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# Preface to the special issue "Triggered and induced seismicity: probabilities and discrimination"

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Triggered and induced seismicity are the earth response to transient non-tectonic phenomena. In a common definition, a triggered earthquake is assumed as an event whose occurrence is anticipated in view of the background seismicity rate. The triggering process, caused by a transient phenomena, only concerns the nucleation of a small region of the rupture area, whereas the entire rupture is controlled by the background stress. An induced event, in change, is entirely (e.g. in terms of rupture size and energy released) controlled by its causative origin and would not occur without it. A complementary, stress-based approach to define the boundary among triggered and induced seismicity was discussed by McGarr and Simpson (1997), in the specific framework of anthropogenic seismicity. According to their classification, a broader term of "stimulated" seismicity could be used to describe both triggered and induced seismicity.

Transients which can induce or trigger seismicity can either be of natural or anthropogenic origin. Natural phenomena which can favour seismicity include rain, snow, pore pressure changes, magma dikes, and geothermal and volcanic processes. Earthquake–earthquake interactions may also be considered as a specific case of triggered seismicity. A second, important group of induced and triggered events are those of anthropogenic origin. Different human-related activities may favour, or inhibit, the earthquake occurrence, e.g. by inducing local stress perturbations, affecting the subsurface strain, or inducing changes in the pore pressure. Known cases of human operations which can induce seismicity or microseismicity include mining operations and mass shifts, water reservoir impoundment, drilling, oil- and gas-field exploitation, hydro-fracturing, and fluid injection and removal.

The theme of induced seismicity, and more specifically of anthropogenic induced seismicity, is nowadays of great interest, not only for the scientific community, but also for the society. On one side, several new techniques have been developed and applied for the purpose of mining, hydrocarbon production, hydraulic fracturing or fluid injection/removal. Related geo-engineering operations can possibly significantly modify the seismicity rate, either inducing or inhibiting the seismicity at different scales. A

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second, relevant aspect is that anthropogenic induced seismicity is often affecting regions which are considered tectonically aseismic, which consequently poses the problem to account for induced seismicity towards a proper hazard assessment. Figure 1 shows the magnitude and spatial distribution of selected anthropogenic induced events in Europe in the last century, following different types of human activities and operations, which have been recollected within a new induced seismicity catalogue (the updated version is available at http://mine.zmaw.de). The introduction of a traffic light system with defined actions depending on the magnitude of the recorded events (e.g. the Basel Deep Heat Mining Project) is an example of the interaction between the industry and society.

Special issues on induced/triggered seismicity have been frequently published. However, it is the first time that a special issue on this topic is published on the *Journal of Seismology*. Among the specific novelties which characterize this issue are the specific seismological viewpoints of collected contributions, the aim to discuss the natural/induced/triggered seismicity discrimination problem, and the focus on probabilistic methodological approaches and applications. This issue recollects recent significant scientific advances in the monitoring, analysis, and discrimination of induced and triggered earthquakes, as well as specific applications to different induced and triggered seismicity cases, both anthropogenic and driven by natural processes. Since no clear rules have so far been accepted by the scientific community regarding the discrimination between natural, triggered, and induced earthquakes, the issue has a specific focus on the discrimination problem and has the wish to contribute and further stimulate the scientific discussion in this sense. A second relevant topic concerns the development and adoption of probabilistic approaches, both for the determination of the origin of seismicity, its

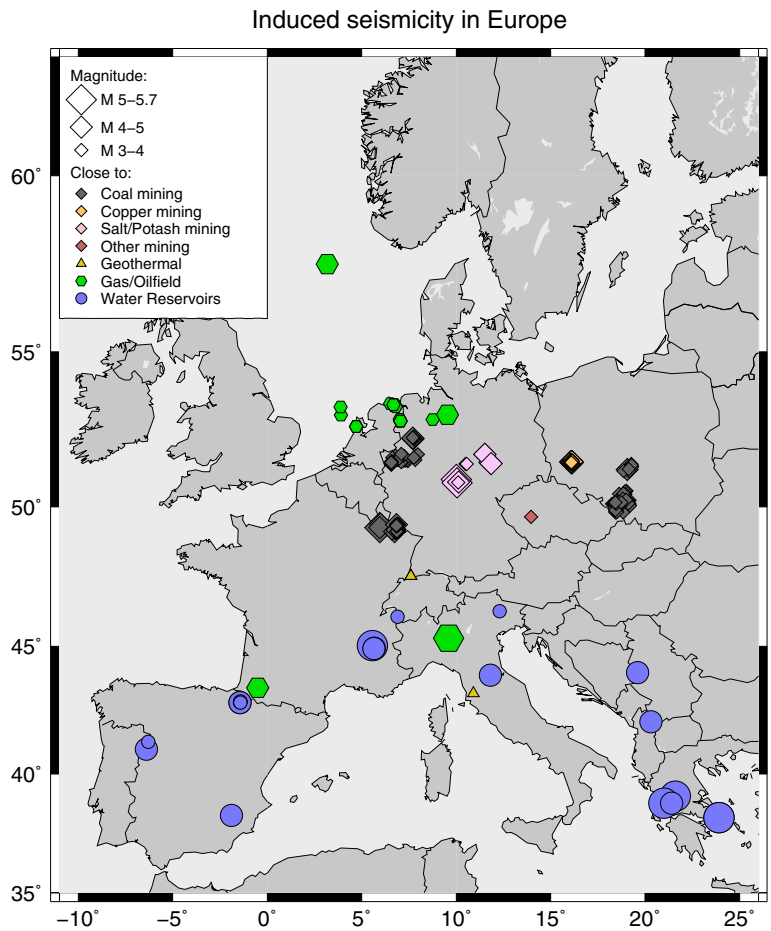


**Fig. 1** Selected anthropogenic induced seismicity in Europe since 1888. The catalogue (updated version accessible at http://mine.zmaw.de) includes anthropogenic induced earthquakes with magnitude above 2. Although updated information has been collected for several countries, the catalogue is still incomplete, will be progressively updated in future, and is open for external contributions

source characteristics, and its relation to other natural phenomena and human activities, and to evaluate seismic hazard for induced and triggered seismicity.

The collected manuscripts mostly focus on anthropogenic induced seismicity, although the case of natural induced seismicity by dikes is also treated (Passarelli et al. 2012). Anthropogenic seismicity is discussed for mining operations (Rudziński and Dębski 2012; Cesca et al. 2012), water reservoirs (Mallika et al. 2012), gas field exploitation (Kraaijpoel and Dost 2012; Cesca et al. 2012), and geothermal systems (Barth et al. 2012; Plenkers et al. 2012; Häge et al. 2012; Dinske and Shapiro 2012).

Following a scientific and geophysical viewpoint, different techniques are developed, discussed or applied, including source location (Rudziński and Dębski 2012; Häge et al. 2012; Husen et al. 2012), moment tensor inversion (Cesca et al. 2012), source parameters estimation (Husen et al. 2012; Barth et al. 2012), waveform cross correlation (Plenkers et al. 2012), catalogue assessment, and magnitude distribution (Dinske and Shapiro 2012; Häge et al. 2012; Barth et al. 2012). Finally, results from laboratory studies associated to pore pressure changes are discussed in Turuntaev et al. (2012).

The discrimination problem is treated here in different works. Cesca et al. (2012) and Passarelli et al. (2012) propose different probabilistic approaches for the discrimination among natural and induced/triggered events. A probabilistic approach is also discussed in Barth et al. (2012), which focuses on the assessment of the probability to exceed given magnitude thresholds in different injection phases. Klose (2012) discusses the relation between mass shifts and different induced earthquake source parameters and recompiles a catalogue of relevant induced/triggered events. Finally, the contribution of Dahm et al. (2012), which summarizes an open discussion involving a large number of experts and researchers, attempts to describe the state of the art with respect to the problem of natural, induced, and triggered earthquake discrimination to set up possible guidelines and a framework for the development of a discrimination/decision scheme, and presents possible modules that may be implemented there.

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