

EXAMPLES OF SEISMICITY IN ITALY, RELATED AND NOT RELATED TO INDUSTRIAL ACTIVITIES IN THE SUBSURFACE

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Since hydrofracking is used for shale gas production, human induced seismicity has become a subject of increasing interest, especially in the US and Canada (Ellsworth, 2013). In Italy, however, hydraulic fracturing is not practiced, not only because the appropriate shale gas formation is lacking, but also because the technical commission of the Ministry of the Environment outlawed the use of any type of fracking technology for hydrocarbon exploitation (Zaratti, 2013).

Therefore, the discussion about anthropogenic seismicity in Italy was “triggered” for the first time after the deadly M_w 6.2 Emilia earthquake in May 2012 (Scognamiglio et al., 2012; Cesca et al., 2013). Since this seismic sequence occurred in vicinity of gas and oil production sites, the question raised, whether variations in crustal stressing accompanying the hydrocarbon exploitation may have influenced the generation of these earthquakes. As a first consequence, an **I**nternational **C**ommission on **H**ydrocarbon **E**xploration and **S**eismicity in the **E**milia region (ICHESE) was charged to investigate whether the 2012 earthquake sequence was induced or triggered by industrial activities in the area. The ICHESE-commission argued that the stress change in the upper crust generated by the productive activity at the Cavone oilfield was most likely too small to have induced a seismic event, but that earthquake triggering could not be completely excluded.

In 2014, the Superior Institute of Environmental Protection and Research published a report about documented and hypothesized cases of triggered or induced seismicity in Italy. Based on this report and on behalf of the Directorate-General for Safety of Mining and Energy Activities – National Mining Office for Hydrocarbons and Geo-Resources a group of experts compiled the “Italian Guidelines for monitoring the seismicity, underground deformation and pore pressure” (ILG, Dialuce et al., 2014). The ILG describe the governmental regulations, especially regarding hydrocarbon exploitation waste-water injection, and CO₂ storage. A more recent edition of the ILG concerning geothermal energy production was issued in 2016 (Terlizzese, 2016). The ILG prescribe standards for monitoring pore pressure, micro-seismicity and ground deformation and direct the application of a four-stage traffic light protocol (actually applied exclusively for reinjection of waste water), depending on magnitude, PGV and PGA.

The Istituto Nazionale di Geofisica e Vulcanologia (INGV) has been charged of managing multi-parametric monitoring systems in three test areas, namely, Minerbio (gas storage), Cavone and Val d’Agri (hydrocarbon exploitation/waste water reinjection), and to provide indications concerning successful and critical aspects of the first edition of the ILG.

We give a general overview about examples of seismicity in Italy related and not related to human activity in the subsurface and present recent works shedding (some) light on the question whether some of the hypothesized cases of triggered/induced seismicity in Italy (ISPRA, 2014) can be confirmed or excluded.

In the case of anthropogenic seismic events occurring in times before digital seismic monitoring (pre-nineties), as the Caviaga earthquake in 1951, new findings about historical seismicity combined with hypocenter relocation (Caciagli et al., 2015) suggest the cancellation of this event from the ISPRA-report.

Concerning the Emilia earthquakes of 2012, the geomechanical model by Astiz et al. (2014), the physical approach by Dahm et al. (2015), as well as pore pressure monitoring during production realized in the framework of LabCavone (commissioned by UNMIG, <http://labcavone.it/it/a/mise>) showed that the Emilia events of 20th and 29th May 2012 were neither induced nor triggered by depletion of the oil field, and that both earthquakes are exclusively of tectonic origin.

The strongest seismic event ever recorded in Italy in an area with geothermal energy production was the M_w 4 earthquake (2000) at Mt Amiata, with epicenter near Piancastagnaio. Relocation of the event by using an updated crustal velocity model, as well as an independent hypocentral depth estimation lead to a focal depth similar to the production level. Considering however, that historical earthquakes in the area reached magnitudes up to $M_{5.3}$, it cannot be decided if this event was of anthropogenic or natural origin.

A further example concerns the seismicity observed during the preparatory phase of a future CO_2 extraction from a deep well (PSS1) in the Upper Tiber Valley (UTV). For the three main events ($2.9 < M_L < 3.2$) recorded in 2010 thrust fault mechanisms were calculated. These events are located in the vicinity of the active low-angle Alto Tiberina Normal Fault, thus thrust faults are geologically unexpected. As they occurred before starting the CO_2 production excludes any anthropogenic influence.

In the framework of a medium-enthalpy geothermal exploitation project, seismicity and soil gas emissions have been monitored in the area of Castel Giorgio-Torre Alfina (central Italy) since 2014. Seismicity recorded by a local network at Torre Alfina before the energy production shows that the M_L estimations are poorly constrained and mostly incompatible with magnitudes determined by the National Seismic Network (Braun et al., 2018a). Such differences are due to inaccurate attenuation laws and correction factors, especially for stations at local distances. Thus, the question comes up, which magnitude should be calculated (M_L , M_d , M_w) and how significant is generally the use of the magnitude for the application of the ILG-traffic light.

A final example concerns the upper crustal seismicity observed near the Montedoglio reservoir, situated in the UTV, and investigates potential effects of stress variations due to water level variations. Beyond seasonal oscillations - only significant long-term water level changes lead to important seismic events, especially after previous pressure levels have been exceeded ("stress shadow effect", Kaiser, 1950). Even a decrease by 14 m of the dry line, after the rupture of the dam crest, caused no significant associable earthquake. Crustal stress variations expected from the static load of the water column have been modeled and compared to the local seismicity, in order to understand the elastic and undrained response.

The result suggests that the induced instantaneous stress changes are rather small at the distances where larger earthquakes occur (Braun et al., 2018b).

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