Relative Significance of Controlling Factors on the Seismogenesis of Induced Seismicity in the Southern Montney Play

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Summary

Many factors, both natural and anthropogenic, can influence the seismogenic pattern of injection-induced earthquakes (IIE). In this study, we first build an enhanced earthquake catalog with the S-SNAP method (Tan et al., 2019) to detect and locate earthquakes that occurred between 1 January 2017 and 31 December 2018 (Fig.1). Then we compile a comprehensive fluid injection history for the southern Montney play in northeast British Columbia, Canada to explore the relative significance of the potential controlling factors of IIE. Based on the spatiotemporal distributions of IIE and injection wells, we first show that hydraulic fracturing (HF) operations are most likely responsible for the increased seismicity in the region. For areas with comparable HF activities, the regional geological setting could be the primary factor correlating with the distribution of IIE (Fig.2). Specifically, the HF-related IIE are more likely to be induced by stimulations performed in the Fort St John Graben area than in the two neighboring areas (i.e., the Hudson Hope Low and southern apron). One possible reason is that the FSJG has been intensely segmented and faulted in block during the subsidence process (e.g., Barclay et al, 1990). A recent study based on the spatiotemporal distribution of HF-related IIE and high-resolution 3-D seismic images near Fort St. John reveals multiple buried thrust faults extending from the basement up to the Montney formation and a pervasive system of transverse structures (Riazi and Eaton, 2020).

Given the same geological setting and order of injected volume, our investigations further reveal that the HF-targeted stratigraphic formation is the next important factor deciding the activity level of IIE. Specifically, the number of HF stages targeting the Upper Montney (UM) is about 5 times

of that targeting the Lower-Middle Montney (LMM), yet the LMM HF stimulations are responsible for the majority of IIE in the area. The seismic response rate to HF injections into the LMM could be at least one order of magnitude higher than all other Montney sub-formations. One possible interpretation of the higher triggering capacity of LMM could be due to its relative proximity to the crystalline basement. We speculate that the relatively porous and permeable carboniferous formations immediately beneath the Montney (i.e., the Belloy, Stoddart, and Debolt, Fig. 1) may play an important role. Our results provide an important framework for effective mitigation of the seismic hazard due to IIE while maintaining the development efficiency of unconventional hydrocarbon resources.

References

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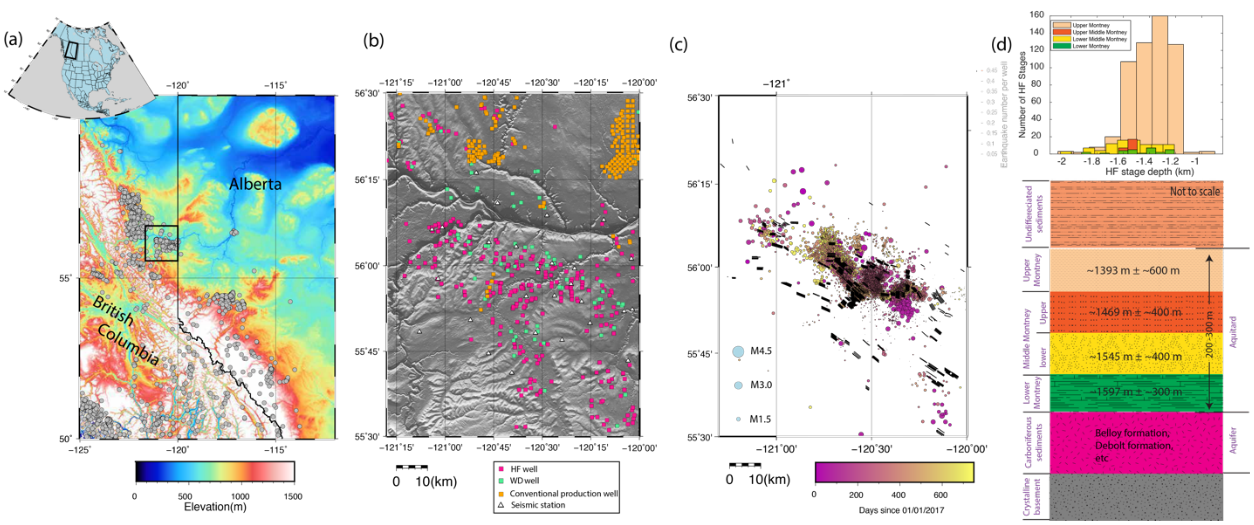

Fig.1 Spatial distribution of earthquakes and injection wells in western Canada. (a) Grey circles mark epicenters of M3+ seismicity in northeastern British Columbia and western Alberta between 2011 and 2020 as reported by Natural Resources Canada. The black rectangle marks the study area. (b) Seismic stations, conventional oil-and-gas production wells, hydraulic fracturing (HF) wells and wastewater disposal (WD) wells in the study area. (c) Earthquakes detected and located by the S-SNAP method. (d) The top panel shows the number of HF stages in each Montney formation. The bottom panel is a scheme diagram of the stratigraphic column describing the geological context of the Montney formations.

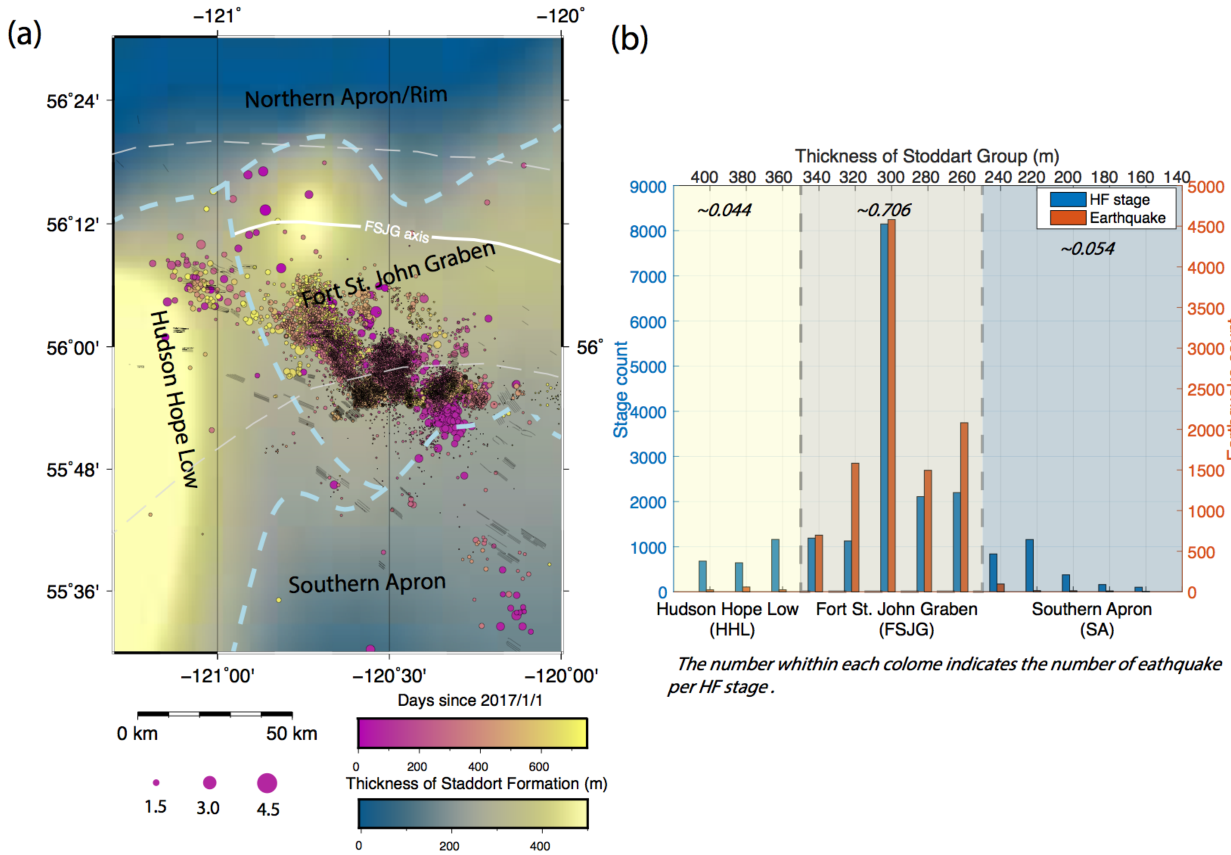

Fig 2. (a) Spatiotemporal relationship between IIE relative to the geological settings. The thick blue dashed line represented the inferred edges for different tectonic elements from this study, the white line shows the FSJG axis adopted from O'Connell (1994), and the thin dashed line shows the origin edges of FSJG adopted from Barclay et al (1990) (b) The seismicity rate and number of HF stages within each 20 m thickness interval of Stoddart Group (SG). The differentiations of these three tectonic elements are based on the seismic triggering capacity as mentioned in the discussion section. Note that the numbers of earthquakes and HF stages within the 400 m thickness column also include the ones located above the 400 m thickness of SG.