Earthquakes Induced by Water Injection at ˜3 km Depth within the Rongchang Gas Field, Chongqing, China

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Unwanted water, amounting more than 1,000,000 m^3, has been injected intermittently at a pumping pressure of 2.1-2.9 MPa to 2.6-2.9 km depth within the Rongchang gas field, western Chongqing, China, since July 1988. The injections have induced more than 32,000 surface-recorded earthquakes, including 2 of M5+, 14 of M4+, and more than 100 of M3+ up until the end of 2006. We systematically examined the epidemic-type aftershock sequence (ETAS) model and the temporal evolution of several statistical properties of the earthquake sequence, including the seismic b-value and the spatial correlation length and fractal dimension of the hypocenters. The statistical results indicate that ETAS modeling is a promising method in terms of identifying fluid signals in seismicity patterns, even in the case of poor hypocenter data. The random component in the ETAS model can be considered as an indicator of fluid-driven activity, while the rate of Omori-law-type aftershocks indicates stress-triggering of the preceding earthquakes. We observed three distinct seismic activity phases that were coincident with different injection periods(Figure. 1). Phase-I corresponds to initial injections with low injection frequencies, and shows a vast majority of Omori-type self-triggered events and only 8% externally forced (fluid-induced) activity. Phase-II corresponds to a period of high injection rates, and shows intense earthquake activity characterized by a high percentage (45%) of fluid-driven earthquakes. Phase-III demonstrates decreasing seismicity as a result of a lowering in the injection rate; more than 70% of earthquakes occurred randomly over time, indicating the dominance of external triggering by pore-pressure diffusion. The physical mechanism that induced the Rongchang earthquake sequence was a Coulomb stress change caused by pore-pressure diffusion and transformed from seismic slip of preceding earthquakes. A pressure increase of 2.1-2.9 MPa at the injection well is more than sufficient to induce failure within the local formations. The present study supports the existence of a local threshold value of Coulomb stress change above which changes in seismicity occur.

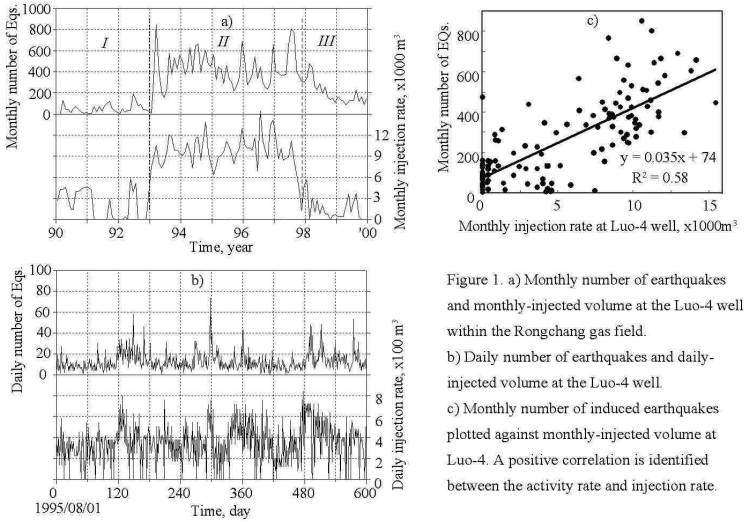

Figure 1. a) Monthly number of earthquakes and monthly-injected volume at the Luo-4 well within the Rongchang gas field.
b) Daily number of earthquakes and daily-injected volume at the Luo-4 well.
c) Monthly number of induced earthquakes plotted against monthly-injected volume at Luo-4. A positive correlation is identified between the activity rate and injection rate.