

This exercise was designed for:

Students who are non majors

Students who have learned about plate tectonics and earthquakes

Students who have learned about science and critical thinking

This exercise will be done when students are learning about and thinking about various sources of energy.

This exercise can be done before or after students have learned about waste.

Goals of this exercise:

- Use large online data set (IRIS earthquake viewer) to assess human induced earthquakes

- Build better critical thinking skills through examination and discussion of data about the risks of fracking (and wastewater injection)

- Understand fracking, wastewater injection, choices about energy sources, dealing with waste, types of waste, risks of human induced earthquakes

- Students should read this article before coming to class:

<http://www.nytimes.com/2011/02/06/us/06earthquake.html? r=2>

- Students will complete this exercise in class. My hope is that they will see other wastewater injection swarms like Oklahoma 2014.

- They will do some research before the next class period

- The next class period will be a discussion about fracking, wastewater injection, risks and benefits of all sources of energy.

Grades will be based on the following rubric.

Critical Thinking Scoring Rubric

Rating Criteria	NA	Rating Scale					
		Emerging		Developing		Mastering	
Summarized problem, question, or issue		Does not attempt to or fails to identify and summarize accurately.		Summarizes issue, though some aspects are incorrect or confused. Nuances and key details are missing or glossed over.		Clearly identifies the challenge and subsidiary, embedded, or implicit aspects of the issue. Identifies integral relationships essential to analyzing the issue.	
		1	2	3	4	5	6
Considers context and assumptions		Approach to the issue is in egocentric and socio-centric terms. Does not relate to other contexts. Analysis is grounded in absolutes, with little acknowledgement of own biases. Does not recognize context and underlying ethical implications.		Presents and explores relevant contexts and assumptions, although in a limited way. Analysis includes some outside verification, but primarily relies on authorities. Provides some consideration of assumptions and their implications.		Analyzes the issue with a clear sense of scope and context, including an assessment of audience. Identifies influence of context. Questions assumptions, addressing ethical dimensions underlying the issue.	
		1	2	3	4	5	6
Communicates own perspective, hypothesis, or position.		Position is clearly adopted with little consideration. Addresses a single view of the argument, failing to clarify the position relative to one's own. Fails to justify own opinion or hypothesis is unclear or simplistic.		Presents own position, which includes some original thinking, though inconsistently. Justifies own position without addressing other views or does so superficially. Position is generally clear, although gaps may exist.		Position demonstrates ownership. Appropriately identifies own position, drawing support from experience and information not from assigned sources. Justifies own view while integrating contrary interpretations. Hypothesis demonstrates sophisticated thought.	
		1	2	3	4	5	6
Analyzes supporting data and evidence		No evidence of selection or source evaluation skills. Repeats information without question or dismisses evidence without justification. Does not distinguish between fact and opinion. Evidence is simplistic, inappropriate or not related to topic.		Demonstrates adequate skill in selecting and evaluating sources to meet information need. Use of evidence is selective, discerns fact from opinion and may recognize bias. Appropriate evidence is provided although exploration is routine.		Evidence of source evaluation skills. Examines evidence and questions accuracy and relevance. Recognizes bias. Sequence of presentation reflects clear organization of ideas, subordinating for importance and impact.	
		1	2	3	4	5	6
Uses other perspectives and positions		Deals with a single perspective and fails to discuss others' perspective. Adopts a single idea with little question. Alternatives are not integrated. Ideas are obvious. Avoids discomforting ideas. Treats other positions superficially. No evidence of self-assessment.		Begins to relate alternative views. Rough integration of multiple viewpoints. Ideas are investigated in a limited way. May overstate conflict or dismiss alternative views hastily. Analysis of other views mostly accurate. Some evidence of self-assessment.		Addresses diverse perspectives from a variety of sources to qualify analysis. Any analogies are used effectively. Clearly justifies own view while respecting views of others. Analysis of other positions is accurate and respectful. Evidence of reflection and self-assessment.	
		1	2	3	4	5	6
Assesses conclusions, implications, and consequences		Fails to identify conclusions, implications, and consequences, or conclusion is a simplistic summary. Conclusions are absolute, and may attribute conclusion to external authority.		Conclusions consider evidence of consequences extending beyond a single issue. Presents implications that may impact other people or issues. Presents conclusions as only loosely related to consequences. Implications may include vague reference to conclusions.		Identifies and discusses conclusions, implications, and consequences. Considers context, assumptions, and evidence. Qualifies own assertions. Consequences are considered and integrated. Implications are developed and consider ambiguities.	
		1	2	3	4	5	6

Helpful references:

Ausbrooks, S.M. and Doerr, E., 2007, Enola Swarm Area - Faulkner County, Arkansas: Arkansas Geological Survey, Digital Geohazard Map GH-EQ- ENOLA-002, one sheet.

Horton, S., 2012, Disposal of hydrofracking waste fluid by injection into subsurface aquifers triggers earthquake swarm in central Arkansas with potential for damaging earthquake: Seismological Research Letters, V.83, No.2, p. 250-260.

<https://www.fas.org/sgp/crs/misc/R43836.pdf>

<http://ar.water.usgs.gov/ozarks/shalegas.html>

<https://www.youtube.com/watch?v=5V6Kuv5Qt1Y>

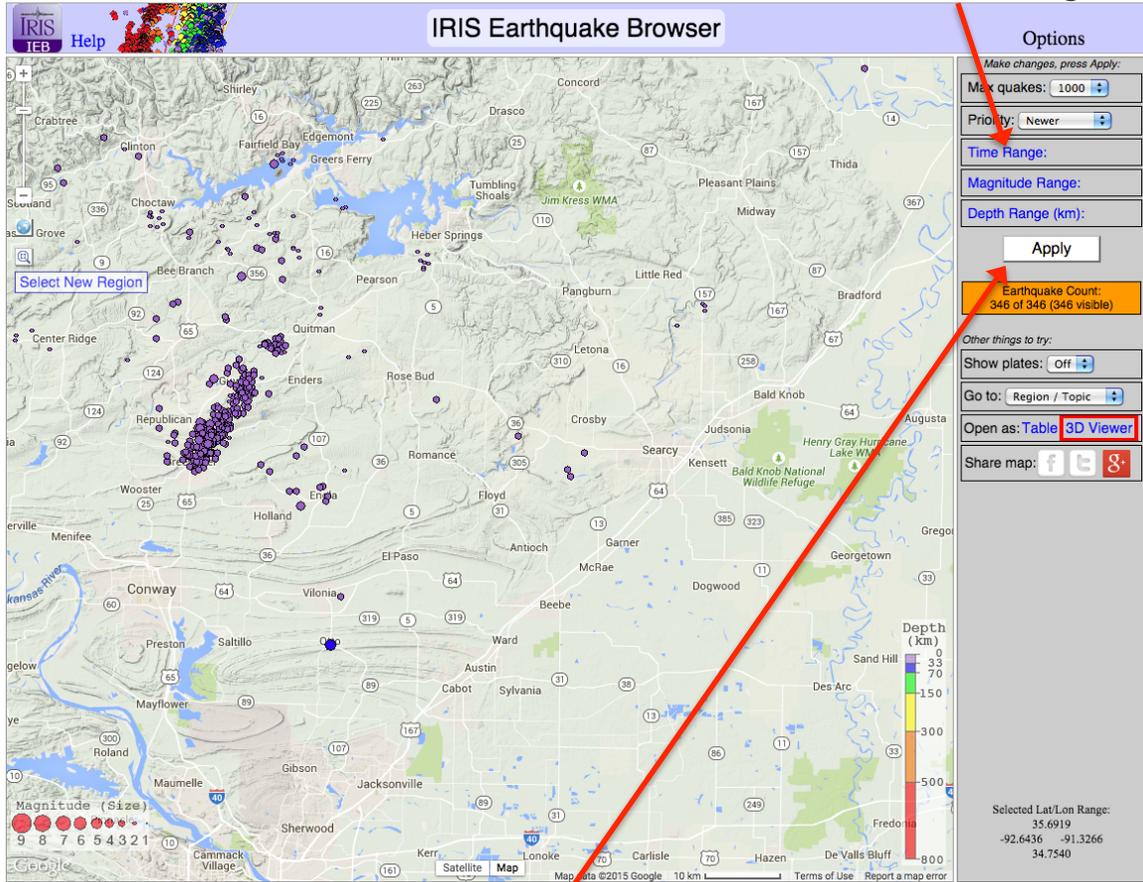
[http://www.aogc.state.ar.us/notices/Ex.1B-Permanent Disposal Well Moratorium Area.pdf](http://www.aogc.state.ar.us/notices/Ex.1B-PermanentDisposalWellMoratoriumArea.pdf)

http://www.nytimes.com/2011/02/06/us/06earthquake.html?_r=0

<http://pubs.usgs.gov/sir/2012/5273/>

Does Fracking cause earthquakes? **INSTRUCTOR COPY**

1. Go to: <http://ds.iris.edu/ieb>
2. Zoom in to the United States and then to Arkansas. Zoom until your window looks similar to this: (note lat/long ranges in the bottom right).
3. Next, click on the time range:



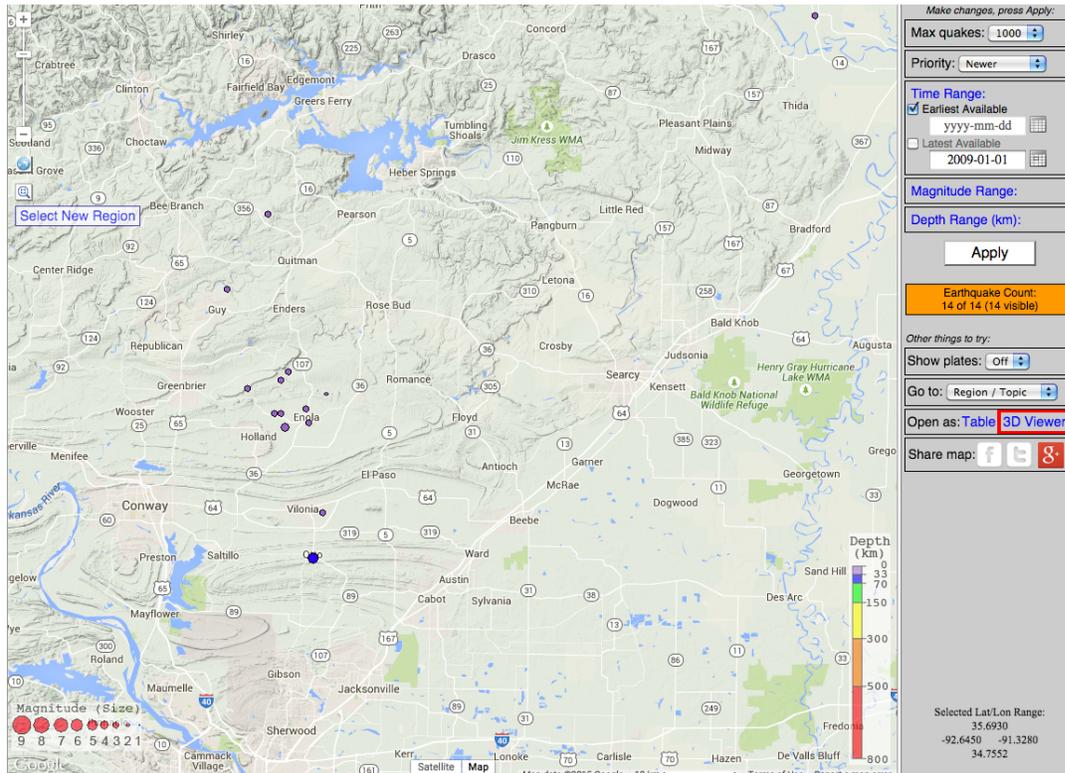
4. For Time Range, uncheck latest available and choose the date shown. Before you do, scroll backward to the earliest date. Don't forget to press Apply.

Time Range:

Earliest Available
yyyy-mm-dd

Latest Available
2009-01-01

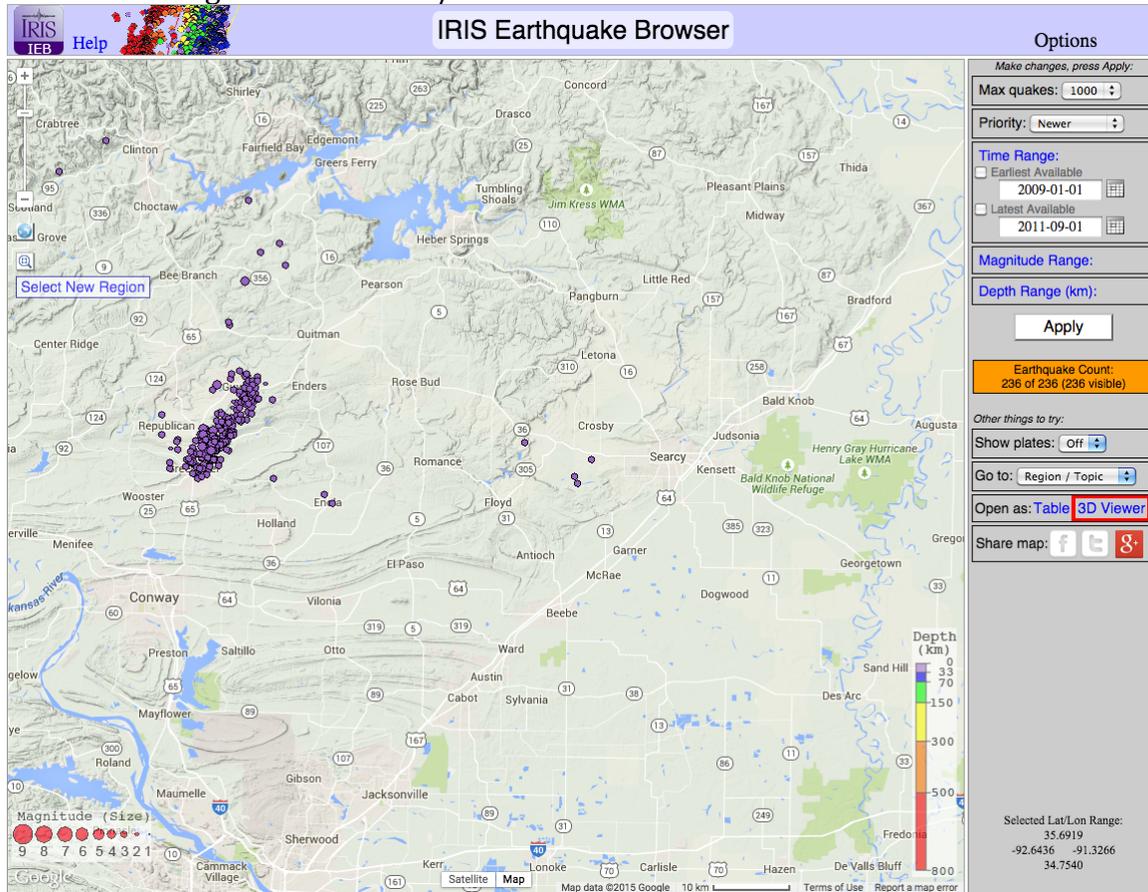
This is the image I accessed in 6/2015:



- What is the earliest available date for data here? ~(Jan 70)~
- What is the earthquake count? ~14
- What is the time range? ~39 years 468 months
- This is an average of how many quakes per year: 14/39 = ~.35/year (one every 3 years)

5. Next, choose the following dates: 2009-01-01 to 2011-09-01
Don't forget to press Apply.

This is the image I accessed in 6/2015:



- What is the earthquake count? ~236
- What is the time range? 2.5 years 32 months
- This is an average of how many quakes per year: per month
 $236/2.5 \text{ years} = \sim 96/\text{year}$ or $236/32 \text{ months} = \sim 7/\text{month}$

6. Compare the average rate of earthquakes for question 4 to that of question 5.
What is the rate of increase: $96/0.35 = \sim 275X$

7. Do you notice any other changes in the earthquakes between the two time frames listed? (location, magnitude, depth?). (It will help to look at both the 3D viewer and the Table View (bottom right))

Discuss:

8. Fracking for oil and gas in this area began in around 2005. According to the Arkansas Geologic Survey: *“The Fayetteville Shale Formation (Upper Mississippi) is the current focus of a regional shale-gas exploration and development program within the eastern Arkoma Basin of Arkansas. Approximately 2.5 million acres have been leased in the Fayetteville Shale gas play with a cumulative production of 5,150 Bcf since drilling began in 2004.”*

Maps of the areas of this country and specifically Arkansas where fracking has been taking place are shown on the at the end of this exercise. Compare these maps to your map area in this exercise.

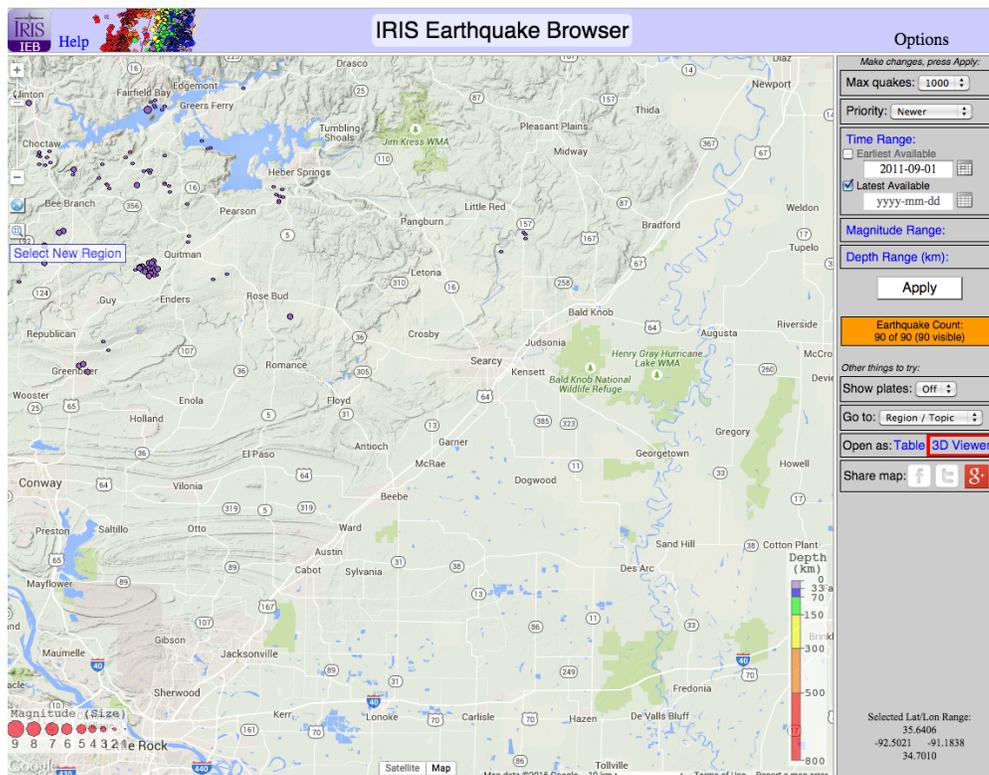
Could these earthquakes be associated with fracking?_____

NOTE: Deep well injection was stopped ~mid 2011 in the area of the quakes. You may want to have students look at quakes from Sept 2011 til present to see if there is a difference.

9. List below what further information one would need or further questions one should ask or further research one would need to do to determine the answer to this question.

10. The state of Arkansas banned wastewater injection in the area of the earthquake swarm in 2011. Does this seem to have made a difference? Go back to the IRIS earthquake viewer and change the dates again. Start in 9/1/2011 and go until today. Don't forget to press Apply.

This is the image I accessed in 6/2015



- a. What is the earthquake count? ~90
- b. What is the time range? ~4 yrs years 44 months
- c. This is an average of how many quakes per year: 22.5 per month ~2
- d. Was there a change in the number or pattern of earthquakes after wastewater injection was stopped? _____ Discuss:

11. Go back to the IRIS earthquake viewer. Look elsewhere in the United States. Are there other areas where there appears to be an increase in earthquakes in areas of fracking? (Use the maps provided with this exercise as your guide) _____ If so where? _____

For this area, use the IRIS earthquake browser to begin to test if this is true by changing the time parameters to before and after fracking began in the area.

Describe what you found:

Hopefully, they will see the Oklahoma swarm of 2014 and begin to play around with this.

12. For next time:

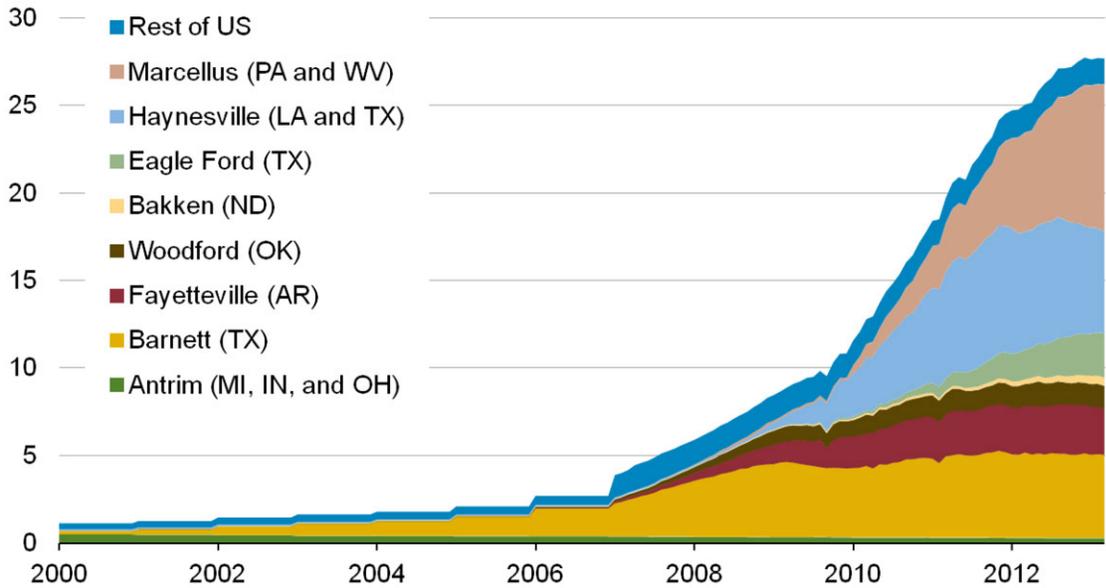
This is the meat of this exercise! The whole point is to get them to think critically about this issue and assess the information they find about it:

a. Find information that supports that fracking or fracking related activities can cause earthquakes. List at least two web addresses/references here, briefly explain each says and include why you feel this source is credible.

b. Find information that supports that fracking or fracking related activities does not cause earthquakes. List at least two web addresses/references here, briefly explain what each says and include why you feel this source is credible.

13. Assume you work for the Arkansas Geological Survey and the public wants to know if these earthquakes are human induced. Write a statement to release to the public about your findings:

shale gas production (dry)
billion cubic feet per day



Sources: LCI Energy Insight gross withdrawal estimates as of March 2013 and converted to dry production estimates with EIA-calculated average gross-to-dry shrinkage factors by state and/or shale play.