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Very detailed seismic pattern and migration inferred from the April 2010 Pietralunga (northern Italian Apennines) micro-earthquake sequence

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ABSTRACT

We propose a very detailed picture of seismicity that occurred in the proximity of the Alto Tiberina Fault (ATF, northern Italian Apennines), a low angle normal fault, by presenting the pattern and evolution of a seismic sequence on the hanging wall of the ATF in the first months of 2010 that was characterized by about 1000 events with M_L ranging from −0.7 to 3.8.

To capture the rupture kinematics of the investigated area, a cross-correlation technique was initially applied to calculate very accurate time shifts among the events of the sequence, and then to relocate them. The whole sequence was relocated with the double-difference method, which includes both absolute travel-time measurements and cross-correlation differential travel-times. The new locations confirm that the seismic activity was mainly arranged along a NW–SE-oriented structure that ranged in depth from 4 km to 6 km, with dipping towards NE at an angle of ca. 65°. In comparison with geological data, the position of the seismic sequence is compatible with the evaporite Triassic layer. The main nodal planes are consistent with the spatial evolution of the aftershocks and with the tensional state of stress in the area.

An analysis of waveform similarity was performed at a reference station by merging the capability of the cross-correlation technique and the bridging algorithm. The detected mutiplets allow us to emphasize the anisotropic spatial and temporal migrations of the seismicity that occurred along a 307° N strike direction with an averaged propagation velocity of ca. 0.4 km/day. We explain the highlighted anisotropic behavior of the migration with the hypothesized presence of overpressured fluids and with physical properties of Triassic evaporites. This suggests the importance of such very detailed relocation of weak and micro-seismicity for improvement of our knowledge of fault system geometry and its evolution.

1. Introduction

The accurate location of micro-seismicity occurrences makes it possible to discover fault architecture and to provide very detailed pictures of the fault systems (Chiaraluce et al., 2011). However, preliminary earthquake locations after seismic sequences and swarms depict a large-scale (kilometer) spatial description of fault zones. The relatively high magnitude of completeness characterizes earthquake catalogs of seismic sequences and prevents precise descriptions of fault systems (Valoroso et al., 2013; Wiemer and Wyss, 2000).

Over the last decade, the performances and dynamics of three-component seismic instruments and the growth of seismic networks have provided the scientific community with the opportunity to analyze earthquake data obtained with improved magnitude detection thresholds and improved network resolution. Furthermore, several methods have been developed to more precisely and accurately define earthquake locations (Got et al., 1994; Waldhauser and Ellsworth, 2000). These recent improvements have allowed investigations into the detailed geometry of active faults and the observation of seismic migration through the spatio-temporal evolution of the seismicity (Chiaraluce et al., 2011; Pacchiani and Lyon-Caen, 2009; Valoroso et al., 2013).

As well as earthquake relocation, analysis of earthquake similarity can provide other information about the rheological properties, kinematic behavior, and spatio-temporal evolution of a fault system (Valoroso et al., 2013). Clusters of similar events have been investigated using several techniques: cross-spectral techniques (Got et al., 1994; Sherbaum and Wendler, 1986), pattern recognition (Joswig, 1995), fractal approaches (Smalley et al., 1987), syntactic pattern recognition schemes (Zhinzhin et al., 1992, 1994), non-linear correlation techniques (Schulte-Theis and Joswig, 1993), dendogram analysis (Schulte-Theis, 1995), and cross-correlation techniques (e.g., Augliera et al., 1995; Cattaneo et al., 1997, 1999; Ferretti et al., 2005; Massa et al., 2006a, 2006b).

In the present study, new seismological insights and more detailed features were investigated relating to the micro-seismicity in the northern Italian Apennines associated with the spatio-temporal evolution

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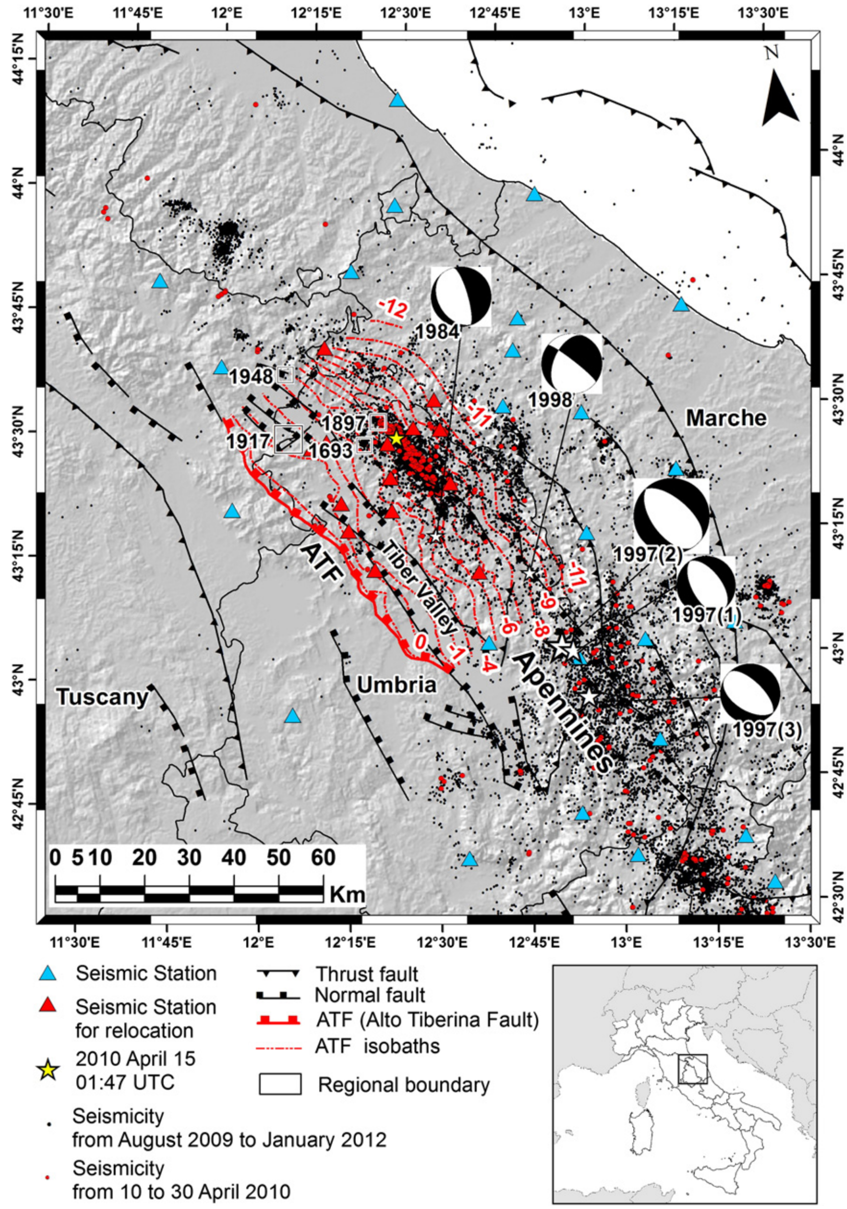

Fig. 1. The seismicity, seismic network, and tectonic framework of the Umbria–Marche region. Black circles; seismicity from August 2009 to January 2012. Red circles; seismicity from April 10 to 30, 2010. Yellow star, the April 15, 2010 (01:47), M_L 3.8 earthquake. Black squares, historical earthquakes. White stars, recent moderate earthquakes. Light blue triangles, INGV seismic stations. Red triangles, seismic stations used to relocate the seismic sequence of April 2010. Inset: Umbria–Marche region in relation to Italy.

of April 2010, M_L 3.8, seismic sequence (hereinafter referred to as the Pietralunga sequence). The April 15, 2010 mainshock triggered a relevant number of aftershocks, which extended for about one month, which has provided a dataset composed of about 1000 weak earthquakes (smallest M_L below 0). These occurred at shallow crustal levels between 4 km and 6 km in depth, and they were recorded by a dense seismic network that is equipped with high dynamic, high performance three-component digital instruments. The seismic network covers the area over the Alto Tiberina Fault (ATF), a low angle normal fault (LANF) that acts as a basal seismic detachment and accommodates extensional deformation together with a complex normal fault system that is located in its hanging wall (Chiaraluce et al., 2007). The ATF is a topic of debate relating to the possibility that moderate-to-large earthquakes nucleate on LANFs or that creeping is the fault style (Chiaraluce et al., 2007, and references therein). In the tectonic setting of the Italian Apennines, seismicity migration episodes along the strike of a fault system or along a preferred direction can be observed during seismic sequences related to moderate earthquakes: e.g., the M_w 5.9 1997 Colfiorito earthquake (Catalli et al., 2008) and the M_w 6.1 2009 L'Aquila earthquake (Chiaraluce et al., 2011). These migrations are often related to the presence of overpressurized fluids and to diffusion processes (Antonioli et al., 2005; Miller et al., 2004; Noir et al., 1997). The monitoring and detailed reconstruction of seismicity patterns and the spatio-temporal evolution in the extensional tectonic Italian Apennine context are important to understand the preparatory phases of the main earthquakes (Chiaraluce et al., 2011).

In the present study, we have used precise manual P-phase and S-phase catalogs to apply the double-difference technique (Waldhauser, 2001; Waldhauser and Ellsworth, 2000) to relocate events. This is combined with the bridging technique, which has been proposed by many authors (e.g., Aster and Scott, 1993; Cattaneo et al. 1997, 1999; Deichmann and Garcia-Fernandez, 1992; Ferretti et al., 2005; Massa et al., 2006a) to gather the Pietralunga sequence into families of similar events.