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INDICE - *CONTENTS*

G. CUCURNIA – L’alluvione di Marina di Carrara (Toscana, Italia) del 5 novembre 2014: descrizione dell’evento meteo-idrologico ed analisi dei fattori geografici e geomorfologici predisponenti.
Marina di Carrara (Tuscany, Italy) flood on November 5, 2014: description of the meteo-hydrological event and analysis of predisposing geographic and geomorphological factors. pag. 5

R. GRIFONI CREMONESI – Grotte, fosse, circoli di pietre, offerte vegetali e animali, acque e simboli: testimonianze di culti e riti nella Preistoria italiana.
Caves, ritual pits, stone circles, vegetables and animals offerings, water and symbols: evidences of cults and rites in the Italian Prehistory. » 15

P. BALOCCHI – Tectonics and seismotectonics of high Dragone valley between Piandelagotti and Montefiorino villages (Northern Apennines, Italy).
Tettonica e sismotettonica dell’alta valle del Dragone tra i paesi di Piandelagotti e Montefiorino (Appennino Settentrionale, Italia). » 29

A. PETROCCIA, M. BONASERA, S. NERONE, F. CASO, M. MORELLI, D. BORMIOLI, G. MOLETTA – Geological guide to the excursion in the upper Maira Valley (Western Alps, Italy).
Guida geologica all’escursione in alta Valle Maira (Alpi Occidentali, Italia). » 41

S. MERLINO – The OD nature of perrierite and chevkinite.
La natura OD di perrierite e chevkinite. » 55

C. BIAGIONI – A new occurrence of a Mg-rich member of the chabazite series from Tuscany (Italy).
Un nuovo ritrovamento di un termine ricco in Mg della serie della cabasite dalla Toscana (Italia). » 61

S. PAGNOTTA, M. LEZZERINI – Comparison between Leeb and Knoop hardness on metakaolin-based geopolymers.
Confronto tra la durezza di Leeb e Knoop di geopolimeri a base di metacaolino. » 67

F. RAPETTI – La pioggia a Livorno (Toscana, Italia) (1857-2019).
The rain in Leghorn (Tuscany, Italy) (1857-2019). » 75

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Paolo Balocchi [1]

TECTONICS AND SEISMOTECTONICS OF HIGH DRAGONE VALLEY BETWEEN PIANDELAGOTTI AND MONTEFIORINO VILLAGES (NORTHERN APENNINES, ITALY)

Abstract - P. Balocchi, *Tectonics and seismotectonics of high Dragone valley between Piandelagotti and Montefiorino villages (Northern Apennines, Italy).*

A small seismic sequence in the high Modena Apennines (Sant'Anna Pelago area) occurred in the 2018-2019 period with a main earthquake of M_W 3.6 on July 1, 2018. The existent geological literature does not suggest the presence of a Quaternary active fault that can explain this seismic sequence. Small earthquakes are related to the same seismogenic process of strong earthquakes and, generally, earthquakes are generated by minor structures associated with regionally important faults, which define the main rupture zone. The structural analysis of mesoscopic faults in outcropping rock-units, and the analysis of hypocentres distribution, provided important information on the geometry, kinematics, and tectonic stress of the main regional fault systems responsible for the occurred seismic event. This paper proposes the seismotectonic model of high Dragone valley, when the mesostructural analysis describes the main surface fault systems and the horst and graben structure of Riccovolto village, while, the analysis of hypocentres distribution shows a shallow detachment structure. The model represents clearly an active extensional system of regional importance.

Key words - seismic cluster, detachment, horst and graben, strike-slip fault, Modino unit, Northern Apennines, Italy

Riassunto - P. Balocchi, *Tettonica e sismotettonica dell'alta valle del Dragone tra i paesi di Piandelagotti e Montefiorino (Appennino Settentrionale, Italia).*

Una piccola sequenza sismica nell'area di Sant'Anna Pelago, si è verificata nel periodo 2018-2019 con un terremoto principale di M_W 3,6 del 1° luglio 2018. La letteratura geologica esistente non prevede l'esistenza di una faglia quaternaria attiva che motivi questa sequenza sismica. I piccoli terremoti sono legati agli stessi processi sismogenetici dei forti terremoti e, generalmente, sono generati da strutture minori associate alle faglie di importanza regionale, che definiscono la zona di rottura principale. L'analisi strutturale delle faglie mesoscopiche nelle unità affioranti, e l'analisi della distribuzione degli ipocentri, ha fornito importanti informazioni sulla geometria, sulla cinematica e sullo stress tettonico dei principali sistemi di faglie regionali. Questo articolo propone il modello sismotettonico dell'alta valle del Dragone, dove l'analisi mesostrutturale descrive i principali sistemi di faglie superficiali e la struttura horst and graben di Riccovolto, mentre, l'analisi della distribuzione degli ipocentri mostra una struttura di scollamento poco profondo. Questo modello rappresenta chiaramente un sistema estensionale attivo di importanza regionale.

Parole chiave - cluster sismico, scollamento, horst e graben, faglia trascorrente, unità Modino, Appennino settentrionale, Italia

Introduction

A small seismic sequence in the Sant'Anna Pelago area, occurred in 2018-2019 period with a main earthquake of M_W 3.6 on July 1, 2018. Other earthquakes occurred in the area, and they show a typical geometry of a seismic cluster. The geological maps of this area (ISPRA, 2000; Cerrina Ferroni *et al.*, 2002a, 2002b; Plesi *et al.*, 2002a), do not support the existence of Quaternary faults that can motivate the seismic sequence. Furthermore, in scientific literature is not described a seismogenic source (DISS Working Group, 2015) responsible for this seismic sequence.

The structural analysis of mesofaults, on different outcrops, can give information on the geometry, deformation and stress, along the surface faults (Balocchi, 2014; Balocchi & Santagata, 2018), and the analysis of the distribution of hypocentres can provide very important information on the geometry of the deep seismogenic source, as described in some papers (Balocchi *et al.*, 2016; Chiaraluce *et al.*, 2014; Cheloni *et al.*, 2017; Balocchi & Riga, 2017, 2018). Furthermore, studies carried out on low-magnitude earthquakes can provide useful information on the seismotectonic and seismogenic context as well as on the seismic processes that generated the sequence and the strong earthquakes associated (Chiaraluce *et al.*, 2004; Chiarabba *et al.*, 2014). Small earthquakes, in fact, are related to the same seismogenic processes of strong earthquakes. In general, they are associated with minor seismogenic structures, which along with the main ones, determine the main rupture zone.

The comparison between structural geological data and seismological data is very important to describe the tectonic and seismotectonic model of the seismogenic source both at the surface and in the crust. For these reasons, this study is designed to analyze the mesofaults, with the aim of determining the geometry and kinematic of the main fault systems and possible macroscale structures. Furthermore the seismological analysis of the earthquakes distribution, with the objective of determining the geometry and kinematics of crustal sources and their possible seismic clusters. The ultimate goal is to describe the tecton-

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ics and seismotectonics model of the high Dragone creek valley between Piandelagotti and Montefiorino villages.

REGIONAL GEOLOGY AND TECTONICS

The Northern Apennines is a thrust and fold belt (Elter, 1960; Reutter & Groscurth, 1978) mainly formed in the Tertiary. It is commonly considered as the result of the convergence between the European plate and Adria microplate, a fragment of the more extended Africa plate (Boccaletti *et al.*, 1971; Boccaletti & Guazzone, 1972). The convergence generates a subduction plane approximately inclined at 65-70° plunging beneath the Appennines (Malinverno & Ryan, 1986; Doglioni, 1991; Carminati *et al.*, 1999; Doglioni *et al.*, 1999; Scrocca *et al.*, 2006; Riguzzi *et al.*, 2010).
The Apennine chain derives from the deformation of different Meso-Cenozoic paleogeographic domains, formed during the rifting of the Ligure-Piemontese ocean (Abbate *et al.*, 1970). Subsequently the closure of the Ligure-Piemontese ocean, caused the building up of an accretionary prism (Treves, 1984), the complete consumption of the oceanic lithosphere, and finally the collision of the two continental plates with the formation of orogenic wedge, where rocks that previously occupied paleogeographic domains side by side now are overlapped. During the closing phase of the Ligure-Piemontese ocean, the Liguri units overlapped forming an oceanic accretionary prism, where the different tectonic units are bounded by thrust faults. Above these units, the Epiligure succession sedimented inside piggy-back basins (Ricci Lucchi & Ori, 1985; Bettelli *et al.*, 1989a, 1989b). The Ligurian accretionary prism overthrust progressively the Tuscan units, which had previously settled on the continental Adria crust.
The geology of the high Dragone creek valley (Nardi & Tongiorgi, 1962; Bertolli & Nardi, 1966; Plesi *et al.*, 2002a, 2002b; Puccinelli *et al.*, 2016a, 2016b) is characterized by the presence of rocks belonging to the Ligurian (Upper Jurassic-Middle Eocene) and to the underlying Tuscan units (Cretaceous-Miocene). These two groups of units crop out in the area with a juxtaposition relation, due to fault contacts of regional importance (Bettelli *et al.*, 2002; Plesi *et al.*, 2002a; Puccinelli *et al.*, 2016a). The units belonging to the Ligurian are outcropping in the northern and southern sector, while the Tuscan units in the central sector and South-East sector (Fig. 1).
The Ligurian units in the southern block are represented by the Caio tectonic unit (Bettelli *et al.*, 1989b; Plesi *et al.*, 2002a, 2002b), characterized on the macroscale by the Argilliti di San Siro (Cenomanian-Upper Campanian) and the overlying Flysch di Caio (Upper Campanian) formations, and the Ottone tectonic unit

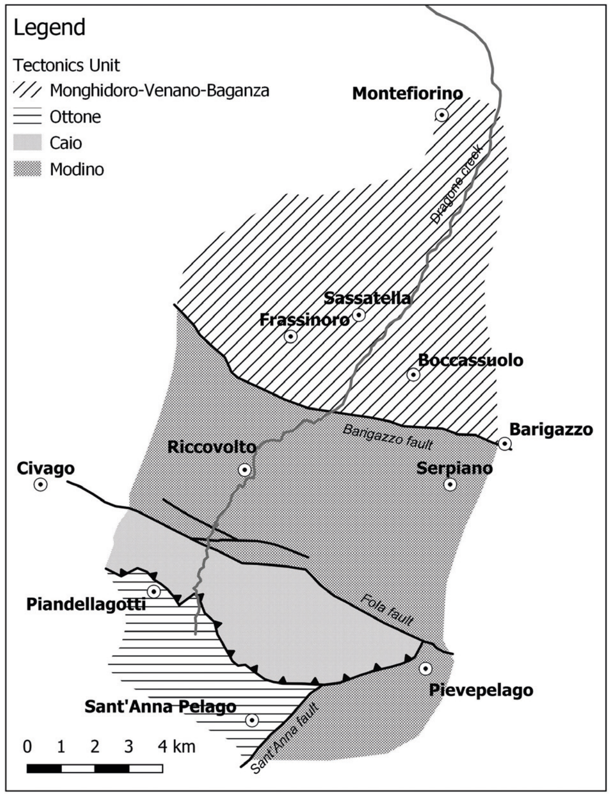

Figure 1. Schematic tectonics map of area with tectonics unit and main fault systems.

(Puccinelli *et al.*, 2016a, 2016b), characterized by Complesso di Casanova and Flysch di Ottone formations. The tectonic contact between the Caio and Ottone tectonic unit is characterized by overthrust.
In the northern area the Monghidoro tectonic unit (Upper Cretaceous-Paleocene) represents the highest Ligurian unit outcropping in the area. The unit is characterized, on the macrostructural scale, by the alternation of upright e overturned limbs, that they follow each other vertically and horizontally over relatively large distances. The lower part of the unit is characterized by a upright succession outcropping along the Dragone valley and, it is composed only of the Monte Venere formation. The middle zone of the studied area is represented the overturned succession, that it is outcropping further north, where the Dragone creek flow into Dolo creek. According to some authors (Bettelli & Panini, 1992), the upright and overturn limbs, which originally constituted the Rossenna syncline, they were cut from an extensional fault of regional importance. This unit overlaps the Venano tectonic unit (Upper Cretaceous) or, the Baganza tectonic unit (Jurassic-Cretaceous), where it is present.
The Venano unit (Daniele *at al.*, 1996) is represented at the macroscopic scale by overturned limbs of Arenarie di Poggio Mezzature and Argilliti dell'Uccelliera

formations, while the Baganza unit is characterized by the Argille a Palombini formation and ophiolites.
The rocks belonging to the Modino tectonic unit out crop in the central area and in the South-East sector. The most important macrostructural characteristic is represented from subdivision into tectonic scales by lateral and vertical extension, more or less large, which determine alternations of upright and overturned limbs.
The northern Apennine sector between the Secchia river and the Idice creek is characterized by an extensional tectonics that mainly affects the Ligurian nappe, after its emplacement on the Tuscan units. This extensional tectonics was manifested starting from the Messinian through the genesis of high-angle fault systems with longitudinal direction to the Apennine chain, that it mostly concerns the Ligurian units and the Epiligure succession (Bettelli *et al.*, 2002a; Balocchi, 2014). The "internal lineament" (Bettelli *et al.*, 2002b) is the most important of these fault systems, which constitutes the emerging boundary between the Tuscan and the Ligurian units of the upper Modena and Bologna Apennines. It is represented by several normal fault systems in the Apennine direction, by extending from the Dolo valley to the Futa Pass. Transversal, SW-NE direction, tectonic lines to the Apennine chain are associated with these longitudinal, NW-SE direction faults. They represent vertical strike-slip transfer faults and are generated by the segmentation and the *en échelon* arrangement of the various segments that make up the "internal lineament" (Bettelli *et al.*, 2002b). In the studied area, the single segment of the "internal lineament" is represented by the Barigazzo fault system (Bettelli *et al.*, 2002b), characterized by NE dip-direction and NW-SE direction (Martelli *et al.*, 2016). This system involves the Modino tectonic unit and lowers the Ligurian units of the northern area. These faults are superimposed on tectonic elements related to the compression phase, and in some places the normal faults reactivate the existing weak areas (Martelli *et al.*, 2016).
In the geological and seismotectonic maps (Plesi *et al.,* 2002b; Martelli *et al.,* 2016a, 2016b) the tectonic contact between the Caio and the Modino tectonic units (informally named by various field geologists as the "Fola fault", as the homonym medieval bridge located near Pievepelago), is described as high-angle normal fault by NW-SE direction. Its longitudinal extension has different interpretations, in fact in the geological map it extends from Pievepelago towards Civago with a continuation towards NW, while in the seismotectonic map it is described with longitudinal extension of a few kilometers from the Dragone creek to Civago, and always with continuation towards NW.
The Barigazzo fault system that juxtapose Ligurian and Tuscan units, are considered potentially active in the seismotectonic cartography (Martelli *et al.,* 2016a, 2016b). This hypothesis is supported by the description of abundant and numerous natural oil and methane emissions along both sides of the Dragone valley (Martelli *et al.,* 2016a). In particular, these methane emissions define NW-SE alignment, that extends from the Dragone valley towards SE up to Fanano. The emissions were located around Sassatella village, and in the easternmost area of Barigazzo and Boccassuolo. Currently these emissions are extinct due to the exploitation of hydrocarbons in the vicinity of natural vents. However, it is interesting to note, that these manifestations were almost coincident with the normal faults described above, with the Apennines direction, which provided preferential structural paths channels for the ascent of fluids.
A fault systems characterized by NE-SW direction and NW dip-direction is present in the South-East sector (Puccinelli *et al.,* 2016b), and its name in this study is Sant'Anna faults. It is a tectonic contact of overthrusting of Miocene epoch, between Ligurian unit (the Complesso di Casanova in Ottone tectonic unit) outcropping in the west sector, and Modino tectonic unit outcropping in the east sector.

Structural analysis of mesoscopic faults

The structural survey is important to describe the geometry and the kinematics, of the main fault systems. For this reason, the studied outcrops are those in proximity to the macroscopic faults (Fig. 2).
The data on the mesoscopic faults of the Barigazzo system are derived from studies by other authors (Martelli *et al.*, 2016). This system is represented by high-angle normal mesoscopic faults by NW-SE direction and NE dip-direction. These mesoscopic faults in Modino tectonic unit outcrops, almost always move down the Ligurian unit and they show recent activity.
The mesoscopic faults of the Fola system were measured in Marne di Marmoreto formation of the Modino tectonic unit, the tectonic fabric of the formation is characterized by lenticular or lozenge-shaped small rock bodies and bounded by shear surfaces (Remitti *et al.*, 2007, 2011). The Fola system in outcrop, clear cuts the structures by high-angle mesofaults wiyh NW-SE direction and SW dip-direction (Fig. 3). Other normal mesoscopic faults show a W-E direction and they represent a secondary segments of the Fola fault (Fig. 2). This fault systems represents the boundary between Modino tectonic unit in the northern block and Caio tectonic unit in the southern block, a tectonic contact that it moves down the Ligurian units. In outcrops, this normal mesoscopic faults reactivated the preexisting shear surfaces bounding the rock slices (cfr. Martelli *et al.*, 2016a).

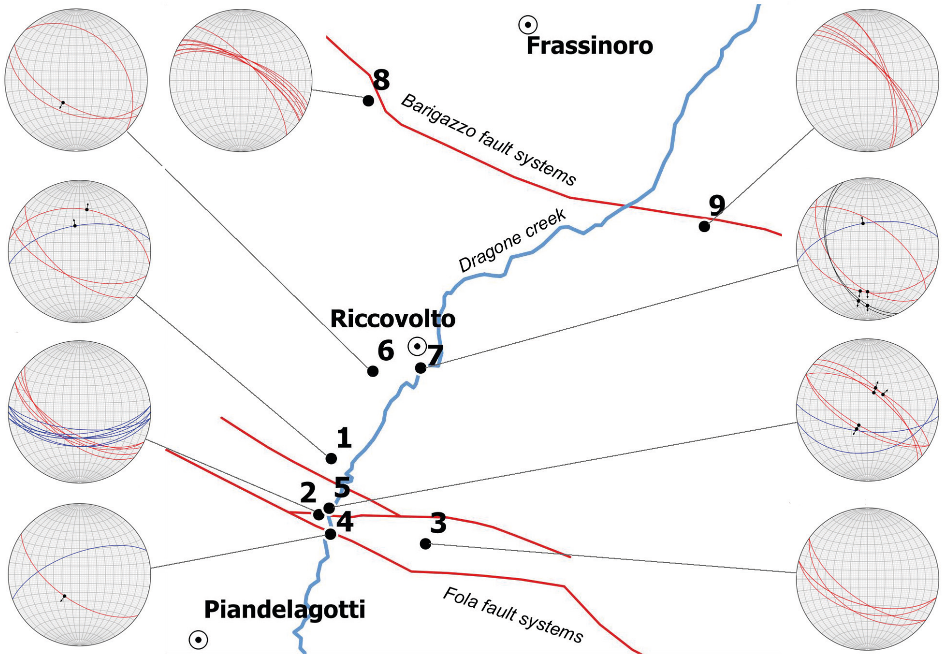

Figure 2. Simplified structural map of study area, with outcrops and mesoscopic faults stereograms.

In the outcrops localized near the Riccovolto village, the mesoscopic faults show geometry similar to that described for the other two fault systems. Furthermore, the outcrop 7 shows the Flysch dell'Abetina Reale above the Argille di Fiumalbo, an overturned succession (Plesi *et al.*, 2002b). The boundary between the two formations is represented by two conjugate normal mesoscopic faults (Fig. 4) displaying clearly that the Abetina Reale on the hanging wall, sliped down with respect the Argille di Fiumalbo forming the foot wall. Other mesofaults show a NNW-SSE direction with the same kinematic indicators of the previous mesoscopic faults. The mesoscopic faults of the outcrop 6 and 7 (Fig. 4) are characteristics of secondary tectonic structures and not related to the two main faults of the Barigazzo and Fola. They can be interpreted as the secondary faults that are generally found in the Horst axis.

Seismology

The seismicity of the high Dragone creek valley area (Fig. 5) has been described with the ISIDe catalogue, of the "Istituto Nazionale di Geofisica e Vulcanologia" (INGV, 2019a). Magnitudes range of 1.0-4.0 and depths shallower than 30 km were taken into account. Data were analysed in order to understand the seismicity evolution over time and obtain a hypocentres cross-section along the seismic sequence.
The seismicity of the area, analysed in the 2015-2019 period (Figs 5a and 6) shows that the earthquakes can be classified as a seismic sequence, with two main earthquakes of M_W 3.9 on December 9, 2016 and M_W 3.6 on July 1, 2018. The earthquakes distribution is quite regular in magnitude and depth with some seismic clusters.
The seismicity in the 2018-2019 period (Figs 5b and 6), after the M_W 3.6 earthquake, increases in the magnitude and number of events and it shows more concentrated of earthquakes in the southern area, forming a seismic cluster near Sant'Anna Pelago village.
In the same periods, the hypocentres time series is more distributed at the depth of 10 km about, with several earthquakes at greater depth.
The Seismic Cross-Section (Fig. 7a) shows how seismicity is concentrated at the depth of 10 km, with a slight tendency to deepen from SW to NE, and it is followed by a depth increase to the NE. The hypocentres distribution shows the preferential alignments of the main earthquakes. The SW-alignment is located at a depth of 10 to 15 km and includes the M_W 3.6 earthquake, while the NE-alignment is in the northern area at more shallow depth. Another alignment is highlighted from the bottom of seismogenic layer, where the hypocentres are more concentrated, that it increases its depth from SW to NE. The Sant'Anna alignment is located at a depth of 8 to 22 km (Fig. 7b) and the hypocentres distribution shows a different thickness of the seismogenic layer between west and east sector. The 3D seismology block (Fig. 8) shows how the earthquakes distribution of the SW-alignment are approximated to a planar surface with NW dip-direction and the depth of the hypocenters increases towards SW

Figure 3. Marne di Marmoreto formation in outcrop 2 (for location see Fig. 2).

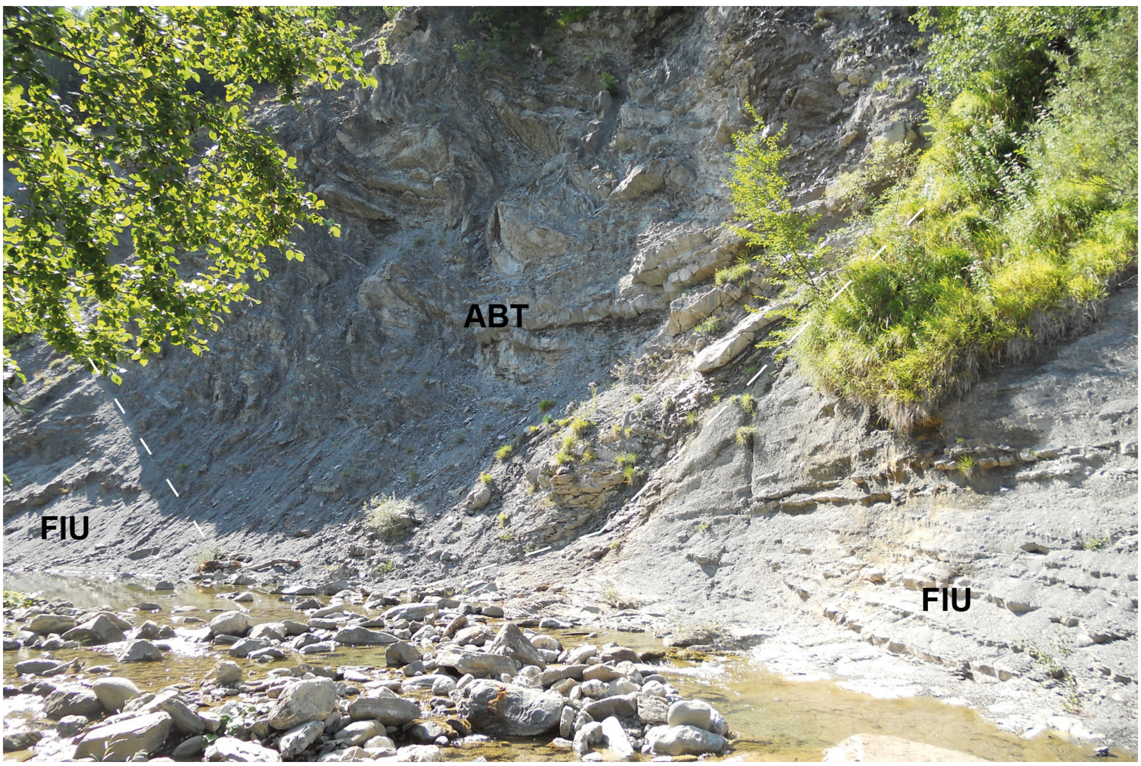

Figure 4. Flysch dell'Abetina Reale (ABT) and Argille di Fiumalbo (FIU) formations in outcrop 7 (for location see Fig. 2). The conjugate mesoscopic faults are shown in dashed white line.

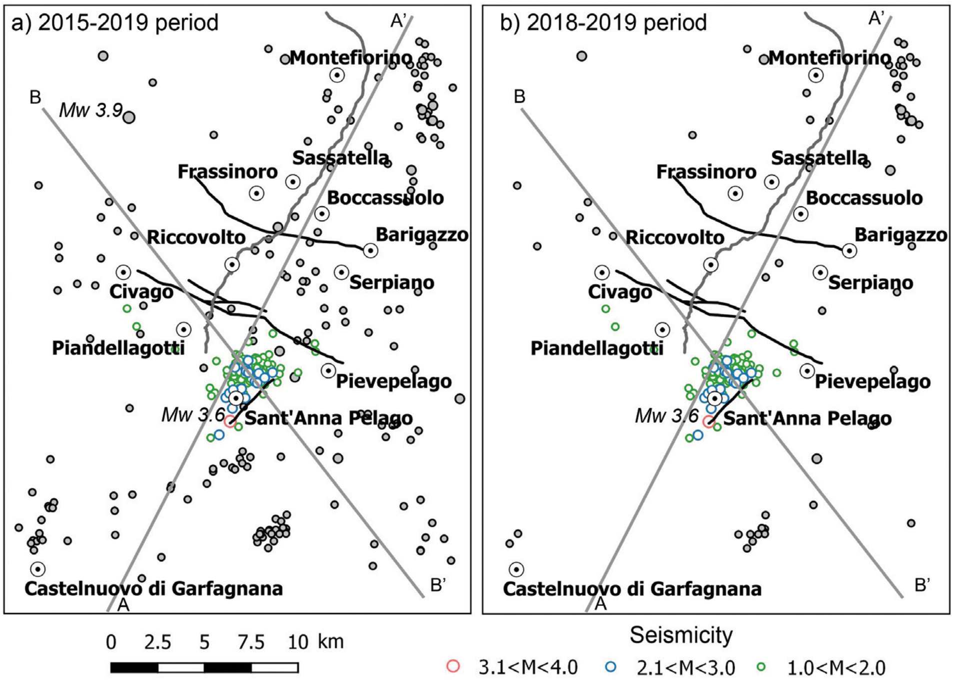

Figure 5. The earthquakes distribution with colours circles size is the earthquakes magnitude in the 2015-2019 period and 2018-2019 period. The earthquakes magnitude of Sant'Anna Pelago seismic cluster is with circumferences. The cross-sections A-A' and B-B' are in the figure 7.

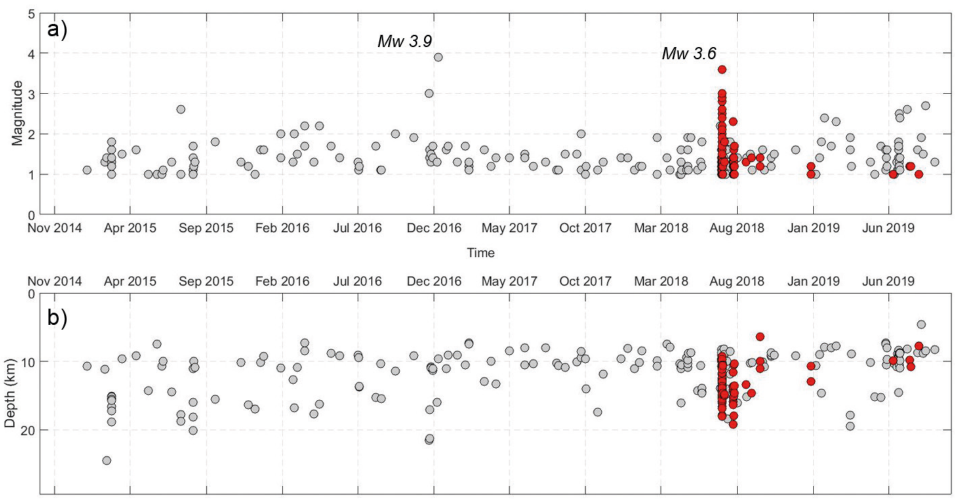

Figure 6. Magnitude (a) and depth (b) seismicity time in 2015-2019 period by grey circles. The San'Anna Pelago seismic cluster is shown with red circles.

along the plane. They show a geometry of seismic cluster, as described in other studies (Doglioni *et al.*, 2015; Petricca *et al.*, 2015; Balocchi *et al.*, 2016; Balocchi & Riga, 2017, 2018) and seismogenic surface (Balocchi *et al.*, 2016). The strongest earthquakes seem to approximate a surface with SW dip-direction. The NE-alignment and bottom of seismogenic layer approximate the strongest earthquakes with two different surfaces by NE dip-direction and different inclination.

The focal mechanisms of the two main earthquakes of M_W 3.9 and M_W 3.6, obtained from the "Time Domain Seismic Moment Tensor" (Dreger, 2003; Sconamiglio *et al.*, 2009; INGV, 2019b) provide us with some useful information about the tectonic stress direction and the geometry and kinematic of the main faults in the Dragone valley area. The tectonic stress main axes indicate a direction of maximum vertical compression and a NE-SW average-direction of maximum horizontal tension.

Tectonic and seismotectonic considerations

The data collected in the outcrop and their structural geological analysis (Fig. 2) allow us to obtain important information to describe the geometry and kinematics of the main fault systems (Fig. 9).

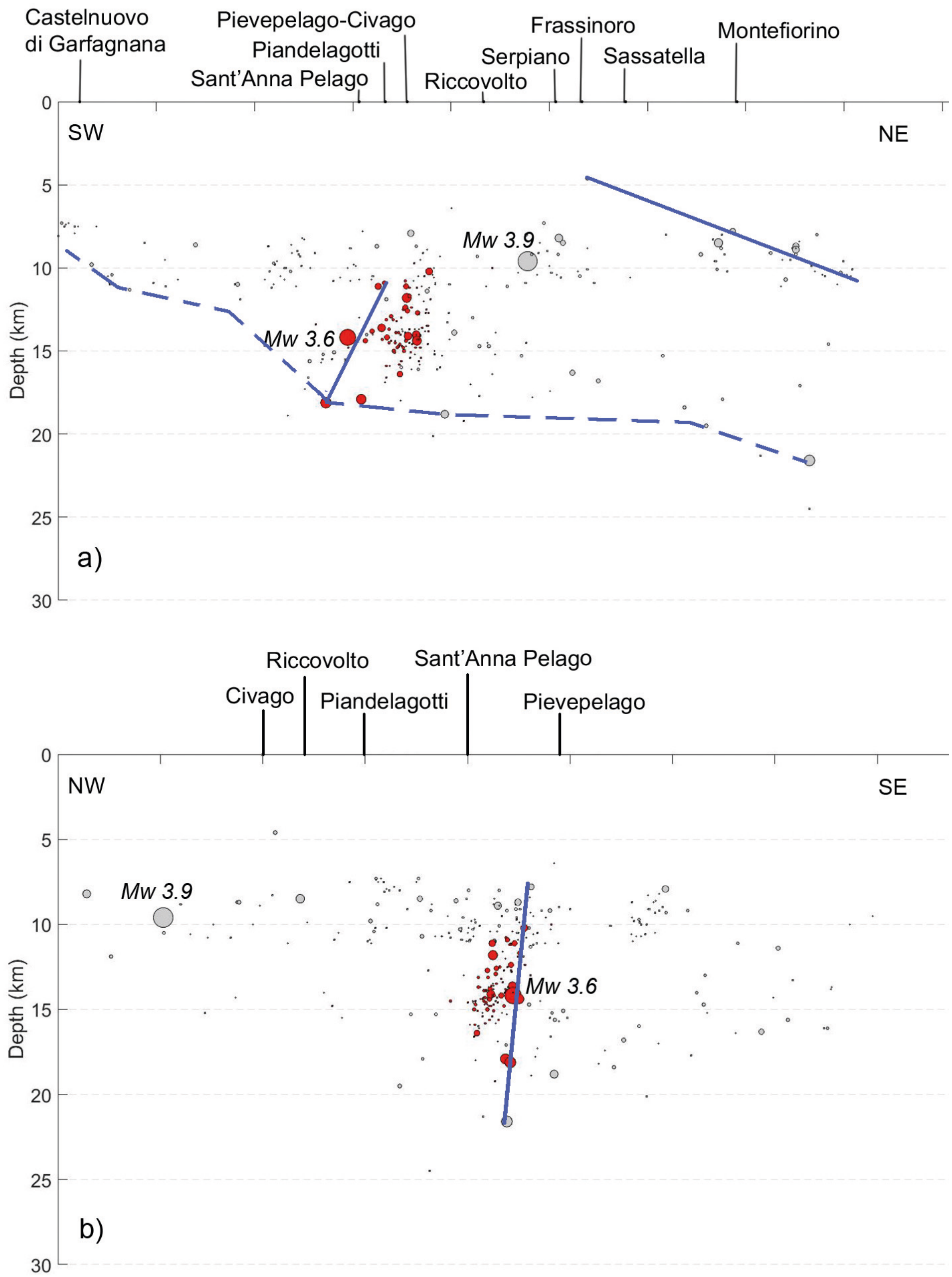

Figure 7. Seismic cross-section with the 2015-2019 seismicity period in grey circles and San'Anna Pelago seismic cluster in red circles, along: a) trace A-A' in fig. 2 with NE and SW alignments are shown by continuous line, while bottom seimogenic layer is in dashed line; b) trace B-B' in fig. 2 with Sant'Anna alignment.

The Modino tectonic unit is limited to the north by the Barigazzo fault system, characterized by high-angle normal faults with NW-SE direction and NE dip-direction. Its southern limit is represented by the Fola fault system, characterized by high-angle normal faults with the same direction of the Barigazzo fault system and SW dip-direction. Furthermore, the Modino tectonic unit in the Riccovolto represents a structural high, characterized by normal conjugated fault systems typical along the Horst axis, and kinematically in agreement with the other systems.

The Barigazzo and Fola fault systems, are the tectonic contacts between the Modino tectonic unit and Monghidoro-Venano-Baganza to the north and Caio tectonic units to the south. These fault systems juxtapose the Tuscan units (Modino tectonic unit) to the Ligurian units (Monghidoro-Venano-Baganza and Caio tectonic units), due to the relative lowering of the second units compared to the first ones. As also the fault systems emerging near Riccovolto village, represent the brittle deformation due to the relative uplift of the Modino tectonic unit, compared to the Ligurian of the northern and southern sector.

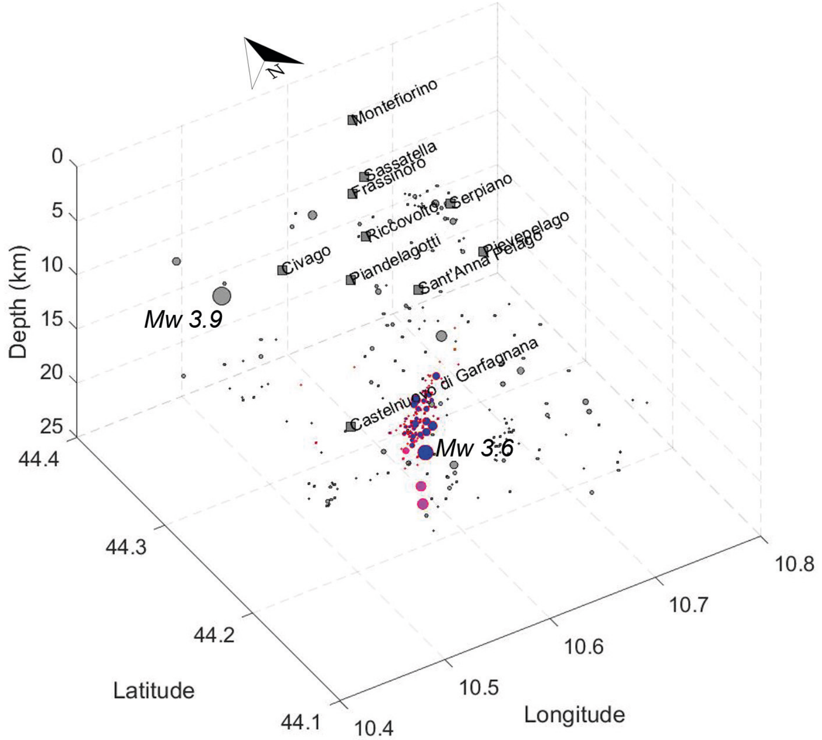

Figure 8. 3D seismic block of study area with 2015-2019 seismicity period in grey circles and San'Anna Pelago seismic cluster in colored circles.

The epicentres distribution of seismic data in 2015-2019 period (Fig. 5a), show a greater concentration in the southern area, where a M_W 3.6 earthquake occurred on July 1, 2018, and Sant'Anna Pelago seismic cluster is nucleated along a Sant'Anna fault surfaces by NE-SW direction, but it is more plausible, that the main fault surfaces is characterized by NW-SE direction and normal kinematics of the Fola fault, in according to the focal mechanism of M_W 3.6 earthquake. The hypocentres analysis by 3D seismology block and cross-section (Figs 7 and 8), shows the preferential alignments of greater magnitude earthquakes, that they tend to approximate a planar surface, that they can be interpreted as deep seismogenic faults (Fig. 9). Moreover the aftershocks of the Sant'Anna Pelago seismic cluster are more distributed along the Sant'Anna fault systems, but the hypocenters increases towards SW along the plane, following the dip-direction of the Fola fault. For this reason it is plausible to hypothesize that the Fola fault is the main structure and the Sant'Anna fault is a secondary structure.

The seismic source of Barigazzo fault systems is located in the northern area at a low depth, characterized by NW-SE direction and NE dip-direction with intermediate dip. It shows a structural continuity in depth and it represents the macroscopic expression of the internal lineament described in the literature (Bettelli *et al.*, 2002a, 2002b). In fact, it represents a normal listric regional fault, with Apennines direction and NE dip-direction.

The seismic source of the Fola fault systems is located at a depth of 10 to 15 km and includes the M_W 3.6 earthquake. It is characterized by NW-SE direction and SW dip-direction with high-angle of inclination and a it is associated with a seismic source of Sant'Anna by NE-SW direction. The Fola fault system represents the macroscopic expression of important high-angle regional normal fault, with Apennines direction and SW dip-direction. The Sant'Anna fault systems can be interpreted as strike-slip fault probably with left-lateral kinematics, in according to stress direction of focal mechanism data of M_W 3.6 earthquake, and it intersects the Fola faults in deep.

Other seismic source is located at the bottom of seismogenic layer, and it is characterized by NW-SE direction and NE dip-direction with low-angle of inclination. It extends its surface, from a depth of 10 km at Castelnuovo di Garfagnana to a depth of 20 km at Montefiorino. The focal mechanism show a regional extension of the high Dragone creek valley area, with NE-SW direction, and it is in agreement with the mesostructural data. This seismogenic layer represents a low-angle normal faults with Apennines direction and NE dip-direction and it is parallel to the top of the basement, as described by some authors (Brozzetti *et al.*, 2007; Eva *et al.*, 2014). Its geometry is similar to detachment of Altotiberina and Castelluccio-Amatrice fault systems (Balocchi & Riga, 2017, 2018).

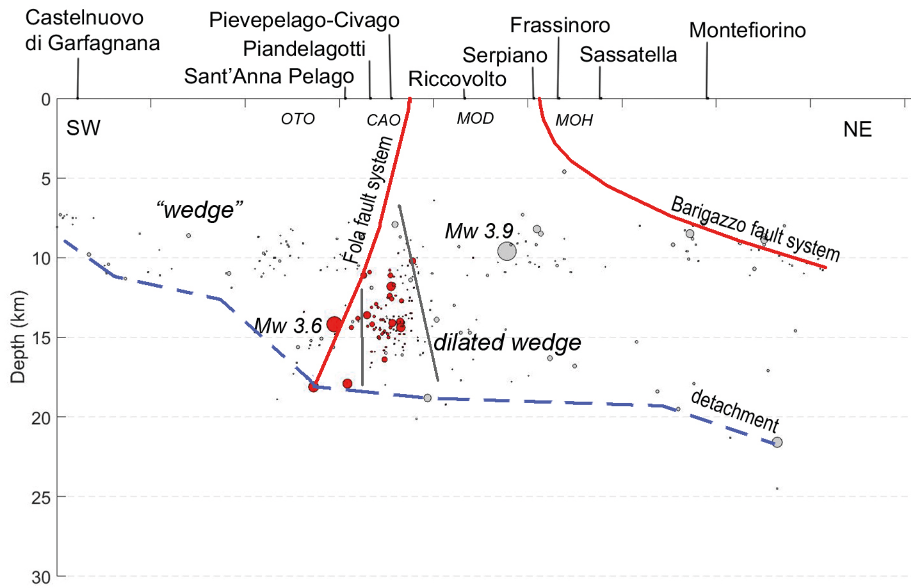

Figure 9. Tectonic and seismotectonic model with main structures of the Barigazzo and Fola fault systems and the detachment. The 2015-2019 seismicity period in grey circles and San'Anna Pelago seismic cluster in colored circles. Tectonic units of Caio (CAO), Monghidoro- Venano-Baganza (MOH), Ottone (OTO) and Modino (MOD).

The Fola fault ends against to the detachment at depth about 15 km, where is nucleate the M_W 3.6 earthquake on July 1, 2018. The Sant'Anna Pelago seismic cluster and its M_W 3.6 earthquake, is distributed in depth, between detachment and Fola fault, and its characteristic is typical of dilated wedge (Balocchi & Riga, 2017).

Final remarks

The study of regional tectonic, mesofaults analysis and seismicity, allowed to get a seismotectonics cross section, where the geometry and seismogenesis of main structures is described.
The tectonic and seismotectonics model consist of two main structures: the Barigazzo system is a normal fault with Appennines direction and NE dip-direction, and the Fola system is a high-angle normal fault with same direction of previous one, and SW dip-direction (Fig. 9). This regional structure represents a horst and graben, where the structural high of Riccovolto is the horst, while low structural of the north and south areas are the two grabens (Fig. 9).
This study, based on seismological data, describes the detachment, that it is another important regional structure, it is a low-angle normal fault with NW-SE direction and NE dip-direction. The detachment extends its plane at south of Castelnuovo di Garfagnana, which roughly corresponds to the Garfagnana north seismogenic source (DISS Working Group, 2018), while its extension to the north is not clear.
The Sant'Anna fault system is a tectonic contact with NE-SW direction, between Ligurian and Modino tectonic units, and it can be interpreted like a strike-slip fault, probably a tear-fault with left-lateral kinematics. The hypocenters show a control in the thickness seismogenic layer, within two different sector delimited by this fault. This structure intersects the Fola fault to deep, and it drives the distribution of aftershocks in depth, but the main seismicity is strongly connected to the Fola fault systems, in accordance with the focal mechanism and the hypocenters distribuition.
The conjugate faults of Fola and the detachment form a "wedge" that, being subjected to gravity, it collapses generating a graviquake (Doglioni *et al.*, 2015; Petricca *et al.*, 2015; Balocchi & Riga, 2017). The seismicity of Sant'Anna Pelago seismic cluster is generated by the formation of a dilated wedge, characterised by expansion fractures and dilatancy (Main *et al.*, 2013). The detachment is an important structure in regional seismogenesis. In fact considering some studies conducted in different areas (Chiaraluce *et al.*, 2004; Balocchi & Riga, 2017, 2018; Vadacca, 2020), if the deformation along its fault plane is of stik-slip type then it is plausible that the detachment could generate earthquakes. While, if the deformation is of creep then, the detachment can transfer stress along adjacent faults such as the Fola and Barigazzo fault systems, where earthquakes can happen.
The high Dragon valley is certainly seismically active, and the detachment, Barigazzo and Fola faults are to be considered Quaternary seismogenics structures of regional importance.
The regional geology and structural analysis studies of superficial mesofaults, compared to seismotectonics of deeper faults, are useful for identifying the geom-

etry and kinematics of the fault systems of regional importance, as in this paper, that it describe the high Dragone valley extensional system. This geographical area represents a limited portion of the Emilia-Romagna Apennines, where structural geology data and catalogue on seismogenic structures are not very indicative of Quaternary tectonics (Plesi *et al.*, 2002b; DISS Working Group, 2018). The interpretation of the Fola fault as "dextral traspressional system" (Cerrina Ferroni *et al.*, 2002a, 2002b) is not in agreement with the mesostructural data described in this paper, where it is clearly a Quaternary normal fault. Therefore further investigations are necessary to define a complete seismotectonic model of the Apennine chain. Furthermore, this paper can contribute to a greater knowledge of seismotectonic structures, integrating the structural-geological maps of the Emilia-Romagna Apennines and catalogue of seismogenic sources.

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