Hydraulic Fracturing-induced Seismicity at the Hot Dry Rock Site of the Gonghe Basin in China

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Abstract: Hot dry rock is becoming an important clean energy source. Enhanced geothermal systems (EGS) hold great promise for the potential to make a contribution to the energy inventory. However, one controversial issue associated with EGS is the impact of induced seismicity. In August 2019, a hydraulic stimulation experiment took place at the hot dry rock site of the Gonghe Basin in Qinghai, China. Earthquakes of different magnitudes of 2 or less occurred during the hydraulic stimulation. Correlations between hydraulic stimulation and seismic risk are still under discussion. Here, we analyze the hydraulic stimulation test and microseismic activity. We quantify the evolution of several parameters to explore the correlations between hydraulic stimulation and induced seismicity, including hydraulic parameters, microseismic events, $b$-value and statistical forecasting of event magnitudes. The results show that large-magnitude microseismic events have an upward trend with an increase of the total fluid volume. The variation of the $b$-value with time indicates that the stimulation experiment induces small amounts of seismicity. Forecasted magnitudes of events can guide operational decisions with respect to induced seismicity during hydraulic fracturing operations, thus providing the basis for risk assessment of hot dry rock exploitation.

Key words: EGS, hot dry rock, hydraulic stimulation, induced seismicity

1 Introduction

As one of the new clean energies with huge reserves, hot dry rock is characterized by being a continuous and stable energy supply, with a high efficiency for recycling and renewable energy, which can reduce greenhouse gas emissions and improve the environment. Hot dry rock is a hot rock mass buried deep in the rock strata, with a high temperature. The first hot dry rock project for extracting underground geothermal energy was conducted at Fenton Hill, New Mexico, USA (Murphy et al., 1983). Enhanced geothermal systems (EGS) are currently the most efficient method with which to mine heat from hot dry rock (HDR) reservoirs (Cui and Wong, 2021). The key technology of EGS is reservoir transformation, which can not only form an artificial geothermal reservoir in a low permeability high temperature rock mass, but also improve overall heat exchange efficiency (Na et al., 2014). Therefore, EGS has significant potential to contribute to the world’s energy inventory. In EGS, the rock mass is stimulated hydraulically by pumping fluids through an injection well under high pressure to the target depth. The process carries a risk of producing not only micro-earthquakes but also possibly moderate-to-large magnitude earthquakes. When EGS sites are located close to urban areas as an efficient local source of heating, any induced seismic activity large enough to be felt can result in public concern in regions with a high population. Thus, it is of great strategic significance to be well aware of the possibility of inducing earthquakes for the purposes of coordinating risk assessment and industrial activity.

Several EGS projects have been associated with induced seismicity. In early December 2006, large scale fluid injection was carried out at 5 km depth below the city of Basel, Switzerland, for geothermal reservoir enhancement. The largest of the induced earthquakes, which had a magnitude of $M_I$, 3.4, was strongly felt in the Basel area and led to the termination of the project after only six days of stimulation (Kraft and Deichmann, 2014). In November 2017, an earthquake with a magnitude of 5.4 occurred to the north of Pohang, South Korea. According to the subsequent investigation, the Pohang earthquake was triggered by the injection of high-pressure water into a geothermal well by the Pohang geothermal power station (Lee et al., 2019). In Alberta, Canada, a sharp increase in seismic activity has a relationship with hydraulic stimulation (Atkinson et al., 2016; Schultz et al., 2018). For the Lower Rhine Graben Site in Soultz-sous-Forêt, France and the Geysers Field in California, USA, a series of key factors controlling the induced seismicity has been revealed (Evans et al., 2005; Majer et al., 2007). In these studies, causative hypotheses including pore elasticity and...
the precise mechanisms of fluid-rock interaction have been developed, in order to explain different aspects of the observations (Shapiro, 2015; Verdon et al., 2015). Primarily physics-based approaches suggest a hydro-mechanical model of fluid migration through the rock matrix and cracks (Kohl and Megel, 2007; Baisch et al., 2009). However, these mechanical studies are associated with large uncertainties, and the theoretical models often significantly underestimate the amount of induced seismicity (Li et al., 2018). It is difficult to provide guidance for the fracturing engineering practices, when failure to give warnings can result in immediate disaster.

The Gonghe Basin is a test site for hot dry rock exploration and development in Qinghai province (Liu et al., 2020). Five hot dry rock exploration wells have been drilled since 2015, including well GR1 with a depth of about 3705 m and a corresponding temperature maximum of 236°C, which is basically consistent with the relatively successful EGS projects in the world (Tang et al., 2020). However, earthquakes of different magnitudes also occurred in the exploitation of hot dry rock in the Gonghe Basin. Though most of the earthquakes have had a recorded magnitude of 2 or less, the public is concerned about the magnitude of current and future earthquakes, fearing that a swarm of microseismic events might trigger a major catastrophe (Luo et al., 2021). As a result, hydraulic stimulation was forced into suspension several times. In order to evaluate the hydromechanical properties of the reservoir and to characterize its response to the stimulation tests, the correlations between the seismological and hydrological observations must be investigated in detail.

Here, we focus on correlations between the hydraulic stimulation and induced seismicity at the hot dry rock site of Gonghe Basin. We aim to make operational decisions during hydraulic fracturing operations to mitigate induced seismicity. For example, fluid volume or pressure could be reduced, or stimulation could be directed away from areas showing fault reactivation. The seismicity associated with the hydraulic parameters and the events followed the Gutenberg-Richter distribution permitting us to populate statistical models of the seismicity, extrapolating from them to make forecasts of the magnitudes of expected events. Firstly, the microseismic activity at different stages of fracturing was analyzed, including microseismic events and their magnitude. The relationship between hydraulic parameters and microseismic event distribution was then discussed, including the fluid volume, injection rate and pressure. The evolution of the b-value during the stimulation test was then examined, including the frequency-magnitude distribution of the events and the temporal variations of the b-value during the stimulation period. Finally, the event magnitudes induced by fluid injection were predicted. The risk assessment of the induced microseismic activity provides a warning for future industrial exploitation.

In the following parts of this paper, Section 2 describes briefly the geological background and seismic network. Section 3 demonstrates the hydraulic parameters and microseismic event distribution. We discuss the correlation between microseismic activity and hydraulic stimulation in Section 4. We then examine the evolution of the b-value during the stimulation test and predict the event magnitudes in Section 5. Finally, the conclusions and some advice are provided in Section 6.

2 Geological Background and Seismic Network

2.1 Geological background

The Gonghe Basin lies in the Qilian–Qingling–Kunlun fold system of the Central Asian Orogenic Belt. A large number of intrusive rocks, such as granite, granodiorite and diorite, are exposed in the area around the basin (Zhang et al., 2018). The Gonghe Basin is a rhombus-shaped fault basin, with a northwest–west spreading geometry, Fig. 1 showing its location. The fault zone igneous rock belt around the Gonghe Basin is well-developed, providing favorable conditions for the transfer of heat from deep to shallow. The fault structures at different depths are conducive to thermal activity, with the shallow fault structures promoting the rapid diffusion of geothermal energy and the deep fault structures cutting the lower crust. Accordingly, the faults provide the favorable prerequisite of a water channel for the heat recovery process.

The study area is located on the southeastern edge of the Gonghe Basin. Due to the complexity of the geological structure in the Gonghe-Guide Basin, the study area is surrounded by several strike-slip faults, e.g., the Qinghai South Mountain fault, Heka South Mountain fault, Ela Mountain fault and Zhama Mountain fault (Zhang et al., 2019). The faults have a stronger permeability and aperture than common fractures. The hydraulic fracturing technology is applied for reservoir stimulation in the target region to connect the natural faults and fractures. The tectonomagmatic zone might serve as a hydraulic channel for the upward convection of deep geothermal fluids. The NW–NWW strike-slip faults were formed in the nearly SN and NE tectonic compressive stress field. The NWW deep fractures are well-developed on the northern Tibetian Plateau.

2.2 Seismic network

A well-designed seismic network is a prerequisite for real-time seismic monitoring, high-resolution data acquisition and the analysis of induced seismicity. The
distribution of the geophone array is designed to completely cover the entire area of surveillance. The focus of the array method is to obtain the maximum range of distance offset at any position in the monitoring target area. The seismic rays in the seismic wave propagation area are transmitted at the widest range of different angles possible.

The microseismicity induced through injection has been monitored by a surface network. The matrix-shaped array with 45 geophones was arranged in the study area. The distance between two geophones was about 1500 m. The sensors were buried below the ground surface at a depth of 15 m. The study area was equipped with our self-developed acquisition system, named GEIWSR-III. The CDJ-S2C-2 type three-component sensors were used during the stimulation test. The natural frequency was 2 Hz, with a sampling frequency of 1 kHz. The seismic network used in the study is shown in Fig. 2.

3 Hydraulic Stimulation Test and Microseismic Events

3.1 Hydraulic parameters of the stimulation test

Hydraulic fracturing was stimulated in exploratory well GR1. The pressure response was recorded and the overpressure measured at the wellhead. The injection proceeded in five stages, consisting of a pressure diagnostic test, acid test, slickwater test, temporary plugging test and glue test. Fluids were injected at different injection rates during the different stages. A total of 2913 m$^3$ fluids were injected into the drilled open-hole section. The pressure was less than 41 MPa. The hydraulic parameters and the microseismic events that took place during the stimulation test are shown both in Table 1 and Fig. 3.

In the pressure diagnostic test, water was injected into the well at an injection rate of 0.5 m$^3$/min. With the gradual increase of injection rate and pressure, microseismic events began to generate. Since it was the initial stage of injection, several tests of increasing and decreasing injection rate were carried out. During the acid test, the pressure continued increasing, to a maximum of 31.56 MPa. 40 m$^3$ acid was injected at a rate of 1.2 m$^3$/min. After 120 m$^3$ water was replaced, the acid completely entered the target formation. The injected acid rapidly reacted with the formation, resulting in the change of local stress and increasing the brittleness of the formation. There was a rise in the number of events. In the slickwater test, the pressure and the injection rate were gradually increased. The injected fluid volume reached 1000 m$^3$. The microseismic events increased significantly. During the temporary plugging test, the pressure reached a maximum of 40.22 MPa. The injection rate was increased from 1.2 m$^3$/min to 1.6 m$^3$/min to expand the crack to the target area. The last stage was the glue test. Though the injected liquid volume and the injection rate were decreased, the pressure was increased. There was a residual microseismic activity.

Comprehensive analysis of the above five stages of the stimulation test shows that the injected fluid volume was

![Fig. 2. Seismic network for real-time seismic monitoring.](image-url)

![Fig. 3. Hydraulic parameters and microseismic events during the stimulation test. The blue curve is the injection rate. The red curve is the pressure. The black spots are microseismic events.](image-url)

<table>
<thead>
<tr>
<th>Date</th>
<th>Fracturing operation</th>
<th>Injection rate (m$^3$/min)</th>
<th>Fluid volume (m$^3$)</th>
<th>Pressure (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2019.8.26</td>
<td>Fracture diagnostic test</td>
<td>0.5</td>
<td>203</td>
<td>22.40–39.70</td>
</tr>
<tr>
<td>2019.8.27</td>
<td>Acid test</td>
<td>1.2</td>
<td>160</td>
<td>16.81–31.56</td>
</tr>
<tr>
<td>2019.8.28</td>
<td>Slickwater test</td>
<td>1.2–2.0</td>
<td>1000</td>
<td>30.10–39.89</td>
</tr>
<tr>
<td>2019.8.29</td>
<td>Temporary plugging test</td>
<td>1.2–1.6</td>
<td>1000</td>
<td>20.52–40.22</td>
</tr>
<tr>
<td>2019.8.30</td>
<td>Glue test</td>
<td>0.7–1.3</td>
<td>550</td>
<td>29.55–40.19</td>
</tr>
</tbody>
</table>
accumulated to a certain extent and the microseismic events increased at the end of the slickwater test, but the magnitude remained within a specific range. After the glue experiment, the microseismic events continued to occur and the magnitude of the microseismic events increased significantly. The phenomena indicate that the microseismic activity was still persisting for a short time.

3.2 Microseismic event distribution

The stimulation generated a swarm of microseismic events. Among hundreds of triggered events observed on the surface network, we only kept a record of the 1309 microseismic events that were clearly detected, in order to determine a reliable location. Firstly, five high quality signals were effectively extracted. The initial velocity model was constructed according to acoustic well logging. Then, the wavefield travel time double difference error correction technology was used to process microseismic signals with a high ground noise level (Jiang et al., 2016). The velocity model was optimized by a very fast simulated annealing algorithm to improve the reliability of the location. Finally, the microseismic events were located, using reverse-time migration amplitude superposition technology.

The depth distribution of the located events is shown in Fig. 4. The two main peaks were between 3450 m and 3700 m, the seismicity mainly increasing within this depth range. A number of events occurred as deeply as 200 m below the bottom of the well. It is possible that the applied stimulation strategy encouraged the stimulation of a deeper section. Overall, the seismic activity was high throughout the entire stimulation test.

4 Analysis between Microseismic Activity and Hydraulic Parameters

4.1 Seismicity associated with hydraulic parameters

In order to evaluate the correlation between seismicity and hydraulic fracturing, we analyzed the influence of hydraulic parameters on microseismic events. The distribution of microseismic magnitude against various fracturing parameters is shown in Fig. 5. During the initial phase of fracturing, the injection rate and the pressure increase slowly. The total volume of fluid is less. There are fewer small-magnitude microseismic events, with no regularity. In the subsequent phase, the large-magnitude microseismic events have an upward trend with increase of the total fluid volume. However, there is no obvious correlation between the continuous occurrence of large-magnitude microseismic events and increases of injection rate and pressure.

The net pressure is the difference between the fluid flow pressure in the fracture and the formation closure pressure. The net pressure of the fracture can be used to evaluate the shape of the fracture in the reservoir and understand the activity of the microseismic event. Since the net pressure cannot be directly obtained during the stimulation test, we used the pump pressure during fracturing to analyze the relationship between the magnitude of the microseismic events and the growth rate of the net pressure. The net pressure is calculated as follows (Smith and Montgomery, 2015):

\[ P = P_b + P_h - \Delta P_{fr} - \Delta P_{entry} - P_c \]  

where \( P_b \) is the pump pressure, which is from the pressure count at the wellhead. \( P_h \) is the hydrostatic column pressure, which is calculated by the average density of sand fluid and the depth of well. \( \Delta P_{fr} \) is the hole friction and \( \Delta P_{entry} \) is the fracture inlet friction, which can be calculated as follows:

\[ \Delta P_{fr} = \eta \frac{L}{D} \]  

\[ \Delta P_{entry} = \eta \frac{L}{D} \]
obtained by analyzing fluid volume. $P_c$ is the fracture closure pressure, which is given by analyzing the G-function curve.

In order to comprehensively explore the seismicity associated with hydraulic parameters, we also tracked the later database of microseismic magnitude and net pressure. The magnitude related to the net pressure at different stages is presented in Fig. 6. At the earlier stage, the growth rate of net pressure is consistent with the change in maximum magnitude. Overall, the growth rate of net pressure had a certain correlation with the maximum magnitude. The maximum magnitude increases with the growth rate of net pressure. With the progress of the fracturing process, microseismic activity has increased significantly, with microseismic events with large magnitude also occurring frequently. However, we found that the maximum net pressure and the growth rate of the net pressure are not related to the maximum magnitude in the later stages. Therefore, the pressure construction scheme should focus on controlling the net pressure to reduce the occurrence of large-scale microseismic events at the initial stage of fracturing. The effects of geological structure, formation fracture development and rock failure should be further considered at the later stages of fracturing.

4.2 Stress field and focal mechanism

We examined the detail of the distribution in the stress field using logging data, the fault survey record and fracture information. The distribution of stress is shown in Fig. 7. At a depth of about 1360 m, the principal stress plays the dominant role. Due to the great difference in lithology change, the data points are relatively centralized with the increase in the number of grids. At a depth of about 2000 m, the principal horizontal stress continues to increase to about 60 MPa. The orientation of the maximum horizontal stress is NE55.6. The minimum horizontal stress range of the well bottom is about 69–75 MPa and the gradient is 0.0142–0.0195 MPa/m. The maximum horizontal stress range of the well bottom is about 69–75 MPa and the gradient is 0.0235–0.0245 MPa/m. Overall, the principal stress shows an increasing trend from shallow to deep, the overall change being uniform.

The P-wave polarity and amplitude data was used for focal mechanism determination to indirectly rupture characteristics of microseismic activity. A grid search over the entire solution space was performed to find the best-fitting focal mechanism (Snoke, 2003). The 111 largest microseismic events were selected for P-wave polarity analysis. Distribution of induced microseismic events at depths below 3300 m during fracturing is shown in Fig. 8. The microseismic events are mainly concentrated around the well. The extent of the microseismic events is roughly 0.75 km in length, 0.7 km in width and 0.6 km in height at a depth below 3300 m. The large microseismic event during the stimulation occurred on the southeast side of the bottom of the well. The microseismic events are more active on the southwest and northeast sides of the well during the reservoir reformation period. The results of the focal mechanism determination are shown in Fig. 9. The tensile fracture is basically not caused by conventional fracturing. The direction of fracture stress is mostly NW.

5 Analysis of the Seismicity Induced by Hydraulic Fracturing

5.1 Evolution of the b-value

The Gutenberg-Richter relationship provides a fundamental statistical description of seismicity within a given region (Gutenberg and Richter, 1944). The b-value, or slope of the semilogarithmic magnitude-frequency distribution, quantifies the relative distribution of large and small events. We used the maximum likelihood estimate, originally introduced by Aki (1965), to calculate the b-value given by:

$$b = \frac{\log_{10}(e)}{M_c - M}$$  

where $e$ is the base of the natural logarithm. $M_c$ is the minimum magnitude of completeness. $M$ is the average seismic moment magnitude for events at or above the magnitude of completeness ($M_c$). Here, we use the Entire Magnitude Range (EMR) method to estimate $M_c$ for the study area of Gonghe Basin. The probability of a seismic
network detecting an earthquake under a certain magnitude $M$ can be expressed as (Woessner and Wiemer, 2005):

$$q(M | \mu, \sigma) = \begin{cases} \frac{1}{\sigma \sqrt{2\pi}} \int_{-\infty}^{M_c} \exp\left(-\frac{(M - \mu)^2}{2\sigma^2}\right) dM, & M < M_c \\ 1, & M \geq M_c \end{cases}$$  \hspace{1cm} (3)$$

where $\mu$ is the magnitude corresponding to an earthquake with 50% probability, which is used to describe the ability of a network to monitor earthquakes. $\sigma$ is the standard deviation, which describes the change in speed of the seismic detection ability of an incomplete network with magnitude. The probability density of an observed earthquake after normalization can be written as (Huang et al., 2016):

$$P(M | \beta, \mu, \sigma) = \frac{e^{-\beta M} q(M | \mu, \sigma)}{\int_{-\infty}^{\infty} e^{-\beta M} q(M | \mu, \sigma) dM}$$  \hspace{1cm} (4)$$

where $\beta = b \ln 10$. $M_c$ is explicitly expressed in the detection density function. The maximum likelihood estimate is used to calculate $M_c$. We selected a subset of the seismic catalogue of the microseismic monitoring data from the Gonghe Basin in Qinghai province. The local magnitude $M_L$ has been calculated from the seismic signal duration as:

$$M_L = \frac{\lg(A) + R(\Delta)}{2}$$  \hspace{1cm} (5)$$

where $A$ is the maximum amplitude of the S-wave signal. $A_N$ is the maximum amplitude in the NS direction. $A_E$ is the maximum amplitude in the EW direction. $\Delta$ is the epicentral distance in km. $R(\Delta)$ is the calibration function of the local magnitude, which is determined as 2.0, according to the corresponding $\Delta$ with 0–5 km in the Qinghai area. Since our monitoring sensor is velocity-type, the amplitude is obtained by integrating the collected data, then calculating the magnitude by using formulae (5) and (6). $M_L$ in the range $-0.5$–$2.5$ is included to determine the b-value. The b-value calculation code is freely available, together with the seismicity analysis software package ZMAP (Wiemer, 2001). The frequency-magnitude distribution of the events during the stimulation period is presented in Fig. 10. The minimum magnitude of completeness is $-0.2$ in the curve, which indicates a strong
monitoring ability. The b-value for the entire recording period is about 1.3. It exhibits a high value, which is a typical phenomenon that fluid participates in, in the process of the induced seismicity (Wyss et al., 2001). Thus, in the case of the stimulation experiment, the injection leads to a large production of small magnitude events. We found the frequency-magnitude distribution of slightly larger earthquakes starting from magnitude 0.7 or 0.9 has a small b-value. This suggests that slightly large earthquakes may tend to tectonic activity, rather more than fluid-driven. In particular, there is a visible bulge in the frequency-magnitude relationship at $M_L = 1.0$. The main reason for this is the insufficient data completeness for the small magnitude events.

To examine the influence of the increase of injection rate on the coefficient of the Gutenberg-Richter curve, we calculated the temporal variations of the b-value during the stimulation. Evolution of the b-value during the stimulation test is shown in Fig. 11. The change of $M_L$ during the stimulation is presented in Fig. 12. The trend for different mean values is consistent and it agrees well with this. The b-value suddenly decreased to about 1.0 on August 27th, 2019, then it increased slightly on August 30th, 2019. Since the increase of the b-value is often associated with the presence of fluid in the fractures zone (Cuenot, 2008), the early high b-value seems to be induced by the increase of injection rate. The rapid change of the injection rate is likely to produce a large proportion of small events, corresponding to the high b-value. The drop of the b-value does not last long, because the fluid reaches already reaches extensively throughout the stimulated zone. The fractures have already slipped and the increase of pore fluid pressure is not large enough to induce more shearing on these fracture planes. The b-value increases until the fluid reaches less stimulated zones and/or the pressure is sufficiently high to induce another shearing event.

5.2 Statistical forecasting of event magnitudes

Furthermore, we applied an event magnitude forecasting model to guide operational decisions, with respect to induced seismicity (Clarke, 2019). The correlation between cumulative water injection and the cumulative injection volume are used to forecast event magnitudes induced by fluid injection. The predicted maximum magnitude can be expressed as (Hallo et al., 2014):

$$M_{\text{max}} = \frac{2}{3} \log_{10} \left( \frac{S_{\text{eff}} \cdot \Delta V \left( \frac{3}{b} - b \right)}{b \cdot 10^{31}} \right) + \frac{2}{3} \log_{10} \left( 10^{b} - 10^{-b} \right) \quad (7)$$

$$S_{\text{eff}} = \sum M_0 / \mu \Delta V \quad (8)$$

where $\delta$ is the probabilistic half-bin size defined around $M_{\text{max}}$; $S_{\text{eff}}$ is the observed value of seismic efficiency, $\sum M_0$ is the cumulative moment release, $\mu$ is the shear modulus. $\Delta V$ is the cumulative injection volume.

$S_{\text{eff}}$ is calculated by formula (8). Based on $S_{\text{eff}}$ and the b-value, the size of the largest expected event can be estimated by formula (7). We calculated observed earthquakes in the magnitude range of −0.5 to 2.0 during the whole injection period. Distribution of the $M_{\text{max}}$ during the stimulation test is shown in Fig. 13. The radius of each sphere is proportional to the magnitude. The predicted results are depicted by the blue line. We determined the magnitude among the 260 events during August 27th and August 30th, 2019. The large events that occurred during the stimulation experiment, were on 28th August, 2019, which was the day after the end of the postfracturation test. We estimated the maximum magnitude of 1.98–3.
Since the predicted $M_{\text{max}}$ was designed to serve for risk prediction, the predicted results are often high. The stimulation experiment can be adjusted and controlled, according to the distribution of $M_{\text{max}}$.

6 Conclusions

The potential and limits of monitoring induced seismicity was evaluated for hydraulic stimulation at the hot dry rock site of Gonghe Basin. In this study, we discussed the correlation between microseismic events and hydraulic parameters. We examined the evolution of the b-value during the stimulation test. We assessed the induced seismicity risk for future stimulations from the predicted maximum magnitude, using the observed seismicity and injection parameters. The analysis of the behavior of the seismicity relative to the hydraulic parameters gives important information about the geothermal reservoir.

From the seismicity induced by fluid injection during the stimulation experiments, the increase or decrease of the injection rate affects the number and magnitude of generated events, but it has no obvious relationship with the continuous occurrence of the larger microseismic events. The microseismic events are more active on the southwest and northeast sides of the GR1 well during the reservoir reformation period. The tensile fracture is basically not caused by conventional fracturing. We also used a statistical model to estimate an upper boundary for the largest expected event size during injection. The magnitudes of the events were forecast to guide operational decisions with respect to induced seismicity.

To our knowledge, this work is one of the earliest case studies of hydraulic fracturing-induced seismicity at the hot dry rock experimental geothermal site of Gonghe Basin in Qinghai. We provide a scenario to consider for risk assessment of projects involving geothermal energy extraction from the hot dry rock at Gonghe Basin and elsewhere. Admittedly, the overall slippage on the fracture planes is still unknown. In particular, we do not have a clear knowledge of local mechanisms during hydraulic stimulation. Whether the fluid can suppress seismicity in the reservoir needs to be investigated further, in conjunction with the historical data.

Acknowledgements

This work is funded by a grant from the National Key R&D Program of China (Grant nos. 2018YFB1501803, 2019YFC1804805-4), the National Natural Science Foundation of China (Grant No. 42074178), Chinese Geological Survey projects (Grant No. DD2019135) and the Education Department of Jilin Province, China (Grant No. JJKH20200945KJ). We thank the Chinese Geological Survey for providing the support to install the stations at the site. We would like to thank the ZMAP software package for processing the monitoring data. We would also like to thank the editor for editorial handing and anonymous reviewers for meticulous and insightful reviews.

Manuscript received Jul. 30, 2021

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