Spatial and temporal evolution of micro-earthquakes during Multi-cycle operation of the Hutubi underground gas storage, Xinjiang, China

Bo Zhang[1], Baoshan Wang[1,2,3*], Zhanbo Ji[1], Jinxin Hou[1], Lu Li[1], Bin Wei[4], Wu Ni-Er[4], Zhide Wu[5]

1. Key Laboratory of Seismic Observation and Geophysical Imaging, Institute of Geophysics, China Earthquake Administration, Beijing, China.
2. School of Earth and Space Sciences, University of Science and Technology of China, Hefei, China.
3. Mengcheng National Geophysical Observatory, University of Science and Technology of China, Hefei, China.
4. Earthquake Agency of Xinjiang Uygur Autonomous Region, Urumqi, China.
5. Research Institute of Petroleum Exploration and Development, Langfang, China.

1. Introduction

Underground Gas Storages (UGSs) are important large-scale industrial facilities used to bridge the gap between the natural gas consumption and supply. The UGS production (periodical natural gas injection into and extraction from UGS) can cause changes of the subsurface stresses and probably the local seismicity pattern. The UGS related seismicity has important effects on the UGS safety and local seismic hazard, but is rarely reported, comparing to well-documented seismicity associated with liquid injection and extraction.

As the largest Underground Gas Storage in China, the Hutubi UGS is well equipped with seismic observations from the beginning of the UGS operation, which provides an unprecedented to investigate the seismicity related to the periodical UGS operation.

2. Geologic settings & UGS Operation

Hutubi Underground Gas Storage is located in the uplifted Hutubi anticline near the North Tianshan. There are three near east-west reverse faults tend to southwest develop along the axis of Hutubi anticline and cut through the formation of Ziniquanzi formation.

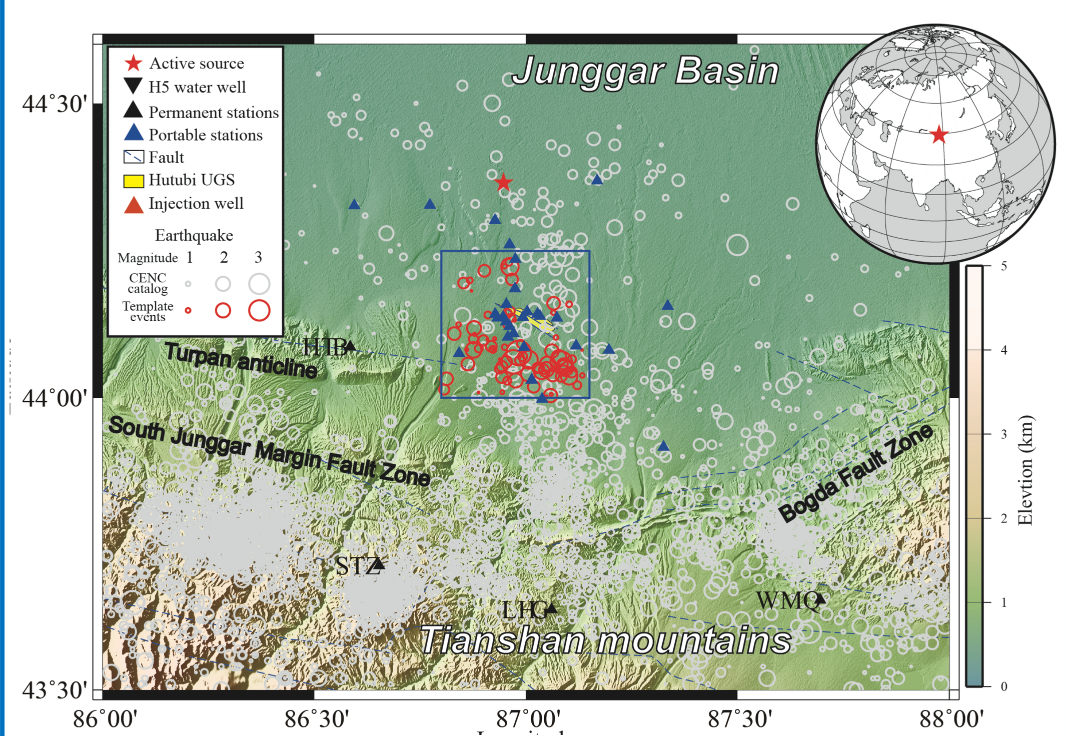

Figure 1. Map of Hutubi UGS and the catalog form CENC.

The Hutubi gas field was reconstructed as underground gas storage. The designed total storage capacity and working gas volume of Hutubi UGS are 10.7 billion cubic meters and 4.51 billion cubic meters, respectively, and the maximum daily gas injection volume is 11.23 million cubic meters.

To the end of 2018, the Hutubi UGS has experienced five injection/loading and extraction/unloading cycles and one injection period (Ⅰ - Ⅴ & Ⅵi in Figure. 3c).

3. Data processing & Detected result

To monitor the seismicity around the Hutubi UGS, we first detect micro-earthquakes from the continuous seismic records using the Matched and Filtered Technique (MFT, Meng & Peng, 2012).

And then we relocate the detected events using double difference method (Waldhauser & Ellsworth, 2000).

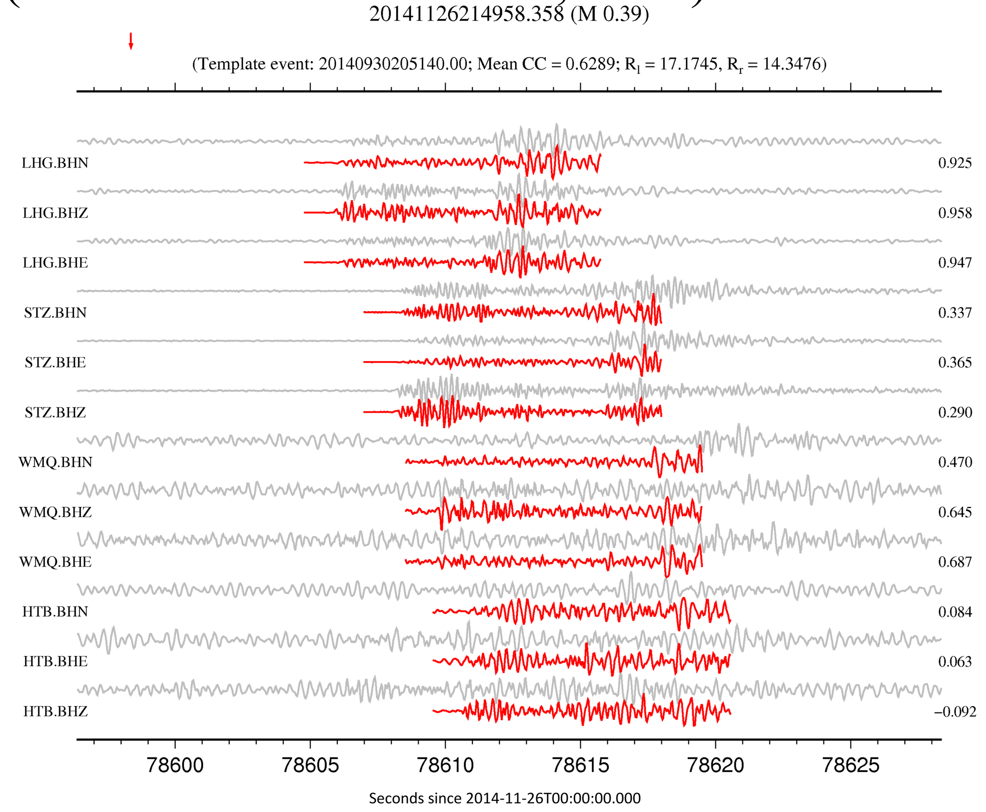

Figure 2. Comparisons of template seismograms (red traces) with portion of the seismic signal detected in the continuous waveform data (grey traces) in MFT. The determined origin time, mean CC, and SNRs are marked under the corresponding titles, and the origin time is labelled by red arrow.

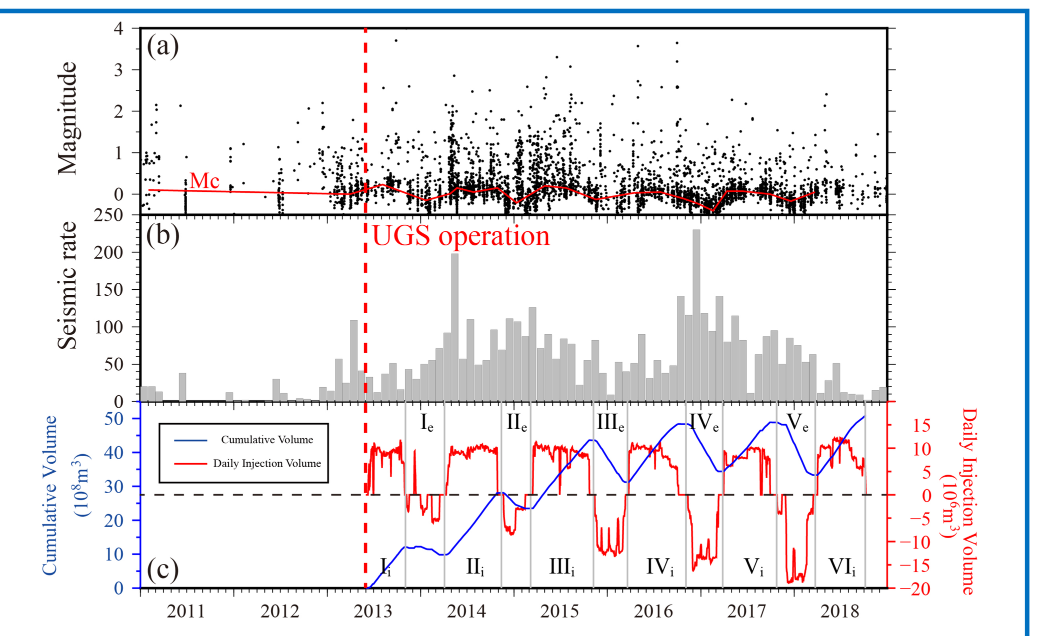

Figure 3. Time series of the detected events (a & b) and operating of gas storage (c).

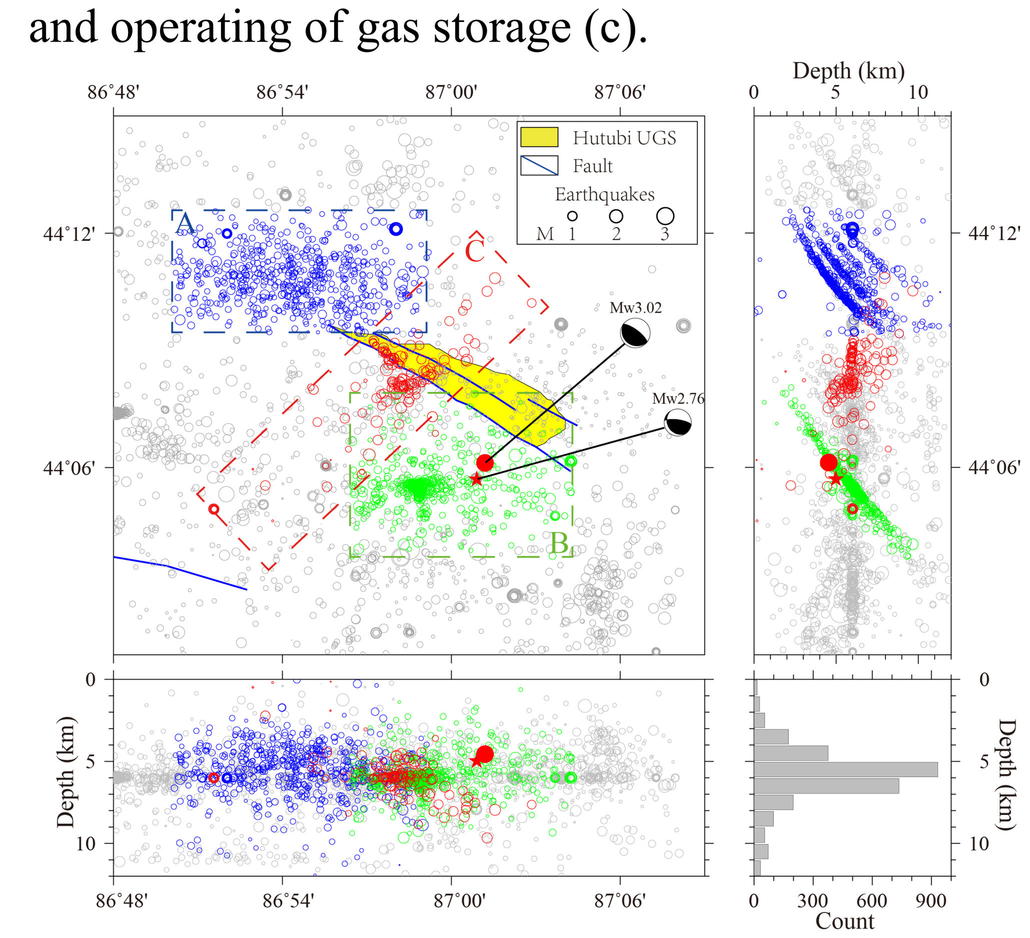

Figure 4. The map view of detected events. More than half of the seismic events are distributed 5-7 km. It can be divide into three clusters (A, B, & C) according to its distribution.

4. Seismicity of three main clusters near the Hutubi UGS

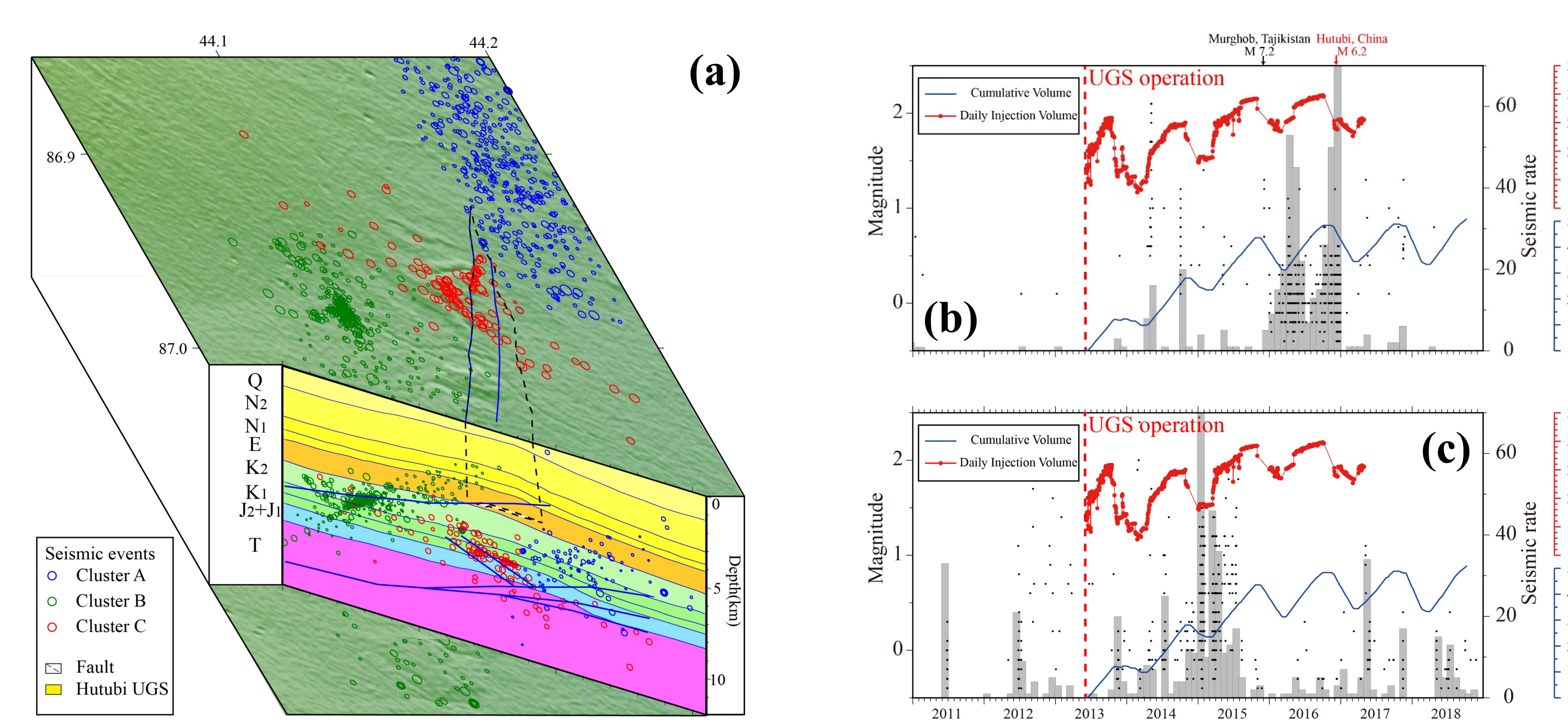

Figure 5. Spatial-temporal distribution around Hutubi UGS. According to its spatial distribution, we divide the regional seismicity into three main clusters. The cluster A, B, and C are marked as blue, red, and green cycles, respectively. The seismicity in cluster A and B are shown in (b) and (c) . The M-t plot (black dots) and the seismic rate per month (grey histogram) indicated that the b-cluster event mainly occurs when the storage capacity gradually increases, while the a-cluster event mainly occurs after the end of the capacity increase.

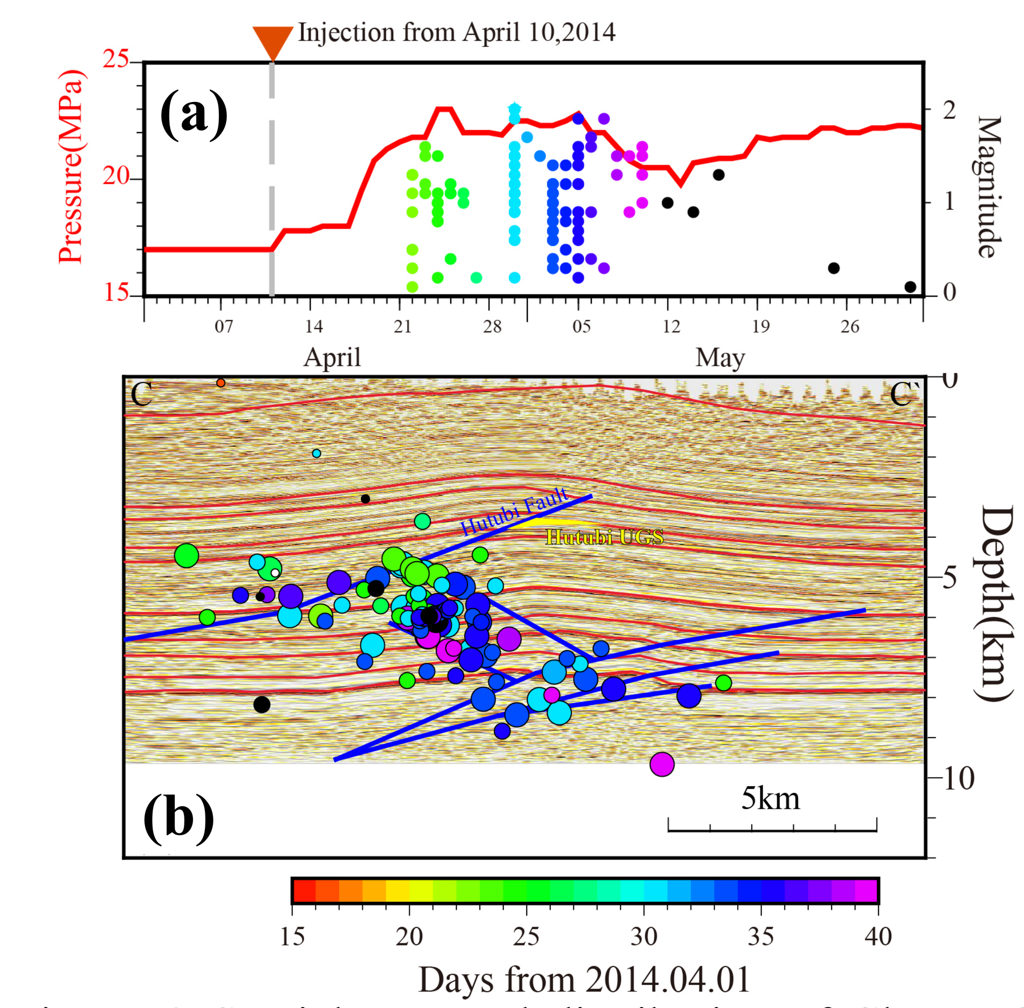

Figure 6. Spatial-temporal distribution of Cluster C. The magnitude time plot (a) and the profile cross the UGS (b). Seismic events are denoted by solid circles and filled by its origin time. It shows the characteristics of migration to the deep.

5. Stress or Fluid Diffusion?

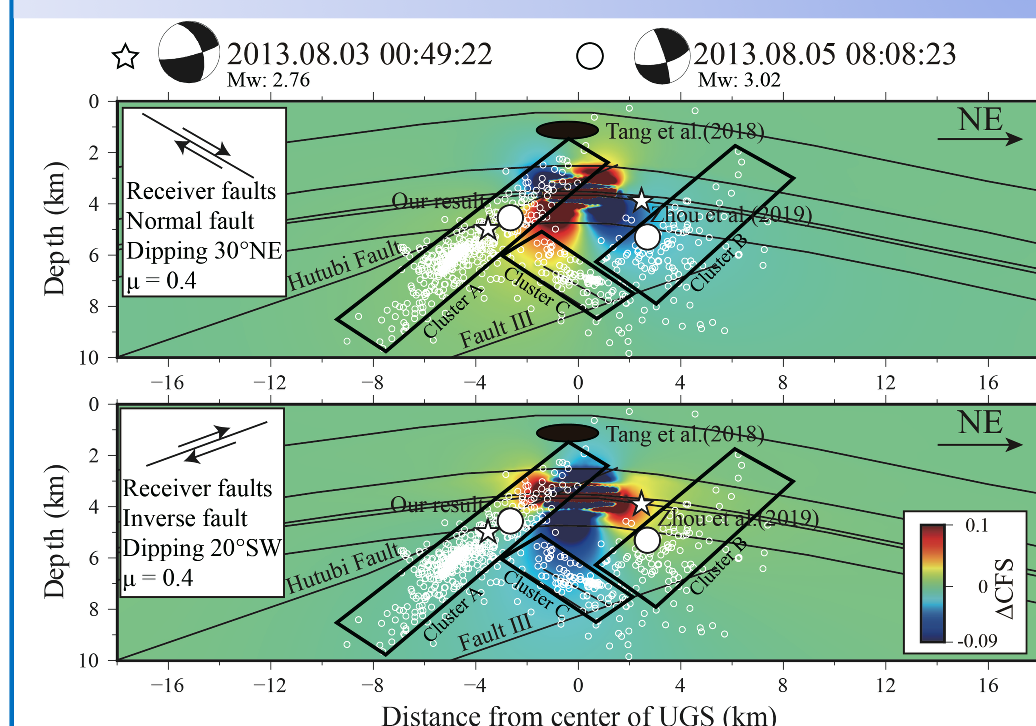

Figure 7. Coulomb stress perturbation induced by the operation of Hutubi UGS at the begin of second injection. (a) and (b) show Coulomb stress perturbation with different receiver faults the spatial distribution characteristics from different angles.

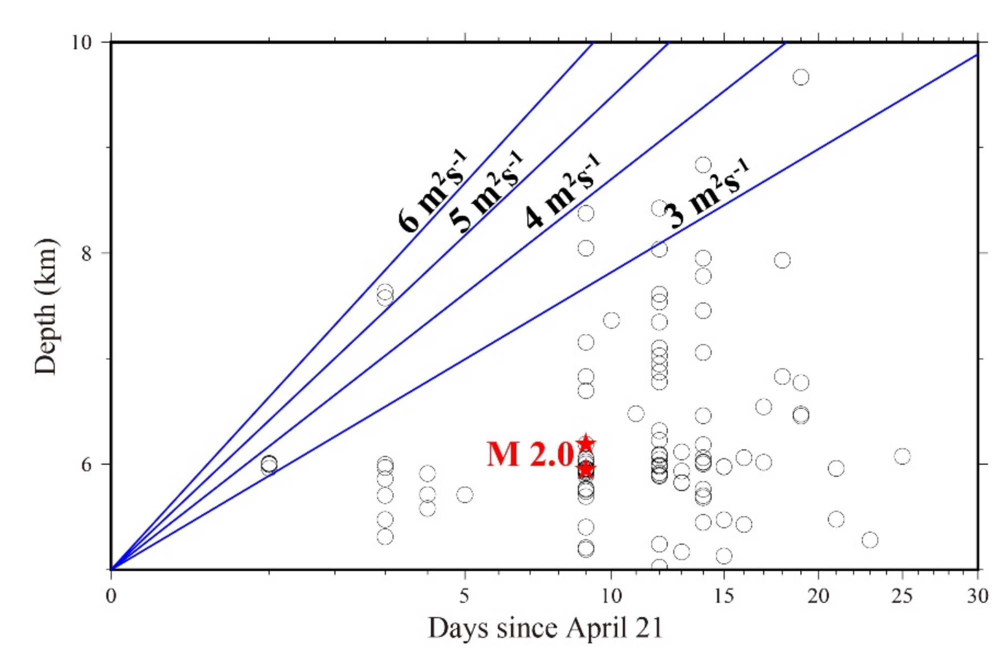

Figure 8. The depth distribution of cluster C with a square root time scale. Blue lines correspond to predictions from a diffusion model.

6. Conclusions

1. Seismicity related to the operation of gas storage in Hutubi area. Their physical mechanisms may be different. In the different periods of operation of the gas storage, the mechanism of induced earthquakes in the surrounding area is different.
2. Understanding the mechanism of seismicity around gas storage will help us to adjust the operation strategy of gas storage to reduce the seismic risk. Continuous high-precision seismic activity monitoring can effectively monitor the state of natural gas storage and reservoir trap, and improve the security of gas storage operation.