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Interactive comment on "Fracking bad language: Hydraulic fracturing and earthquake risks" *by* Jennifer J. Roberts et al.

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The paper presents an interesting study into the language used to describe hydraulic fracturing-induced seismicity, and how that language, and the understanding of that language, differs between experts and the general public.

I feel that the provision of a little more context as to the history of hydraulic fracturing, and the concomitant history of hydraulic fracturing-induced seismicity (HF-IS hereafter), would benefit the paper. In particular, while the focus of this study is on the views of the UK public, a slightly more global view may still be required because, while the UK public will likely be impacted primarily by newsworthy events in the UK, most experts are likely to have followed the development of the industry across the world (especially

since the UK, with only 3 shale wells ever stimulated, represents a very small part of the world's shale gas story). To add some context, I provide some brief comments on the history of HF-IS below. I also recommend Verdon and Bommer (2020) for further details of cases of HF-IS around the world.

HF-IS is dependent on certain geological/geomechanical conditions being met: (i) pre-existing tectonic faults must be present in, or near to, the target reservoir; (ii) the stress conditions in the reservoir (or surrounding formations) must be conducive to generating slip (having a high shear stress relative to normal stress); (iii) the frictional properties of the faults must be such that any slip is accommodated by rapid rupture and the release of seismic energy; (iv) the perturbation generated by the hydraulic fracturing operations must be sufficient to induce slip on nearby faults.

Hence, the likelihood of generating HF-IS will be strongly dependent on the particular geological conditions within a specific reservoir. It will also depend on the nature of the specific hydraulic fracturing operation – "hydraulic fracturing" and "fracking" are commonly-used catch-all terms, but in practice may describe operations ranging from the use of a few 100 m3 via a vertical well in a "conventional" reservoir, to the use of tens of thousands of m3 via multi-stage stimulation in horizontal wells targeting a shale reservoir (with many orders of magnitude difference in permeability between "conventional" and "shale" formations).

As a result, the occurrence of HF-IS is observed to vary significantly. Many major shale plays, such as the Barnett (Texas), Bakken (North Dakota), and Marcellus (Pennsylvania), have experienced little to no HF-IS despite thousands of wells being drilled and hydraulically stimulated (Verdon et al., 2016; van der Baan and Calixto, 2017; Skoumal et al., 2018). In contrast, hydraulic fracturing of the Duvernay and Montney formations has generated HF-IS with magnitudes ranging between $4 < M < 5$ (e.g., Kao et al., 2018). In the Sichuan Basin, China, hydraulic fracturing has generated HF-IS with $M > 5$, although debate continues as to whether events are actually triggered by hydraulic fracturing or salt dissolution mining (e.g., Lei et al., 2019). It is certainly not true to claim, as the authors do on line 183, that the UK has experienced the highest recorded magnitudes of HF-IS.

Rates of HF-IS are even observed to vary significantly even within a basin – for example, while stimulation of the Montney and Duvernay shales in the West Canadian Sedimentary Basin (WCSB) has generated numerous cases of induced seismicity, extensive hydraulic fracturing has also taken place overlying formations such as the Cardium and Mannville (tight gas sandstones) without generating any recorded cases of HF-IS. Similarly, Skoumal et al. (2018) show a lack of HF-IS during stimulation of the Marcellus formation in the Appalachian Basin, but that stimulation of the underlying Utica shale has produced several cases.

Hydraulic fracturing has been used since the late 1940s (Montgomery and Smith, 2010). For much of this time, it was used in conventional formations, and no cases of HF-IS were reported. During the 2000s, hydraulic fracturing was adapted for use in shale formations. Among the most significant plays to be developed at the start of the shale gas "boom" was the Barnett, followed by the Marcellus and the Bakken. All three of these plays have been, in essence, aseismic. This, combined with the years of observations of aseismic hydraulic fracturing from conventional and tight gas formations, led the US National Research Council (2013) to state that "shale gas recovery does not pose a high risk for inducing felt seismic events (M > 2)".

The first case of HF-IS to be felt and widely reported were the events that occurred during hydraulic fracturing of the Preese Hall well in Lancashire in 2011 (Clarke et al., 2014). In fact, during this time cases of HF-IS were also occurring in the Horn River Basin, British Colombia (e.g., Farahbod et al., 2015), although the Horn River events were not widely reported at the time (perhaps related to the fact that population density in north-eastern B.C. is extremely low). Since then, as the use of hydraulic fracturing began to be used in more shale gas plays around the world, more cases of HF-IS have been reported. All of the cases identified in Verdon and Bommer (2020) were induced by hydraulic fracturing in shale reservoirs, and we are not aware of any cases of felt

seismicity induced by hydraulic fracturing in tight sandstone or conventional reservoirs. This may be a factor of the lower volumes of fluid typically used for hydraulic fracturing in tight and conventional reservoirs, and the fact that HF-IS is typically observed to scale with injected volume (e.g., Schultz et al., 2018; Clarke et al., 2019).

Considering the cases identified in Table 1 of Verdon and Bommer (2020), most of these cases occurred (or at least were described in publications) from 2014 onwards. Hence, while I obviously can't speak on behalf of the US National Research Council, I very much doubt that, if asked to re-assess the risks if HF-IS today, that they would come to the same conclusion as they did in 2012. Given the timelines described above, the fact that the data collection for this study took place in 2014 makes it particularly interesting (or challenging, depending on one's perspective), since this would represent a time of flux in terms of our understanding of HF-IS. Given the conclusions of the US National Research Council (2013) study, it would not be unreasonable to expect experts to surmise that the risks of HF-IS were low. Eight years down the line from the US National Research Council study, our knowledge of the factors that influence HF-IS has grown substantially. For my own part, the question "do you associate shale gas with earthquakes?" would be met with the answer "that depends, both on the geomechanical characteristics of the formation being targeted, and the nature of the hydraulic fracturing operation being proposed" (which, as described above, can vary by orders of magnitude within the catch-all term "hydraulic fracturing").

Similarly, since 2014, attempts have also been made to harmonize the language used to describe seismic events of different magnitudes that might occur at shale gas sites (e.g., Eaton, 2018). It would be fascinating to know whether the expert judgements and public views might have shifted since 2014, though I presume a repeat of the work presented would now be difficult to do. However, I do feel that a little more context in terms of the state of the science on HF-IS, and where it was in 2014 compared to today, would help provide important context for the results.

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