Geophysical Research Abstracts
Vol. 16, EGU2014-14380, 2014
EGU General Assembly 2014

Analysis of Scaling Parameters of Event Magnitudes by Fluid Injections in Reservoirs

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We continue to elaborate scaling parameters of observed frequency-magnitude distributions of injection-induced seismicity. In addition to pumped fluid mass, b-value and seismogenic index (Shapiro et al., 2010, Dinske and Shapiro, 2013), one more scaling was recognised by the analysis of the induced event magnitudes. A frequently observed under-representation of events with larger magnitudes in comparison with the Gutenberg-Richter relation is explained by the geometry and the dimensions of the hydraulically stimulated rock volume (Shapiro et al., 2011, 2013). This under-representation, however, introduces a bias in b-value estimations which then should be considered as an apparent and transient b-value depending on the size of the perturbed rock volume. We study in detail in which way the seismogenic index estimate is affected by the apparent b-value. For this purpose, we compare b-value and seismogenic index estimates using two different approaches. First, we perform standard Gutenberg-Richter power-law fitting and second, we apply frequency-magnitude lower bound probability fitting as proposed by Shapiro et al. (2013). The latter takes into account the finite size of the perturbed rock volume. Our result reveals that the smaller is the perturbed rock volume the larger are the deviations between the two sets of derived parameters. It means that the magnitude statistics of the induced events is most affected for low injection volumes and/or short injection times. At sufficiently large stimulated volumes both fitting approaches provide comparable b-value and seismogenic index estimates. In particular, the b-value is then in the range of b-values universally obtained for tectonic earthquakes (i.e. 0.8 - 1.2). Based on our findings, we introduce the specific magnitude which is a seismotectonic characteristic for a reservoir location. Defined as the ratio of seismogenic index and b-value, the specific magnitude is found to be a magnitude scaling parameter which is unaffected by the size of perturbed rock volume. Using both seismogenic index model and specific magnitude model we predict magnitude frequencies for different scenarios and compare them to observed data. We conclude that the seismogenic index model provides proper results which confirms its applicability as a predictive tool and, thus, it is valuable for assessment as well as mitigation of seismic hazard by fluid injections.