Advances in Geo-Energy Research

Vol. 6, No. 3, p. 269-270, 2022

Research highlight

Hydraulic fracturing-induced seismicity characterization through coupled modeling of stress and fracture-fault systems

Gang Hui[1], Zhangxin Chen[1,2]*, Shengnan Chen[1], Fei Gu[3]

[1]*Department of Chemical and Petroleum Engineering, University of Calgary, Calgary, AB T2N1N4, Canada*

[2]*College of Petroleum Engineering, China University of Petroleum (Beijing), Beijing 102249, P. R. China*

[3]*Research Institute of Petroleum Exploration and Development CNPC, Beijing 10083, P. R. China*

Keywords:
Fracturing-induced seismicity
stress and pressure pathway
fracture-fault systems

Cited as:
Hui, G., Chen, Z., Chen, S., Gu, F. Hydraulic fracturing-induced seismicity characterization through coupled modeling of stress and fracture-fault systems. Advances in Geo-Energy Research, 2022, 6(3): 269-270.
https://doi.org/10.46690/ager.2022.03.11

Abstract:
This work summarizes our recent findings on hydraulic fracturing-induced seismicity nucleated in the Duvernay shale reservoirs within the Western Canada Sedimentary Basin. A coupled model of in-situ stress and fracture-fault systems was built to quantify four-dimensional stress and pressure changes and spatiotemporal seismicity nucleation during hydraulic fracturing. Five triggering mechanisms were successfully recognized in seismicity-frequent areas, including a direct hydraulic connection between impermeable faults and hydraulic fractures, fault slip owing to downward pressure diffusion, fault reactivation due to upward poroelastic stress perturbation, aftershocks of mainshock events, and reactivation of natural fractures surrounding the faults. This work shed light on how fracturing operations triggered the induced seismicity, providing a solid foundation for the investigation of controlling factors and mitigation strategies for hydraulic fracturing-induced seismicity.

Recently, hydraulic fracturing (HF)-induced seismicity during the development of unconventional reservoirs has been frequently reported in West Europe, North America, and East Asia (Atkinson et al., 2016). An HF-induced seismicity characterization requires a comprehensive understanding of fracturing fluid injection, a pathway for pressure and stress perturbation (i.g., fracture-fault networks), and reactivation of pre-existing faults. Such three elements refer to site-specific geological, geomechanical, and hydrodynamical features that contribute to HF-induced seismicity, which had not been well understood in previous works. Therefore, an integrated method is required to comprehensively characterize HF-induced seismicity through multifactor analysis.

An integrated approach was developed to characterize HF-induced seismicity via coupled modeling of stress and fracture-fault systems (Hui et al., 2021a). For stress determination, the rock mechanics features sourced from triaxial compression experiments were employed to obtain in-situ stress tensors (Fig. 1(a)). An ant-tracking approach was used to identify pre-existing faults by tracing structural discontinuities within a three-dimensional reflection seismic survey. Propagations of hydraulic fractures were simulated on the basis of the rock mechanics, in-situ stress, and fracturing parameters. Such heterogeneous hydraulic fractures propagate and communicate with pre-existing seismogenic faults, generating complex fracture-fault systems and providing a pathway for pressure perturbation (Fig. 1(b)). Guided by the linear poroelasticity theory, the coupled model of stress and fracture-fault systems was built (Fig. 1(c)), aiming to characterize the four-dimensional mutations of stress and pressure features surrounding the pre-existing faults (Hui et al., 2021b). Finally, the Mohr-Coulomb Failure Criterion was adopted to determine the spatiotemporal reactivation of related faults and thus recognize the triggering mechanisms of induced seismicity (Fig. 1(d)).

The field cases in Fox Creek, a seismicity-frequent area in Western Canada, were investigated to prove the applicability

Yandy Scientific Press

*Corresponding author.
E-mail address: hui.gang@ucalgary.ca (G. Hui); zhachen@ucalgary.ca (Z. Chen); snchen@ucalgary.ca (S. Chen); gufei2011@petrochina.com.cn (F. Gu).

Received May 19, 2022; revised May 26, 2022; accepted May 30, 2022; available online May 30, 2022.

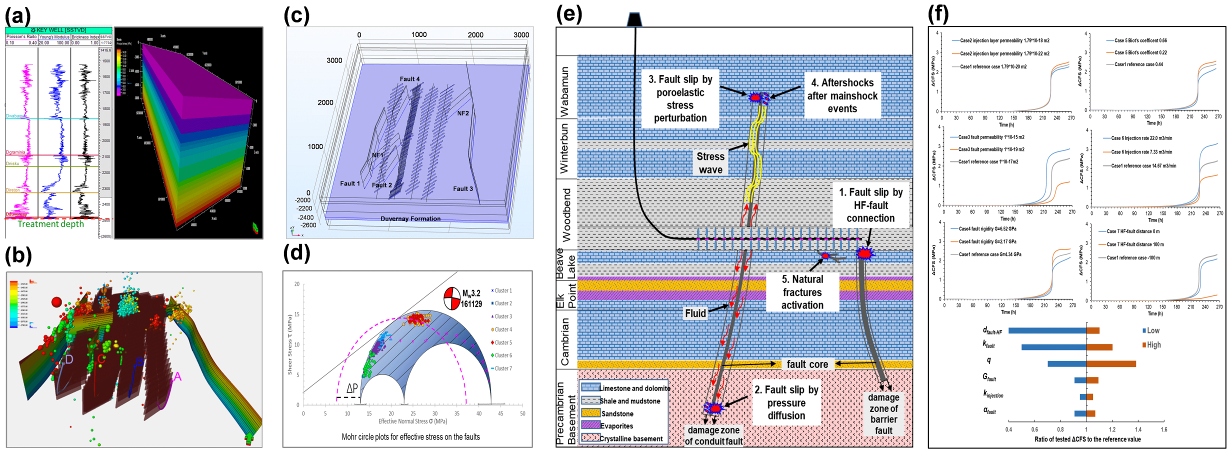

Fig. 1. (a) Rock mechanics features and in-situ stress field, (b) Fracture-fault networks, (c) Coupled modeling of stress and fracture-fault systems, (d) Mohr circles, (e) Five triggering mechanisms of HF-induced seismicity, (f) Feature importance analysis. Figures are modified with permission from Hui et al. (2021a-2021d).

of the approach above and five types of triggering mechanisms of HF-induced seismicity were identified (Fig. 1(e)) (Hui et al., 2021c). The first mechanism is a direct hydraulic connection between impermeable faults and hydraulic fractures. In this scenario, large magnitude events were triggered by pore pressure changes within a stimulated formation. The second one is a fault slip by downward pressure diffusion, which diffuses fluid pressure from a fracturing site downward into a basement. The third mechanism is a fault slip by poroelastic stress perturbation, in which poroelastic effects in response to fracturing fluid injection reactivate a seismogenic fault. The fourth one is aftershocks of mainshock events. Fault activation related to mainshocks rearranges a regional stress field, which induces the aftershocks in a region with positive CFS (i.e., Columb Failure Stress) changes. The last one is the reactivation of natural fractures surrounding faults. The earthquake clusters with a b-value (i.e., the slope of a seismicity frequency and magnitude plot) larger than 2.0 indicated fracture reactivation, suggesting that small-scale natural fractures were reactivated in the vicinity of a seismogenic fault. Different coupled models with varying geological and operational factors were built to quantify the factors contributing to induced seismicity (Hui et al., 2021d). Feature importance analysis suggests that a large HF-fault distance, a high-permeable fault, and a large fluid injection rate are the top three controlling factors of induced seismicity in a field case (Fig. 1(f)). Therefore, enlarging a distance between fracturing wells and high-permeable faults, and reducing a fracturing size job would mitigate potential seismicity risks in seismicity-frequent areas.

This work provides insights into how HF triggered the induced seismicity in unconventional resources development. The coupled modeling of stress and fracture-fault systems was conducted to quantify four-dimensional stress and pressure changes and spatiotemporal seismicity nucleation during HF, which successfully recognized five triggering mechanisms in seismicity-frequent areas. This work also provides a solid foundation for the discussion of controlling factors and mitigation strategies for HF-induced seismicity.

Acknowledgement

This research has been made possible by contributions from the Natural Sciences and Engineering Research Council (NSERC).

Conflict of interest

The authors declare no competing interest.

References

Atkinson, G. M., Eaton, D. W., Ghofrani, H., et al. Hydraulic fracturing and seismicity in the western Canada sedimentary Basin. Seismological Research Letters, 2016, 87: 631-647.

Hui, G., Chen, S., Chen, Z., et al. An integrated approach to characterize hydraulic fracturing-induced seismicity in shale reservoirs. Journal of Petroleum Science and Engineering, 2021a, 196: 107624.

Hui, G., Chen, S., Chen, Z., et al. Investigation on two Mw 3.6 and Mw 4.1 earthquakes triggered by poroelastic effects of hydraulic fracturing operations near crooked lake, Alberta. Journal of Geophysical Research: Solid Earth, 2021b, 126: e2020JB020308.

Hui, G., Chen, S., Chen, Z., et al. Comprehensive characterization and mitigation of hydraulic fracturing-induced seismicity in Fox Creek, Alberta. SPE Journal, 2021c, 26(5): 2736-2747.

Hui, G., Chen, S., Gu, F., et al. Insights on controlling factors of hydraulically induced seismicity in the Duvernay East Shale Basin. Geochemistry, Geophysics, Geosystems, 2021d, 22: e2020GC009563.