been associated with the 1570 Ferrara earthquake. For an in-depth analysis of seismogenesis in this region, the reader can refer to the individual source in this Database.

The strike of this source was based on that of the mapped regional structures (N85°-115°). The dip was based on geological observations and geometrical considerations (25°-55°). The rake represents pure thrusting, based on geological observations (80-100). The minimum and maximum depth were based on geological observations and on geometrical considerations concerning the thrust geometry (1.0 and 8.0 km, respectively). The slip rate was inferred from geological observations in adjacent structures that share the same tectonic environment with the Poggio Rusco-Migliarino source (0.1 – 0.5 mm/y). The maximum magnitude was taken from that of the largest individual source associated (Mw 5.5).

The displacement found in this area by reconstructing the geometries of fold and restoring the compaction of sediments and the deformation allow to estimates the Pleistocenic slip rates of 0,42 mm/yr (Maesano et al. in preparation).

Associated Individual Seismogenic Source(s)

ITIS090 Ferrara

Code	**ITIS090**		
Name	Ferrara		
Compiled By	Rovida, A., and P. Burrato		
Latest Update	31/05/2005		
	Parameter	**Qual.**	**Evidence**
Location (Lat/Lon)	44.8901 / 11.4977	OD	Based on macroseismic, geological and geomorphological data.
Length (km)	5.1	ER	Calculated using the relationships from Wells and Coppersmith (1994).
Width (km)	4	ER	Calculated using the relationships from Wells and Coppersmith (1994).
Min Depth (km)	1.4	OD	Based on geological data.
Max Depth (km)	4.5	OD	Based on geological data.
Strike (deg)	88	OD	Based on geological and geomorphological data.
Dip (deg)	50	OD	Based on geological data.
Rake (deg)	90	EJ	Inferred from geological data, constrained by orientation of T axes.
Slip Per Event (m)	0.35	ER	Calculated from Mo using the relationship from Hanks and Kanamori (1979).
Slip Rate (mm/y)	0.1 - 0.5	EJ	Unknown, values assumed from geodynamic constraints.
Recurrence (y)	700 - 3500	EJ	Inferred from slip rate and average displacement.
Magnitude (Mw)	5.5	LD	Value adopted from the historical earthquake catalogue CPTI04.

Associated earthquake		
Latest Eq	17 Nov 1570	CPTI04.
Penultimate Eq	Unknown	See "Commentary" for information.
Elapsed Time	430	As of year 2000 (assigned datum).

The existence of the Ferrara Source is based on data regarding the recent tectonic activity of the Ferrara Arc (Burrato et al., 2003; Boccaletti and Martelli, 2004) and on subsurface data (Pieri and Groppi, 1981; Boccaletti and Martelli, 2004) constrained by the occurrence of the 17 November 1570 earthquake.

The DISS catalogue proposes the following geometrical characteristics for the source: the strike (N88°) is chosen according to that of the active thrust NW of Ferrara; the fault dips 50° towards the south, according to subsurface seismic profiling; the rake is assumed to be 90° (pure thrusting), based on geodynamic considerations constrained by active stress determined through borehole breakout data; the down-dip width (4 km) is obtained by seismic profiling; the minimum and maximum depth (1.4 and 4.5 km respectively) are determined through subsurface geological data; the length (5.1 km) is obtained by scaling relationships with width, constrained by 1570 earthquake magnitude.

The Ferrara Source is associated with the 17 November 1570 earthquake (Me 5.5), whose epicentral area is located at Ferrara. The proposed source is more consistent with geological data than with macroseismic ones. Nevertheless, higher intensities are widespread around the epicentral area and may be due to local amplifications as testified also by the large number of liquefaction effects reported in the same area (Boschi et al, 2000; Prestininzi and Romeo, 2000). The source is located taking into account the effects on the course of the Po river at Stellata that may be due to a coseismic deformation of the riverbed. Moreover, the location of the source is consistent with the deviation of the Po River near Stellata and the convexity toward the north of the course between Stellata and Pontelagoscuro identified by Burrato et al. (2003).

The recent activity of the fault is assessed by seismic reflection profiles showing that it cuts deposits dated less than 450 ka and also drives an anticline deforming the top of the Upper Pliocene sequence. The recent activity is constrained by observations on the present drainage network and the related deposits and by the historical reconstructions of river courses.

OPEN QUESTIONS

1) What is the average return period of the Ferrara Source? The current catalogue (CPTI, 2004), spanning about 1000 years, reports only the 1570 earthquake that can be associated with the outermost part of the Ferrara Arc.

2) What is the seismic behaviour of the Ferrara Source? The length of the mapped blind thrust is higher than that of the Ferrara Source. Have the remaining part already ruptured?

ITCS047 Castelvetro di Modena - Castel San Pietro Terme

Code	**ITCS047**		
Name	Castelvetro di Modena-Castel San Pietro Terme		
Compiled By	Burrato, P., and S. Mariano		
Latest Update	12/09/2007		
	Parameter	**Qual.**	**Evidence**
Min Depth (km)	2	OD	Based on geological data from various authors.
Max Depth (km)	8	OD	Based on geological data from various authors.
Strike (deg)	85 - 135	OD	Based on geological data from various authors.
Dip (deg)	20 - 40	OD	Based on geological data from various authors.
Rake (deg)	80 - 100	EJ	Inferred from regional geological data.
Slip Rate (mm/y)	0.1 - 0.5	EJ	Derived from geological data concerning adjacent structures.
Max Magnitude (Mw)	5.6	OD	Derived from maximum magnitude of associated individual source(s).

This composite source straddles the region across the upper Reno R. valley, around the city of Bologna, and belongs to the Pedeapenninic Thrust Front. It is a NE-verging fault system, in part made of small arcs, at the Emilia-Romagna foothills of the Northern Apennines chain.

Historical and instrumental catalogues (Boschi et al., 2000; Gruppo di Lavoro CPTI, 2004; Pondrelli et al., 2006; Guidoboni et al., 2007) show a concentration of both intermediate (4.5 < Mw 5.0) and damaging seismicity in the central and wester sector of the region. The key earthquakes have occurred on (from east to west): the 3 January 1505 (Mw 5.5, Bologna), 20 April 1929 (Mw 5.5, Bolognese), and 20 July 1399 (Mw 5.4, Modenese). Just south of the area, the 6 February 1455 (Mw 5.4, Bolognese) event took place.

This area holds a seismogenic potential based on subsurface data (Pieri and Groppi, 1981; Cassano et al., 1986), evidence of drainage anomalies (Amorosi et al., 1996), and structural analysis (Castellarin et al., 1985) that suggest the current tectonic activity of the Pedeapenninic Thrust Front in this region.

Two segments of this source have been associated with the 1505 and 1929 earthquakes. For an in-depth analysis of seismogenesis in this region, the reader can refer to the relative individual sources.

The strike of this source was based on that of the mapped regional structures (N85°-135°). The dip was based on subsurface data and on geometrical considerations (20°-40°). The rake represents pure thrusting, based on geological observations (80-100). The minimum and maximum depth were based on geological observations and on geometrical considerations concerning the thrust geometry (2.0 and 8.0 km, respectively). The slip rate was inferred from geological observations in adjacent structures that share the same tectonic environment with the Castelvetro di Modena-Castel San Pietro Terme source (0.1 – 0.5 mm/y). The maximum magnitude was taken from that of the largest individual source associated (Mw 5.6).

Associated Individual Seismogenic Source(s)

ITIS103 Crespellano

Code	**ITIS103**		
Name	Crespellano		
Compiled By	Burrato, P., P. Vannoli and A. Rovida		
Latest Update	11/09/2007		
	Parameter	**Qual.**	**Evidence**
Location (Lat/Lon)	44.4775 / 11.1575	OD	Based on macroseismic, geological and geomorphological observations.
Length (km)	5.6	OD	Based on geological and geomorphological observations.
Width (km)	4.3	ER	Calculated using the relationships from Wells and Coppersmith (1994).
Min Depth (km)	2	OD	Based on geological and geomorphological observations.
Max Depth (km)	4.5	OD	Based on geological and geomorphological observations.
Strike (deg)	98	OD	Based on geological and geomorphological observations.
Dip (deg)	35	OD	Based on geological and geomorphological observations.
Rake (deg)	90	EJ	Inferred from geological data, constrained by orientation of T axes.
Slip Per Event (m)	0.4	ER	Calculated from Mo using the relationship from Hanks and Kanamori (1979).
Slip Rate (mm/y)	0.1 - 0.5	EJ	Unknown, values assumed from geodynamic constraints.
Recurrence (y)	800 - 4000	EJ	Inferred from slip rate and average displacement.
Magnitude (Mw)	5.6	LD	Value adopted from the historical earthquake catalogue CPTI04.

		Associated earthquake
Latest Eq	20 Apr 1929	CPTI04.
Penultimate Eq	Unknown	See "Commentary" for information.
Elapsed Time	71	As of year 2000 (assigned datum).

DISS proposes the existence of the Crespellano Source based on the evidence of the recent tectonic activity of the Pedeapenninic Thrust Front (Castellarin et al., 1985; Amorosi et al., 1996; Boccaletti and Martelli, 2004) and on subsurface data (Pieri and Groppi, 1981; Cassano et al., 1986; Boccaletti and Martelli, 2004) constrained by the occurrence of the 20 April 1929 earthquake.

The Pedeapenninic Thrust Front is traditionally considered an active out-of-sequence thrust of the Northern Apennines belt, with a continuous trace along the Apennines foot-hills defined by geologic and geomorphic evidence of activity (e.g., Boccaletti et al., 2004). However, recent papers proposed that the geomorphic feature of the pede-Apennines foot-hills is not the expression of a continuos shallow thrust fault (Picotti and Pazzaglia, 2008). According to this view, most of the regional deformation would be taken by a deep, blind thrust ramp responsible of the large scale geomorphology of the Northern Apennines foot-hills.

The DISS compilers propose the following geometrical parameters for the source: the strike (N98°) is chosen to follow that of the Pedeapenninic Thrust Front, of which the Crespellano Source is a segment; the fault dips 35° towards the South, according to subsurface seismic profiling; the rake is assumed to be 90° (pure thrusting), based on geodynamic considerations constrained by mesostructures affecting recent deposits of the area; the down-dip width is obtained by seismic profiles and constrained by scaling relationships with the 1929 earthquake magnitude; the minimum and maximum depth (2.0 and 4.5 km respectively) are constrained by subsurface geology; the length (5.6 km) is obtained by scaling relationships with the 1929 earthquake magnitude.

The Crespellano Source is associated with the 20 April 1929 earthquake (Mw 5.6) reported by CPTI (2004) and having its epicentral area between about 5 km south of the mountain front near Monteveglio. Our source model is consistent with the highest damage. In the same area, Boschi et al. (2000) report landslides, surface fractures and enhanced gas discharge in nearby gas and mud volcanoes.

The location of the source is constrained to the east by the occurrence of the source of the Mw 5.5 3 January 1505 earthquake (CPTI, 2004).

This source is also consistent with evidences of recent activity of the Pedeapenninic Thrust Front south of Bologna, consisting of triangular facets, the presence of a growth anticline and a fault scarp affecting Holocene alluvial fans. The rivers flowing south of Bologna are characterized by high erosional activity and by the presence of three orders of uplifted terraces.

OPEN QUESTIONS

1) What is the average return period of the Crespellano Source?

2) Was the evolution of the 1929 seismic sequence, characterized by three strong shocks on the same day, driven by diffusive spreading of subsurface fluids?

3) Does this part of the Pedeapennic Thrust Front rupture in repeated events with M around 5.5 or can it rupture also in larger events?

4) Is there any relationship between the 1929 earthquakes and those occurred to the east in 1505, 1779 and 1801 along the Pedeapenninic Thrust Front?

ITIS091 Caselecchio di Reno

Code	**ITIS091**		
Name	Casalecchio di Reno		
Compiled By	Burrato, P., P. Vannoli and A. Rovida		
Latest Update	11/09/2007		
	Parameter	**Qual.**	**Evidence**
Location (Lat/Lon)	44.4695 / 11.2425	OD	Based on macroseismic, geological and geomorphological observations.
Length (km)	5	OD	Based on geological and geomorphological observations.
Width (km)	3.9	ER	Calculated using the relationships from Wells and Coppersmith (1994).
Min Depth (km)	2	OD	Based on geological and geomorphological observations.
Max Depth (km)	4.2	OD	Based on geological and geomorphological observations.

Strike (deg)	90	OD	Based on geological and geomorphological observations.
Dip (deg)	35	OD	Based on geological and geomorphological observations.
Rake (deg)	90	EJ	Inferred from geological data, constrained by orientation of T axes.
Slip Per Event (m)	0.4	ER	Calculated from Mo using the relationship from Hanks and Kanamori (1979).
Slip Rate (mm/y)	0.1 - 0.5	EJ	Unknown, values assumed from geodynamic constraints.
Recurrence (y)	800 - 4000	EJ	Inferred from slip rate and average displacement.
Magnitude (Mw)	5.5	LD	Value adopted from the historical earthquake catalogue CPTI04.

Associated earthquake		
Latest Eq	03 Jan 1505	CPTI04.
Penultimate Eq	Unknown	See "Commentary" for information.
Elapsed Time	495	As of year 2000 (assigned datum).

DISS compilers propose the existence of the Casalecchio di Reno Source based on the evidence of the recent tectonic activity of the Pedeapenninic Thrust Front (Castellarin et al., 1985; Amorosi et al., 1996; Boccaletti and Martelli, 2004) and on subsurface data (Pieri and Groppi, 1981; Cassano et al., 1986; Boccaletti and Martelli, 2004) constrained by the occurrence of the 3 January 1505 earthquake.

The DISS compilers propose the following geometrical parameters for the source:the strike (N90°) is chosen according to that of the Pedeapenninic Thrust Front; the fault dips 35° towards the South, according to subsurface seismic profiling; the rake is assumed to be 90° (pure thrusting), based on geodynamic considerations constrained by mesostructures affecting recent deposits of the area; the down-dip width is obtained by seismic profiles and constrained by scaling relationships with the 1505 earthquake magnitude; the minimum and maximum depth (2.0 and 4.2 km respectively) are constrained by subsurface geology; the length (5 km) is obtained by scaling relationships with the 1505 earthquake magnitude.

The Casalecchio di Reno Source is associated with the 3 January 1505 earthquake (Mw 5.5) reported by CPTI (2004) and having its epicentral area between Zola Predosa and Bologna, while a recent re-evaluation of macroseismic data (Boschi and Guidoboni, 2003) shifts the epicentre a few kilometres to the NW and assess a Me 5.7 for it. Our source model is consistent with the highest damage, reported in both cases at Zola Predosa, Bologna and S. Lorenzo in Collina.

In the same area, Boschi et al. (2000) report landslides and surface fractures, while Prestininzi and Romeo (2000) report also liquefaction at Zola Predosa.

The location of the source is constrained to the east by the occurrence of another Me 5.4 earthquake on 20 January 1505 (reported by Boschi and Guidoboni, 2003), and to the west by the 20 April 1929 earthquake (CPTI, 2004).

This source is consistent with evidences of recent activity of the Pedeapenninic Thrust Front south of Bologna, consisting of triangular facets, the presence of a growth anticline and a fault scarp affecting Holocene alluvial fans. The rivers flowing south of Bologna are characterized by high erosional activity and by the presence of three orders of uplifted terraces.

OPEN QUESTIONS

1) What is the average return period of the Casalecchio di Reno Sources?

2) What is the relationship between the 3 and 20 January 1505 earthquakes? Should the first event have triggered the rupture of another segment of the Pedeapenninic Thrust Front to the west?

3) Does this part of the Pedeapenninic Thrust Front rupture in repeated events with M around 5.5 or can it rupture also in larger events?

4) Is there any relationship between the 1505 earthquakes and those occurred to the east in 1505, 1779 and 1801 and to the west in 1929 along the Pedeapenninic Thrust Front?

ITCS001 Castel San Pietro Terme – Meldola

Code	**ITCS001**		
Name	Castel San Pietro Terme-Meldola		
Compiled By	Burrato, P., and S. Mariano		
Latest Update	12/09/2007		
	Parameter	**Qual.**	**Evidence**
Min Depth (km)	2	OD	Based on geological data from various authors.
Max Depth (km)	8	OD	Based on geological data from various authors.
Strike (deg)	110 - 140	LD	Based on geological data from various authors.
Dip (deg)	30 - 40	LD	Based on geological data from various authors.
Rake (deg)	80 - 100	LD	Based on geological data from various authors.
Slip Rate (mm/y)	0.1 - 0.5	EJ	Derived from geological data concerning adjacent structures.
Max Magnitude (Mw)	5.8	OD	Derived from maximum magnitude of associated individual source(s).

This composite source straddles the region to the left of the upper Savio R. valley, toward the city of Bologna (northwest of the source) and just south of Forlì, and belongs to the Pedeapenninic Thrust Front. It is a NE-verging fault system, in part made of small arcs, at the Emilia-Romagna foothills of the Northern Apennines chain.

Historical and instrumental catalogues (Boschi et al., 2000; Gruppo di Lavoro CPTI, 2004; Pondrelli et al., 2006; Guidoboni et al., 2007) show a dense concentration of both intermediate (4.5 < Mw 5.0) and damaging seismicity in the region. The key earthquakes have occurred on (from southeast to northwest): the 11 August 1483 (Mw 5.7, Romagna Meridionale); 19 February 1911 (Mw 5.4, Romagna Meridionale); 30 October 1870 (Mw 5.6, Meldola); 3 July 1428 (Mw 5.6, Predappio); 4 April 1383 (Mw 5.4, Forlì); 21 September 1813 (Mw 5.3, Romagna Centrale); 17 July 1781 (Mw 5.5, Romagna); 5 May 1935 (Mw 5.3, Faentino), and the most prominent earthquake of 4 April 1781 (Mw 5.9, Faentino). Just south of the area, the 30 April 1279 (Mw 5.5, Rocca San Casciano) event took place.

Subsurface data (Pieri and Groppi, 1981; Cassano et al., 1986), evidence of drainage anomalies (Amorosi et al., 1996), and structural analysis (Castellarin et al., 1985) suggest the current tectonic activity of the Pedeapenninic Thrust Front in this area.

A segment of this source has been associated to the 1781 earthquake. For an in-depth analysis of seismogenesis in this region, the reader can refer to the relative individual source.

The strike of the source was based on that of the mapped regional structures (N110°-140°). The dip was based on geological observations and geometrical considerations (30°-40°). The rake represents pure thrusting, based on geological observations (80-100). The minimum and maximum depth were based on geological observations and on geometrical considerations concerning the thrust geometry (2.0 and 8.0 km, respectively). The slip rate was inferred from geological observations in adjacent structures that share the same tectonic environment with the Castel San Pietro Terme-Meldola source (0.1 – 0.5 mm/y). Maximum magnitude was taken from that of the largest individual source associated (Mw 5.8).

Associated Individual Seismogenic Source(s)

ITIS093 - Faenza

Code	**ITIS093**		
Name	Faenza		
Compiled By	Burrato, P., P. Vannoli and A. Rovida		
Latest Update	11/09/2007		
	Parameter	**Qual.**	**Evidence**
Location (Lat/Lon)	44.2636 / 11.8067	OD	Based on macroseismic, geological and geomorphological observations.
Length (km)	8.4	OD	Based on geological and geomorphological observations.
Width (km)	5.7	ER	Calculated using the relationships from Wells and Coppersmith (1994).
Min Depth (km)	4.5	OD	Based on geological and geomorphological observations.
Max Depth (km)	7.8	OD	Based on geological and geomorphological observations.
Strike (deg)	108	OD	Based on geological and geomorphological observations.
Dip (deg)	35	OD	Based on geological and geomorphological observations.
Rake (deg)	90	EJ	Inferred from geological data, constrained by orientation of T axes.
Slip Per Event (m)	0.4	ER	Calculated from Mo using the relationship from Hanks and Kanamori (1979).
Slip Rate (mm/y)	0.1 - 0.5	EJ	Unknown, values assumed from geodynamic constraints.
Recurrence (y)	800 - 4000	EJ	Inferred from slip rate and average displacement.
Magnitude (Mw)	5.8	LD	Value adopted from the historical earthquake catalogue CPTI04.

		Associated earthquake
Latest Eq	04 Apr 1781	CPTI04.
Penultimate Eq	Unknown	See "Commentary" for information.
Elapsed Time	219	As of year 2000 (assigned datum).

The DISS compilers propose the existence of the Faenza Source based on data regarding the recent tectonic activity of the Pedeapenninic Thrust Front (Castellarin et al., 1985; Amorosi et al., 1996; Boccaletti and Martelli, 2004) and on subsurface data (Pieri and Groppi, 1981; Cassano et al., 1986; Boccaletti and Martelli, 2004) constrained by the occurrence of the 4 April 1781 earthquake.

The geometrical parameters for the source are the following: the strike (N108°) is chosen to follow that of the Pedeapenninc Thrust Front, of which the Faenza Source is a segment; the fault dips 35° towards the South, according to subsurface seismic profiling; the rake is assumed to be 90° (pure thrusting), based on geodynamic considerations constrained by mesostructures affecting recent deposits of the area; the down-dip width is obtained by seismic profiles and constrained by scaling relationships with the 1781 earthquake magnitude; the minimum and maximum depth (4.5 and 7.8 km respectively) are constrained by subsurface geology; the length (8.4 km) is obtained by scaling relationships with the 1781 earthquake magnitude.

The Faenza Source is associated with the 4 April 1781 earthquake (Mw 5.8) reported by CPTI (2004) and having its epicentral area between about 4 km south of the mountain front, SW of Faenza. Our source model is consistent with the location of the highest damage, and fit well with the macroseismic pattern that suggests the activation of a surficial source.

In contrast to this hypothesis, Picotti et al. (2009) hypothesize that this earthquake was produced by the Riolo Terme normal fault. This fault belongs to a set of normal fault occurring along the foot-hills of the Northern Apennines, showing evidence of Late Pleistocene-Holocene activity, and interpreted to develop along the outer shell of a large growing anticline as a consequence of a local inversion of the stress field (Picotti et al., 2009).

However, this interpretation does not fit the damage distribution of the 1781 earthquake, leaving most of the higher damaged sites in the foot-wall of the fault, in contrast with common observations of stronger felt reports in the hangingwall of normal faulting earthquakes (due to closer position respect to the hypocenter).

The seismogenic potential of the normal faults studied by Picotti et al. (2009) is also at odd with their secondary nature: the normal faults formed as a consequence of warping of an anticlinorium driven by the activity of a deep blind thrust, and with this hypothesis the main seismogenic source should be considered the deep blind thrust.

OPEN QUESTIONS

1) What is the average return period of the Faenza Source?

2) Does this part of the Pedeapenninic Thrust Front rupture in repeated events with M around 5.5 or can it rupture also in larger events?

ITCS011 Mordano – Guarniera

Code	**ITCS011**		
Name	Mordano-Guarniera		
Compiled By	Burrato, P., and S. Mariano		
Latest Update	07/09/2007		
	Parameter	**Qual.**	**Evidence**
Min Depth (km)	3	LD	Based on geological data from various authors.
Max Depth (km)	8	LD	Based on geological data from various authors.
Strike (deg)	95 - 145	OD	Based on geological data from various authors.
Dip (deg)	20 - 40	OD	Based on geological data from various authors.
Rake (deg)	80 - 100	EJ	Inferred from geological data, constrained by orientation of T axes.
Slip Rate (mm/y)	0.1 - 0.5	EJ	Derived from geological data concerning adjacent structures.
Max Magnitude (Mw)	5.9	OD	Derived from maximum magnitude of associated individual source(s).

This composite source straddles the region to the left of the lower Savio R. valley, between the cities of Ravenna (to the northeast) and Forlì (to the south), forming a part of the Ferrara Arc thrust front. This fault system is the NE-verging inner arc in the north-eastern sector of the Northern Apennines chain, between the Romagna foothills and the the Po Plain.

Historical and instrumental catalogues (Boschi et al., 2000; Gruppo di Lavoro CPTI, 2004; Pondrelli et al., 2006; Guidoboni et al., 2007) show a sparse intermediate (4.5 < Mw 5.0) seismicity in the region, with the notable exception of the 11 April 1688 (Mw 5.9, Romagna) earthquake well within the area, and the 725 A.D. (Mw 5.6, Classe-Ravenna) one, to the northeast ot the region. One could also include the 10 July 1570 (Mw 5.2, Forlì) event. Just to the southeast of the area, the 11 August 1483 (Mw 5.7, Romagna Meridionale) event has occurred.

Subsurface data (Pieri and Groppi, 1981; Cassano et al., 1986) and evidence of seemingly rapid active deformation at the surface described by numerous authors, suggest the tectonic activity of the buried anticlines at the rear of the Ferrara Arc.

A segment of this source has been associated with the 1688 Romagna earthquake. For an in-depth analysis of seismogenesis in this region, the reader can refer to the relative individual source.

The strike of this source was based on that of the mapped regional structures (N95°-145°). The dip was based on geological observations and geometrical considerations (25°-40°). The rake represents pure thrusting, based on geological observations (80-100). The minimum and maximum depth were based on geological observations and on geometrical considerations concerning the thrust geometry (3.0 and 8.0 km, respectively). The slip rate was inferred from geological observations in adjacent structures that share the same tectonic environment with the Mordano-Guarniera Source (0.1 – 0.5 mm/y). The maximum magnitude was taken from that of the largest individual source associated (Mw 5.5).

Associated Individual Seismogenic Source(s)

ITIS100 Bagnacavallo

Code	**ITIS100**		
Name	Bagnacavallo		
Compiled By	Burrato, P., and G. Valensise		
Latest Update	06/09/2007		
	Parameter	**Qual.**	**Evidence**
Location (Lat/Lon)	44.4391 / 11.9777	OD	Based on macroseismic, geological and geomorphological data.
Length (km)	9	ER	Calculated using the relationships from Wells and Coppersmith (1994).
Width (km)	5.9	ER	Calculated using the relationships from Wells and Coppersmith (1994).
Min Depth (km)	4.5	OD	Based on seismic profile and geomorphological observations.
Max Depth (km)	7.5	OD	Based on seismic profile and geomorphological observations.
Strike (deg)	119	OD	Based on geological and geomorphological observations.
Dip (deg)	30	OD	Based on seismic profile and geomorphological observations.
Rake (deg)	90	OD	Inferred from geological data, constrained by orientation of T axes.
Slip Per Event (m)	0.5	ER	Calculated from Mo using the relationship from Hanks and Kanamori (1979).
Slip Rate (mm/y)	0.1 - 0.5	EJ	Unknown, values assumed from geodynamic constraints.
Recurrence (y)	1000 - 5000	EJ	Inferred from slip rate and average displacement.
Magnitude (Mw)	5.9	LD	Value adopted from the historical earthquake catalogue CPTI04.

	Associated earthquake	
Latest Eq	11 Apr 1688	CPTI04.
Penultimate Eq	Unknown	See "Commentary" for information.
Elapsed Time	312	As of year 2000 (assigned datum).

Based on the analysis of the subsurface data provided by the oil industry (Cassano et al., 1986; Pieri and Groppi, 1981) and on geomorphological observations provided by several investigators, DISS compiler propose the existence of a major blind thrust (Bagnacavallo Source) having the following geometrical characteristics:

- the strike is chosen according with the general orientation of mapped tectonic structures;
- the fault dips 30° towards the SW, in agreement with subsurface evidence and based on the characteristic distance between the synclinal and anticlinal axes;

- the rake is assumed to be 90 (pure thrusting) based on strike and on general geodynamic considerations;
- the down-dip width is based on the characteristic distance between the synclinal and anticlinal axes and on the assumptions made concerning the minimum and maximum faulting depth;
- the minimum and maximum depth are constrained by subsurface geology, by the symmetry of the anticline and by the general aspect-ratio of the anticline-syncline couple;
- the length is based on scaling with width and constrained by geomorphological observations.

Current catalogues (CPTI, 2004) report a large event in 1688 (Me 5.9) that falls very close to the Bagnacavallo Source, having its epicentral area in Cotignola (Imax=IX).

The DISS compilers associate this historical earthquake with the Bagnacavallo Source. The preferred source model is consistent with the largest damage having been reported in Cotignola, Bagnacavallo, Solarolo, Russi and Lugo. A further constraint for the southeastern edge of the source could be represented by the occurrence of a large aftershock near Russi on 18 April 1688, a week after the mainshock (reported by Boschi et al., 1997).

This source belongs to the Romagna Folds the more internal folds of the Ferrara-Romagna Arc, that represents the outermost propagation of the Apennines compressional wedge.

The reconstruction of the drainage system made by Gambi (1949) shows progressive attraction of the Senio and Lamone rivers towards each other in an area located around the town of Cotignola; downstream this area the two rivers are progressively shift sideways. The analysis of the rivers channel behaviour constrain the position of the syncline and of the anticline.

Ferrari et al. (1985) and Boschi et al. (1997) report the occurrence of floods of the Senio and Lamone rivers in the Cotignola area about ten days after the earthquake. These accounts are consistent with sudden coseismic uplift of the anticline and subsidence of the syncline driven by the blind thrust fault.

The position of the active anticline, located by means of geomorphological observations, is slightly shifted to the north-east with respect to the geological anticline mapped on the basis of geophysical exploration data. This observation may be the evidence of growth of the thrust fault along dip (the top of the fault plane becomes shallower).

The Bagnacavallo Source is very well developed in the subsurface, but has a limited geomorphic expression. The frequent and substantial diversions and shifts of the rivers flowing around it suggest that this is a rather fast structure.

OPEN QUESTIONS

1) What is the average return time of the Bagnacavallo Source? Current catalogues (CPTI, 2004), which cover a time span of about 1,000 years, report only the large 1688 event as falling very close to it.

2) What is the seismic behaviour of the Bagnacavallo Source? Does it rupture only in large M 6 rather infrequent events? Or it can also rupture in smaller earthquakes in the M range 5-5.5, alternated with long aseismic periods?

ITCS039 Riminese onshore

Code	**ITCS039**		
Name	Riminese onshore		
Compiled By	Basili, R., U. Fracassi and S. Mariano		
Latest Update	03/08/2006		
	Parameter	**Qual.**	**Evidence**
Min Depth (km)	3	OD	Based on geological data.
Max Depth (km)	7	OD	Based on geological data.
Strike (deg)	120 - 140	OD	Based on geological data from various authors.
Dip (deg)	25 - 35	OD	Based on geological data from various authors.
Rake (deg)	80 - 100	OD	Based on geological data.
Slip Rate (mm/y)	0.1 - 0.5	EJ	Derived from geological data concerning adjacent structures.
Max Magnitude (Mw)	5.7	LD	Derived from maximum magnitude of associated individual source(s).

Associated Active Faults or Folds

#	Type	Name	Reference
90	Fold	Rimini	Vannoli et al. [2004]

This composite source straddles the region between the Marche and Romagna, around the city of Rimini, and is part of the Umbro-Marche Apennines outer onshore thrust. This front is the NE-verging fault system at the eastern border of the Northern Apennines chain, parallel to the Marche coast.

Historical and instrumental catalogues (Boschi et al., 2000; Gruppo di Lavoro CPTI, 2004; Pondrelli et al., 2006; Guidoboni et al., 2007) show numerous damaging earthquakes that have occurred in the central and southern sector of the area. The key events are (from southeast to northwest), the 17 May and 16 August 1916 (both Mw 5.9, Alto Adriatico) double earthquake (their true epicenters probably lying just offshore this area), the 14 April 1672 (Mw 5.6) and 25 December 1786 (Mw 5.7) events, and the 17 March 1875 (Mw 5.7) earthquakes. The area also shows a sparse intermediate (4.5 < Mw 5.0) seismicity.

Various evidence all strongly suggest that the region is undergoing NE-SW trending compression, including earthquake focal mechanisms (Frepoli and Amato, 1997) and borehole breakout data (Montone et al., 2004) that illustrated a NW-SE trending minimum stress axis. Although presently available field data is still unclear, the Riminese onshore source can be thought as the possible northerly sector of the Northern Marche thrust, for which blind thrust faulting has been recognised as the active tectonic mechanism responsible for seismogenic faulting.

Two segments of this source have been associated with the 1786 and 1875 earthquakes, respectively. For an in-depth analysis of seismogenesis in this region, the reader can refer to those individual sources.

The strike of this source was based on that of the mapped regional structures (N120°-140°). The dip was based on geological observations and geometrical considerations (25°-35°). The rake is assumed to represent pure thrusting, based on geological observations (80-100). The minimum and maximum depth were based on subsurface data and on geometrical considerations concerning the thrust geometry (3.0 and 7.0 km, respectively). The slip rate was inferred from geological observations in adjacent structures that share the same tectonic environment with the Riminese onshore source (0.1 – 0.5 mm/y). The maximum magnitude was taken from that of the largest individual source associated (Mw 5.7).

Associated Individual Seismogenic Source(s)

ITIS035 Rimini

Code	**ITIS035**		
Name	Rimini		
Compiled By	Basili, R., and G. Valensise		
Latest Update	31/10/2001		
	Parameter	**Qual.**	**Evidence**
Location (Lat/Lon)	44.0048 / 12.516	OD	Based on geological data.
Length (km)	8	ER	Calculated using the relationships from Wells and Coppersmith (1994).
Width (km)	6	ER	Calculated using the relationships from Wells and Coppersmith (1994).
Min Depth (km)	3	OD	Based on geological data.
Max Depth (km)	6	OD	Based on geological data.
Strike (deg)	132	LD	Based on geological data from various authors.
Dip (deg)	30	LD	Based on geological data from various authors.
Rake (deg)	90	EJ	Inferred from geological data.
Slip Per Event (m)	0.21	ER	Calculated from Mo using the relationship from Hanks and Kanamori (1979).
Slip Rate (mm/y)	0.1 - 0.5	EJ	Unknown, values assumed from geodynamic constraints.
Recurrence (y)	420 - 2100	EJ	Inferred from slip rate and average displacement.
Magnitude (Mw)	5.6	LD	Value adopted from the historical earthquake catalogue CPTI99.

The northern Marche coastal zone is presently affected only by low seismic activity, but damaging earthquakes struck this area in the recent past (e.g. in 1930, Senigallia). A NW-SE trending minimum stress axis and a NE-SW trending maximum compressional stress axis were shown respectively by bore-hole breakouts and earthquake focal mechanisms (Mariucci et al., 1999; Frepoli and Amato, 1997). The available field geological observations are still inadequate to devise a fully convincing correlation between the occurrence of earthquakes and realistic seismogenic sources. However, the most realistic hypothesis that can be envisaged to-date on the basis of the local geologic setting considers the blind thrust-faults located at the leading-edge of the Apennine accretionary prism as the main active and probably seismogenic faults in the area. In addition, it seems likely that two parallel fault- alignments of this sort exist along the northern Marche offshore. The Rimini source is correlated with the 25 December 1786 ÒRimineseÓ earthquake. The seismogenic fault may correspond to a blind thrust-plane driving the growth of the anticline detected in the area by Bally et al. (1986) through geophysical prospecting. The location, geometry and width of fault at depth are based on the seismic reflection profile by Bally et al. (1986). Its size conforms to what is predicted by empirical relationships between length/width and magnitude relative to the 25 December 1786 "Riminese" earthquake.

OPEN QUESTIONS

1) This source suggest the presence of an active thrust fault between the Apennines piedmont and the Adriatic coast. Could this fault belong to a longer fault system?

2) Do two parallel active thrust systems exist along the Adriatic coast?

ITIS036 Val Marecchia

Code	**ITIS036**		
Name	Val Marecchia		
Compiled By	Basili, R., and G. Valensise		
Latest Update	31/10/2001		
	Parameter	**Qual.**	**Evidence**
Location (Lat/Lon)	44.0988 / 12.4616	OD	Based on geological data.
Length (km)	9	ER	Calculated using the relationships from Wells and Coppersmith (1994).
Width (km)	6	ER	Calculated using the relationships from Wells and Coppersmith (1994).
Min Depth (km)	3	OD	Based on geological data.
Max Depth (km)	6	OD	Based on geological data.
Strike (deg)	132	LD	Based on geological data from various authors.
Dip (deg)	30	LD	Based on geological data from various authors.
Rake (deg)	90	EJ	Inferred from geological data.
Slip Per Event (m)	0.27	ER	Calculated from Mo using the relationship from Hanks and Kanamori (1979).
Slip Rate (mm/y)	0.1 - 0.5	EJ	Unknown, values assumed from geodynamic constraints.
Recurrence (y)	540 – 2700	EJ	Inferred from slip rate and average displacement.
Magnitude (Mw)	5.7	LD	Value adopted from the historical earthquake catalogue CPTI99.

Associated earthquake		
Latest Eq	17 Mar 1875	CPTI04.
Penultimate Eq	Unknown	See "Commentary" for information.

Elapsed Time	125	As of year 2000 (assigned datum).

The northern Marche coastal zone is presently affected only by low seismic activity, but damaging earthquakes struck this area in the recent past (e.g. in 1930, Senigallia). A NW-SE trending minimum stress axis and a NE-SW trending maximum compressional stress axis were shown respectively by bore-hole breakouts and earthquake focal mechanisms (Mariucci et al., 1999; Frepoli and Amato, 1997). The available field geological observations are still inadequate to devise a fully convincing correlation between the occurrence of earthquakes and realistic seismogenic sources. However, the most realistic hypothesis that can be envisaged to-date on the basis of the local geologic setting considers the blind thrust-faults located at the leading-edge of the Apennines accretionary prism as the main active and probably seismogenic faults in the area. In addition, it seems likely that two parallel fault-alignments of this sort exist along the northern Marche offshore.

This source is correlated with the 17 March 1875 "Romagna Sud-Orientale" earthquake. The seismogenic fault may correspond to a blind thrust-plane driving the growth of a coastal anticline. The location and geometry of the fault plane are based on local geologic and geomorphic observations and are partly extrapolated from the similarity between this area and the adjacent ones. In addition, the reports of a tsunami (Boschi et al., 1995) help locating the fault near the shoreline. The size of the fault conforms to what is predicted by empirical relationships between length/width and magnitude relative to the 17 March 1875 "Romagna Sud-Orientale" earthquake.

OPEN QUESTIONS

1) The intensity data points for the 1875 earthquake are rather sparse where the fault plane is presumed to project to the surface. May this imply that the causative fault is elsewhere?

2) Could this fault be located offshore?

ITCS030 Riminese offshore

Code	**ITCS030**		
Name	Riminese offshore		
Compiled By	Basili, R., and S. Mariano		
Latest Update	24/09/2007		
	Parameter	**Qual.**	**Evidence**
Min Depth (km)	3	OD	Based on geological data.
Max Depth (km)	7	OD	Based on geological data.
Strike (deg)	120 – 140	LD	Based on geological data from various authors.
Dip (deg)	25 – 35	LD	Based on geological data from various authors.
Rake (deg)	80 – 100	EJ	Inferred from geological data.
Slip Rate (mm/y)	0.1 - 0.5	EJ	Derived from geological data concerning adjacent structures.
Max Magnitude (Mw)	5.9	LD	Derived from the strongest earthquake occurred in the region.

Associated Active Faults or Folds

#	**Type**	**Name**	**Reference**
97	Fold	Offshore Rimini South	Basili and Barba [2007]
96	Fold	Offshore Rimini North	Basili and Barba [2007]

This composite source straddles the Adriatic Sea just east of the city of Rimini and is the southernmost part of the Umbro-Marche Apennines outer offshore thrust. This front is the NE-verging fault system at the eastern border of the Northern Apennines chain, parallel to the Marche coast.

Historical and instrumental catalogues (Boschi et al., 2000; Gruppo di Lavoro CPTI, 2004; Pondrelli et al., 2006; Guidoboni et al., 2007) show numerous damaging earthquakes that have occurred onshore of the area. However, one should note that the automatic treatment of the intensity data used to compile the historical catalogues places all epicenters inland by default, including the numerous cases where damage distribution convincingly suggests a more plausible offshore location. Here this is the case for the 17 May and 16 August 1916 (both Mw 5.9) Alto Adriatico double earthquake.

The tectonic activity of this region is still not clearly documented but a plausible interpretation is that it is an offshore splay of the Northern Marche blind thrust. Subsurface data by Bally et al. (1986) have well imaged offshore anticlines whose growth would be caused by the NE-ward advancing thrust. Various evidence suggest that the region just onshore is undergoing NE-SW trending compression, including earthquake focal mechanisms all along the outer onshore front (Frepoli and Amato, 1997), while borehole breakout data (Montone et al., 2004) illustrated a NW-SE trending minimum stress axis.

The two main segments of this source have been associated with the 1916 earthquakes. For an in-depth analysis of seismogenesis in this region, the reader can refer to the individual source.

The strike of this ource was based on that of the mapped regional structures (N120°-140°). The dip was based on subsurface data and geometrical considerations (25°-35°). The rake is assumed to represent pure thrusting, based on geological observations (80-100). The minimum and maximum depth were based on subsurface data and on geometrical considerations concerning the thrust geometry (3.0 and 7.0 km, respectively). The slip rate was inferred from geological observations in adjacent structures that share the same tectonic environment with the Riminese offshore source (0.1 – 0.5 mm/y). The maximum magnitude was taken from the largest damaging earthquake occurred within the area (Mw 5.9).

Associated Individual Seismogenic Source(s)

ITIS034 Rimini offshore North

Code	**ITIS034**		
Name	Rimini offshore North		
Compiled By	Basili, R., and G. Valensise		
Latest Update	31/10/2001		
	Parameter	**Qual.**	**Evidence**
Location (Lat/Lon)	44.0917 / 12.6595	OD	Based on geological data.
Length (km)	8	ER	Calculated using the relationships from Wells and Coppersmith (1994).
Width (km)	5	ER	Calculated using the relationships from Wells and Coppersmith (1994).
Min Depth (km)	3	OD	Based on geological data.
Max Depth (km)	5.5	OD	Based on geological data.
Strike (deg)	132	LD	Based on geological data from various authors.
Dip (deg)	30	LD	Based on geological data from various authors.
Rake (deg)	90	EJ	Inferred from geological data.
Slip Per Event (m)	0.36	ER	Calculated from Mo using the relationship from Hanks and Kanamori (1979).
Slip Rate (mm/y)	0.1 - 0.5	EJ	Unknown, values assumed from geodynamic constraints.
Recurrence (y)	720 - 3600	EJ	Inferred from slip rate and average displacement.
Magnitude (Mw)	5.7	LD	Value adopted from the historical earthquake catalogue CPTI99.

Associated earthquake		
Latest Eq	17 May 1916	CPTI04.
Penultimate Eq	Unknown	See "Commentary" for information.
Elapsed Time	84	As of year 2000 (assigned datum).

The northern Marche coastal zone is presently affected only by low seismic activity, but damaging earthquakes struck this area in the recent past (e.g. in 1930, Senigallia). A NW-SE trending minimum stress axis and a NE-SW trending maximum compressional stress axis were shown respectively by bore-hole breakouts and earthquake focal mechanisms (Mariucci et al., 1999; Frepoli and Amato, 1997). The available field geological observations are still inadequate to devise a fully convincing correlation between the occurrence of earthquakes and realistic seismogenic sources. However, the most realistic hypothesis that can be envisaged to-date on the basis of the local geologic setting considers the blind thrust-faults located at the leading-edge of the Apennine accretionary prism as the main active and probably seismogenic faults in the area. In addition, it seems likely that two parallel fault-alignments of this sort exist along the northern Marche offshore.

The Rimini offshore North source is correlated with the 17 May 1916 "Alto Adriatico" earthquake. The seismogenic fault may be correlated with a blind thrust-plane which drives the growth of the offshore anticline detected by Bally et al. (1986) through geophysical prospecting. Location, geometry and width of fault at depth are based on the seismic reflection profile by Bally et al. (1986). Its size conforms to what is predicted by empirical relationships between length/width and magnitude relative to the 17 May 1916 "Alto Adriatico" earthquake.

OPEN QUESTIONS

1) This source suggest the presence of an active thrust fault in the Adriatic offshore. Could this fault belong to a longer fault system?

2) How many parallel active thrust systems exist along the Adriatic coast?

3) Are these active fault-systems entirely seismogenic?

ITIS033 Rimini offshore South

Code	**ITIS033**		
Name	Rimini offshore South		
Compiled By	Basili, R., and G. Valensise		
Latest Update	31/10/2001		
	Parameter	**Qual.**	**Evidence**
Location (Lat/Lon)	44.0387 / 12.7406	OD	Based on geological data.
Length (km)	8	ER	Calculated using the relationships from Wells and Coppersmith (1994).
Width (km)	5	ER	Calculated using the relationships from Wells and Coppersmith (1994).
Min Depth (km)	3	OD	Based on geological data.
Max Depth (km)	5.5	OD	Based on geological data.
Strike (deg)	132	LD	Based on geological data from various authors.
Dip (deg)	30	LD	Based on geological data from various authors.
Rake (deg)	90	EJ	Inferred from geological data.
Slip Per Event (m)	0.26	ER	Calculated from Mo using the relationship from Hanks and Kanamori (1979).
Slip Rate (mm/y)	0.1 - 0.5	EJ	Unknown, values assumed from geodynamic constraints.
Recurrence (y)	520 - 2600	EJ	Inferred from slip rate and average displacement.
Magnitude (Mw)	5.6	LD	Value adopted from the historical earthquake catalogue CPTI99.

Associated earthquake		
Latest Eq	16 Aug 1916	CPTI04.
Penultimate Eq	Unknown	See "Commentary" for information.
Elapsed Time	84	As of year 2000 (assigned datum).

The Rimini offshore South source is correlated with the 16 August 1916 "Alto Adriatico" earthquake. The seismogenic fault may be correlated with a blind thrust-plane driving the growth of the offshore anticline and detected by Bally et al. (1986) through geophysical prospecting. The location, geometry and width of the fault at depth are based on the seismic reflection profile by Bally et al. (1986). Its size conforms to what is predicted by empirical relationships between length/width and magnitude relative to the 16 August 1916 "Alto Adriatico" earthquake.

OPEN QUESTIONS

1) This source suggest the presence of an active thrust fault in the Adriatic offshore. Could this fault belong to a longer fault system?

2) How many parallel active thrust systems exist along the Adriatic coast?

3) Are these active fault-systems entirely seismogenic?

Associated Debated Seismogenic Source(s)

ITDS001 Broni – Stradella

This debated source is located in the northern part of the Emilia arc. This seismogenic source was first proposed by Benedetti et al. (2003) based on geological and geomorphological evidence.

5.5.5 Seismogenic sources of the Northern Apennines (extensional)

The Northern Apennines are often described as a convergent orogenic wedge that has experienced orogen-perpendicular extension coeval with and in close proximity to the locus of crustal shortening and accretion (Bennet et al. 2012). Different geodynamic models were invoked to explain the contemporaneity of compression along the fronts and the extension in inner part of the Apenninic chain and this peculiarity is still matter of debate.

The main extensional structures are recognized along the regional NE dipping low-angle normal fault system called Etrurian Fault System (EFS) that runs from northern Tuscany to southern Umbria (Boncio et al., 2000). Individual fault segment of EFS are associated with the main extensional basins of the northern Apennines. Geological and seismological evidences suggest that the EFS controls active extension and seismic release all along this stretch of the Apennines.

ITCS026 Lunigiana

Code	**ITCS026**		
Name	Lunigiana		
Compiled By	Burrato, P., and G. Valensise		
Latest Update	14/05/2010		
	Parameter	**Qual.**	**Evidence**
Min Depth (km)	1	OD	Based on geological and seismological data from Solarino (2007).
Max Depth (km)	10	OD	Based on geological and seismological data from Solarino (2007).
Strike (deg)	310 - 330	OD	Based on geological data.
Dip (deg)	30 - 45	OD	Based on geological and seismological data from Solarino (2007).
Rake (deg)	260 - 280	EJ	Inferred from geological data.
Slip Rate (mm/y)	0.1 - 1	EJ	Unknown, values assumed from geodynamic constraints.
Max Magnitude (Mw)	6	EJ	Assumed from regional seismological data.

This composite source is an extensional belt that straddles the region near the Taro R. valley, within the Ligurian and Tosco-Emilian Apennines. This Source can be seen as the possible northwestern prolongation of the NE-dipping Etrurian Fault System, marking the northwestern extensional border of the Northern Apennines.

Historical and instrumental catalogues (Boschi et al., 2000; Gruppo di Lavoro CPTI, 2004; Pondrelli et al., 2006; Guidoboni et al., 2007) show a dense intermediate (4.5 < Mw 5.0) to damaging seismicity within the area, besides the key damaging earthquakes of (from northwest to southeast) 14 February 1834 (Mw 5.6, Alta Lunigiana), and 7 May 1481 (Mw 5.8, Lunigiana).

This source includes a set of faults that possibly mimick the inherited structures that border the extensional basins, and that have been in part coseismically reactivated during the earthquakes. This would particularly fit the southern sector of the area, where seismic moment release has been larger.

Some segments of this source have been associated with the key earthquakes of this region. For an in-depth analysis of seismogenesis in this region, the reader can refer to the associated Individual Sources.

The strike of the Source was based on that of the mapped structures (N310°-330°). The dip was based on subsurface data and geometrical considerations (30°-45°). The rake represents pure extension, based on geological observations (260°-280°). The minimum and maximum depth were based on subsurface data and on geometrical considerations (1.0 and 10.0 km, respectively). The slip rate was inferred from geological observations in adjacent structures that share the same tectonic environment with the Lunigiana source (0.1 - 1.0 mm/y). The maximum magnitude was taken from the largest damaging earthquake occurred within the source (Mw 6.0).

Associated Individual Seismogenic Source(s)

ITIS085 Pontremoli

Code	**ITIS085**
Name	Pontremoli

Compiled By	Burrato, P., P. Vannoli and S. Gambini		
Latest Update	02/10/2007		
	Parameter	**Qual.**	**Evidence**
Location (Lat/Lon)	44.3691 / 9.9076	OD	Based on geological data.
Length (km)	7.1	OD	Based on geological and geomorphological data.
Width (km)	5.9	ER	Calculated using the relationships from Wells and Coppersmith (1994).
Min Depth (km)	2	OD	Based on geological and seismological data.
Max Depth (km)	5.9	OD	Based on geological and seismological data.
Strike (deg)	329	LD	Based on geological data from various authors.
Dip (deg)	42	LD	Based on seismological data from Solarino (2007).
Rake (deg)	270	LD	Based on geological data from various authors.
Slip Per Event (m)	0.3	ER	Calculated from Mo using the relationship from Hanks and Kanamori (1979).
Slip Rate (mm/y)	0.1 - 1	EJ	Unknown, values assumed from geodynamic constraints.
Recurrence (y)	300 - 3000	EJ	Inferred from slip rate and average displacement.
Magnitude (Mw)	5.7	LD	Value adopted from the historical earthquake catalogue CPTI04.

1.1.1.1.11. Associated earthquake

Latest Eq	14 Feb 1834	CPTI04.
Penultimate Eq	Unknown	See "Commentary" for information.
Elapsed Time	166	As of year 2000 (assigned datum).

The geometry of the Pontremoli Source is based on geological and geomorphologic observations on the Lunigiana basin. The source is included in the database as a 7 km long, 6 km large, N329-striking and N42-dipping pure normal fault. This fault belongs to the northernmost segment of the Etrurian Fault System outcropping along the western margin of the Lunigiana basin. The existence and position of this source follows the suggestion of several papers dealing with the Etrurian Fault System (EFS; Boncio et al. [2000]). According to Boncio et al. [2000], the EFS is a sytem of low-angle, NE-dipping normal faults, that runs from northern Tuscany to southern Umbria. The well-known Alto Tiberina Fault comprises the central-southern termination of the EFS, and it is the best constrained part of this fault system. The EFS is associated in Tuscany to the main extensional basins that dissect the northern Apennines, and in some cases host the seismogenic sources of large normal faulting earthquakes. From north to south they are: the Lunigiana, Garfagnana, Mugello and Casentino basins. The Lunigiana and Garfagnana basins are two structural depressions limited by NW-SE extensional faults filled with upper Pliocene middle/upper Pleistocene continental deposits. The two basins are delimited near the northern margin of the Alpi Apuane by a SW-NE/WSW-ENE oriented transverse structure (called the Marciano-Minucciano strike-slip fault by Scandone, 2007), which according to Scandone (2007) acted as a dextral transfer accommodating the sinistral offset of the basin axes and of the marginal faults.

OPEN QUESTIONS
1) What are the relationships between the Pontremoli Source and the Aulla Source?
2) What are the structural relationships between the sources bordering the Lunigiana and Garfagnana basins?

ITIS067 Aulla

Code	**ITIS067**		
Name	Aulla		
Compiled By	Burrato, P.		
Latest Update	02/10/2007		
	Parameter	**Qual.**	**Evidence**
Location (Lat/Lon)	44.2201 / 10.0252	OD	Primarily based on the location of the associated historical earthquake.
Length (km)	9	OD	Based on geological, geomorphological and seismological data.
Width (km)	7	OD	Based on geological, geomorphological and seismological data.
Min Depth (km)	1	OD	Based on geological, geomorphological and seismological data.
Max Depth (km)	5.5	OD	Based on geological, geomorphological and seismological data.
Strike (deg)	320	OD	Based on geological data from various authors.
Dip (deg)	40	OD	Based on seismological data from Solarino (2007).
Rake (deg)	270	LD	Based on geological data from various authors.
Slip Per Event (m)	0.3	ER	Calculated from Mo using the relationship from Hanks and Kanamori (1979).
Slip Rate (mm/y)	0.1 - 1	EJ	Unknown, values assumed from geodynamic constraints.
Recurrence (y)	300 - 3000	EJ	Inferred from slip rate and average displacement.
Magnitude (Mw)	5.8	LD	Value adopted from the historical earthquake catalogue CPTI04.

1.1.1.1.12. Associated earthquake

Latest Eq	05 May 1481	CPTI04.
Penultimate Eq	Unknown	See "Commentary" for information.
Elapsed Time	519	As of year 2000 (assigned datum).

The geometry of the Aulla Source is based on geological and geomorphologic observations on the Lunigiana basin. The source is included in the database as a 9 km long, 7 km large, N320-striking and N40-dipping pure normal fault. This source belongs to the northernmost segment of the Etrurian Fault System outcropping along the western margin of the Lunigiana basin. The existence and position of this source follows the suggestion of several papers dealing with the Etrurian Fault System (EFS; Boncio et al. [2000]).

OPEN QUESTIONS
1) What are the structural relationships between the Pontremoli Source and the Aulla Source?

2) What are the structural relationships between the sources bordering the Lunigiana and Garfagnana basins?

ITCS083 Garfagnana

Code	**ITCS083**		
Name	Garfagnana		
Compiled By	Burrato, P., S. Mariano and G. Valensise		
Latest Update	14/05/2010		
	Parameter	**Qual.**	**Evidence**
Min Depth (km)	1	OD	Based on geological and seismological data from Solarino (2007).
Max Depth (km)	10	OD	Based on geological and seismological data from Solarino (2007).
Strike (deg)	300 - 310	OD	Based on geological data.
Dip (deg)	30 - 45	OD	Based on geological and seismological data from Solarino (2007).
Rake (deg)	260 - 280	EJ	Inferred from geological data.
Slip Rate (mm/y)	0.1 - 1	EJ	Unknown, values assumed from geodynamic constraints.
Max Magnitude (Mw)	6.4	OD	Derived from maximum magnitude of associated individual source(s).

This composite source is an extensional belt that straddles the region near the Serchio R. valley, within the Ligurian and Tosco-Emilian Apennines. This Source can be seen as the possible northwestern prolongation of the NE-dipping Etrurian Fault System, marking the northwestern extensional border of the Northern Apennines.

Historical and instrumental catalogues (Boschi et al., 2000; Gruppo di Lavoro CPTI, 2004; Pondrelli et al., 2006; Guidoboni et al., 2007) show a dense intermediate (4.5 < Mw 5.0) to damaging seismicity within the area, besides the key damaging earthquakes of 11 April 1837 (Mw 5.6, Alpi Apuane), and the destructive 7 September 1920 (Mw 6.5) event.

This source includes a set of faults that possibly mimick the inherited structures that border the extensional basins, and that have been in part coseismically reactivated during the reported earthquakes . This would particularly fit the southern sector of the area, where seismic moment release has been larger.

Some segments of this source have been associated with the key earthquakes of this region. For an in-depth analysis of seismogenesis in this region, the reader can refer to the Individual Sources in this Database.

The strike of the Source was based on that of the mapped structures (N300°-310°). The dip was based on subsurface data and geometrical considerations (30°-45°). The rake represents pure extension, based on geological observations (260-280). The minimum and maximum depth were based on subsurface data and on geometrical considerations (1.0 and 10.0 km, respectively). The slip rate was inferred from geological observations in adjacent structures that share the same tectonic environment with the Garfagnana source (0.1 - 1.0 mm/y). The maximum magnitude was taken from the largest damaging earthquake associated with the source (Mw 6.4).

Associated Individual Seismogenic Source(s)

ITIS050 Garfagnana North

Code	**ITIS050**		
Name	Garfagnana North		
Compiled By	Vannucci, G., and G. Valensise		
Latest Update	31/10/2001		
	Parameter	**Qual.**	**Evidence**
Location (Lat/Lon)	44.1792 / 10.3151	LD	Primarily based on the location of the associated historical earthquake.
Length (km)	18	OD	Based on geological and geomorphological data.
Width (km)	11.3	ER	Calculated using the relationships from Wells and Coppersmith (1994).
Min Depth (km)	1	OD	Based on geological and geomorphological data.
Max Depth (km)	8.3	AR	Derived from dip, width and min depth.
Strike (deg)	305	OD	Based on geological and geomorphological data.
Dip (deg)	40	OD	Based on geological and geomorphological data.
Rake (deg)	270	EJ	Inferred from geological data.
Slip Per Event (m)	0.79	ER	Calculated from Mo using the relationship from Hanks and Kanamori (1979).
Slip Rate (mm/y)	0.1 - 1	EJ	Unknown, values assumed from geodynamic constraints.
Recurrence (y)	790 - 7900	EJ	Inferred from slip rate and average displacement.
Magnitude (Mw)	6.4	ER	Calculated using the relationships from Wells and Coppersmith (1994).

1.1.1.1.13. Associated earthquake

Latest Eq	07 Sep 1920	CPTI04.
Penultimate Eq	Unknown	See "Commentary" for information.
Elapsed Time	80	As of year 2000 (assigned datum).

The Serchio Valley, commonly referred to as Garfagnana, is an active tectonic area that corresponds with a ~40 km-long, very well expressed physiographical feature. The recent evolution of this major tectonic feature can be interpreted as controlled by the activity of two large normal faults aligned along the axis of the Serchio Valley.

The northernmost of these faults is included in DISS as the Garfagnana North individual source and is interpreted as the causative source of the destructive 7 September 1920 earthquake. Its length and width are constrained by the characteristics of this historical earthquake. The strike obtained from intensity data has been slightly rotated northward (17°) to match the orientation of the main valley floor. The proposed source is a moderately blind normal fault dipping towards the northeast and producing progressive lowering of the valley floor with respect to the Alpi Apuane (to the west) and to the crest of the Apennines (to the east). This configuration is somehow confirmed by unpublished seismic lines obtained by AGIP in the adjacent Lunigiana basin. The lines show the existence of a 40-50° northeast-dipping master fault that would represent the northwestward prolongation of the Altotiberina Fault well imaged in northern Umbria. The entire valley is bounded to the north by the Sarzana-Equi Terme Line and to the south by the Viareggio-Val di Lima-Bologna Line, which also appear to form the main boundaries of the block corresponding to the Alpi Apuane. Two additional important transverse lineaments, the Secchia Line and the Massa-Mt.

Cervarola Line, subdivide the Serchio Valley into two nearly equal (17-20 km) portions separated by the small Mt. Perpoli ridge.

All of these lineaments are marked by anomalous thermal springs, which shows that these are important lithospheric discontinuities rather than shallow-rooted features generated during the latest compressional tectonic phase. In its turn, this circumstance suggests that these lineaments represent major segment boundaries that are not likely to be violated during a large earthquake. The distribution of damage in 1920 and several other lines of evidence (location of major aftershocks, occurrence of historical earthquakes roughly coinciding and aligned with the Mt. Perpoli ridge) also evident surface breaks are reported for this fault.

Possible evidence for coseismic faulting associated with the 1920 earthquake is reported for Minucciano, but these ruptures seem to accommodate passive reactivation of an old lineament rather than testifying to the Holocene activity of a youthful normal fault. Many faults in bedrock are exposed on both sides of the valley, but no conclusive evidence of Holocene faulting is seen throughout the area.The fault configuration envisioned for this source comprises a typical case of "mimicking", where present-day faulting generates strains that emphasise the already strong topographic imprint left by an older tectonic regime. In other words, the Garfagnana North Source is producing bowl-shaped deformation of a trough that existed prior to the onset of present-day extension and that was eventually filled by lacustrine sedimentation. These lake deposits are presently being eroded away as a result of breaching of the Serchio River at Chiusa di Calavorno (near the junction with the river Lima), probably due to an increased erosional power caused by significant Middle and Late Pleistocene regional uplift.

OPEN QUESTIONS

1) Is there any undetected direct surface evidence for the 1920 earthquake? What is the role of the Minucciano Fault?

2) Is the case of Garfagnana another example of a youthful normal fault that is working its way against a well-established post-compressional landscape?

3) Can the slight departure between the geological and intensity-based solutions for this source (17° in strike, 5 km in absolute location) be explained in terms of northward directivity of rupture in 1920?

4) Does the location of the 11 April 1837 earthquake mark the northern end of this source?

ITIS051 - Garfagnana South

Code	**ITIS051**		
Name	Garfagnana South		
Compiled By	Vannucci, G., and G. Valensise		
Latest Update	31/10/2001		
	Parameter	**Qual.**	**Evidence**
Location (Lat/Lon)	44.0685 / 10.5247	OD	Based on geological and geomorphological observations.
Length (km)	15	OD	Based on geological and geomorphological data.
Width (km)	10	ER	Calculated using the relationships from Wells and Coppersmith (1994).
Min Depth (km)	1	OD	Based on geological and geomorphological data.
Max Depth (km)	7.4	AR	Derived from dip, width and min depth.
Strike (deg)	307	OD	Based on geological and geomorphological data.
Dip (deg)	40	OD	Based on geological and geomorphological data.

Rake (deg)	270	EJ	Inferred from geological data.
Slip Per Event (m)	0.38	ER	Calculated from Mo using the relationship from Hanks and Kanamori (1979).
Slip Rate (mm/y)	0.1 - 1	EJ	Unknown, values assumed from geodynamic constraints.
Recurrence (y)	380 - 3800	EJ	Inferred from slip rate and average displacement.
Magnitude (Mw)	6.1	ER	Calculated using the relationships from Wells and Coppersmith (1994).

The southernmost fault, which is included in the Database as Garfagnana south, lacks of a large historical earthquake associated. Its length and width are constrained by similarity with the adjacent Garfagnana North Source and based onstructural constraints. The proposed source is a moderately blind normal fault dipping towards the northeast and producing progressive lowering of the valley floor with respect to the Alpi Apuane (to the west) and to the crest of the Apennines (to the east).

This configuration is somehow confirmed by unpublished seismic lines obtained by AGIP in the adjacent Lunigiana basin.

OPEN QUESTIONS

1) Is tilting of the Lower Serchio Valley sufficient evidence for the Late Pleistocene and Holocene activity of this fault? Could some direct evidence (a fault scarp) be found along the rather inaccessible mountain front to the southwest of the valley?

2) What is the recurrence interval of this fault? Has it really been quiescent throughout the entire known history?

3) Is the case of Garfagnana another example of a youthful normal fault that is working its way against a well-established post-compressional landscape?

4) What is the meaning of the concentration of background seismicity all around this source?

ITCS037 Mugello - Città di Castello – Leonessa

Code	**ITCS037**		
Name	Mugello-Citta' di Castello-Leonessa		
Compiled By	Burrato, P., P. Vannoli, U. Fracassi and S. Mariano		
Latest Update	30/04/2010		
	Parameter	**Qual.**	**Evidence**
Min Depth (km)	0.5	EJ	Inferred from regional tectonic considerations.
Max Depth (km)	8	EJ	Inferred from regional tectonic considerations.
Strike (deg)	280 - 330	EJ	Inferred from regional geological data.
Dip (deg)	25 - 40	EJ	Inferred from regional geological data.
Rake (deg)	260 - 280	EJ	Inferred from regional geological data.
Slip Rate (mm/y)	0.1 - 1	EJ	Unknown, values assumed from geodynamic constraints.
Max Magnitude (Mw)	6.2	OD	Derived from maximum magnitude of associated individual source(s).

This composite source runs for 200+ km along the backbone of the Northern Apennines, from ca. the latitude of the city of Pistoia (to the northwest) to the upper Nera R. valley (to the southeast), and forms the core of the Etrurian Fault System extensional belt. This source is a complex, low-angle shallow fault array that marks the western extensional border of the Northern Apennines.

Historical and instrumental catalogues (Boschi et al., 2000; Gruppo di Lavoro CPTI, 2004; Pondrelli et al., 2006; Guidoboni et al., 2007) show a dense intermediate (4.5 < Mw 5.0) to damaging seismicity within the area, particularly in the northwestern and southeastern sectors. Moreover, the key damaging and destructive earthquakes have occurred on (from northwest to southeast): 13 June 1542 (Mw 5.9, Mugello), 29 June 1919 (Mw 6.2, Mugello), 26 April 1917 (Mw 5.8, Monterchi-Citerna), 25 December 1352 (Mw 6.0, Monterchi), 26 April 1458 (Mw 5.9, Città di Castello), 13 Jan 1832 (Mw 5.8, Foligno), 15 Sep 1878 (Mw 5.5, Montefalco), and 5 June 1767 (Mw 5.4, Spoletino).

The Etrurian Fault System (also referred to in the literature as the "Altotiberina Fault") is a low-angle normal fault of regional extents, recognised by means of field evidence (Boncio et al., 1998) and subsurface data (Anelli et al., 1994; Barchi et al., 1998). The Etrurian Fault System s.s. reaches depths of 12-14 km beneath the Umbria-Marche fold-and-thrust belt (Boncio et al., 1998 and 2000). The numerous geological and seismological studies indicate the activity of the extensional belt, suggesting its role as the basal detachment of the W-dipping seismogenic normal faults found to the east. In particular, Boncio et al. (2000b) propose that (a) the Etrurian Fault System exerts a structural control on the lower depth of the seismogenic layer in this region, and that (b) its shallowest hanging wall block generates frequent seismic swarms and small magnitude earthquakes.

Some segments of this source have been associated with the key earthquakes of this region. For an in-depth analysis of seismogenesis in this region, the reader can refer to the individual sources.

The strike of this source was based on that of the mapped structures (N280°-330°). The dip was based on subsurface data and geometrical considerations (25°-40°). The rake represents pure extension, based on geological observations (260-280). The minimum and maximum depth were based on subsurface data and on geometrical considerations (0.5 and 8.0 km, respectively). The slip rate was inferred from geological observations in adjacent structures that share the same tectonic environment with the Mugello-Sansepolcro-Trevi source (0.1 – 1.0 mm/y). The maximum magnitude was taken from the largest damaging earthquake associated with the area (Mw 6.2).

Associated Individual Seismogenic Source(s)

ITIS086 Mugello East

Code	**ITIS086**		
Name	Mugello East		
Compiled By	Baroux, E.		
Latest Update	31/05/2005		
	Parameter	**Qual.**	**Evidence**
Location (Lat/Lon)	43.9569 / 11.4683	OD	Based on geological and geomorphological observations.
Length (km)	14	OD	Based on geological and geomorphological data.
Width (km)	9.8	ER	Calculated using the relationships from Wells and Coppersmith (1994).
Min Depth (km)	0.6	OD	Based on geological and geomorphological data.
Max Depth (km)	6.9	OD	Derived from dip, width and min depth.
Strike (deg)	298	OD	Based on geomorphological and geological observations.
Dip (deg)	40	OD	Based on geomorphological and geological observations.
Rake (deg)	270	OD	Based on geological and macroseismic observations.
Slip Per Event (m)	0.45	ER	Calculated from Mo using the relationship from Hanks and Kanamori (1979).
Slip Rate (mm/y)	0.1 - 1	EJ	Unknown, values assumed from geodynamic constraints.
Recurrence (y)	450 - 4500	EJ	Inferred from slip rate and average displacement.
Magnitude (Mw)	6.2	LD	Value adopted from the historical earthquake catalogue CPTI04.

1.1.1.1.14. Associated earthquake

Latest Eq	29 Jun 1919	CPTI04.
Penultimate Eq	Unknown	See "Commentary" for information.
Elapsed Time	81	As of year 2000 (assigned datum).

This is the source responsible of the 29 June 1919 earthquake. The data are based on geomorphologic observations and the geological previous studies. The source is included in the database as a 14.0 km long, 9.8 km large, N298° strike and 40°N dipping pure normal fault. This segment would be a part of the Etrurian Fault System proposed by Boncio et al. (2000).

The macroseismic data of the 1919 earthquake suggest a fault orientation quite different respected to the source orientation proposed in DISS, but this difference can reasonably suppose a significant role of the site effects due to the shape of the basin itself and the high contrast between the sediments and the bedrock bellow. Delle Donne et al. (2003) proposed in their poster evidences of surface faulting oriented

NE-SW, in the eastern part of the Mugello Basin, due, according to the authors, to the 1919 earthquake. They proposed this conclusion on the basis of the macroseismic epicentre location and the fault orientation.

According to the tectonics and geological profiles (Benvenuti, 2003; GE.MI.NA, 1963; Sanesi, 1965) the geometry of the Plio-Quaternary sediment filling seems to indicate a synsedimentary normal faulting. The two episodes of sedimentation separated by a discontinuity are interpreted by Benvenuti and colleagues as the consequences of episodes of thrusting located some kilometres north-eastward. Another possibility could be an extensional tectonics with a movement on the Etrurian Fault System, which include the 1919 source. The several episodes of sedimentation and erosion could be explained by eustatic movement.

OPEN QUESTIONS

1) Is there any surface faulting expression of the 1919 earthquake?
2) The Mugello is a piggy-back basin or due to the activity of a normal fault?
3) Is the tectonic responsible of the formation of the basin yet the same?

ITIS087 Mugello West

Code	**ITIS087**		
Name	Mugello West		
Compiled By	Burrato, P., and E. Baroux		
Latest Update	10/09/2007		
	Parameter	**Qual.**	**Evidence**
Location (Lat/Lon)	44.0092 / 11.3308	OD	Based on geological and geomorphological observations.
Length (km)	9	OD	Based on geological and geomorphological data.
Width (km)	7	OD	Based on seismic profile from Barchi (2007).
Min Depth (km)	1	OD	Based on seismic profile from Barchi (2007).
Max Depth (km)	4.5	OD	Based on seismic profile from Barchi (2007).
Strike (deg)	301	OD	Based on geomorphological and geological observations.
Dip (deg)	30	OD	Based on seismic profile from Barchi (2007).
Rake (deg)	270	OD	Based on geological data, constrained by orientation of T axes.
Slip Per Event (m)	0.3	ER	Calculated from Mo using the relationship from Hanks and Kanamori (1979).
Slip Rate (mm/y)	0.1 - 1	EJ	Unknown, values assumed from geodynamic constraints.
Recurrence (y)	300 - 3000	EJ	Inferred from slip rate and average displacement.
Magnitude (Mw)	5.9	LD	Value adopted from the historical earthquake catalogue CPTI04.

1.1.1.1.15. Associated earthquake

Latest Eq	13 Jun 1542	CPTI04.
Penultimate Eq	Unknown	See "Commentary" for information.

Elapsed Time	458	As of year 2000 (assigned datum).

This is the preliminary version of the source of the 23 June 1542 earthquake, based on geomorphologic observations and the geological previous studies. The source is included in DISS as a 9.0 km long, 7.0 km large, N280° strike and 40°N dipping pure normal fault. This segment would be a part of the Etrurian Fault System proposed by Boncio et al (2000).

The macroseismic data of the 1542 earthquake suggest a fault orientation quite different respected to the source proposed, but it can reasonably supposed a important role of the site effects due to the shape of the basin itself and the high contrast between the sediments and the bedrock bellow.

OPEN QUESTIONS

1) Is there any surface faulting expression of the 1542 earthquake ?
2) The Mugello is a piggy-back basin or due to the activity of a normal fault?
3) Is the tectonic responsible of the formation of the basin yet the same?

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Review of the Delivrable 1, Group 1.

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This report entitled «Review of the active faulting in the Po Plain» presents a tentative analysis of an exhaustive catalogue of the potential seismogenic sources related to the seismic hazard in the Po Plain.

The Po plain recent deformation is mainly characterized by well-developed nearly E-W fold and thrust belts, with both south- and north-verging structures in the north and south of the Po plain, respectively. These deformation domains are related to the frontal Alpine and Apennines compressional tectonic regime.

Due to a high sedimentation rate and relatively low fault slip rates, the tectonic signals are subdued, and thus, nearly impossible to be detected at the surface. Consequently in the Po Plain, predominant active faulting is characterized by buried and blind reverse faults, without any surface rupture. Other seismic events with potential (direct or indirect) effects in the Po plain could be produced by faults in Apennine extensional tectonic domain. These sources, which are easier identified and characterized, are related to normal faults affecting the mountain belt.

Nearly more than eighty potentially seismogenic sources were investigated and/or synthetized by INGV through a review of existing documents and papers, complemented by new data from some peculiar zones; for example, structural observations, seismic lines, and computer-aided analyses of the topography and landscape, as well as instrumental and historical seismicity.

Subsurface geometry could be identified [suggested] by structural cross-sections, and maybe high resolution topographic surveys; it does not seem that was carried in several sites!

This preliminary study allows defining more than 80 Sources classified in three categories:

- Individual seismogenic sources
- Composite seismogenic sources
- Debated seismogenic sources

To be sure I well understand this classification of the propose data base (that has been improved since long time by Italian team, mainly from the INGV) with respect to the usual segmentation nomenclature or terminology for seismic active fault in seismic hazard assessment study.

Individual seismogenic sources:

- Does an individual source mean a "segment" in the usual terminology?
- Do you consider a characteristic behavior for this individual seismogenic sources? That is, seismogenic fault segments with similar length of surface rupture in each event, and consequently, nearly the same magnitude per event with regular recurrence time intervals.
- Is it possible to have a more realistic approach taking into account probable aseismic deformation, not rupturing the entire segment during an event?

Composite seismogenic sources:

- Does this correspond to a fault zone with non-identified individual segments and segment boundaries?

If I well understood, these "composite sources" correspond to unspecified number of individual sources, and thus, an assemblage of unknown number of segments, with unknown segment lengths! Could you specify this assumption?

For each of these seismogenic sources the authors determined:

- Fault or source geometry parameters (strike, dip, length, width)
- Slip direction during faulting
- Co-seismic displacement (slip per event)
- Recurrence time
- Magnitude
- Slip rate

All these parameters are clearly important in the assessment of the regional seismic hazard. This study provides more than eighty "sources" comprising 40 composite sources that are capable to produce events with magnitudes between 5.5 and 6.8, and 38 sources producing events with magnitudes varying between 5.3 and 6.8.

I know that these are very difficult to estimate with accuracy in particular in these conditions of subdued tectonics, i.e., prominently blind faulting. For this reason, I am surprised that you did not try to discus uncertainties of these parameters particularly for the geologically-derived magnitudes deduced from scaling law considering rupture geometry, which in turn is expected by the knowledge of the fault geometry.

Problem related with the peculiar fault geometry within the fold and thrust belts.

I don't discuss the geometric parameter determined for individual seismic sources related to normal faults of Apennine. This should be easy to define, probably by the direct measurements along faults rupturing the surface; generally in normal faulting domains fault planes are clearly exposed in outcrops. To the contrary, in imbricate fold-and-thrust belts, the determination of geometric parameters of a fault, and thus a seismogenic source is probably more difficult due to coexisting thin- and thick-skinned tectonics.

In the Po plain (particularly in the southern Po plain), the geological cross-sections provide evidence for some ramp anticlines that are rooted either in the Triassic layers (?) or in other "décollement" levels such as Mesozoic shales and/or turbidites (?) testifying for thin-skinned tectonics. Other faults are rooted within the basement implying thick-skinned tectonics. The combination of deep-seated faults and listric décollement faults (damping within shales and or evaporate cover beds), may be interpreted as depth partitioning of deformation into thin- and thick-skinned tectonic styles. One problem related to this peculiar geometry is that a fault could not usually characterize by a simple planar geometry, because the fault dip often changes with depth.
The existence of thick- and thin-skinned tectonics imply that faults affecting the basement could produce events with magnitudes higher than the events caused by faults developed only within the sedimentary cover.
Please be aware of the difficulties related to this particular and complex geometry, and additionally, the faults that are principally blind thrust!

Transfer faults, tear faults and oblique ramps

In a fold and thrust belt, faults characterized by significant strike-slip component of faulting (pure strike-slip to oblique strike-slip faulting), often affect the thrust system, oblique or normal to the orientation of the belt. These faults, named tear faults (pure strike-slip), oblique ramp (oblique strike-slip), or transfer (oblique to strike-slip) faults either accommodate differences in shortening rates across the thrust system or "transform" the kinematic variations within the deformation belt. Their size can be significant even if they are secondary faults within the fault and thrust system. There are some few oblique or pure strike slip faulting events deduced from the focal mechanisms testifying for possible oblique ramps, tear faults, or transfer faults within the fold and thrust belts. Did you look for evidence of these potential kinds of faults, in order to evaluate their seismic importance, and if necessary, to calculate their related "source" characteristics?

Fault Slip rate

Fault slip rate is obviously a fundamental parameter in the assessment of the regional seismic hazard, and has a direct influence on the recurrence time.

I have some remarks considering the slip rate:

1- The more interesting parameter in term of seismic hazard assessment is the "true" slip rate, i.e., the rate of the overall slip on the fault plane (along the rupture), in the direction of the fault slip vector. But, generally we deduce slip in the horizontal or vertical planes using geological and geomorphic features, PPS, etc.. For this reason, generally authors specify if those are horizontal or vertical displacement rates. In this deliverable it is not all time easy to know which component of the slip rate is reported.

2- In addition it seems not so difficult to deduced the "true" fault slip by projection of the statistically deduced average rake deduced from the focal mechanisms; indeed, the average true slip rate can be deduced (1) from one of the horizontal or vertical slip rates combined with slip-vector deduced from focal mechanism rake of the slip, projected on the given fault geometry, or (2) from the average focal mechanism slip (rake) on an regionally significant fault direction calculated statistically.

3- Temporal changes in the tectonic regime and slip rates imply that an average slip rate integrated on a long period of time cannot be representative of the present-day slip rate in relation with the active tectonic regime. Several studies reported recent changes in the Mediterranean geodynamic domain, along with a drastic reorganization during late Cenozoic and/or Quaternary (e.g., Calais et al., 2003, EPSL, 216, 81-92; Nocquet and Calais, 2004, Pure applied Geophy., 161, 21p.; Goes et al., 2004, EPSL, 226, 335-345; Billi et al., 2011, BSGF, 182-4, 279-303). Take into account the date of these changes for determining significant slip rates (if possible?).

Does not the Schio-Vicenza fault active? I was intrigued by this N-trending morphologically well-marked lineament in the SE Alps domain. Does not it an (active) fault, and thus a potential source?

"Quickly" looking at the length of the DISS composite sources, some magnitudes seems me relatively underestimated. This concerns particularly the DISS Composite sources for the southern

Po Plain, for example, ITCS051 (Novi-Poggio Renatico, Mmax 5.9), ITCS050 (Poggio Rusco-Migliarino, Mmax 5,5), reactivated during the last M: 6-6.2 20 May earthquake.

The percentage of strain rates, related to active faulting, that is released by aseismic displacements is clearly unknown. This is true for all the study faults in moderate seismicity area, but particularly true within fold and thrust deformation domains?

Minor comments:

- Difficult to judge the quality of the active faulting studies reviewed in pages 24 to 29. These are synthesized within a small text. Locations of figures, sections, maps could help the reader.
- In this synthesis some rates are not consistent: 7 mm/yr, 2,5 mm/yr!
- How do you interpret the very deep event (15, 30 km…)?
- Some references in the text are not listed in the reference list: ex.: Scrocca et al. (207), Boccaletti (2011), Livio et al. 2009 a or b.

In summary: this is a hard effort and a good study, but how is it possible to improve the knowledge of seismogenic sources related to inaccessible, buried and blind faults?

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