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A "Bad Moon Rising" in Rocky Mountain House - is brine disposal responsible for induced seismicity?

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Summary

New evidence suggests recent seismicity (2013-present) in the Rocky Mountain House Seismogenic Zone is attributable to wastewater disposal, particularly after the disposal zone was changed from the Leduc Formation to the Wabamun Formation by the operator in 2013.

Background

Although most wells in Alberta have no correlation with induced earthquakes, the Rocky Mountain House Seismogenic Zone (RMHSZ) defies this trend. The RMHSZ is a long-lived (1970's to present) cluster of induced earthquakes in west-central Alberta historically attributed to gas production from the Strachan D3-A Leduc sour gas pool (1-3), although this has been difficult to prove due to a lack of on-site monitoring (3). This region has experienced 5 of the 10 largest earthquakes in Alberta's recorded history and is now the focus of a recent (2013 to present) resurgence in seismic activity (Figure 1; 4,5). Stern et al. (2013) noted that earthquake counts in this area peaked in 1972; seismicity then declined slowly over time in a trend that closely mirrored gas production until the gas pool was depleted in 2012 (4,5). In this model, the removal of gas from the reservoir released deeper-seated thrust faults via poroelastic effects (1-3). Seismic hazard in this region is exacerbated by its location in the Foothills of the Rocky Mountains, which are extensively faulted and fractured due to deformation during the Laramide orogeny (e.g., 6, 7).

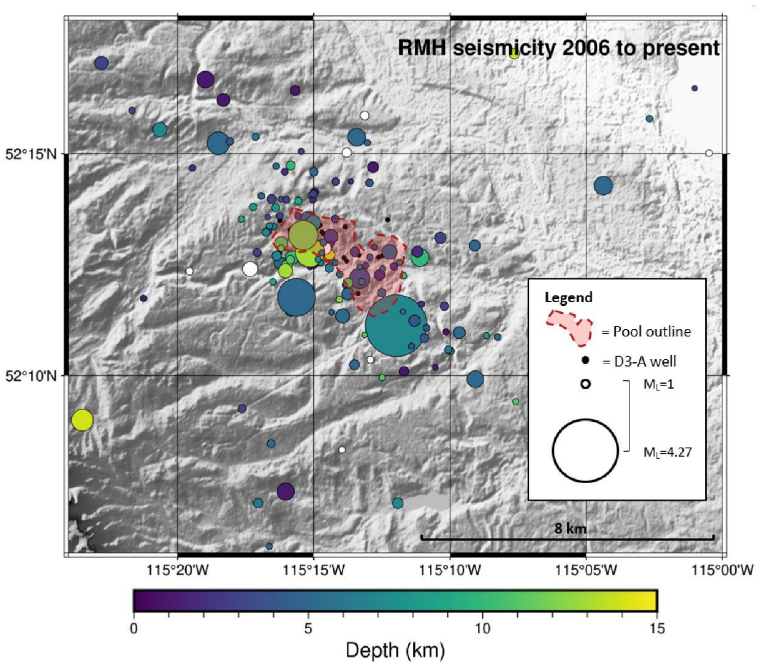

Figure 1: Map of earthquake hypocentres, magnitudes, and depths in the Rocky Mountain House Seismogenic Zone from 2006 to present. Map generated using pyGMT, geoLOGIC systems (2021) and AER earthquake catalogue (4).

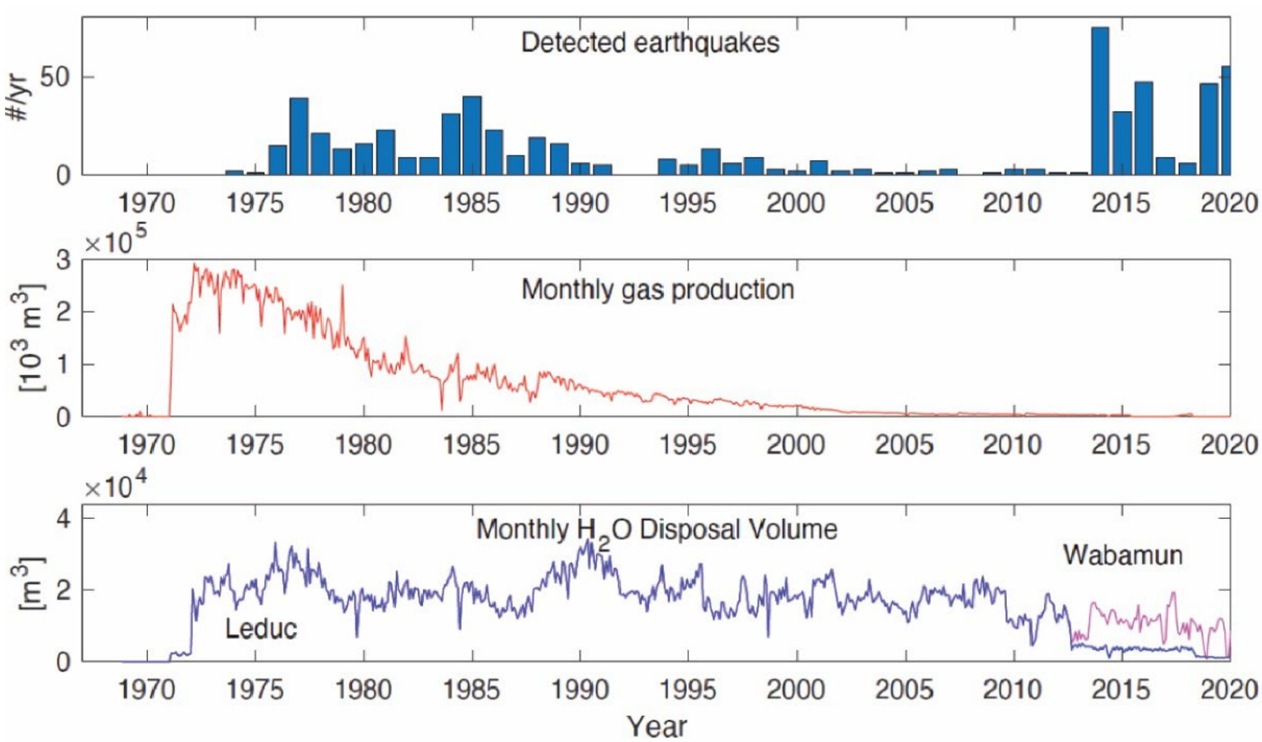

Figure 2: Chart of earthquake counts (blue bars) over time in the RMHSZ compared to monthly gas production rates and monthly WD volume taken from geoSCOUT (geoLOGIC systems, 2021). As reported by Stern et al. (2013), detected earthquake counts closely mirrored monthly gas production, although this trend changes post-2013. This is associated with a coincident change in waste disposal volume and stratigraphic zone from the Leduc Formation to the Wabamun Group (pink).

The gas production theory is problematic considering the resurgence of seismicity in the RMHSZ after the cessation of gas production in 2013; this cannot be accounted for by increased regional monitoring sensitivity. The uptick in regional seismicity in the RMHSZ is characterized by a stark increase in the regional rate of seismicity and includes 3 events that exceeded M_L 3.3 (4, 5). The largest of these, a M_L 4.26 event, occurred on August 9th, 2014, and had substantial consequences for the public: residents felt strong ground motions (maximum intensity of IV-V), a nearby gas plant was automatically shut down and flared gas as a precaution, and a power outage lasted for several hours (8). The RMHSZ merits further study, particularly in light of mounting new evidence indicating a link between seismicity and wastewater disposal (8).

The RMH earthquake cluster is associated with the Strachan D3-A pool, a prolific Devonian-aged Leduc reef that has produced 1.3 Tcf (trillion cubic feet, or 3.68 x 10^{10} m^3) of sour gas (9.4% H_2S by volume) along with 8.2 MMBbl (million barrels; 1.3 x 10^6 m^3) of co-produced brine since its discovery in 1967 (geoLOGIC systems, 2021). WD and water injection for secondary recovery began alongside gas production in 1970 and is linked to 3 injection wells located south of the northwest tip of the pool (6-33-37-9W5, 10-30-037-9W5, and 10-16-37-10W5); 8.83 x 10^6 m^3 of fluid has been injected as of April 2021 (geoLOGIC systems, 2021). Publicly available fluid injection data from geoSCOUT (Figure 2) shows the operator of the injector wells in the RMHSZ switched from the Leduc Formation to a stratigraphically higher dolomitic zone, the Devonian

Wabamun Group, for wastewater disposal in 2013 (geoLOGIC systems, 2021); this timing is intriguing as the switch coincides with the increase in seismicity.

Although industrial fluid injection operations like hydraulic fracturing have been conclusively linked to the rise in induced seismicity rates across the Western Canada Sedimentary Basin (WCSB; e.g.: 9-11), the prevalence of induced seismicity from wastewater disposal in western Canada is not well understood. Despite occurring across the WCSB, wastewater disposal has only been clearly linked to induced seismicity in the Cordel (12) and Musreau Lake Fields (13), and these events do not correlate with disposal volume or rate.

Unlike the WCSB where HF-induced seismicity dominates, the main source of induced seismicity in the USA is from WD into deeply buried formations close to crystalline basement (e.g., 14; 15). Fracture networks increase the rock volume affected by pore pressure perturbations during fluid injection and increase induced seismicity risk (16), so *a priori* knowledge of fault geometry and geologic setting (i.e., proximity to basement, which is often pervasively fractured and faulted) can aid in seismic hazard modelling (17). Schultz et al. (2016) conjectured that the spatial association of induced events in the RMHSZ with Devonian reefs may imply that the Paleozoic and Precambrian strata are in hydraulic communication via deep-seated faults associated with the Laramide orogeny (18). Although geophysical evidence for these faults has not been found in this region (19), Ekpo et al. (2018) recently observed large-scale basement faults in seismic near Leduc reefs north of the RMHSZ (~54°N; 20), which could support similar geology further south in the RMHSZ.

Methodology and Expected Results

Three factors must combine for induced seismicity to occur (21): 1) nearby faults must be large enough to produce earthquakes, 2) fluid pathways must exist from the injection point to those faults, and 3) the fluid pressure change must be sufficiently large. It is hypothesized that increased seismicity in the RMHSZ is due to wastewater disposal occurring in a faulted and fractured reservoir that is predisposed to earthquakes. Proving this requires a definitive link between induced seismicity in the RMHSZ and wastewater disposal, as well as providing evidence that faults exist and are likely to trigger seismicity in this region.

Data sources for this study include the provincial monitoring network (4), as well as a seismograph monitoring array installed near Condor, Alberta in July 2020 to monitor a geothermal pilot project. Well log data is provided by geoLOGIC systems (2021). Data processing will occur in REDPy, ObsPy, and NonLinLoc, open-source software (22-24). These programs will be used to detect, locate, and cluster earthquakes into groups characteristic of their source. This will be supplemented with a velocity model generated from publicly available sonic log data in geoSCOUT. Faults will be interpreted in Petrel, software licensed by the University of Calgary, and their degree of spatiotemporal correlation with seismicity established using a multilinear regression.

It is expected that earthquake counts and hypocentre locations will reflect the slow migration of fluids through the reservoir. As a result, earthquake hypocentres are expected to migrate away from the point of injection along dolomitized or faulted regions. Combining this data with geophysical well log data and publicly available fluid injection data will enable the determination of the strength of spatiotemporal correlation, if any, between earthquake locations and fluid injection in this region. Mirroring what is seen in the United States, it is predicted that seismicity will correlate with fluid injection rates and volume. Lastly, increased earthquake activity is expected closer to critically stressed faults, which may not necessarily be associated with basement if the reservoir is naturally fractured. If no correlation to depth is observed, this suggests basement faults may not be present.

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