Towards a More Robust and Transparent Simplified Scheme for the Discrimination of Induced from Natural Seismicity

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Earthquake sequence near Newdigate, UK, March-July 2018

Largest event had magnitude $M_L$ 3.0, four others exceeded $M_L$ 2.0

Seven of the events were reported to be felt by local population, with a maximum EMS intensity of V for the largest earthquake.
Groups opposed to oil production in The Weald protested following the earthquakes. And inevitably there were claims about fracking.

The events occurred in an area with many small oilfields, the closest being Brockham and Horse Hill.
Surrey quake fears

Sir, A moratorium is urgently needed on hydrocarbon exploration in the area of Surrey recently affected by 12 earthquakes. We believe that public health and the environment are not being adequately protected given the unstable geology, which had not been identified before permits were issued for the currently active drill sites.

The abrupt onset of the earthquake cluster recorded by the British Geological Survey at Newdigate since April 1 requires an explanation, and gives rise to our concerns about safety. Oil drilling, extraction and re-injection can cause earthquakes.

There are two oil sites in the immediate area: Horse Hill and Brockham. A causal link with either well site cannot be ruled out, so we need the full picture for the risk assessment. Well integrity in these circumstances is a serious concern.

The moratorium on drilling, re-injection and flow testing should be put in place immediately and remain in force until the records of fluid injection and local faulting activity have been comprehensively surveyed and interpreted, and the triggering mechanism for this quake cluster properly understood.

We call on the energy secretary and regulatory bodies to address this issue without delay.

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In response to the letter in *The Times*, the UK Oil & Gas Authority called a meeting in October 2018, which about 20 specialists—including signatories of the letter, the oil companies, and the British Geological Survey—to discuss the evidence regarding the possible connection of the earthquakes to the Brockham and Horse Hill oil fields.

**OGA Newdigate Seismicity Workshop – 3 October 2018**

**Summary and conclusion**

“The workshop participants concluded that, based on the evidence presented, there was no causal link between the seismic events and oil and gas activity although one participant was less certain and felt that this could only be concluded on ‘the balance of probabilities’ and would have liked to see more detailed data on recent oil and gas surface and subsurface activity.”

[https://www.ogauthority.co.uk/media/5174/2018_11_23-newdigate-workshop-summary-finalv3.pdf](https://www.ogauthority.co.uk/media/5174/2018_11_23-newdigate-workshop-summary-finalv3.pdf)
The shallow earthquakes are not inconsistent with previous activity in this part of the UK, where focal depths in sedimentary basins are generally much smaller than in other areas.

The epicentres were much closer to Horse Hill (~4 km) than to Brockham (~8 km), but the events started before any operational activities at the Horse Hill well.
The Brockham field is separated from the earthquakes by several normal faults that are likely to act as baffles to fluid propagation.
A notable outcome from the OGA meeting was that both the proponent for the events being induced and several participants who arrived at the opposite conclusion, made their case on the basis of applying the criteria of Davis & Frohlich (1993).

“The Davis and Frohlich (1993) criteria provide a reasonable framework within which to assess in a general sense whether events might be anthropogenic. However, the participants felt that these criteria also generate ambiguities. An alternative, more robust set of criteria, developed by academia, perhaps including a more quantitative assessment, would be desirable, especially in cases such as this where significant public interest is involved.”
Davis & Frohlich (1993) Criteria

Temporal Correlation
1. Are these events the first known earthquakes of this character in the region?
2. Is there a clear correlation between injection and seismicity?

Spatial Correlation
3a. Are epicentres near wells (< 5 km)?
3b. Do some earthquakes occur at or near injection depths?
3c. If not, are there known geologic structures that may channel flow to the sites of earthquakes?

Injection Practices
4a. Are changes in fluid pressure at well bottoms sufficient to encourage seismicity?
4b. Are changes in fluid pressure at hypocentral locations sufficient to encourage seismicity?

All questions answered, if possible, with “yes”, “no” or, in some cases, “yes?” or “no?”

Final assessment determined by sum of “yes” and “yes?” responses (which are treated as being equivalent)

• Each question is given equal weight, although some factors may be far more important than others in determining whether or not seismic events are induced or natural
  • Assign different weights to different questions to reflect their importance
• “Yes” and “Yes?” treated as equivalent (=1)
  • Assign scores to questions that reflect the degree of certainty
• “No”, “no?” and questions that could not be answered all treated as equivalent (=0)
  • Remove unanswerable questions from scoring
• The final rating does not give any indication of how good is the available evidence
  • Provide a separate rating for the completeness of the available data
• No questions posed regarding evidence that might support a tectonic origin
  • Positive scores for induced, negative scores for tectonic
Questions for which different positive (induced) and negative (induced) scores can be assigned.

Assess the completeness of the data available to make the assessment (i.e., to respond to these questions and assign scores).
Evidence Strength Ratio (ESR)

A parameter to qualify the degree of constraint on the assessment

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ESR = \left( \frac{|\text{Maximum } - \text{ ve points given available data}| + |\text{Maximum } + \text{ ve points given available data}|}{\text{Total number of } + \text{ ve and } - \text{ ve points that can be scored in the framework}} \right) \times 100
\]
Induced Assessment Ratio (IAR)

Having determined the ESR, the case is assessed using only the available scores:

The total length of this bar reflects the ESR.
Induced Assessment Ratio (IAR)

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IAR = \frac{\text{Summed score}}{\text{Maximum points given available data}} \times 100
\]
### Application to UK Cases

#### Newdigate sequence, 2018

<table>
<thead>
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<th>Time of Assessment</th>
<th>Horse-Hill 1</th>
<th>Brockham</th>
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<tr>
<td></td>
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<td>IAR</td>
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<tr>
<td>Early (June 2018)</td>
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<td>+15%</td>
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<td>Final</td>
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#### Preese Hall, 2011

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<td></td>
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<tr>
<td>Early (April 2011)</td>
<td>42%</td>
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<tr>
<td>Final</td>
<td>82%</td>
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Regulators and operators require simple assessment procedures to distinguish induced/triggered seismicity from natural earthquakes, for which question-based schemes such as that proposed by Davis & Frohlich (1993) are well suited.

We propose a new framework that maintains the simplicity of such approaches while addressing shortcomings related to their implementation and interpretation.

A full paper on the framework is currently undergoing minor revision for publication in *Seismological Research Letters*—would be very grateful for additional feedback!