Injection-induced seismicity

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Although cases of seismicity induced by human activities have been known and documented for decades, the seismic hazard associated with the exploitation of deep geothermal energy and possibly with future endeavours to store large amounts of CO_2 in the underground are often underestimated. Although there are several examples of successful geothermal and CO_2 storage operations that did not cause any felt earthquakes, recent cases of promising projects aimed at tapping geothermal energy at depths of several kilometres have raised serious public concern about the seismic risks associated with such projects. Among the reasons for underestimating the hazard of induced seismicity are fundamental misconceptions regarding the occurrence of natural seismicity and the processes which can trigger seismic events. Thus it is often thought that earthquakes occur only at greater depths (> 5 km) in the crystalline basement and that the shallower sedimentary rocks are not strong enough to store sufficient stress to produce significant earthquakes. Many examples documented in the seismological literature show that this is not true and that earthquakes with magnitudes of 5 and more can occur at depths of only a few km in the sedimentary cover. It is furthermore often believed that it requires massive perturbations of the state of stress to trigger earthquakes. This also is incorrect: increasing evidence suggests that large parts of the Earth's crust are quite near its point of failure (critically stressed) and that even small perturbations of the complex interaction between fluids and faults can decrease the resistance to failure sufficiently to trigger an earthquake. The injected fluids rarely exceed the level of the least compressive stress in the crust and it is not the amount or pressure of an injected fluid that supplies the energy to generate an earthquake. The fluids merely decrease the resistance to failure, and it is the ambient tectonic stress that drives the seismic activity. Among other aspects, this also means that the distinction between enhanced or engineered geothermal systems (EGS) on the one hand and hydrothermal systems on the other, although important, should not be overemphasized when it comes to assess the seismic hazard associated with such projects. Examples of natural seismicity at shallow depth such as the Magnitude 5 event of Annecy (France), the earthquake sequence of Fribourg (Switzerland) or rain-induced seismicity in Germany and Switzerland as well as seismicity induced by human activity (in particular the geothermal project of Basel) serve to illustrate these points.

The fundamental processes that lead to induced earthquakes are understood, however, we still are not able to quantify uniquely the relative importance of the different parameters (e.g. depth, ambient stress, rock friction, fluid pressures and volumes, etc.). Moreover, in individual cases we usually do not have sufficient information to assess the seismic hazard associated with a particular project before it is started. This poses significant problems for the project developers, the regulatory authorities and the public. New paradigms in the way deep geothermal projects and CO_2 storage facilities are regulated need to be established. The number of successful projects worldwide for the exploitation of deep geothermal energy and the storage of CO_2 is small, so that the empirical data base is limited and we are not able to say with confidence why some projects have caused felt earthquakes and others have not. Thus, if deep geothermal energy and the underground storage of CO_2 is to contribute significantly towards the mitigation of the global energy crisis and climate change, we need to openly exchange all the available information and engage in a constructive dialog among all stakeholders -- project developers, authorities, science and the public.

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The complete Basel Risk Study and other reports can be downloaded from:
http://www.wsu.bs.ch/geothermie

Selected references regarding shallow and rain-induced seismicity:

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