Shallow seismicity migration in a normal fault test site in northern Apennines (Italy)

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In 2008-2010 a high-density, real-time seismic network has been installed in the northern Apennines, integrating the INGV permanent national network. While the national network uses satellite links and leased telephone lines, the additional stations are connected with WiFi radio links and INGV-made GAIA digitizers. In march 2010, 10 additional remote stations were installed to further improve the monitoring. At present, a total of 30 stations are operational in the area.

The scientific target of the network, funded by INGV and by the Italian Ministry of Research (project Airplane RBPR05B22J) is to understand the deformation process in the area, characterized by: i) extension at 2-3 mm/yr; ii) a regional east-dipping, low-angle normal fault (the Alto Tiberina Fault, ATF) that limits the seismicity downward in the upper 10-15 km of the crust; iii)historical earthquakes as large as M6.5; iv) a high rate of background seismicity. The extensional area is underlayed by the west-dipping Adriatic continental slab with seismicity down to 70-80 km below the belt. During the first year of operation, we located more than 3,000 local earthquakes with magnitude in the range -0.5 to 3.8. Part of the seismicity, located with both absolute and relative techniques, clusters on shallow high-angle normal faults above the ATF, and shows a clear migration both along strike (at about 0.5 km/day) and in depth. This pattern has strong similarities with that observed in previous large normal faulting events in the Apennines, and is likely related to fluid migration. Such a dense network allows us to detect seismogenic processes with an unprecedented detail. Data are accumulating fast and will illuminate other parts of this complex fault system. Ongoing developments include a continuous GPS network and borehole seismometers.

motivations

To investigate the spatial relationship between seismicity and a Low Angle Normal Fault (LANF): the Alto Tiberina Fault (ATF), imaged by reflection profiles, and to help define the ATF system.

To understand its role in the seismogenesis of central Italy: is it able to generate M~6 earthquakes, as suggested by historical data?

To understand how fluid flow and/or pore pressure relaxation affect seismic sequences in its terms of seismicity migration and multiple shock sequences (as in 1997).

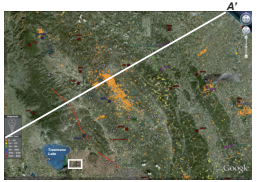
To look for shallow earthquake clusters on the ATF, in the perspective of a deep drilling of the fault (MOLE project, mole.ingv.it).

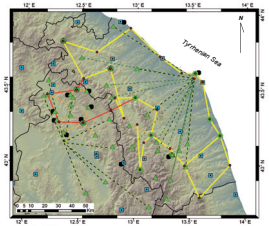
the network

Besides the permanent INGV network (RSN, red squares), in 2007-2009 a dense real-time regional network (yellow squares) has been installed and integrated in the RSN, using radio links and a 155Mb backbone net of the Marche Region. In this way, we could improve the satellite-connected national network with real-time and less expensive links (funds by INGV and Project FIRB AIRPLANE by Ministry of Research (contract no. RBPR05B2ZJ).

In addition, a temporary campaign started in spring 2010 and will be operated for one year (white squares). Next monitoring steps include seismic instruments in three 200m deep boreholes (light blue circles). Blue circles are deep (4-8 km) boreholes drilled in the 80's-90's for oil exploration. Epicenters of earthquakes occurred in 2010 are also shown

The red line is the surface trace of the ATF. The white line AA' is the trace of the profile on the right. The white box depicts station MLN9 shown on the right.





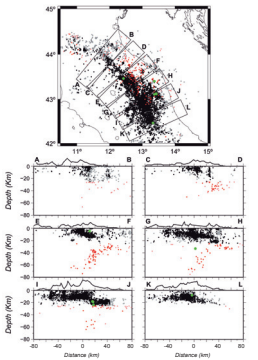
the deep structure

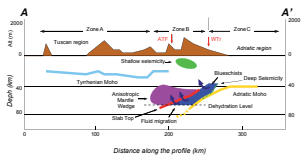
The seismicity distribution (2002-2010) at depth shows a clear west-dipping plane, related to the Adriatic continental plate subducted below the northern Apennines (Selvaggi and Amato, 1992; Chiarabba et al., 2005; De Luca et al., 2009). The lower plate is not continuous along the belt, showing along-dip continuity only in the central sector, where the ATF is well visible on top. (Green circles are M>3.5 between 2009 and 2010; darker colors are for best located events).

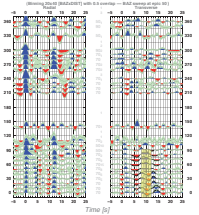
Analysis of teleseismic receiver functions has suggested slab dehydration and fluid migration below the region (Piana Agostinetti et al., In press on EPSL, see sketch below).

Within this project, data from both permanent and temporary arrays are being used to constrain better the deep structure and the relations with the shallow seismicity.

Here we show an example of preliminary RF analysis at station MLN9, close to Lake Trasimeno, where the Adriatic slab is deeper. We see a strong positive pulse at 12s that is likely related to the top of the Adriatic slab. Anisotropic structure is also evident in the transverse component of the RF (the yellow box) probably due to anisotropy in the wedge and/or in the subducted crust (figure on the right).



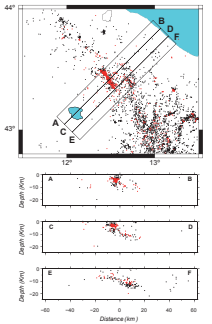


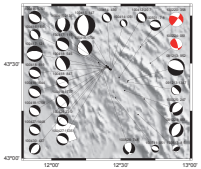


Shallow seismicity is abundant

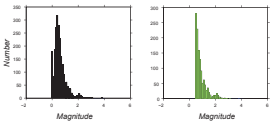
in the region, with normal faulting earthquakes mostly located on the hanging wall of the ATF. With the improved network we have located 6,125 earthquakes in one year (Aug. 2009 - Jul. 2010) with magnitudes from negative values to 4.8. Seismicity of the area was previously studied by Chiaraluce et al., 2007. They observed microseismic activity highlighting a major low angle plane interpreted as the ATF and minor syn- and antithetic normal faults located on its hanging-wall.

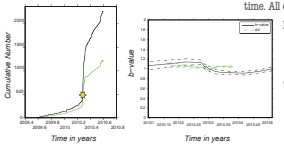
crustal seismicity





Distribution of 2009 - 2010 events for different classes of magnitude: left all events, right after completeness analysis and removal of events with Ml<0.5.





Left: cumulative number of events versus time. All events (black line); M>0.5 (green line). Right: - b-value versus time. All events (black line); M>0.5 (green line). There is no evident temporal change of b-value, since fluctuations lie within uncertainties.

A sudden increase

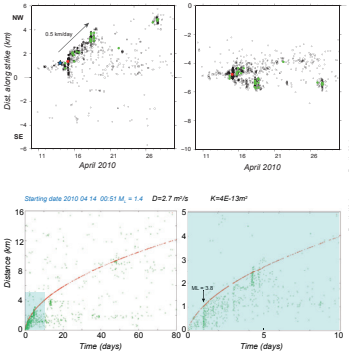
of seismicity rate occurred on April 2010 and a M3.8 event (the largest of this sequence) occurred at ~5 km depth on April 15th (01:47 UTC). The enhanced rate of earthquake production, which lasted for less than one month, started a few days before the largest shock of the sequence.

The seismic activity of this period shows a clear migration pattern both along strike and in depth. HypoDD relocated earthquakes show a NE-dipping fault, with seismicity moving from SE to NW.

The along-strike migration to NW is clear from April 14th (M3.8 main shock) to April 19, with a pause and another step on April 26-28.

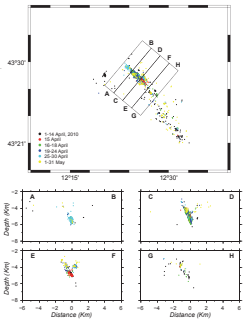
The seismicity migrates about 3 km in 5 days, i.e., about 0.5-0.6 km/day. Seismicity migrates also in depth bilaterally, from 5 km to 3.5 and 6 km.

migration seismicity



The spatio-temporal distribution of seismicity is consistent with the diffusion process of pore-pressure relaxation. Position (see blue star above) and origin time (2010/04/14) are plotted in distance (r) versus time (t). The black line is the triggering front defined by $r = \sqrt{4\pi D t}$, assuming $D_{iso} = 2.7\ m^2/s$. This value of hydraulic diffusivity yields a permeability value of $4 \cdot 10^{-12}\ m^2$ assuming $C_t = 2.9 \cdot 10^{-9}\ Pa^{-1}$; $\nu = 10^{-3}\ Pa \cdot s$; $\varepsilon = 0.05$.

These values of diffusivity and permeability are smaller than those inferred for the 1997 Umbria-Marche seismic sequence (migration 1 km/day, $D_{iso} = 90\ m^2/s$, $K = 4 \cdot 10^{-12}\ m^2$).



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