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Where the next strong earthquake in the Italian peninsula? Insights by a deterministic approach

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ABSTRACT An attempt is made at gaining insights into the possible location of the next strong earthquake ($M > 5.5$) in the Italian peninsula, by considering the regularity patterns of seismic activity so far recognized in the peri-Adriatic zones (since 1400 A.D.) and their possible connection with the ongoing tectonic setting. This analysis suggests that at present the probability of major shocks is highest in the northern Apennines, and lowest in Calabria and southern Apennines, while an intermediate probability is tentatively assigned to the central Apennines and eastern Southern Alps. Some considerations on the possible seismotectonic consequences of the large westward motion of the Anatolian system after the post-1939 seismic activation of the North Anatolian fault system suggest that the boundary zones of the Sicily wedge (with particular regard to the Vulcano-Syracuse fault system) may as well be prone to large shocks. The identification of the above priority zones may help to better manage the initiatives for seismic risk mitigation in the Italian area. At present, the proposed approach cannot provide significant information on the relative probability of major shocks in the Italian zones not cited in this study.

Key words: seismic hazard, seismotectonics, Italian region.

1. Introduction

A reliable recognition of the zones most prone to next strong earthquakes would help to choose the best strategy for mitigation of seismic risk in Italy. We argue that this information may tentatively be achieved by relying on the hypothesis that the location of major earthquakes in a given tectonic context is mainly conditioned by the spatio-temporal distribution of past seismicity.

The present knowledge about the large-scale geodynamics and present tectonic setting in the study area (e.g., Mantovani *et al*., 2006, 2007a, 2007b, 2009; Viti *et al*., 2006, 2011) suggests that the Adriatic plate (Adria hereafter), stressed by the convergence of the confining plates (Africa, Eurasia and Anatolian-Aegean system), tends to move roughly northwards (Fig. 1). Such motion is supposed to be very slow during quiescent periods, while it locally accelerates (during co-seismic and post-seismic phases) in response to major decoupling earthquakes on the eastern, western and northern peri-Adriatic boundaries, in line with the well-known concept suggested by a number of authors (e.g., Bott and Dean, 1973; Anderson, 1975; Pollitz, 2003; Heki and Mitsui, 2013).

Each strong shock in a peri-Adriatic zone triggers a perturbation of the strain field, defined

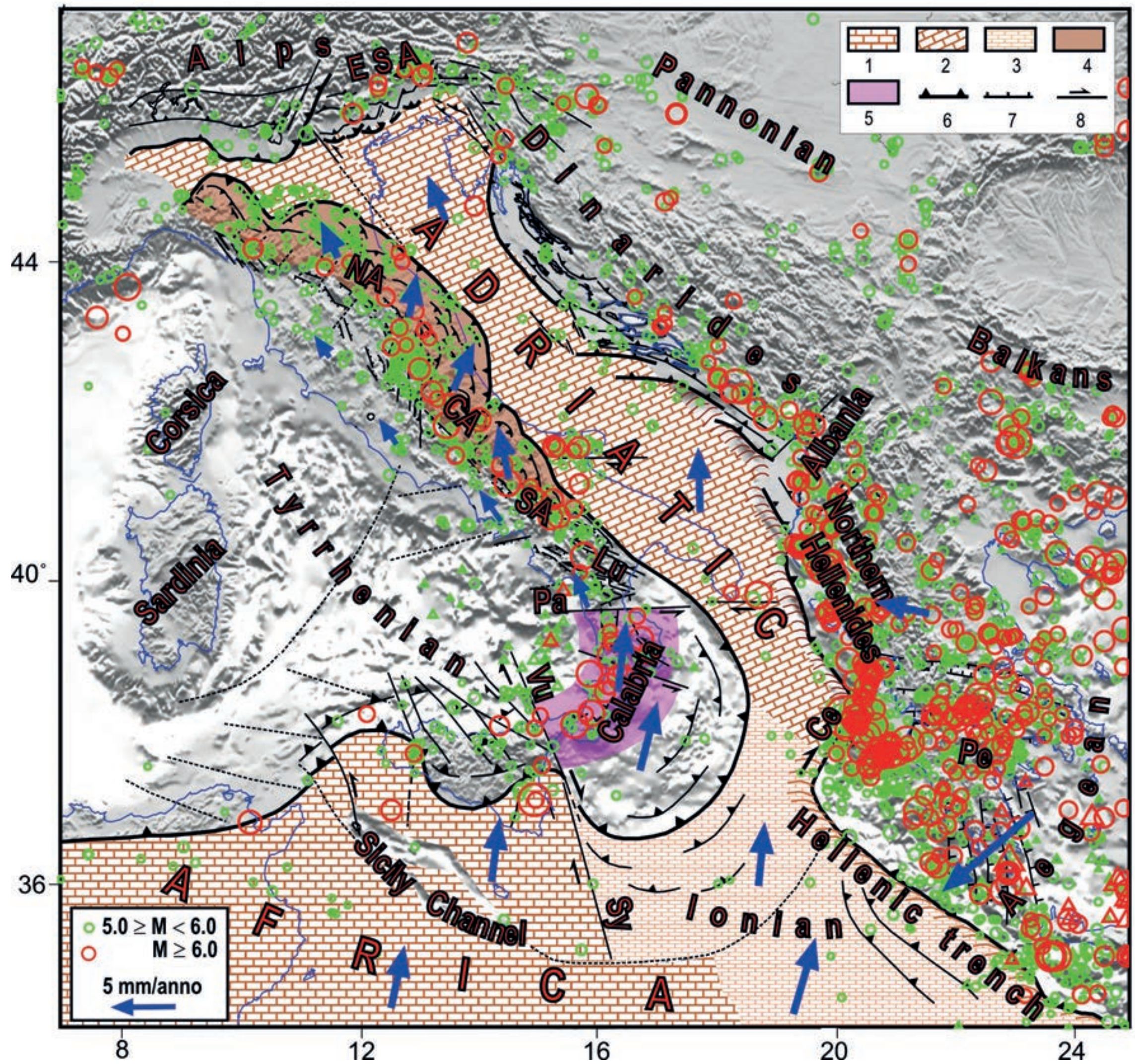


Fig. 1 - Post-early Pleistocene kinematic and tectonic patterns in the central Mediterranean area (from Mantovani *et al.*, 2006, 2009, 2012a, 2014b; Viti *et al.*, 2006, 2011). 1, 2) African and Adriatic continental domains; 3) Ionian oceanic domain; 4) Outer sector of the Apennine belt carried by the Adriatic plate; 5) Calabrian wedge; 6, 7, 8) Major compressional, extensional and transcurrent tectonic features. Blue arrows show a tentative reconstruction of the kinematic pattern with respect to Eurasia (from Mantovani *et al.*, 2007b; Viti *et al.*, 2011). Circles and triangles respectively indicate the epicentres of shallow and deep (h > 60 km) earthquakes occurred in the period 1600-2013. Seismicity data from: Ergin *et al.* (1967); Rothé (1971); Ben-Menahem (1979); Makropoulos and Burton (1981); Iannaccone *et al.* (1985); Comninakis and Papazachos (1986); Ambraseys and Finkel (1987); Anderson and Jackson (1987); Eva *et al.* (1988); Jackson and McKenzie (1988); Benouar (1994); Godey *et al.* (2006); Rovida *et al.* (2011); ISC Catalogue (www.isc.ac.uk/iscbulletin). Other references in the Appendix. CA = Central Apennines; Ce = Cephalonia fault; ESA = eastern Southern Alps; Lu = Lucanian Apennines; NA = northern Apennines; Pa = Palinuro fault; SA = southern Apennines; Vu = Vulcano fault system; Sy = Syracuse fault system.

as post-seismic relaxation (e.g., Pollitz *et al.*, 2006; Ryder *et al.*, 2007; Ergintav *et al.*, 2009; Ozawa *et al.*, 2011), that, propagating through the plate, may reach mature faults (i.e., favorably oriented and prone to failure) at the contiguous boundary sectors, where the probability of seismic activation may significantly increase (Rydelek and Sacks, 1990; Pollitz *et al.*, 1998, 2004, 2012; Mikumo *et al.*, 2002; Freed, 2005; Freed *et al.*, 2007; Brodsky, 2009; Lay *et al.*, 2009; Durand *et al.*, 2010; Luo and Liu, 2010).

In this work, we point out the evidence and arguments that may support the above seismotectonic scheme. First, we synthetically describe the present knowledge about the ongoing tectonic setting, then we discuss the possible connection between the short-term development (tens to hundreds of years) of the proposed plate kinematics and the time pattern of seismicity in the main peri-Adriatic fault zones occurred since 1400 A.D. This study also takes into account the information so far gained, by numerical simulation, about the effects of post-seismic relaxation triggered by major earthquakes in peri-Adriatic regions (Viti *et al.*, 2003, 2012, 2013; Mantovani *et al.*, 2008, 2010, 2012b).

2. Present geodynamic/tectonic context in the central Mediterranean area

Seismotectonic activity in the peri-Adriatic regions is primarily conditioned by the roughly northward motion of Adria and the interaction of such plate with the surrounding orogenic belts (Fig. 1). This interaction is mainly accommodated by compressional deformation on the eastern (northern Hellenides, Dinarides) and northern (eastern Southern Alps) boundaries and by a complex strain pattern on the western Adria border (Apennines). Underthrusting of Adriatic lithosphere mainly develops beneath the northern Hellenides (from the Ionian Islands to Albania) and southern Dinarides (e.g., Louvari *et al.*, 2001; Aliaj, 2006; Benetatos and Kiratzi, 2006; Kokkalas *et al.*, 2006; Kastelic *et al.*, 2013). Seismotectonic activity is highest in the northern Hellenic sector since the shortening of that zone is due to converging blocks (Adria and the Anatolian Aegean system), while at the southern Dinarides tectonic activity is mainly due to the motion of Adria with respect to the almost fixed Carpatho-Pannonian-Balkan system. The relative motion between the southern Hellenic sector (Peloponnesus wedge), facing the Ionian oceanic lithosphere, and the northern Hellenic sector, facing the Adriatic continental domain (Mantovani *et al.*, 2006), is mainly accommodated by dextral transpression at the Cephalonia fault system (e.g., Louvari *et al.*, 1999).

The relative motion between the northern part of Adria and the northern Dinarides is allowed by a dextral transpressional fault system (e.g., Markusic and Herak, 1999; Kuk *et al.*, 2000; Poljak *et al.*, 2000; Burrato *et al.*, 2008). The Adriatic lithosphere underthrusts the Alpine edifice at the eastern Southern Alps (e.g., Bressan *et al.*, 2003; Galadini *et al.*, 2005).

The tectonic context is more complex in the Apennine belt (Fig. 1), where the outer sector of that chain is forced by belt-parallel compression, induced by the Adriatic plate, to separate from the inner Tyrrhenian side of the chain and to extrude laterally, at the expense of the adjacent Adriatic domain (Mantovani *et al.*, 2006, 2009; Viti *et al.*, 2006, 2011; Cenni *et al.*, 2012). The sinistral transtensional decoupling between the outer escaping wedges and the inner almost fixed belt mainly develops along the axial part of the chain, where several intramontane basins have generated in the Quaternary (e.g., Piccardi *et al.*, 2006 and references therein). On the other hand, compressional deformation develops on the outer front of the extruding wedges, where they overthrust the Adriatic domain (e.g., Scisciani and Calamita, 2009). In the central Apennines, the decoupling between the outer mobile sector and the almost fixed western part of that belt is accommodated by two major SE-NW sinistral transtensional fault systems (L'Aquila and Fucino: e.g., Piccardi *et al.*, 1999, 2006; Elter *et al.*, 2012).

The outward extrusion and uplift of the Calabrian wedge, guided by the Palinuro and Vulcano-Syracuse transcurrent fault systems (Fig. 1), are driven by belt-parallel compression. This interpretation is fairly consistent with the structural tectonic features evidenced by the seismic surveys (Finetti, 2005; Guarnieri, 2006; Del Ben *et al.*, 2008) and is compatible with the major Quaternary tectonic deformation in that zone (Mantovani *et al.*, 2006, 2009; Viti *et al.*, 2011).

The relative motion between the Calabrian wedge and the Apennine extruding belt (Fig. 1) is accommodated by the system of NW-SE sinistral strike-slip faults recognized in the Lucanian Apennines (e.g., Catalano *et al.*, 2004; Viti *et al.*, 2006; Caputo *et al.*, 2008; Ferranti *et al.*, 2009). To the south, this system is confined by the Palinuro fault (e.g., Finetti and Del Ben, 1986, 2005; Viti *et al.*, 2006; Del Ben *et al.*, 2008).

3. Short-term plate kinematics and spatio-temporal distribution of major earthquakes in the peri-Adriatic zones

Taking into account the tectonic context described above and the fact that a seismic activation of a peri-Adriatic sector may influence the probability of strong shocks in the other boundary zones, one could expect to observe regularities in the spatio-temporal distribution of seismicity along the peri-Adriatic zones. This possibility may be checked by analysing the seismicity patterns that have developed in the main peri-Adriatic zones since 1400 A.D. (Fig. 2). In this regard, one could display the release of seismic energy over time, but we think that reporting the annual sum of seismic slips, inferred by the average slip-magnitude relationship suggested by Wells and Coppersmith (1994), provides an information more representative of the effects of major decoupling earthquakes on the kinematics of the Adriatic plate with respect to the surrounding structures (Fig. 2). The same diagrams also show the total seismic slip over intervals of ten years, in order to give insights into how such effect has concentrated over time. This last information may be useful to recognize how rapidly the surrounding structures have been stressed by the effects of the triggering earthquakes. In this regard, it must be recalled that the brittle and frictional behaviour of rocks, and thus the probability of seismic sliding, increases as the value of the induced strain rate increases (Kato *et al.*, 2003; Niemeijer and Spiers, 2007; Savage and Marone, 2007).

The time patterns shown in Fig. 2 point out that in the zones here considered seismicity is mostly discontinuous over time, with periods of high activity separated by almost quiescent phases. Furthermore, one could tentatively recognize a progressive northward migration of seismic crises, through the eastern (northern Hellenides and Dinarides) and western (Apennines) boundaries of Adria, up to reach the northernmost boundary zones (eastern Southern Alps and northern Dinarides). This could suggest that the peri-Adriatic decoupling earthquakes involved in each sequence may have allowed the whole Adria plate to make a further step (roughly 1-2 m) towards Europe.

Some traces of one possible sequence could be recognized in the central and northern peri-Adriatic zones, where a significant increase of seismic activity took place, from about the middle of the XV century in the Albania and southern Dinarides zone, to the beginning of the

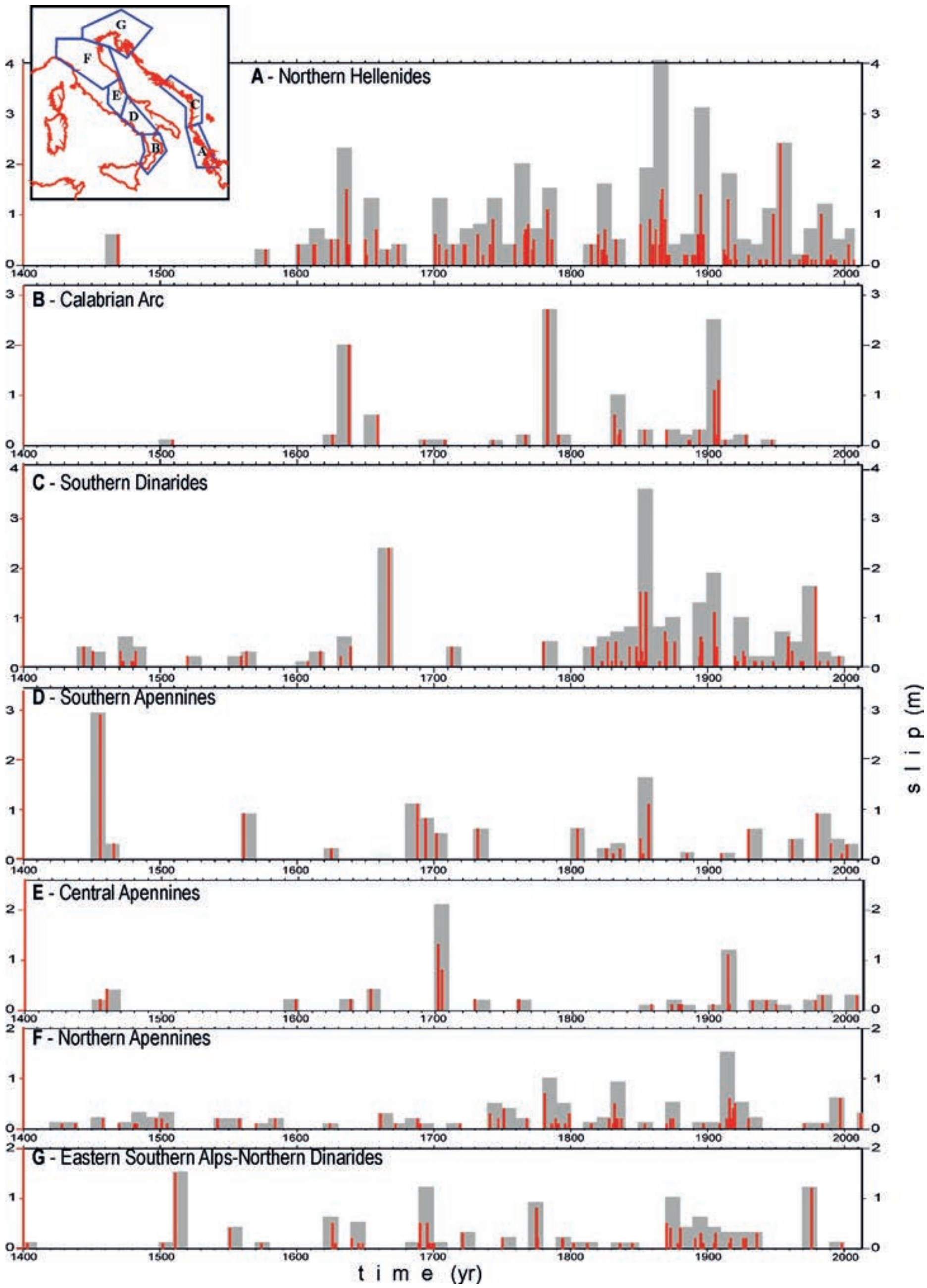


Fig. 2 - Time pattern of shallow seismic activity in the main peri-Adriatic tectonic zones since 1400 A.D. The geometries of the zones considered are shown in the inset. Red bars in the diagrams indicate the total seismic slip (metres) occurred during the related year, computed by the relation $\log_{10}u$ = -4.8+0.69M, where u is the average seismic slip on the fault (in metres) and M is the earthquake magnitude (Wells and Coppersmith, 1994). Vertical grey boxes indicate the sum of seismic slips over decades. Seismicity data are listed in the Appendix.

XVI century in the northern Adriatic front (Fig. 2). The comparison of the seismicity pattern that have occurred since 1456 (Fig. 3A) and the one related to the previous period (Fig. 3B) points out the considerable increase of activity that the central and northern peri-Adriatic zones underwent after the occurrence of major seismic crises in the Albania-southern Dinarides (1444-

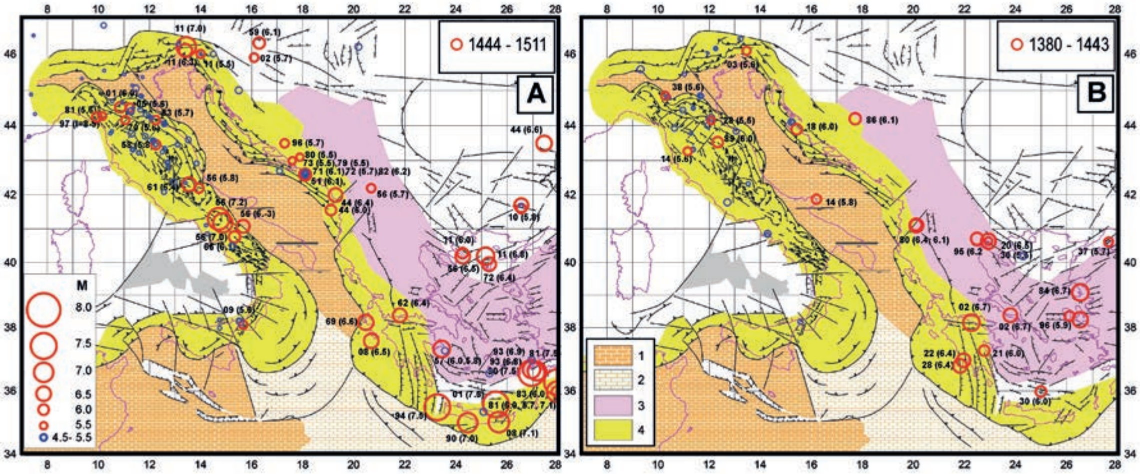
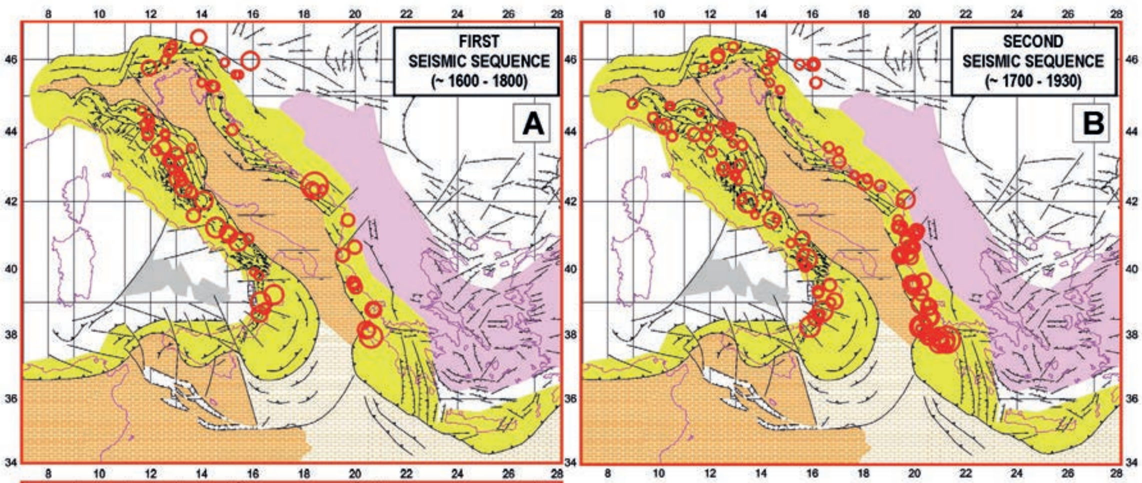


Fig. 3 - A) Distribution of major earthquakes (red circles) during the time interval 1444-1511, presumably related to the first seismic sequence (Fig. 2); B) Seismic activity that preceded (1380-1443) the seismic phase shown in (A). 1) Africa-Adriatic domain; 2) Oceanic Ionian domain; 3) Alpine metamorphic belt; 4) Orogenic belts. The sources of seismicity data are given in the captions of Fig. 1 and the Appendix. Other symbols as in Fig. 1.

1451) and southern Apennines (1456). Since the information on seismic activity in the northern Hellenides and Calabria is very scanty for the time prior to 1600, the starting phase of this presumed sequence can hardly be recognized. This sequence was followed by a long period of moderate activity in most peri-Adriatic zones (Fig. 2).

The first presumably complete sequence may have been triggered by a considerable increase of seismic activity in the northern Hellenides sector during the first decades of the XVII century. This triggering crisis was followed by a significant increase of seismic activity in almost all other peri-Adriatic zones, up to reach the northern front of Adria in the first half of the XVIII century (Fig. 2). On the northern Adriatic front, major seismic activity lasted up to about the end of the XVIII century and then underwent a drastic reduction for a relatively long period, until 1870.

A drastic increase of seismic activity at the northern Hellenides in the last decades of the XVIII century may have determined the beginning of a new seismic sequence. Another seismic period soon occurred in the same zone from 1815 to 1826. This sequence continued to develop with several major events in Albania, southern Dinarides and southern Apennines. In the central Apennines, a relatively long period of moderate seismic activity was interrupted by a very strong shock in 1915 (Fucino, $M = 7.0$), which was followed by several strong earthquakes in the northern Apennines in the period 1916-1920. The space-time distribution of major events during the above seismic sequence (1915-1920) is consistent with the tectonic implications of the proposed tectonic context in the Apennine belt, as argued by Mantovani *et al.* (2010, 2012b). In particular, the quantification of the effects of the post-seismic relaxation induced by the 1915 Fucino and subsequent (1916-1920) strong earthquakes shows that each event of such crisis just occurred when the respective source zone was reached by the highest values of the strain and strain rate perturbation induced by the previous shocks (Viti *et al.*, 2012, 2013). Moreover, such results point out that the strain regimes associated with post-seismic perturbations roughly agree



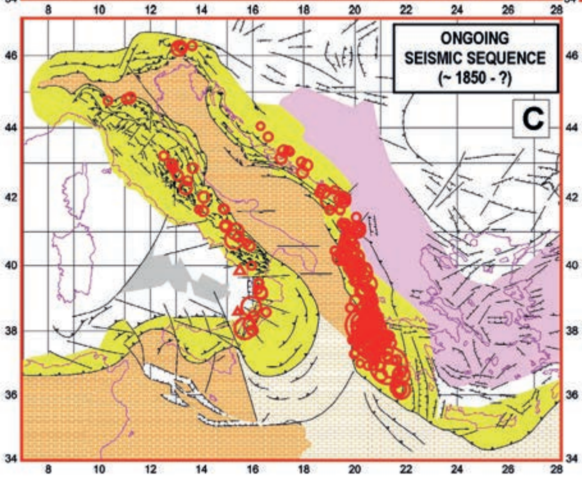


Fig. 4 - Distribution of the major earthquakes ($M \geq 5.5$) which occurred during the last three migrating sequences shown in Fig. 2. See the caption of Fig. 3.

with the styles of seismic faulting recognized in the Apennine zones activated during the 1916-1920 sequence.

The last presumed seismic sequence was triggered by a phase of very high seismic activity in the northern Hellenides (from about 1850 to 1872), which was soon followed by another crisis roughly lasting from 1885 to 1903. As in previous cases, the above crises were accompanied by major earthquakes in Calabria (1870, $M = 6.1$; 1905, $M = 6.9$; 1908, $M = 7.2$).

Then, seismic activity occurred in the southern and central sectors of the Dinarides and Apennines, whereas the northern sectors of those belts have so far been affected by scarce activity, only constituted by one major seismic crisis in the eastern Southern Alps (1976, $M = 6.5$, 6.0) and few shocks (1971, $M = 5.7$; 1979, $M = 5.9$; 1984, $M = 5.7$; 1997, $M = 5.7$, 6.0, 5.5, 5.7; 2012, $M = 5.9$, 5.8) in the northern Apennines. This evidence could imply that the ongoing sequence has not yet undergone a full development, as is also suggested by the spatial distribution of major earthquakes in the last 3 sequences (Fig. 4).

Thus, if one could rely on the fact that seismic activity in the peri-Adriatic zones is affected by a systematic tendency to migrate from south to north, the evidence shown in Figs. 2 and 4 would indicate that the probability of hosting the next major shock is higher in the northern zones (northern Apennines, northern Dinarides and eastern Southern Alps) than in the southern zones (Calabria and southern Apennines). An intermediate probability may tentatively be predicted for the central Apennines, where a significant seismic activity has already occurred, even if less intense than in previous seismic sequences.

Other insights into the most probable location of the next major earthquake in the Italian peninsula may be gained by considering two significant correlations so far recognized between major seismic crises in southern Italian zones and Hellenic/Dinaric sectors (Viti *et al.*, 2003; Mantovani *et al.*, 2010, 2012b), as discussed in the next two sections.

4. Correlation between major earthquakes of southern Apennines and southern Dinarides

The possibility that seismic crises in the southern Dinarides may influence the probability of strong earthquakes in the southern Apennines has been pointed out in previous studies (Viti *et al.*, 2003; Mantovani *et al.*, 2010, 2012b). A significant example of the proposed seismic interrelation was the fact that the strong earthquake (M = 7.0) occurred on April 1979 in the Montenegro area of southern Dinarides was followed on November 1980 by a major event (M = 6.9) in the Irpinia zone of southern Apennines (Fig. 5).

The reliability of the presumed interrelation between seismic activities in the above two zones is suggested by the main features of the structural/tectonic context, as tentatively reconstructed in the schematic cross-section of Fig. 5. In particular, such section suggests that the occurrence of seismic slip at the thrusting fault beneath the southern Dinarides, like the one activated by the 1979 Montenegro event (e.g., Benetatos and Kiratzi, 2006), allows a roughly NE-ward motion of the adjacent Adriatic domain, which may cause a reduction of the upward flexure of this lithosphere. Such process is expected to induce extensional strain in the opposite border of that plate, beneath the southern Apennines, where the activation of the belt-parallel normal faults recognized in that zone (e.g., Ascione *et al.*, 2007) may be favoured. This hypothesis is compatible with the quantification of the effects of the strain perturbation that was induced in the Irpinia zone by the 1979 Montenegro event (Viti *et al.*, 2003; Mantovani *et al.*, 2010, 2012b). The possible relationship between stress/strain rate increase and triggering of seismic activity has been suggested by a number of authors (e.g., Pollitz *et al.*, 1998; Toda *et al.*, 2002; Viti *et al.*, 2003, 2012, 2013).

The possible systematic character of the presumed interconnection between Dinaric and Apennine seismic sources is suggested by the fact that in the last two centuries all shocks with $M \geq 6.0$ in the southern Apennines have been preceded within few years (less than 5) by one or more earthquakes with $M \geq 6.0$ in the southern Dinarides (Fig. 6). The regularity of the above correspondence does not change significantly if weaker shocks ($M \geq 5.5$) are considered, since only one of the 15 Apennine events was not preceded by equivalent Dinaric earthquakes. Since the probability that such a regular correspondence occurs by chance is very small (Mantovani *et al.*, 2010, 2012b), the observed interrelation might reflect a tectonic connection between the zones involved.

The fact that the significant time correlation discussed above can be recognized for the most recent, complete and reliable part of the seismic catalogue might delineate a tool for recognizing the periods when the probability of strong shocks in southern Apennines is undergoing a significant increase. In particular, the main features of the observed correlation would suggest

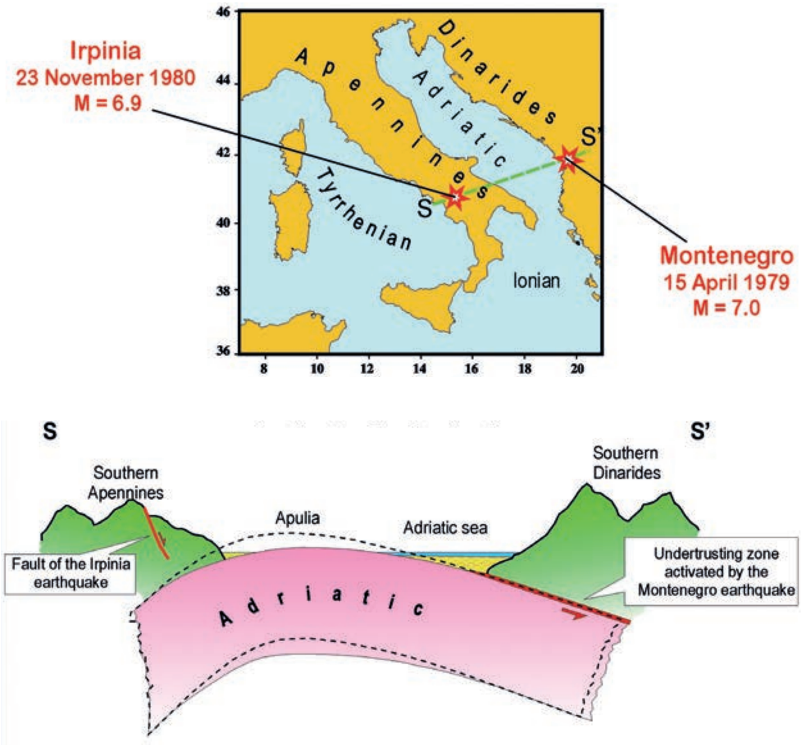


Fig. 5 - Structural sketch through a transversal cross-section in the southern Adriatic area. The upward flexured Adriatic lithosphere is overthrusted by the Dinaric belt, on one side, and by the Apennine belt, on the other side (e.g., Moretti and Royden, 1988; De Alteriis, 1995). The vertical scale is exaggerated to make more evident the possible effect of a seismic slip (red half arrow) at the thrust fault beneath the southern Dinarides. The dashed line in the section shows an indicative reconstruction of the Adriatic profile before the Montenegro seismic slip. Red stars indicate the epicentres of the 1979 (M = 7.0) Montenegro and 1980 (M = 6.9) Irpinia earthquakes.

that a fault in the first zone can hardly activate without the contribution of a post-seismic perturbation triggered by one or more major shocks in the other zone. Thus, the fact that no major earthquakes have occurred in the southern Dinarides since 1996 might imply that at present the probability of a strong shock in the southern Apennines is relatively low.

5. Correlation between major earthquakes in Calabria and northern Hellenides

Another significant correlation has been recognized (Mantovani *et al.*, 2008, 2012b) between the major earthquakes of Calabria and those of the northern Hellenides sector lying between the Cephalonia fault system and Albania (Fig. 7). The hypothesis that a strong seismic activation of the latter thrust zone may increase the probability of major earthquakes in Calabria is consistent with the tectonic interpretation sketched in Fig. 7, similar to the one proposed for the previous interrelation. This scheme suggests that a significant seismic slip at the Hellenic thrust fault zone may produce a reduction of the upward flexure of the Adriatic lithosphere, favouring the outward gravitational sliding of the Calabrian wedge and consequently the seismic activation of normal and strike-slip faults in that highly tectonized wedge (Mantovani *et al.*, 2008, 2009, 2012b).

The suggested interaction of the above seismic sources is compatible with the quantification of the effects of post-seismic relaxation induced by strong earthquakes in the northern Hellenides, which indicates that such phenomenon may account for the time of occurrence of some major Calabrian shocks (Mantovani *et al.*, 2008, 2012b).

The possible systematic character of the seismic interrelation is supported by the fact that

Southern Dinarides (M > 5.6)	Southern Apennines (M ≥ 5.5)
1823 (5.7)	1826 (5.8)
1827 (6.5)	1831 (5.5)
1833 (6.5)	1836 (6.0)
1843 (6.2),1848 (6.4), 1851 (6.0, 6.6, 6.2, 6.3),1852 (6.2)	1851 (6.4),1853 (5.6)
1853 (5.7).1855 (6.8. 6.6)	1857 (7.0)
1869 (6.2. 6.0). 1870 (6.5)	
1876 (6.3)	1885 (5.5)
1894 (5.9).1895 (6.2).1896 (6.2. 5.9)	
1905 (6.0. 6.6). 1906 (6.4). 1907 (6.2. 5.7)	1910 (5.7)
1926 (5.8. 5.8). 1927 (6.0)	1930 (6.6)
1959 (6.2. 5.9). 1962 (6.2)	1962 (6.1. 5.7)
1979 (7.0, 5.7, 6.4)	1980 (6.9)
1982 (5.7), 1988 (5.7)	1990 (5.8, 5.5)
1996 (6.0)	1998 (5.6)

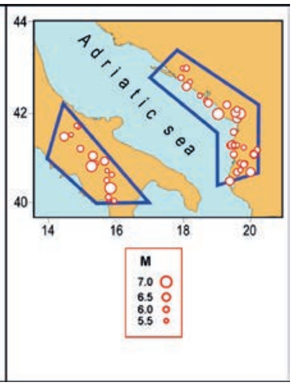


Fig. 6 - The map shows the geometry of the zones implied in the presumed interrelation between southern Dinaric and southern Apennine seismic sources. The list reports the year and magnitude of the main seismic events occurred in such zones after 1810. In bold the events with $M \geq 6.0$.

all Calabrian shocks with $M \geq 6.0$ were preceded, within 10 years, by at least one event with $M \geq 6.5$ in the Hellenic zone (Table 1). Even if lower magnitudes ($M \geq 5.5$) are considered, the correspondence remains fairly significant, since only 2 of the 26 Calabrian events were not preceded by equivalent shocks in the northern Hellenides. The above evidence would suggest that a major earthquake can hardly occur in Calabria if, a few years before, significant seismic activity has not activated the northern Hellenides thrust zone (Mantovani *et al.*, 2008, 2012b).

One could remark that the presumed correlation between northern Hellenic and Calabrian strong earthquakes is not much evident in the latest period, since the last three major events that occurred in the first zone were not followed by major shocks in the second zone (Table 1). It must also be noted that since 1947 no major earthquakes ($M > 5.5$) have occurred in Calabria and that such long quiescence (67 years) is rather anomalous with respect to the previous seismic activity of that zone, given that from 1626 to 1947 the average inter-event time between $M \geq 5.5$ shocks was of about 12 years and never exceeded 41 years.

As argued in a previous work (Mantovani *et al.*, 2012b), we suggest that the above drastic change of seismicity pattern might be an effect of a very rare major tectonic event that considerably perturbed the strain and stress fields in the central Mediterranean region. It concerns the large westward displacement that the Anatolian-Aegean system (Fig. 8) underwent in response to the activation of the whole North Anatolian Fault System (NAFS) that was triggered by the very strong earthquake ($M = 8.0$) occurred in the easternmost sector of such system in 1939 (e.g., Barka, 1996).

While activations of the easternmost (Erzincan zone) and westernmost (Marmara zone) sectors of the NAFS have occurred other times in the past centuries (e.g., Ambraseys and Jackson, 1998), the rare event was the fact that the post-1939 crisis involved the NAFS central sector, that had been almost silent for several centuries. The resulting displacement of the whole Anatolian wedge noticeably strengthened E-W compression in the Aegean region (squeezed between the Anatolian wedge and the Adriatic-Africa plates).

Considering the Minimum Action principle (e.g., Masek and Duncan, 1998; Mantovani *et al.*, 2014b), it is reasonable to suppose that the fast shortening required by such sudden increase of E-W compression was mainly accommodated by the outward extrusion of the Aegean zones (Peloponnesus and central Aegean domain) which face the low buoyancy Ionian oceanic domain. Instead, the shortening of the northern Hellenides and the southernmost Adriatic plate, being confined by high buoyancy orogenic and continental structures, has encountered much higher resistance. This hypothesis is compatible with the fact that since about 1945 seismic

Table 1 - List of major Calabrian and northern Hellenic events occurred since 1600 A.D. in the two zones contoured in Fig. 7. In red the Calabrian events with $M \geq 6.0$ and the Hellenic events with $M \geq 6.5$.

Northern Hellenides ($M \geq 6.0$)	Calabria ($M \geq 5.5$)
1601 (6.3)	
1612 (6.3),1613 (6.3)	
1625 (6.5)	1626 (6.0)
1630 (6.5), 1636 (7.2)	1638 (7.0, 6.9)
1638 (6.3)	
1650 (6.5), 1658 (6.7)	1659 (6.6)
1666 (6.2), 1674 (6.3)	
	1693 (5.7)
1701 (6.6), 1704 (6.4)	1708 (5.5)
1709 (6.2), 1714 (6.3), 1722 (6.3), 1723 (6.3), 1732 (6.6)	
1736 (6.0), 1741 (6.3), 1743 (6.9)	1743 (5.7), 1744 (5.7)
1759 (6.3), 1766 (6.6), 1767 (6.7)	1767 (6.0)
1769 (6.8), 1772 (6.1)	
1773 (6.5)	1783 (7.0, 6.6, 7.0)
1783 (6.6, 6.5), 1786 (6.5)	1791 (6.0)
1815 (6.3), 1820 (6.6)	
1823 (6.3), 1825 (6.7)	1832 (6.6), 1835 (5.8)
1833 (6.5)	1836 (6.2)
1851 (6.8)	1854 (6.2)
1858 (6.4, 6.2, 6.0), 1859 (6.0)	
1860 (6.4), 1862 (6.2, 6.4), 1865 (6.3), 1866 (6.4, 6.3, 6.6), 1867 (7.2), 1869 (6.7, 6.0)	1870 (6.1)
1872 (6.0)	
1885 (6.0)	1886 (5.6), 1887 (5.5)
1893 (6.6)	1894 (6.1)
1895 (6.2, 6.2, 6.5, 6.2), 1897 (6.6), 1912 (6.1)	1905 (7.0), 1907 (5.9), 1908 (7.1), 1913 (5.7)
1915 (6.1, 6.3, 6.0), 1920 (6.0)	1928 (5.8)
	1947 (5.7)
1948 (6.5, 6.5)	
1953 (6.2, 7.0, 6.6)	
1983 (6.7, 6.0)	
2003 (6.2)	

would make more likely the seismic activation of the decoupling zones between the above two wedges (in particular the Vulcano and Syracuse fault systems, Figs. 1 and 8) and of the northern front of the Sicilian wedge.

6. Discussion and conclusions

It is well known that the identification of the zones most prone to next strong earthquakes in Italy would considerably help the best management of initiatives for seismic risk mitigation. Several attempts at achieving such information have so far been carried out by probabilistic estimates, but the results so far obtained can hardly be used for practical purposes (e.g., Mantovani *et al.*, 2012b; Viti *et al.*, 2014 and references therein). This difficulty is clearly connected with the fact that probabilistic earthquake forecasting is mostly based on unreliable

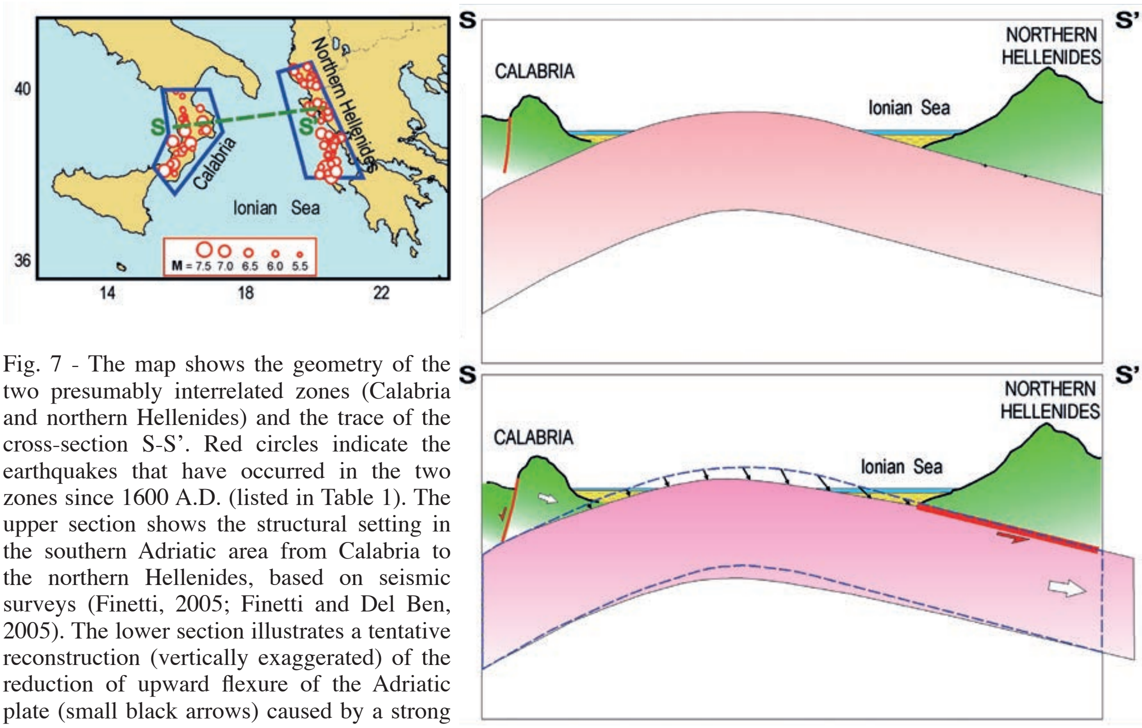


Fig. 7 - The map shows the geometry of the two presumably interrelated zones (Calabria and northern Hellenides) and the trace of the cross-section S-S'. Red circles indicate the earthquakes that have occurred in the two zones since 1600 A.D. (listed in Table 1). The upper section shows the structural setting in the southern Adriatic area from Calabria to the northern Hellenides, based on seismic surveys (Finetti, 2005; Finetti and Del Ben, 2005). The lower section illustrates a tentative reconstruction (vertically exaggerated) of the reduction of upward flexure of the Adriatic plate (small black arrows) caused by a strong decoupling earthquake (red half arrow) at the Hellenic thrust zone. This effect is expected to favour the gravitational sliding of the Calabrian wedge towards the Ionian domain, which may be accompanied by seismic activation (red half arrow) of its main fault systems.

activity has mainly affected the Aegean structures lying south of the Cephalonia fault system and of the North Aegean Trough, whereas only minor seismic activity has occurred at the northern Hellenic thrust zone (Fig. 9).

It is reasonable to think that shortening to the north of the Cephalonia fault has been mainly accommodated by thickening and uplift of the southern Adriatic domain, a process that does not favour the outward escape of the Calabrian wedge and the related seismic effects. This context could explain why since 1947 no major earthquakes have occurred in Calabria (Table 1). During this period, major earthquakes in the Cephalonia fault system might have been only connected with the lateral escape of the Peloponnesus wedge, which has presumably negligible influence on the kinematics of the northern Hellenides and consequently on the tectonic mechanism responsible for the activation of main faults in Calabria (Fig. 7).

On the basis of the evidence and arguments described above, one could expect that at present the probability of strong earthquakes in Calabria is relatively low and that such prediction may continue to be reliable until a significant increase of seismic activity in the northern Hellenides thrust zone occurs again.

However, it must be considered that the above seismotectonic pattern may imply an increased probability of major shocks in the eastern and northern parts of Sicily. This hypothesis assumes that the present resistance to the outward escape of the Calabrian wedge might accelerate the roughly northward escape of the Sicilian wedge (e.g., Mantovani *et al.*, 2009, 2012b), which

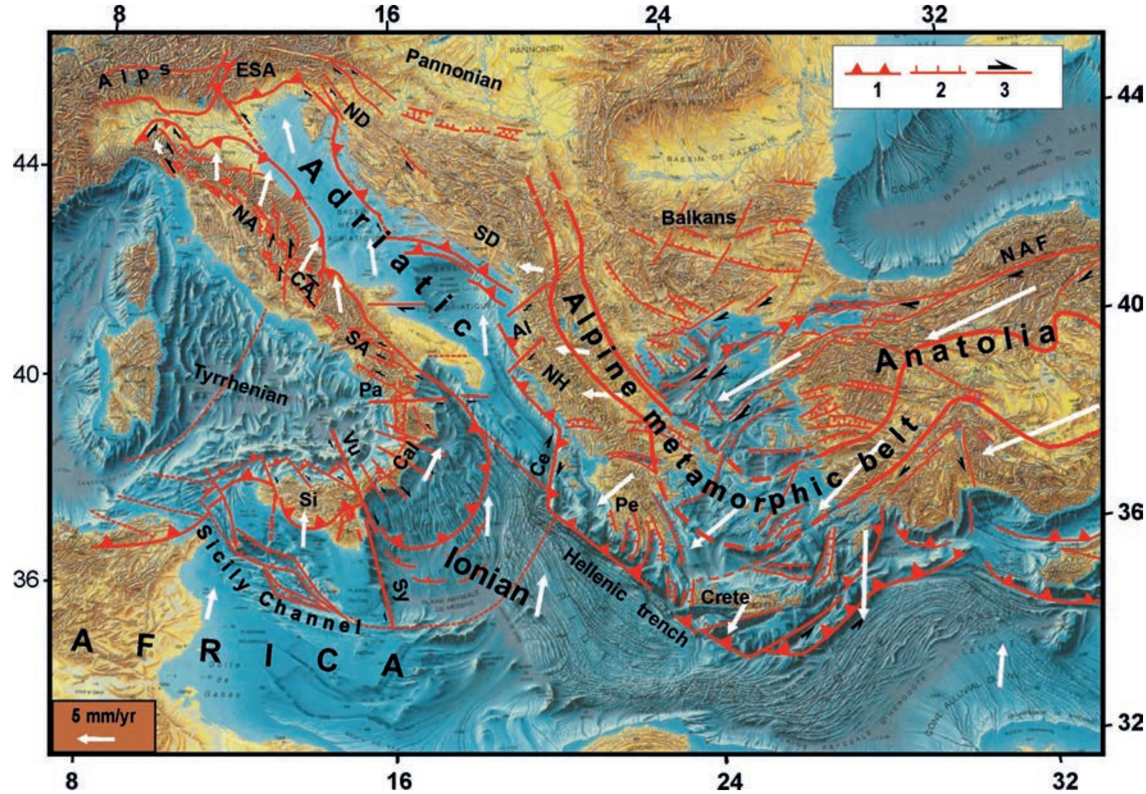


Fig. 8 - Proposed plate/microplate configuration and kinematic pattern in the central Mediterranean and Aegean western Anatolian region (Viti *et al.*, 2011). White arrows indicate the presumed velocity field with respect to Eurasia. Land and seafloor morphological features from de Remur *et al.* (1990). Thick red lines delimitate for reference the inner part of the Alpine metamorphic belt: Al = Albanides; Cal = Calabrian Arc; ND = northern Dinarides; NH = northern Hellenides; SD = southern Dinarides; Si = Sicily. Other symbols and abbreviations as in Fig. 1.

assumptions, in particular the hypotheses that earthquakes are casual and independent events and that the known seismic history can provide significant information on the future behaviour of seismicity. A large set of evidence testifies that the spatio-temporal distribution of major shocks is not casual, but is instead closely connected with the development of tectonic processes (e.g., Mantovani *et al.*, 2010, 2012a, 2012b, 2013; Viti *et al.*, 2012, 2013). Furthermore, the length of seismic catalogues is dramatically shorter than the geological time intervals during which the studied structural systems have been deformed and fractured (e.g., Swafford and Stein, 2007).

The above considerations strongly suggest that the recognition of the priority seismic zones must be attempted by utilizing more reliable deterministic approaches, based on the connection between tectonic processes and seismic activity. This work describes an example of such kind of methodology, which exploits the very detailed reconstruction of the geodynamic and tectonic setting of the central Mediterranean area that is now available (e.g., Mantovani *et al.*, 2009; 2014b; Viti *et al.*, 2011). The validity of the adopted tectonic model is supported by the fact that its major implications are compatible with the main regularities of seismic activity observed in the central Mediterranean region, as discussed in this work and previous papers (Mantovani *et al.*, 2010, 2012a, 2012b, 2013, 2014a; Viti *et al.*, 2003, 2012, 2013).

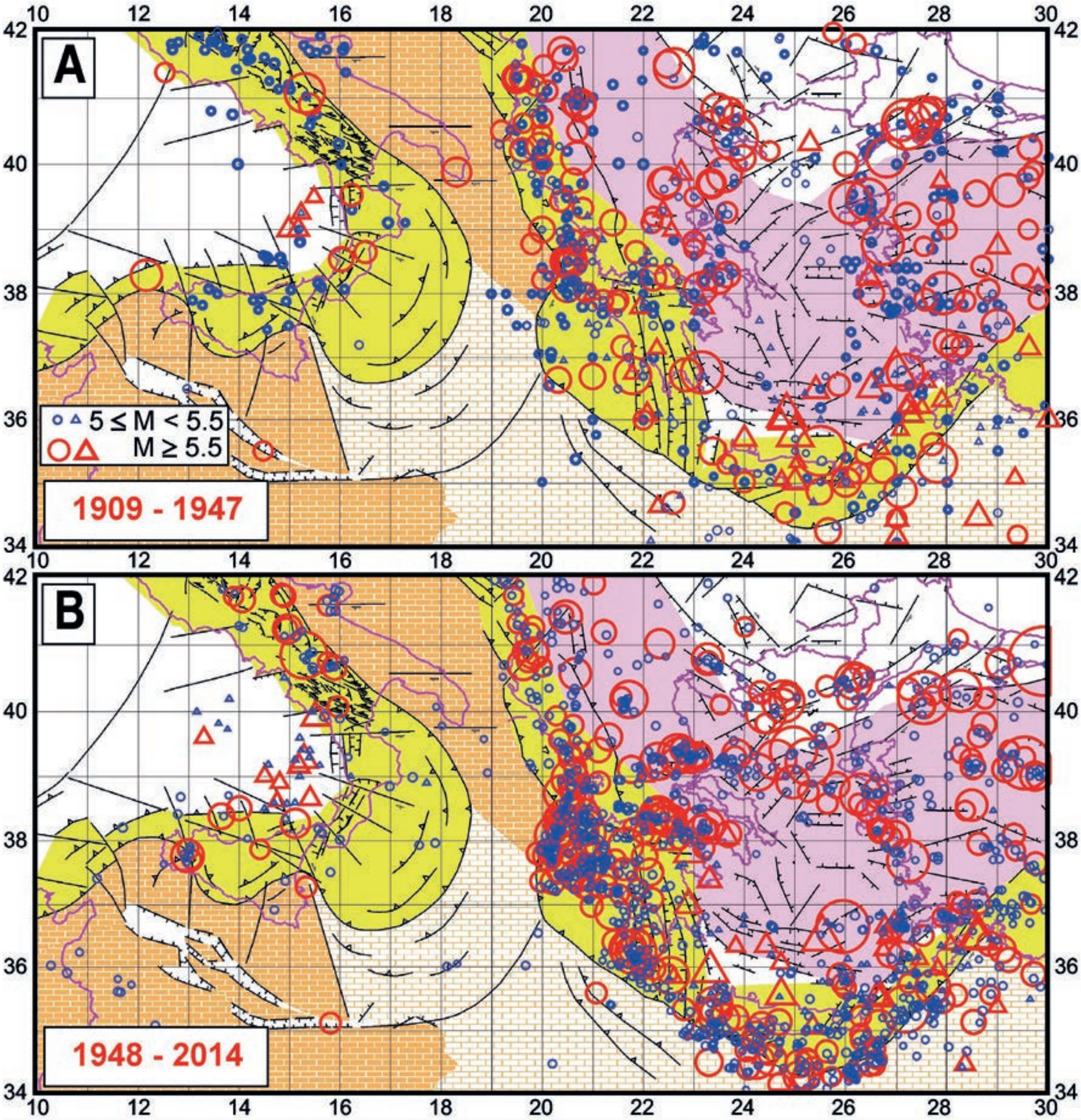


Fig. 9 - Distribution of major earthquakes in two time intervals (1909-1947, A) and (1948-2014, B), which respectively preceded and followed the arrival in the Aegean area of the effects of the large westward displacement of the Anatolian wedge, triggered by the strong earthquake ($M = 8.0$) that occurred in 1939 at the easternmost sector of the NAFS (Mantovani *et al.*, 2001; Cenni *et al.*, 2002). Circles and triangles respectively indicate focal depths lower and greater than 60 km. The sources of seismicity data are listed in the captions of Fig. 1 and in the Appendix. Symbols as in Fig. 3.

The aspect of the proposed interpretation that may allow a tentative recognition of the future paths of major seismicity is the fact that the Adria plate, stressed by the convergence of the confining blocks, tends to move roughly northwards. This movement is achieved by a complex spatio-temporal pattern of local accelerations, allowed by major decoupling earthquakes at the various tectonic boundaries of Adria. The evidence now available seems to indicate that each step forward of Adria takes a period of about 200 years. The known seismic history since 1400

A.D. allows a tentative recognition of two complete sequences of peri-Adriatic events and of a still incomplete sequence that has so far involved decoupling earthquakes in the southern and central sectors of the Apennine belt. In the framework of the proposed interpretation, this evidence implies that the probability of strong earthquakes ($M > 5.5$) is now higher in northern Apennines and eastern southern Alps with respect to the southern zones of the Italian peninsula (southern Apennines and Calabria). An intermediate probability may be associated with the central Apennines, since during the ongoing seismic sequence that zone has already been struck by a number of major shocks, but the total release of seismic energy is significantly lower than the one occurred in previous sequences. Considering that the activation of major fault systems in the eastern southern Alps has often followed the major seismic crises in the northern Apennines, one could also suppose that the present probability of major shocks is highest in that last zone.

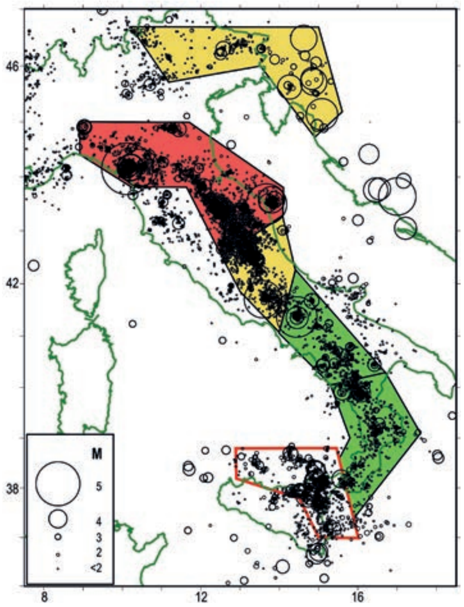
The hypothesis that the probability of major shocks in the southern Apennines and Calabria is now relatively low is also supported by the implications of two fairly regular correlations that have been recognized between the recent seismic activities of such zones and those of Hellenic and Dinaric peri-Adriatic sectors during the previous centuries (Viti *et al.*, 2003; Mantovani *et al.*, 2010, 2012b).

Since significant seismicity regularity patterns have not been recognized for the Italian zones not considered in our study, no prediction is proposed for such zones. The only indication that we tentatively propose, relying on seismotectonic considerations, concerns the eastern and northern sectors of the Sicily wedge, for which we suggest a higher value of earthquake probability, with respect to the other southern Italian zones. This hypothesis is mainly based on the analysis of the possible consequences of the large westward displacement of the Anatolian-Aegean system that occurred after the strong post 1939 seismic activation of the NAFS, as discussed in the text.

A synthesis of the relative probabilities that we suggest for the zones considered is shown in Fig. 10, that also reports the level of background seismicity (recorded events of any magnitude) in the same zones. It is noteworthy that in the last 2 years the number of minor events in the northern Apennines is considerably higher than in the other zones, a feature that is not significantly influenced by the threshold magnitude considered. Although this evidence does not provide any further information on the probability of major earthquakes in the zones involved, it can be considered a signal of enhanced tectonic load in the northern Apennines.

One must be aware that the reliability of the proposed prediction (Fig. 10) cannot easily be evaluated, mainly due to the fact that the limited length of the available seismic history now available only allows the recognition of few migrating seismic sequences through the peri-Adriatic zones (Fig. 2). However, it should be considered that the approach here adopted is not only based on a mere empirical analysis of the seismicity data set, it also relies on a deterministic model based on a tectonic scheme inferred from a very large set of evidence about the most recent (post early Pleistocene) geological evolution of the study area (Mantovani *et al.*, 2006, 2009, 2014b; Viti *et al.*, 2006, 2011). Furthermore, it must be taken into account that the analysis of a dense network of GPS data in the Italian region indicates that the present kinematic pattern of the Apennine belt is fairly compatible with the one deduced by the post-early Pleistocene deformation pattern (Cenni *et al.*, 2012).

Anyway, notwithstanding the possible uncertainties, we think that the indications provided



Seismicity between 1-1-2013 and 31-9-2014 with h≤ 30 Km			
	whole	M ≥ 2	M ≥ 3
Eastern Alps and Northern Dinarides	391	115	24
Northern Apennines	27125	1659	125
Central Apennines	3902	365	20
Southern Apennines	1410	245	25
Calabria	2036	257	17
Eastern Sicily	2009	452	33

Fig. 10 - Relative probabilities of major earthquakes in the Italian zones considered in this study. Red marks the highest probability (northern Apennines), yellow the intermediate probability (central Apennines and eastern Alps-northern Dinarides) and green the lowest probability (southern Apennines and Calabria). The table reports the number of shocks of any magnitude which have occurred in the latest period within the periAdriatic zones here considered (Fig. 2). Seismic data taken from ISIDE Working Group (INGV), 2010. Red contours identify another zone (eastern Sicily) where an high probability of major shocks could be suggested by seismotectonic considerations (see text).

by this study could be useful for the definition of priority criteria, which may help to best manage the limited resources now available for the mitigation of seismic risk in Italy. Even if the proposed prediction proved to be erroneous, the measures so decided would have contributed to significantly increase safety in a zone most probably prone to next strong shocks. Furthermore, given the plausibility of the evidence and arguments presented in this work, we believe that a successful result of the proposed strategy is more likely than its failure.

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Appendix

List of earthquakes used for the diagrams of Fig. 2. *M* = magnitude, Cat = related seismic catalogue: 1) Albini (2004); 2) Ambraseys (1990); 3) Global CMT Catalog (http://www.globalcmt.org/); 4) Gruppo di Lavoro CPTI (2004); 5) Rovida *et al*. (2011)*;* 6) Guidoboni and Comastri (2005); 7) ISIDe Working Group (http://iside.rm.ingv.it), 2010; 8) Karnik (1971); 9) Mariotti and Guidoboni (2006); 10) Seismological Catalogues of Greece (http://www.geophysics.geol.noa.gr/); 11) Makropoulos *et al*. (2012); 12) Margottini *et al*. (1993); 13) Comninakis and Papazachos (1986); 14) Papazachos and Papazachou (1989); 15) Ribaric (1982); 16) Shebalin *et al*. (1974); 17) Stucchi *et al*. *(2012);* 18) Shebalin *et al*. (1998); 19) Toth *et al*. (1988).

Northern Hellenides		
Date (y–m–d)	M	Cat
1469	6.6	17
1577	6.2	17
1601 - 4 - 26	6.3	17
1612 - 5 - 26	6.3	17
1613 - 10 - 12	6.3	17
1625 - 6 - 28	6.5	17
1630 - 7 - 2	6.5	17
1636 - 9 - 20	7.2	10
1638 - 7 - 16	6.3	17
1650	6.5	14
1651 - 2 - 26	5.9	17
1658 - 8 - 24	6.7	17
1666 - 11	6.2	18
1674 - 1 - 16	6.3	17
1701 - 4 - 5	6.6	17
1704 - 11 - 22	6.4	17
1709	6.2	17
1714 - 9 - 8	6.3	17
1722 - 6 - 5	6.3	17
1723 - 2 - 22	6.3	17
1732 - 11	6.6	17
1736	6.0	10
1741 - 6 - 23	6.3	17
1743 - 2 - 20	6.9	10
1759 - 6 - 13	6.3	17
1766 - 7 - 24	6.6	17
1767 - 7 - 22	6.7	17
1769 - 10 - 12	6.8	14
1772 - 5 - 12	6.1	18
1773 - 5 - 23	6.5	10
1783 - 3 - 23	6.6	17
1783 - 6 - 7	6.5	10
1786 - 2 - 5	6.5	17
1815	6.3	17
1820 - 2 - 21	6.6	17
1823 - 6 - 19	6.1	17
1825 - 1 - 19	6.7	17
1826 - 1 - 26	5.8	17
1833 - 1 - 19	6.5	14
1851 - 10 - 12	6.8	17
1858 - 4 - 5	6.0	10
1858 - 9 - 20	6.2	17
1858 - 10 - 10	6.4	17
1859 - 9 - 12	6.0	18
1860 - 4 - 10	6.4	18
1862 - 3 - 14	6.4	17
1862 - 10 - 4	6.2	17
1865 - 10 - 10	6.3	17
1866 - 1 - 2	6.6	17
1866 - 3 - 2	6.3	18
1866 - 12 - 4	6.4	17
1867 - 2 - 4	7.2	17
1869 - 8 - 14	6.0	18
1869 - 12 - 28	6.7	17
1871 - 4 - 9	5.8	17
1872 - 2 - 11	6.0	18
1883 - 6 - 27	5.5	10
1883 - 8	5.5	10
1885 - 12 - 14	6.0	10
1889 - 4 - 1	5.9	17
1890 - 5 - 21	5.9	17
1891 - 6 - 27	5.8	17
1893 - 6 - 14	6.6	17
1895 - 5 - 13	6.2	17
1895 - 5 - 14	6.5	17
1895 - 5 - 15	6.2	17
1895 - 6 - 16	6.2	18
1896 - 2 - 10	5.5	18
1896 - 3 - 18	5.8	18
1897 - 1 - 17	6.6	17
1912 - 1 - 24	6.1	11
1914 - 11 - 27	5.9	11
1915 - 1 - 27	6.1	11
1915 - 8 - 7	6.3	11
1915 - 8 - 10	5.6	11
1915 - 8 - 10	6.0	11
1915 - 8 - 11	5.7	11
1915 - 8 - 19	5.9	11
1917 - 5 - 23	5.6	11
1920 - 10 - 21	5.6	11
1920 - 11 - 26	6.0	18
1920 - 11 - 29	5.5	18
1921 - 9 - 13	5.5	11
1930 - 11 - 21	5.8	18
1938 - 3 - 13	5.7	11
1939 - 9 - 20	5.5	11
1943 - 2 - 14	5.6	11
1948 - 4 - 22	6.5	11
1948 - 6 - 30	6.5	11
1953 - 8 - 9	5.9	11
1953 - 8 - 11	6.6	11
1953 - 8 - 12	7.0	11
1953 - 8 - 12	5.7	11
1953 - 8 - 12	5.9	11
1953 - 10 - 21	6.2	11
1960 - 11 - 5	5.7	11
1967 - 2 - 9	5.5	11
1970 - 7 - 2	5.8	11
1972 - 9 - 17	5.8	11
1973 - 11 - 4	5.8	11
1976 - 1 - 18	5.6	11
1979 - 11 - 6	5.6	11
1983 - 1 - 17	6.7	11
1983 - 1 - 19	5.5	11
1983 - 3 - 23	6.0	11
1987 - 2 - 27	5.6	3
1988 - 5 - 18	5.5	3
1990 - 6 - 16	5.8	3
1992 - 1 - 23	5.6	3
1993 - 6 - 13	5.7	3
1994 - 2 - 25	5.5	3
2000 - 5 - 26	5.6	3
2003 - 8 - 14	6.2	3
2003 - 8 - 14	5.5	3
2007 - 3 - 25	5.7	3

Calabrian Arc		
Date (y–m–d)	M	Cat
1509 - 2 - 25	5.6	5
1626 - 4 - 4	6.0	5
1638 - 3 - 27	7.0	5
1638 - 6 - 8	6.9	5
1659 - 11 - 5	6.6	5
1693 - 1 - 8	5.7	5
1708 - 1 - 26	5.5	5
1743 - 12 - 7	5.7	5
1744 - 3 - 21	5.7	5
1767 - 7 - 14	6.0	5
1783 - 2 - 5	7.0	5
1783 - 2 - 7	6.6	5
1783 - 3 - 28	7.0	5
1791 - 10 - 13	6.0	5
1832 - 3 - 8	6.6	5
1835 - 10 - 12	5.8	5
1836 - 4 - 25	6.2	5
1854 - 2 - 12	6.2	5
1870 - 10 - 4	6.1	5
1886 - 3 - 6	5.6	5
1887 - 12 - 3	5.5	5
1894 - 11 - 16	6.1	5
1905 - 9 - 8	7.0	5
1907 - 10 - 23	5.9	5
1908 - 12 - 28	7.1	5
1913 - 6 - 28	5.7	5
1928 - 3 - 7	5.8	5
1947 - 5 - 11	5.7	5

Southern Dinarides		
Date (y–m–d)	M	Cat
1444	6.4	18
1451	6.1	18
1471	6.1	18
1472	5.7	18
1473 - 1 - 20	5.5	18
1479 - 10 - 20	5.5	18
1480 - 10 - 18	5.5	18
1482 - 2 - 15	6.2	18
1520 - 5 - 17	6.0	17
1559 - 6 - 24	6.0	1
1563 - 6 - 13	6.1	18
1608 - 7 - 25	5.6	17
1617	6.2	18
1632	6.0	17
1639 - 7 - 28	6.4	18
1667 - 4 - 6	7.5	18
1713 - 1 - 0	6.3	17
1780 - 9 - 21	6.5	18
1816	6.3	18
1823 - 8 - 7	5.7	18
1827 - 4 - 17	6.5	18
1830	5.6	18
1833 - 1 - 19	6.5	14
1837 - 10 - 4	5.5	18
1843 - 9 - 5	6.2	17
1843 - 9 - 26	5.6	18

1848	6.4	17
1850 - 4 - 13	5.6	17
1851 - 1 - 20	6.0	18
1851 - 10 - 17	6.2	18
1851 - 10 - 17	6.6	17
1851 - 10 - 20	6.3	18
1851 - 12 - 29	5.5	18
1852 - 8 - 26	6.2	17
1853 - 12 - 11	5.7	18
1855 - 7 - 3	6.6	10
1855 - 7 - 5	6.8	18
1855 - 7 - 16	5.5	18
1855 - 8 - 14	5.5	18
1865 - 10 - 10	5.5	18
1869 - 1 - 10	5.6	18
1869 - 3 - 18	6.0	18
1869 - 4 - 14	5.5	17
1869 - 9 - 1	6.2	18
1870 - 9 - 28	6.5	17
1876 - 6 - 4	6.3	18
1876 - 6 - 5	5.6	18
1894 - 4 - 6	5.9	17
1895 - 5 - 14	5.5	18
1895 - 6 - 21	5.5	18
1895 - 8 - 6	6.2	17
1895 - 10 - 8	5.5	18
1896 - 2 - 10	5.9	17
1896 - 2 - 10	6.2	17
1905 - 6 - 1	6.6	18
1905 - 6 - 1	5.5	18
1905 - 6 - 3	5.5	18
1905 - 8 - 4	6.0	18
1905 - 8 - 6	5.5	18
1906 - 3 - 1	6.4	18
1907 - 8 - 1	5.7	18
1907 - 8 - 16	6.2	18
1920 - 11 - 29	5.6	13
1920 - 12 - 18	5.6	18
1921 - 3 - 30	5.6	11
1922 - 4 - 11	5.6	18
1926 - 12 - 17	5.8	18
1926 - 12 - 17	5.8	18
1927 - 2 - 14	6.0	18
1934 - 2 - 4	5.6	18
1935 - 3 - 31	5.6	11
1940 - 2 - 23	5.5	18
1948 - 8 - 27	5.5	18
1958 - 4 - 3	5.6	18
1959 - 8 - 17	5.9	18
1959 - 9 - 1	6.2	18
1959 - 10 - 7	5.6	18
1962 - 3 - 18	6.2	18
1968 - 11 - 3	5.5	18
1969 - 4 - 3	5.5	11
1970 - 8 - 19	5.5	18
1979 - 4 - 15	7.0	2
1979 - 4 - 15	5.7	11
1979 - 5 - 24	6.4	18
1982 - 11 - 16	5.7	18
1988 - 1 - 9	5.7	18
1996 - 9 - 5	6.0	3

Southern Apennines		
Date (y–m–d)	M	Cat
1456 - 12 - 5	7.2	5
1456 - 12 - 5	7.0	6
1456 - 12 - 5	6.3	6
1466 - 1 - 15	6.1	5
1561 - 7 - 31	5.6	5
1561 - 8 - 19	6.8	5
1625 - 9 - 0	5.8	5
1688 - 6 - 5	7.0	5
1694 - 9 - 8	6.8	5
1702 - 3 - 14	6.5	5
1732 - 11 - 29	6.6	5
1805 - 7 - 26	6.6	5
1826 - 2 - 1	5.8	5
1831 - 1 - 2	5.5	5
1836 - 11 - 20	6.0	5
1851 - 8 - 14	6.4	5
1853 - 4 - 9	5.6	5
1857 - 12 - 16	7.0	5
1885 - 12 - 26	5.5	5
1910 - 6 - 7	5.7	5
1930 - 7 - 23	6.6	5
1962 - 8 - 21	5.7	5
1962 - 8 - 21	6.1	5
1980 - 11 - 23	6.9	5
1990 - 5 - 5	5.8	5
1990 - 5 - 5	5.5	5
1998 - 9 - 9	5.6	5
2002 - 10 - 31	5.7	5
2002 - 11 - 1	5.7	5

Central Apennines		
Date (y-m-d)	M	Cat
1456 - 12 - 5	5.8	6
1461 - 11 - 27	6.4	5
1599 - 11 - 6	6.0	5
1639 - 10 - 7	5.9	5
1654 - 7 - 24	6.3	5
1703 - 1 - 14	6.7	5
1703 - 1 - 16	5.9	17
1703 - 2 - 2	6.7	5
1706 - 11 - 3	6.8	5
1730 - 5 - 12	5.9	5
1762 - 10 - 6	6.0	5
1859 - 8 - 22	5.5	5
1874 - 12 - 6	5.5	5
1879 - 2 - 23	5.6	5
1881 - 9 - 10	5.6	5
1904 - 2 - 24	5.6	5
1915 - 1 - 13	7.0	5
1916 - 11 - 16	5.5	5
1933 - 9 - 26	6.0	5
1943 - 10 - 3	5.8	5
1950 - 9 - 5	5.7	5
1979 - 9 - 19	5.9	5
1984 - 5 - 7	5.9	5
1984 - 5 - 11	5.5	5
2009 - 4 - 6	6.2	5

Northern Apennines		
Date (y-m-d)	M	Cat
1428 - 7 - 3	5.5	5
1438 - 6 - 11	5.6	5
1458 - 4 - 26	5.8	5
1470 - 4 - 11	5.6	5
1481 - 5 - 7	5.6	5
1483 - 8 - 11	5.7	5
1497 - 3 - 3	5.9	6
1501 - 6 - 5	6.0	5
1505 - 1 - 3	5.6	5
1542 - 6 - 13	5.9	5
1558 - 4 - 13	5.8	5
1570 - 11 - 17	5.5	5
1584 - 9 - 10	5.8	5
1624 - 3 - 19	5.5	5
1661 - 3 - 22	6.1	5
1672 - 4 - 14	5.6	5
1688 - 4 - 11	5.8	5
1690 - 12 - 23	5.6	5
1719 - 6 - 27	5.5	5
1741 - 4 - 24	6.2	5
1747 - 4 - 17	5.9	5
1751 - 7 - 27	6.3	5
1768 - 10 - 19	5.9	5
1781 - 4 - 4	5.9	5
1781 - 6 - 3	6.4	5
1781 - 7 - 17	5.6	5
1786 - 12 - 25	5.6	5
1789 - 9 - 30	5.8	5
1791 - 10 - 11	5.5	5
1796 - 10 - 22	5.6	5
1799 - 7 - 28	6.1	5
1815 - 9 - 3	5.5	5
1828 - 10 - 9	5.8	5
1831 - 9 - 11	5.5	5
1832 - 1 - 13	6.3	5
1832 - 3 - 13	5.5	5
1834 - 2 - 14	5.8	5
1837 - 4 - 11	5.8	5
1854 - 2 - 12	5.6	5
1870 - 10 - 30	5.6	5
1873 - 3 - 12	6.0	5
1875 - 3 - 17	5.9	5
1897 - 9 - 21	5.5	5
1909 - 1 - 13	5.5	5
1914 - 10 - 27	5.8	5
1916 - 5 - 17	6.0	5
1916 - 8 - 16	6.1	5
1916 - 8 - 16	5.5	5
1917 - 4 - 26	5.9	5
1918 - 11 - 10	5.9	5
1919 - 6 - 29	6.3	5
1920 - 9 - 7	6.5	5
1930 - 10 - 30	5.8	5
1971 - 7 - 15	5.6	5
1984 - 4 - 29	5.7	5
1997 - 9 - 26	5.7	5
1997 - 9 - 26	6.0	5
1997 - 10 - 6	5.5	5
1997 - 10 - 14	5.7	5
2012 - 5 - 20	5.9	7
2012 - 5 - 29	5.8	7

Eastern Alps – Northern Dinarides		
Date (y-m-d)	M	Cat
1403 - 9 - 6	5.6	5
1502 - 3 - 26	5.7	18
1511 - 3 - 26	7.0	5
1511 - 6 - 25	5.6	17
1511 - 8 - 8	6.3	18
1551 - 3 - 26	6.3	18
1574 - 8 - 14	5.6	5
1626 - 7 - 3	6.5	18
1628 - 6 - 17	5.6	4
1640	6.0	4
1645	5.6	4
1648	5.7	18
1689 - 3 - 10	5.6	4
1690 - 12 - 4	6.5	5
1695 - 2 - 25	6.5	5
1697 - 3 - 15	5.6	4
1699 - 2 - 11	5.6	4
1700 - 7 - 28	5.6	5
1721 - 1 - 12	6.1	5
1750 - 12 - 17	5.9	18
1775 - 10 - 13	6.8	19
1776 - 7 - 10	5.8	5
1794 - 6 - 7	6.0	5
1802 - 1 - 4	5.6	18
1812 - 10 - 25	5.7	5
1836 - 6 - 12	5.5	5
1845 - 12 - 12	5.7	18
1870 - 3 - 1	6.4	18
1870 - 3 - 1	5.6	17
1873 - 6 - 29	6.3	5
1878 - 9 - 23	5.6	17
1880 - 11 - 9	6.3	18
1891 - 6 - 7	5.9	5
1895 - 4 - 14	6.2	5
1897 - 5 - 15	5.6	5
1905 - 12 - 17	5.6	18
1906 - 1 - 2	6.1	18
1916 - 3 - 12	5.6	5
1917 - 1 - 29	5.8	4
1926 - 1 - 1	5.9	5
1928 - 3 - 27	5.8	5
1936 - 10 - 18	6.1	5
1976 - 5 - 6	6.5	5
1976 - 9 - 11	5.6	5
1976 - 9 - 15	5.9	5
1976 - 9 - 15	6.0	18
1976 - 9 - 15	6.0	5
1998 - 4 - 12	5.7	3