Global review of induced and triggered earthquakes

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Disclaimer and terminology

Study background

HiQuake overview

THE HUMAN–INDUCED EARTHQUAKE DATABASE

Injection–induced earthquakes

Society and induced earthquakes

Summary
### Disclaimer

<table>
<thead>
<tr>
<th>Years</th>
<th>Education</th>
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<tr>
<td>2011–2014</td>
<td>B.Sc. (Hons.) Geophysics with Geology (Durham University, UK)</td>
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<tr>
<td>2014–2015</td>
<td>M.Sc. (Distinction) Petroleum Geoscience (Heriot-Watt University, UK)</td>
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<tr>
<td>2015–2016</td>
<td>Research Assistant (ReFINE and Professor Gillian Foulger)</td>
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<tr>
<td>2016–</td>
<td>Ph.D. Applied hydrogeological modelling (Durham University, UK)</td>
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- Not a seismologist
- ‘Big picture science’
Terminology

- ‘Induced’ vs. ‘Triggered’ earthquakes

- **Induced**
  Released energy predominantly of anthropogenic origin

- **Triggered**
  Released energy predominantly of natural origin

**Induced – Anthropogenic influence**
Study background

- Groningen gas field, The Netherlands
  - Production from 1963
  - 2.8 tcm gas in place
  - ~50% natural gas production in the Netherlands

- Induced earthquakes
  - Maximum observed magnitude $M_L 3.4$ (16/08/2012)

- Update the 2013 database
Study background

- Literature review, predominantly peer-reviewed studies
- Report all suggested cases (not our opinion)
HiQuake overview

www.inducedearthquakes.org
Project types

- 730 projects with reported induced seismicity

- Mining, 271, 37%
- Conventional Oil and Gas, 108, 15%
- Water reservoir impoundment, 168, 23%
- Fracking, 29, 4%
- Geothermal, 57, 8%
- Groundwater extraction, 5, 1%
- Unspecified Oil, Gas and Waste water, 12, 2%
- CCS, 2, 0%
- Construction, 2, 0%
- Deep penetrating bombs, 4, 0%
- Research, 14, 2%
- Nuclear explosions, 22, 3%
- Waste fluid disposal, 36, 5%
Mmax range

- Most commonly reported Mmax value $3 \leq M < 4$
Maximum Mmax’s for different project types

- Zipingpu Dam, China
- Gorkha earthquake, Nepal
- Gazli, Uzbekistan
- Cerro Prieto, Mexico
- Bachatsky, Russia
- Emilia sequence, Italy
- Pawnee, USA
- Cannikin Bomb, USA
- Pink Mountain, Canada
- Folkestone, UK
- Rangely, USA
- In Salah, Algeria
Induced earthquakes through time
Induced earthquakes through time

- Total
- Construction
- Fracking
- Groundwater extraction
- Nuclear explosions
- Oil and Gas/Waste fluid injection
- Waste fluid disposal
- CCS
- Conventional Oil and Gas
- Geothermal
- Mining
- Oil and Gas
- Research
- Water reservoir impoundment

Number of max magnitude cases

Cumulative number of max magnitude cases
Induced earthquakes through time

![Graph showing induced earthquakes through time]

- **Total**
- **Construction**
- **Fracking**
- **Groundwater extraction**
- **Nuclear explosions**
- **Oil and Gas/Waste fluid injection**
- **Waste fluid disposal**
- **Cumulative**
- **CCS**
- **Conventional Oil and Gas**
- **Geothermal**
- **Mining**
- **Oil and Gas**
- **Research**
- **Water reservoir impoundment**
Anthropogenic control on $M_{\text{max}}$?
Injection–induced earthquakes

Tectonic control on Mmax?

\[
\begin{align*}
\text{b} &= 1.2 \\
\Sigma &= 0 \\
\text{b} &= 1.2 \\
\Sigma &= -3
\end{align*}
\]
Injection–induced earthquakes

Tectonic or anthropogenic control on Mmax?
Injection–induced earthquakes

Anthropogenic or tectonic control on $M_{\text{max}}$?
Society and induced earthquakes

- $M_L$ 1.5 smallest felt fracking–induced earthquake (BGS, 2016)

- $M_W$ 4.6 in Canada not felt (Atkinson et al., 2016)

Earthquake magnitudes (and peak ground accelerations) require context
Society and induced earthquakes

- We don’t want induced earthquakes to be a risk...

- But we all use electricity, metals, plastics, petrol, etc.

Resource Demand | Seismic Risk
Summary

- Induced earthquakes caused by more industrial activities than generally appreciated.
- HiQuake contains 730 projects, largest proposed induced earthquake has $M_w$ 7.9.
- Recent years have seen an increase in reported injection-induced earthquakes.
- Anthropogenic or tectonic control on $M_{max}$ still uncertain.
- Earthquake magnitudes need consideration in societal context.
- Balance needed between resource demand and seismic risk.
Thank you

www.inducedearthquakes.org

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References


