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# Monitoring of Anthropogenic Seismicity in Italy: State of the Art

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## Abstract

In Italy, the discussion about anthropogenic seismicity started after the deadly M6 Emilia earthquakes in 2012. Occurring these events in an area of gas and oil production, the question raised, whether stress perturbations induced by the exploitation may have triggered these events. In 2014, the Government published monitoring guidelines (ILG) describing regulations regarding hydrocarbon extraction, waste-water injection and $CO_2$ storage. The ILG prescribe the monitoring of pore pressure, microseismicity and ground deformation near sites of industrial activity and direct the application of a four-stage traffic light protocol. INGV has been charged to apply the ILG in three test areas and to provide indications about the applicability of these guidelines. We give a general overview about the state of the art, trying to emphasize critical situations as e.g. problems in magnitude calculation or traffic light thresholds, especially in areas with multiple mining rights.

## Italian Guidelines for Monitoring effects of Industrial activity on the subsurface

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 (Fig. 1). 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 $CO_2$ storage. A more recent edition of the ILG concerning geothermal energy production was issued in 2016 (Terlizzese, 2016). Both guidelines prescribe standards for monitoring pore pressure, microseismicity and ground deformation and direct the application of a four-stage traffic light protocol, depending on magnitude, PGV and PGA (Fig. 2).

| | |
|---|---|
| The ILG demand to report all events of | $M_{max} \leq M_L 1.5$ (green), |
| to reanalyze parameters and for | $M_{green} \leq M_{max} \leq 2.2$ (yellow), |
| to reduce production for | $M_{green} \leq M_{max} \leq 3.0$ (orange), |
| and to halt industrial operations in case of events with | $M_{orange} < M_L$. |

## Experimental application of the ILG

In a three-years experimental phase, the ILG will now be applied in at least four different test areas:

(i) Casaglia (Emilia Romagna, N-Italy) for low-enthalpy geothermal energy production.

(ii) Minerbio (Emilia Romagna, N-Italy) for gas storage;

(iii) Cavone (Emilia Romagna, N-Italy) for hydrocarbon exploitation/waste water reinjection;

(iv) Val d'Agri (Basilicata, S-Italy).

In Italy 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). The National Institute of Geophysics and Volcanology (INGV) has been charged of managing multi-parametric monitoring systems, or to act as an evaluation agency, in these test areas, and to provide indications about the application of these guidelines (Fig. 3).

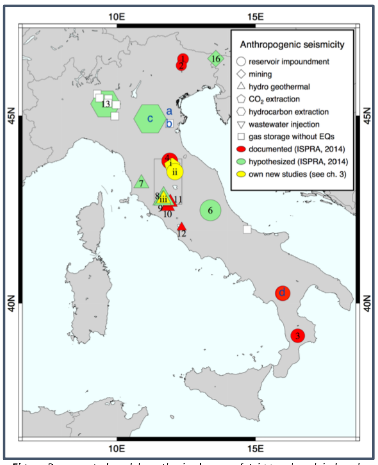


***Fig. 1:*** *Documented and hypothesized case of triggered and induced seismicity in Italy (Braun et al., 2018b).*

| Alert level | Traffic light | $M_{max}$ | PGA (% g) | PGV (cm/s ) |
|---|---|---|---|---|
| 0 | green | $M_{max} \leq 1.5$ | - | - |
| 1 | yellow | $M_{verde} \leq M_{max} \leq 2.2$ | 0.5 | 0.4 |
| 2 | orange | $M_{giallo} \leq M_{max} \leq 3.0$ | 2.4 | 1.9 |
| 3 | red | $M_{arancio} < M_{max}$ | 6.7 | 5.8 |

***Fig. 2:*** *Threshold levels of the four-stage traffic light protocol proposed by Dialuce et al. (2014).*

## Introduction

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). As the Italian geology is not characterized by formations appropriate for shale gas exploitation, the discussion about anthropogenic seismicity in Italy was "triggered" for the first time after the deadly $M_w6.2$ Emilia earthquake in May 2012 (Scognamiglio et al., 2012; Cesca et al., 2013a). 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 **SE**ismicity (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 only the Cavone oilfield and the Casaglia geothermal field were located in the vicinity of the main shocks, concluding that the stress change in the upper crust generated by their activity was most likely too small to have induced a seismic event, but that earthquake triggering could not be completely excluded (Astiz et al., 2014; Dahm et al., 2015). The final recommendation of the ICHESE-report was that all the existing and future activities of hydrocarbon exploitation (oil- and gas-production, wastewater reinjection), gas storage, geothermal energy production will have to be subject of monitoring by high-quality networks, concerning seismicity, ground deformation and pore pressure variations.

## Experimental application of the Governmental Monitoring Guidelines at 4 test sites

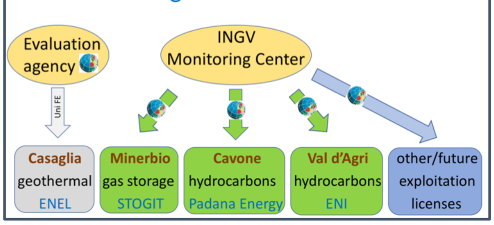


***Fig. 3:*** *Experimental application of the Governmental Monitoring Guidelines (ILG) at four test sites.*

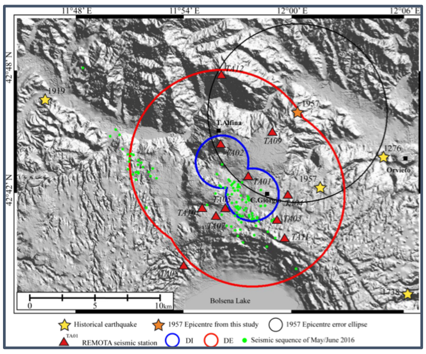


***Fig. 4:*** *The 2016 seismic sequence ($M_{max}$=4.1) at Castel Giorgio: epicenters (green dots) with respect to the inner domain (blue line) and outer domain (red line) (from Braun et al., 2018a).*

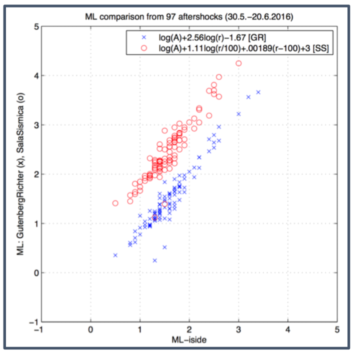


***Fig. 5:*** *The 2016 seismic sequence ($M_{max}$=4.1) at Castel Giorgio: comparison of the magnitudes determined of the local and national seismic networks (Braun et al., 2018a).*

## Some remarks on the application of the ILG

Based on recent experiences made e.g., in the geothermal area of Torre Alfina/Castel Giorgio, where in 2016 a $M_L4.1$ earthquake occurred months before starting the geothermal exploitation (Fig. 4), some annotations concerning the ILG can already be outlined:

One critical question is that companies with new licenses are obligated to realize a one-year monitoring period before starting the industrial operations (zero-line), which is indeed impossible for already existing concessions, producing since decades. With the forthcoming opening of the geothermal market in Tuscany many new concessions are expected to be situated inside or in the direct vicinity of the traditional areas of the main national energy producer, not excluding cases where different companies access the same reservoir. Here the question rises whether the requirement to determine the zero-line is reasonable. Another critical point of the ILG is the lack of any political consequence regarding the future production, in case that the natural seismicity exceeds the magnitude threshold already during the zero-line period.

A further remark concerns the magnitude determination; in this regard the ILG do not specify the magnitude type to be calculated. Seismicity recorded by a local network at a future geothermal production site at Torre Alfina (12 in Fig. 1, Fig. 4) shows that the $M_L$ estimations are mostly incompatible with magnitudes determined by the National Seismic Network (Fig. 5). Such differences are due to inaccurate attenuation laws and correction factors, especially for stations at local distances. In these conditions, the $M_L$ becomes poorly constrained and should be better replaced by the more significant PGA and PGV.

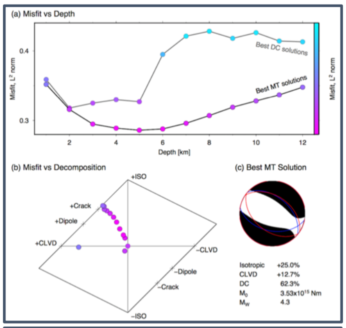


***Fig. 6:*** *(a) Moment tensor inversion of the 30th May 2016 main shock (Mw4.3) computed using waveforms within 100 km of epicentral distance. (a) misfit versus depth, assuming a DC source model (gray line) and full MT model (black line); (b) source-type diagram according to Hudson et al. (1989) (from Braun et al., 2018a).*

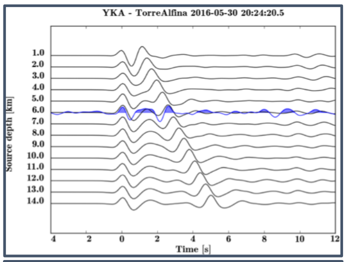


***Fig. 7:*** *Array beam modelling using the Yellowknife-Array (YKA) (from Braun et al., 2018a)*

## Conclusions

Beyond the monitoring purposes, the experimental application of the ILG offers the great opportunity to access high quality data allowing to outline criteria for the discrimination between natural and anthropogenic seismicity. One of these might be to invert the full moment tensor (Cesca et al., 2013b) also for low magnitude events (Fig. 6); a further criterion could be to verify the hypocentral depth by alternative methods, as e.g., depth phase modeling by comparing synthetic array beams with the beam-trace of teleseismic array data (Fig. 7, Braun et al., 2018a).

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