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Shale Gas Extraction and CCS May Induce Serious Seismicity

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Abstract

An equation that represents the relationship between the volume of the injected water \( V \) and the maximum magnitude \( M_{\text{max}} \) of induced earthquakes for various cases, including EGS (Enhanced Geothermal System), is expressed as

\[
M_{\text{max}} = 0.75 \log V - 0.48
\]

Another equation that represents the relationship between the magnitude and the JMA (Japan Meteorological Agency) maximum seismic intensity scale \( SIS_{\text{max}} \) of 40 randomly-selected, inland earthquakes in Japan is expressed as:

\[
SIS_{\text{max}} = 1.36M - 1.12 \log d - 1.11
\]

where \( d \) is the focal depth (m). The equation that follows was derived from the preceding equations.

\[
SIS_{\text{max}} = 1.02 \log V - 1.12 \log d - 1.76
\]

The volume of water injection by shale gas extraction in US was estimated and substituted into the equations, assuming that Eq. (2) could be used also for US earthquakes. The maximum magnitude and seismic intensity scale was predicted to be 6.0 and 3.5 (slight damage to residences), respectively, for the case where extraction had continued for 30 years. This estimate does not conflict with the fact that an \( M_{5.6} \) event occurred five years after shale gas extraction began in the US.

The same procedure was adopted for CCS (Carbon dioxide Capture and Storage) assuming that supercritical \( \text{CO}_2 \) injection had the same effect in inducing seismicity. The injection volume is just 0.001% of the annual \( \text{CO}_2 \) emission in Japan assuming that the allowable seismic intensity scale is 1. The injection of this small amount of \( \text{CO}_2 \) is meaningless. We may have an \( M_{7.1} \) whose \( SIS \) is 5.3 (heavy, significant damage to residences) if we inject 17% (this is IPCC’s expectation) of the \( \text{CO}_2 \) in Japan for 30 years into a CCS site. An \( M_{7.1} \) is apparently not allowed. We need 510,000 CCS sites in Japan in order to inject 17% \( \text{CO}_2 \) safely. It is impossible to construct so many CCS sites.

In conclusion, either shale gas extraction or CCS should be carried out very carefully or we may have severe seismicity.

Keywords: Shale Gas Extraction, CCS, Induced Seismicity
Shale Gas Extraction and CCS May Induce Serious Seismicity

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20 min. incl discussion.
Background and objectives

- Such new underground utilizations as shale gas extraction, CCS, etc. are being practiced.
- IIS (Injection Induced Seismicity) by EGS (Enhanced Geothermal System) as well as induced seismicity by dam construction, deep coal mining, etc. are well known.
- IIS by shale gas extraction and CCS is estimated.
Mechanisms of induced seismicity

Failure criterion

Pore pressure increase  Loading by dam etc.

Stop unreasonable $CO_2$ reduction!
Case studies of IIS

- Injection of contaminated water in Denver: M5.3
- Water injection in EGS in Geysers, California: M4.7
- Waste water from hydrofrac for enhanced recovery of natural gas in Arkansas: M4.7
- Injection of brine from rocksalt dome in Paradox Valley, Colorado: M4.4
Estimation of severity of seismicity
# Used data

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>Nojima fault, Japan (1997)</td>
<td>Water for experiment</td>
<td>540</td>
<td>69</td>
<td>0.6</td>
<td>Nishigami et al. (2002)</td>
</tr>
<tr>
<td>I</td>
<td>KTB, Germany (1994)</td>
<td>Potassium salt solution for experiments</td>
<td>9030</td>
<td>200</td>
<td>1.2</td>
<td>Nishigami et al. (2002)</td>
</tr>
</tbody>
</table>
Magnitude from injected water volume

$M_{\text{max}} = 0.75 \log V - 0.48$

$M_{\text{max}}$  maximum magnitude

$V$  injected water volume ($\text{m}^3$)
Maximum seismic intensity scale from magnitude and focal depth

Based on randomly chosen 40 inland earthquakes in Japan.

\[ SIS_{\text{max}} = 1.36M - 1.12 \log d - 1.11 \]

- \( SIS_{\text{max}} \): Maximum seismic intensity scale (JMA)
- \( M \): Magnitude
- \( d \): Depth (m)

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**JMA (Japan Meteorological Agency) seismic intensity scale**

<table>
<thead>
<tr>
<th>Meter reading</th>
<th>Effect on people</th>
<th>Damage on less earthquake-resistant houses</th>
<th>Peak ground acceleration (m/s²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Not felt</td>
<td>No damage.</td>
<td>&lt; 0.008</td>
</tr>
<tr>
<td>1</td>
<td>Felt by some people indoors.</td>
<td>No damage.</td>
<td>0.008 - 0.025</td>
</tr>
<tr>
<td>2</td>
<td>Felt by many to most people indoors.</td>
<td>No damage.</td>
<td>0.025 - 0.08</td>
</tr>
<tr>
<td>3</td>
<td>Felt by most to all people indoors.</td>
<td>Slight damage.</td>
<td>0.08 - 0.25</td>
</tr>
<tr>
<td>4</td>
<td>Many people are frightened.</td>
<td>Slight damage.</td>
<td>0.25 - 0.80</td>
</tr>
<tr>
<td>5-lower</td>
<td>Most people try to escape.</td>
<td>Suffer damage to walls and pillars.</td>
<td>0.80 - 1.40</td>
</tr>
<tr>
<td>5-upper</td>
<td>Many people find it difficult to move.</td>
<td>Heavy/significant damage.</td>
<td>1.40 - 2.50</td>
</tr>
<tr>
<td>6-lower</td>
<td>Difficult to keep standing.</td>
<td>Collapse.</td>
<td>2.50 - 3.15</td>
</tr>
<tr>
<td>6-upper</td>
<td>Impossible to keep standing.</td>
<td>Collapse.</td>
<td>3.15 - 4.00</td>
</tr>
<tr>
<td>7</td>
<td>Thrown by the shaking.</td>
<td>Severe damage no matter how earthquake-resistant.</td>
<td>&gt; 4.00</td>
</tr>
</tbody>
</table>
Maximum seismic intensity scale from injected water volume and focal depth

\[ SIS_{\text{max}} = 1.02 \log V - 1.12 \log d - 1.76 \]

- \( SIS_{\text{max}} \): maximum seismic intensity scale (JMA)
- \( V \): injected water volume (m\(^3\))
- \( d \): focal depth (m)
Shale gas extraction

Assuming that the relationship between $SIS$, $d$ and $M$ can be used to earthquakes in US.
Number of earthquakes in the Central U.S. increased suddenly in 2009 with shale gas extraction.

It was statistically proven that the increase was not a natural process.

There were shale gas wells within 5 km of hypocenters for Ohio cases.

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Water volume

- **Oil & natural gas**
  - Associated water volume: 0.63% of oil equivalent volume
  - Treated and injected.

- **Shale gas**
  - Hydrofrac: 33% of oil equivalent volume of shale gas.
  - Flow back water (15 - 25% in 30 days) is also treated and injected.

- **50 times water is injected in shale gas extraction to get the same energy.**
  - Severer induced seismicity than conventional oil & gas extraction is anticipated.
# Results

<table>
<thead>
<tr>
<th>Site</th>
<th>Water volume (Mm³/y)</th>
<th>1 year extraction</th>
<th>30 year extraction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$M_{\text{max}}$</td>
<td>$SIS_{\text{max}}$</td>
</tr>
<tr>
<td>Barnett TX</td>
<td>7.1</td>
<td>4.7</td>
<td>1.7</td>
</tr>
<tr>
<td>Fayetteville AR</td>
<td>5.1</td>
<td>4.6</td>
<td>1.6</td>
</tr>
<tr>
<td>Haynesville LA</td>
<td>2.7</td>
<td>4.3</td>
<td>1.3</td>
</tr>
<tr>
<td>Marcellus NY/PA/WV</td>
<td>&lt; 13.5</td>
<td>4.9</td>
<td>2.0</td>
</tr>
</tbody>
</table>

*Depth of injection and hypocenter were assumed to be 1300 m.*

- M6.0 and SIS3.5 would be OK in Japan.
- But how it will be in US?
  - **M6.0 Napa Valley earthquake ($d = 11.3$ km) on Aug. 24, 2014 destroyed the wineries.**

Stop unreasonably from CNN Web Site.

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CCS

Assuming that effects of supercritical CO$_2$ to induce seismicity is the same as those of water.
Conditions

- $d > 800$ m from the supercritical conditions.
- $P > 7.4$ MPa and $T > 304$ K
- $\rho = 469$ (kg/m$^3$) at supercritical condition.

$CO_2$ emission in Japan
- 2.56 Gm$^3$/y (supercritical)
Allowable injection volume for a site

Assuming that
- allowable SIS is 1 (felt by some people indoors) and
- a site operates for 30 years.

26,000 m$^3$/y can be injected with $M_{\text{max}} = 3.9$
- Just 0.001% of annual CO$_2$ emission.

Too little!
No effects!
Meaningless!

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Towards Rock Mechanics in 22nd century!

IPCC wants to inject 17% of $\text{CO}_2$ emission

※ If we inject 17% $\text{CO}_2$ from Japan into a site for 30 years,
   ※ We may have a M7.1 directly underneath.
   ※ $SIS_{\text{max}} = 5.3$ (heavy, significant damage)

※ Out of question!
※ Apparently unallowable!

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How many sites do we need to keep earthquakes allowable?

- We need 510,000 CCS sites!

- Impossible!
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CCS projects in Japan

*Nagaoka*
- 20,000 m³ CO₂ into sandstone at 1,100 m deep.
- $M_{\text{max}}$: 2.7, $SIS_{\text{max}}$: -2
- It's natural that there were no felt earthquakes.

*Tomakomai*
- More than 640,000 m³ CO₂ into sandstone and conglomerate.
- $M_{\text{max}}$: 3.9, $SIS_{\text{max}}$: 0.4
- It's natural that there will be no felt earthquakes.
- Having no felt earthquake does not mean that CCS is safe.

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What do others say?
Zoback & Gorelick (2012) and Zoback (2013)

- Shale gas is OK whereas CCS could be dangerous.

Cappa & Rutqvist (2012 and 2011) and Nicol et al. (2011)

- CCS could be dangerous.
Concluding remarks
Shale gas extraction may induce severe seismicity.

CCS may become either meaningless or dangerous.

Enough attention should be paid to induced seismicity when extracting shale gas or carrying out CCS.
Towards Rock Mechanics in 22nd century!

References


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Stop unreasonable CO$_2$ reduction!
Towards Rock Mechanics in 22nd century!


Stop unreasonable CO₂ reduction!
Nicolas, C., Michel, F., Catherine, D. and Marco, C., Induced Microseismic Activity During Recent Circulation Tests At The Egs Site of Soultz-Sous-Forest (France), Proc. Thirty-Sixth Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, California, January 31 - February 2, 2011, SGP-TR-191 (2011)

