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Preliminary analysis of the microearthquakes-faults association in the Sulmona basin (central Apennines, Italy)

Maria Adelaide Romano ([a]), Rita de Nardis ([a-c]), Giusy Lavecchia ([a]), Marco Garbin ([b]), Laura Peruzza ([b]), Enrico Priolo ([b]), Marco Romanelli ([b]) & Federica Ferrarini ([a])

([a]) GeosisLab, DiSPUTer, Università G. d'Annunzio, Campus Universitario di Madonna delle Piane, 66013, Chieti Scalo (CH), Italy. E-mail: aromano@inogs.it
([b]) Centro Ricerche Sismologiche, Istituto Nazionale di Oceanografia e Geofisica Sperimentale, Via Treviso, 55, 33100, Udine, Italy and Borgo Grotta Gigante, 42/C, 34010, Sgonico (TS), Italy
([c]) Dipartimento della Protezione Civile, Via Vitorchiano, 2, 00189, Roma, Italy

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ABSTRACT

The Sulmona basin and the neighbouring Morrone-Porrara and Majella ridges are a sector of the central Apennines (Italy) characterized by the existence of active normal faults, to which strong historical earthquakes have been associated. At the same time, the instrumental seismicity acquired round here from the national and regional permanent networks is very low, both in number of events and in magnitude.

In order to lower the magnitude threshold of the detectable earthquakes and to obtain a more reliable picture of the microseismicity of this zone, a small temporary seismometric network was deployed around the Sulmona basin for nearly three years (from May 2009 to November 2011).

Data acquired in the first seven months of monitoring (from May to December 2009) allowed us to locate hundreds of very small earthquakes, also with negative magnitudes. The highest recorded magnitudes reached values of 3.7 and the completeness magnitude of the obtained catalogue is equal to 1.1.

The spatial distribution of the recorded microseismicity showed some local clustering, allowing us to advance preliminary observations on the geometric relationships with the outcropping active faults. Moreover, taking into account only the best located events, we were able also to provide an estimate of the seismogenic layer depth.

KEY WORDS: active faults, central Apennines, microseismicity, Sulmona basin, temporary seismic monitoring.

INTRODUCTION

The knowledge on size, geometry and kinematics of the seismogenic faults, is extremely important for seismic hazard purposes. As well documented in literature (De Matteis et al., 2012 and references therein), the analysis of microseismicity may help in defining them, especially when these tectonic structures are either unknown or not outcropping.

The detection and the accurate location of microearthquakes require a minimum number of seismic stations, capable of acquiring good quality signals, arranged at very close distance and with good azimuthal coverage. For this reason the national seismic networks are sometimes not adequate.

Here, we reported some results of a temporary seismic monitoring conducted around the Sulmona basin, in central Italy, between May 2009 and November 2011 (de Nardis et al., 2011; Romano et al., 2013). This sector of the central Apennines is very interesting, because field evidences highlight the presence of SW-dipping active normal faults, with along strike lengths up to 20 km (Fig. 1). As a result, they have a capability of releasing earthquakes with $M_w > 6$ (Wells & Coppersmith, 1994).

In the past, strong earthquakes, such as the 1706 event (M_w 6.8), occurred in the surrounding of Sulmona, but nowadays this area is characterized by very low seismic rates, as demonstrated by the instrumental seismicity catalogues, which span from 1981 to the present. An hypothetical seismic event with magnitudes similar to that of 1706, could cause highly severe damages considering the great number of inhabitants and the rich artistic and cultural heritage of the area. The recent L'Aquila earthquake (6 April 2009, M_w 6.3; Lavecchia et al., 2012) is a dramatic example of this.

In this paper, we analysed the hypocentral distribution of the microseismicity recorded in the first seven months by the Sulmona Temporary Network (STN), in order to highlight possible microearthquakes-faults associations in the area.

SEISMOTECTONIC FRAMEWORK

The Sulmona plain is one of the Quaternary continental basins of the Abruzzo Apennines. Its eastern edge is bounded by the Morrone normal fault system, consisting of two SW-dipping segments which dislocate Late Pleistocene alluvial fans and slope deposits (Gori et al., 2011). This system extends for about 20 km along strike and continues southward with the Porrara normal fault.

The Morrone and Porrara structures, together with the northern Gran Sasso ridge normal faults, belong to the most external, west-dipping and active, extensional alignment recognised in this sector of chain (Lavecchia et al., 2012). Many other active west-dipping normal faults outcrop in a more internal position. Since early-instrumental times, they were the seismogenic sources of relevant earthquakes: the Fucino fault released the 13 January 1915 event (M_w 7), the Barrea fault the 7 May 1984 one (M_w 5.4) and the Paganica fault the dramatically known L'Aquila earthquake (M_w 6.3).

In the same time period, only very low instrumental seismicity was recorded in the Sulmona area, even if

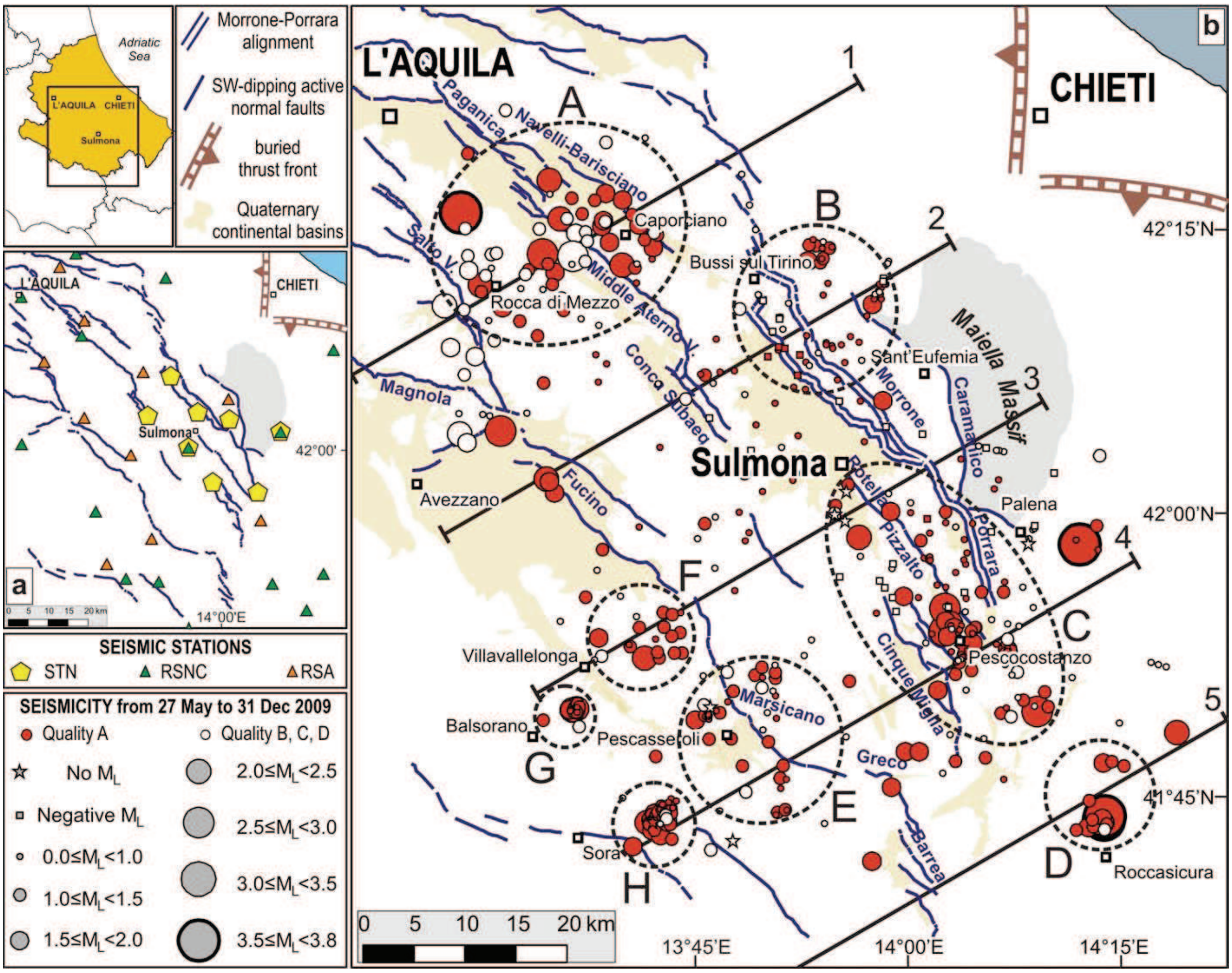

Fig. 1 – Seismicity localized between 27 May and 31 December 2009 in the Sulmona basin and surrounding regions thanks to installation of the Sulmona Temporary Network (STN) as in Romano et al. (2013). a) Map of seismic stations belonging to STN, RSNC (Centralized National Seismic Network) and RSA (Abruzzo Seismic Network) in the study area. b) Epicentral distribution of recorded earthquakes. Capital letters from A to H identify the groups of events described in the text. Numbers from 1 to 5 mark the traces of sections represented in fig. 2.

historically there have been at least three destructive earthquakes ($M_w \geq 5.5$). They occurred in the second century AD, in 1706 and in 1933, and their seismogenic sources have been only hypothesized. The first one has been associated to the Morrone fault system by Gori et al. (2011), while the others, known as the Maiella earthquakes, to the activity of a buried thrust (fig. 1) by Lavecchia et al. (2010).

Another earthquake of comparable magnitude occurred in 1315, but its location in the study area moved from the Sulmona area near to L'Aquila after a revision/update of the historical database (Rovida et al., 2011).

DATA COLLECTION AND ANALYSIS

The Sulmona Temporary Network was installed on 27 May 2009, about 50 days after L'Aquila earthquakes, and worked till 22 November 2011. It consisted of 6 mobile stations and 2 permanent stations belonging to the RSNC (Centralized National Seismic Network), deployed all around the Sulmona plain, near some active normal faults (yellow symbols in fig. 1a). Their recordings were continuous, and the great amount of acquired data (about 170 Gb) was managed off-line. A semi-automatic procedure was adopted for processing and analysing the first seven months of seismic recordings. The dataset of STN arrival times was also enriched with data from the Abruzzo Seismic Network (RSA) and from RSNC (fig. 1a), after evaluating their general quality and consistency.

From 27 May 2009 to 31 December 2009, totally 817 small earthquakes were detected, and 535 of them located (fig. 1b) by using Hypoellipse (Lahr, 1999) and the 1D velocity model estimated ad hoc for this area (Romano et al., 2013). About 66% of located events are of quality A (red circles in figs. 1b and 2), i.e. their horizontal and vertical 68 % confidence interval is $\leq$ 1.34 km. We used these events to evaluate the seismogenic layer depth in the study area. So, relying on the Williams' definition (1996), we found that 17 km is the depth marking the 95 % cutoff of seismicity, and that about 90 % of located earthquakes is between 6 and 17 km.

The local magnitude (M_L) was estimated for all the events, except eight (little stars in fig. 1b) characterized by a low signal-to-noise ratio. M_L values range from -1.5 and 3.7. Note that negative magnitudes (little squares in fig. 1b) are associated only to events located close to the temporary stations, where the STN detection capabilities are the highest. The largest magnitude values are associated to four events, from north to south being: M_L 3.5 on 21 June 2009 (near L'Aquila), M_L 3.7 on 15 September 2009 (near Palena), M_L 3.5 and 3.6 on 4 August 2009 (near Roccasicura).

The association of the instrumental seismicity recorded in the Sulmona area and surrounding regions with the active and possibly seismogenic tectonic structures requires a detailed structural analysis of the geometry of the involved faults. Nevertheless, some preliminary considerations can be pointed out, simply by observing the earthquakes-faults spatial relationships.

At a first glance, it is evident that the located seismicity, although only consisting of very minor events, is not homogeneously distributed, but rather it concentrates in specific tectonic sites. Furthermore, the Sulmona basin area has remained almost aseismic during this period of observation, even if more events than those reported on ISIDE database (http://iside.rm.ingv.it/iside/standard/index.jsp) were recorded.

In order to quantify the spatial distribution of located earthquakes, we estimated their areal density by using a kernel density function, which allowed us to identify eight group of events (A to H in fig. 1b).

Group A is located at the southernmost end of the L'Aquila 2009 sequence. Such a sequence mainly activated the Paganica fault, but the here identified cluster shows microseismic activity further south. It involves both the SW-dipping Middle Aterno Valley fault, which is the southern along strike prosecution of the Paganica fault, and the Navelli-Barisciano fault, an independent SW-dipping Quaternary fault located about 6 km eastward from the Paganica–Middle Aterno Valley fault alignment. However some events are located also at the footwall of the Navelli-Barisciano fault, at depth of about 10 km as most of the others (section 1 in fig. 2).

Group B points out the activity of both the northern portion of the Morrone fault system, mainly at depths of 5 to 10 km, and of an independent rock volume which is located within the Morrone fault footwall at depths between 10 and 18 km (section 2 in fig. 2).

Group C well shows the activity of the SW-dipping Porrara fault mainly at depths between 5 and 12 km. The cluster extends further south of the outcropping Porrara fault, suggesting the possibility that either such fault is longer than up to now known, or a still unrecognized en echelon extensional structure is present (sections 3 and 4 in fig. 2).

Group D consists in a small group of isolated and relatively deep (12 and 18 km) events located nearly 12-15 km outward from the outer extensional front, which in the area coincides with the Barrea faults. The events of such cluster, such as those of group B within the Morrone footwall, do not fit geometrically with any of the known extensional faults (fig. 1 and section 5 in fig. 2). They might be hypothetically associated with the SW-dipping Abruzzo Citeriore Thrust

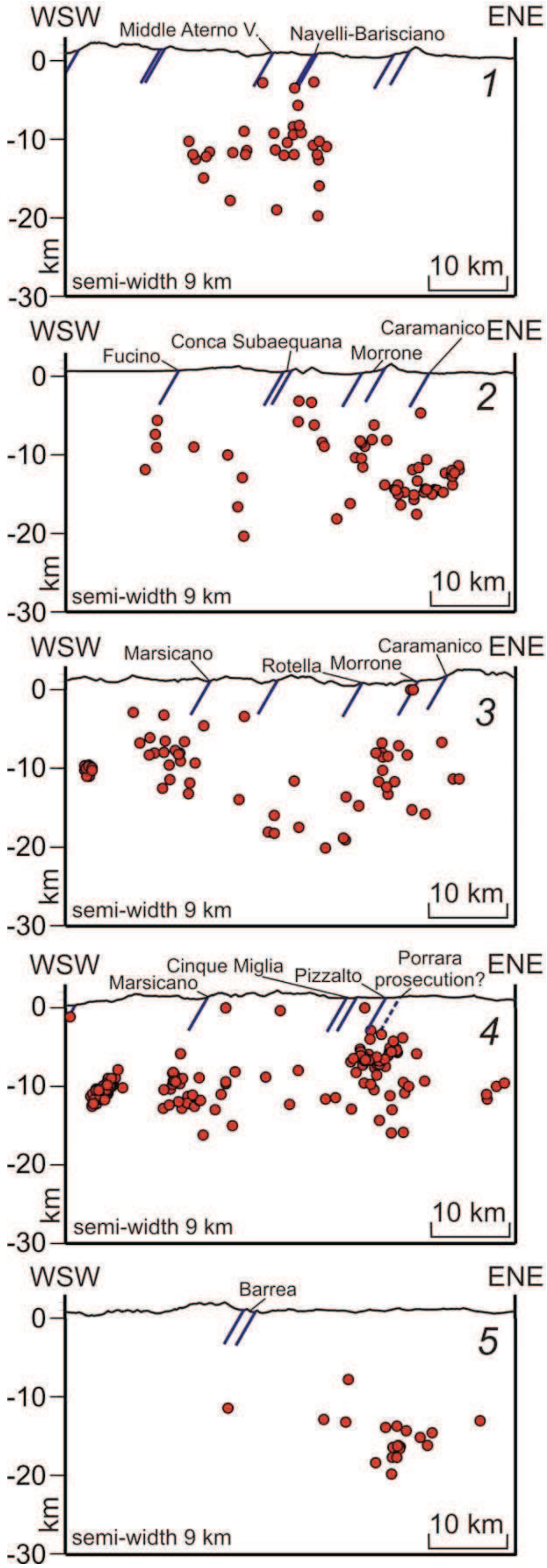

Fig. 2 – Section view of the quality A earthquakes located in this study and projected along the five traces depicted in fig. 1b.

(Lavecchia et al., 2010), the southern prosecution of the Adriatic Basal Thrust (Lavecchia et al., 2007), or to E-W strike-slip faults, similar to that activated during the 2002 San Giuliano earthquake.

Group E comprises events involving both the hangingwall and the footwall of the Marsicano fault (fig. 1b and section 4 of fig. 2), which develops along strike in an intermediate position between the Fucino and Barrea faults. Their depths range between about 5 and 15 km.

Group F fall completely within the Marsicano fault hangingwall, at depths between 4 and 13 km, and may tentatively associated to such structure (fig. 1b and section 3 in fig. 2).

G and H identify two groups of events belonging to two well distinct seismic sequences: the smaller one (about fifteen events) occurred near Balsorano from 29 May to 9 June 2009, and the larger one (of which we located about eighty events) occurred near Sora in October of the same year. The two clusters are aligned in the Apennine direction and at a same depth of about 10 km (sections 3 and 4 in fig. 2); it is plausible that they are associated with the same seismogenic source.

CONCLUSIONS

Thanks to the STN installation, a new detailed picture of seismicity in the Sulmona area has been obtained. Its detection capabilities allowed to reach a completeness magnitude of 1.1, and the accurate location of the recorded microearthquakes allowed to estimate a seismogenic layer depth of 17 km.

By analysing the spatial distribution of acquired seismicity with a kernel density function, some clustering of events has been recognized and preliminary microearthquakes-faults associations have been advanced. A correlation between the located events and the active structures, as the Middle-Aterno Valley, Navelli-Barisciano faults, the Porrara fault and the Marsicano fault was highlighted. As regards the Morrone fault system, it has been possible associate to it only very low seismic activity rate, given that the Sulmona basin area remained almost completely aseismic during the period of observation. Finally, the deep events belonging to the groups B and D have been hypothetically linked to the activity of buried tectonic structures, as the SW-dipping Abruzzo Citeriore Thrust or E-W strike-slip faults, similar to that activated during the 2002 Molise earthquake.

Obviously, a future goal is to constrain such a preliminary interpretation by computing focal mechanism solutions from the most significant microearthquakes of the collected dataset.

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