Can Humans Cause Earthquakes?

Argument-driven Inquiry—Earth-science Lab Investigation

www.iris.edu/hq/inclass/lesson/542

Version 2.0

IRIS
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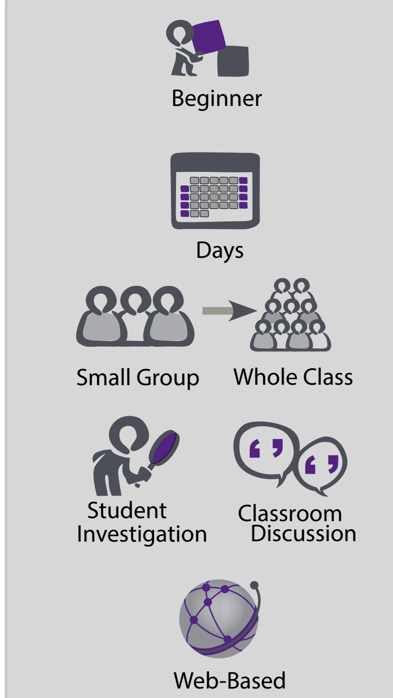
OVERVIEW

Explore the "hot topic" of induced earthquakes with your students through an activity built on the Argument Driven Inquiry (ADI) framework that supports three-dimensional learning (Appendix A). Students propose, support, evaluate, and revise ideas through data gathering, argumentation, and discussion.

Removing hydrocarbons has become an essential activity for humankind. However, their production does not come without the potential to affect the natural and built environments, such as increasing seismic hazards. Students evaluate the science behind this through a classroom-ready lesson that blends crosscutting concepts, disciplinary core ideas, and practices of science and engineering through the eight steps of the ADI process (Sampson and others, 2013). Students explore a research question, determine the data necessary to analyze the question, and collect the data. Through collaborative analysis and interpretation, their data becomes evidence for claims presented in a scientific poster session. Deliberating over conclusions from across the class, and participation in a class discussion about physical processes of induced seismicity sets up teams to further enhance their own arguments. Students collectively participate in, but individually write, a double-blind peer review.

Through participation, students gain an understanding of unconventional oil and gas production (hydraulic fracturing), seismic monitoring, and drawing correlations (or lack thereof) between fluid injection (related to hydrofracking or from wastewater disposal) and earthquake activity.



OBJECTIVES

Students work in small groups to:

- Collect and analyze real earthquake and well data
- Develop and justify a claim based upon the evidence
- Discuss and critique the claims of other groups to identify errors or faulty reasoning
- Prepare an investigative report

TABLE OF CONTENTS

MATERIALS.

- Print Pages SW-1 – SW-6 for Student Worksheets. "Investigation Proposal" required
- Slides: **InducedSeismicity_Figures.pptx**
- One white board per group (2'x3' or similiar works well) plus several colors of white board markers per group
- Optional Google Earth KMZ file provided by IRIS: **OK_Earthquakes_Wells_2010-2012_v1.kmz**
- There are two options for data collection depending on available time:

  Option A: Students may use computer and internet to collect data relevant to the investigation of earthquakes in Oklahoma. Requires computers and internet access.

  Option B: If it is necessary to save time, you can also provide students with data. Print pages SW-7 – SW-13. These resources are derived from the sources at the right.

POTENTIAL SOURCES OF DATA FOR OPTION A

A) IRIS Earthquake Browser http://ds.iris.edu/ieb

B) OK Geologic Survey's fault database www.ou.edu/content/ogs/data/fault.html and OK oil and gas data base www.ou.edu/content/ogs/data/oil-gas.html

C) Census data on population *www2.census.gov/geo/maps/dc10_thematic/2010_Profile/2010_Profile_Map_Oklahoma.pdf*

TEACHER PREP

- Review the ADI framework before you do this activity. See "Stages of Argument-driven Inquiry" in Appendix A and visit www.argumentdriveninquiry.com/8-stages-of-adi.html.
- Guiding questions provided in Appendix B are for use with the Slide presentation.
- "*Goals for Productive Discussion*" are in Appendix C.
- For guidelines on Peer Review (Stage 7), you can select the appropriate grade-level, peer-review guide from www.argumentdriveninquiry.com/instructional-materials.html. The guides are free but you must provide an email to download.

TEACHER TIP

How to make a classroom set of whiteboards our of 4x8 sheets of white panel board for less than $15:
http://fairydustteaching.com/2012/0 3/diy-white-boards-so-cheap/

LESSON DEVELOPMENT

The Guiding Question of this exercise is :

"How could oil and natural gas production in Oklahoma alter the rate and size of earthquakes in Oklahoma?"

STAGE 1: IDENTIFICATION OF TASK & GUIDING QUESTION.

Students explore the topic individually by reading the background in Pages SW-1 & SW-2.

In small groups of 3-5, students review the task and reflect on the questions provided on Page SW-3.

STAGE 2: DESIGN A METHOD & COLLECT DATA

Groups begin by addressing the questions on the top of Page SW-4. The goal of this stage to develop their own Laboratory Investigation Proposal (Page SW-5). See Appendix D for a sample proposal.

Based on the Guiding Question, students work together to determine what type of data they will need to collect, and how they will collect and analyze it.

STAGE 3: ANALYZE DATA & DEVELOP A TENTATIVE ARGUMENT

Students either collect their own data (**Option A**) as they outlined in their "Investigation Proposal" (Page SW-5) or use the optional data handouts on Pages SW-7 through SW-13 (**Option B**)
Each group also needs to create their own white board presentation following the guide on Page SW-4, Figure 4.

STAGE 4: ARGUMENTATION SESSION

The argumentation session (Page SW-4) allows all of the groups to share their group's evidence and arguments. Select one member of each group to stay at the lab station to present their argument. The other group members go to the other lab stations to listen to and critique arguments offered by the other groups.

Students return to their group to share what they learned and to discuss the feedback received by the student who stayed at the table. If necessary, groups may collect more data, and/or revise their argument as necessary

STAGE 5, EXPLICIT & REFLECTIVE DISCUSSION

This stage follows the student's argumentation session, wherein students have looked at each other's work and have discussed it. REMEMBER, content should be build from the students experiences with the investigation. This is not a lecture but a non-scripted, whole-class discussion facilitated by the instructor.

Depending on which Disciplinary Core Ideas you are targeting with this instruction, sample questions have been provided in Appendix B, that are aligned with slides in the slideshow provided. Similar questions can be designed to emphasize Science and Engineering Practices and Cross-Cutting Concepts (Appendix E).

TIME ESTIMATES

Approximation:

Stage 1: 45 min
Stage 2: 45 min
Stage 3: 90-135 min
Stage 4: 45 min
Stage 5: 45 min
Stage 6: 45 min
Stage 7: 45 min
Stage 8: 45 min

ARGUMENTATION

The attempt to support or critique an idea based on criteria that are valued within the scientific community. Scientists rely on different types of criteria to determine if a claim is valid or acceptable. One of the most important is how well a claim fits with the available evidence.

TEACHER TIPS

Be sure to have the "*Nine Talk Moves*" in Appendix C handy to help encourage your students to dig deeper.

Guiding questions are also available in Appendix B.

STAGE 6: WRITE AN INVESTIGATIVE REPORT

Each student independently writes an investigative report. Instructions for completing the report are provided on the student worksheet Page SW6.

STAGE 7: DOUBLE-BLIND PEER REVIEW

*A double-blind peer review is the evaluation of a one's work by one or more individuals of similar competence (i.e. peers) where both the author's and the reviewers are anonymous. In the ADI process, peer review is used to ensure quality and to provide student authors with the feedback they need in order to improve. Here each research team collectively reviews several investigation reports authored by other students. Each report will have had the author's name removed so reviewers don't know who's work they are reviewing. Similarly, the feedback given to the author is also anonymous (the names of the student reviewers are also removed). This stage also helps students learn how to evaluate information in science and develop their ability to read and critique an argumentative text. Double-blind peer review forms can be downloaded from the ADI website (*www.argumentdriveninquiry.com/instructional-materials.html*) at the appropriate grade level for your students.*

STAGE 8: REVISE FINAL REPORT & SUBMIT

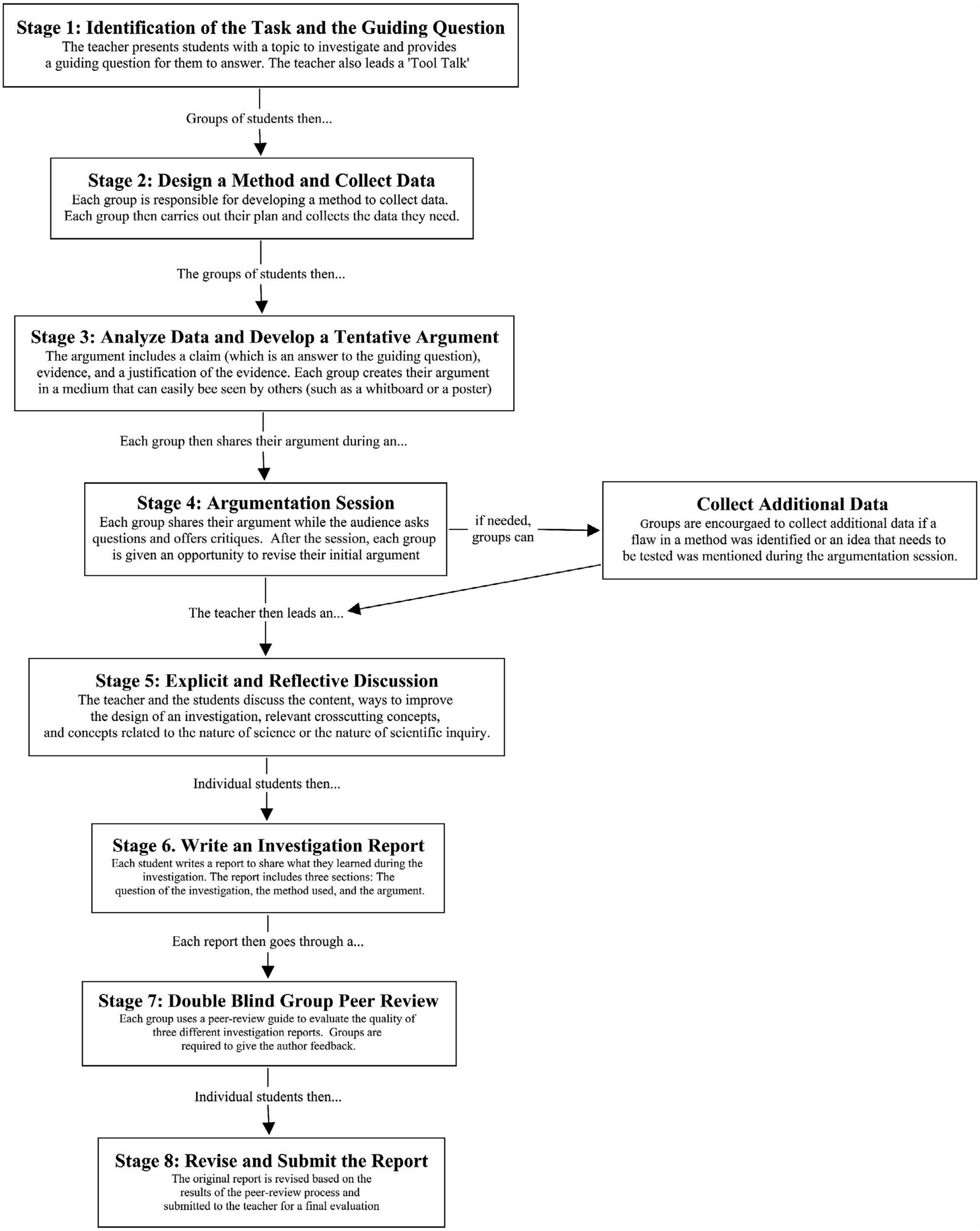
Working individually, students should use the feedback they have received from the peer review process to revise their report. Final reports are then submitted to the teacher.

REFERENCES

Sampson, V., Grooms, J., and Enderle, P. (2013). Argumentation in science and science education: Helping students understand the nature of scientific argumentation so they can meet the new science standards. The Science Teacher, 80(5), 30-33.

Sampson, V., Grooms, J., and Walker, J. (2009). Argument-Driven Inquiry to promote learning and interdisciplinary work in science classrooms. The Science Teacher, 76(8), 42-47.

APPENDIX A: STAGES OF ARGUMENT-DRIVEN INQUIRY



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www.argumentdriveninquiry.com/8-stages-of-adi.html

Argument-Driven Inquiry

APPENDIX B: EXPLICIT AND REFLECTIVE DISCUSSION GUIDE V1.0

Below you will find examples of questions you might ask students to consider during the explicit and reflective discussion. You may choose to use all, none, or some of these questions depending on the Disciplinary Core Idea you are targeting with your instruction.

See also Appendix E for "Targeted 3D-NGSS Learning"

ESS3A Natural Resources

6-8. Humans depend on Earth's land, ocean, atmosphere, and biosphere for different resources, many of which are limited or not renewable. Resources are distributed unevenly around the planet as a result of past geologic processes.

Discussion questions

- *Where does natural gas come from?*
- *Why is there natural gas in OK?*
- *Why do we need to use high-volume hydrolic fracturing to extract the natural gas in OK (or other dense shales)?*

ESS3B Natural Hazards

6-8. Some natural hazards, such as volcanic eruptions and severe weather, are preceded by phenomena that allow for reliable predictions. Others, such as earthquakes, occur suddenly and with no notice, and thus they are not yet predictable. However, mapping the history of natural hazards in a region, combined with an understanding of related geological forces can help forecast the locations and likelihoods of future events.

Discussion questions

- *What is an earthquake? And what processes cause quakes to occur naturally?*
- *Where do most earthquakes occur?*
- *How can we use past seismicity to contribute to forecasting? Prediction?*
- *Has seismicity in OK changed over time?*

ESS3C Human Impacts on Earth Systems

6-8. Human activities have altered the biosphere, sometimes damaging it, although changes to environments can have different impacts for different living things. Activities and technologies can be engineered to reduce people's impacts on Earth.

Discussion questions

- *Is induced seismicity always a bad thing? Or in what ways could induced seismicity be a good thing?*
- *Could there be other potential environmental impacts of hydrofracking besides quakes?*
- *In what ways might unconventional gas production influence earthquake occurrence?*
- *How might engineering and/or technology affect humans causing earthquakes?*

Checklist

Goals for Productive Discussions and Nine Talk Moves

Talk Science in the Inquiry Project

Goal One Help Individual Students Share, Expand and Clarify Their Own Thinking	Notes/Frequency of Use
☐ **1. Time to Think** - Partner Talk - Writing as Think Time - Wait Time	
☐ **2. Say More:** "Can you say more about that?" "What do you mean by that?" "Can you give an example?"	
☐ **3. So, Are You Saying…?:** "So, let me see if I've got what you're saying. Are you saying…?" (always leaving space for the original student to agree or disagree and say more)	
Goal Two Help Students Listen Carefully to One Another	
☐ **4. Who Can Rephrase or Repeat?** "Who can repeat what Javon just said or put it into their own words?" (After a partner talk) "What did your partner say?"	
Goal Three Help Students Deepen Their Reasoning	
☐ **5. Asking for Evidence or Reasoning** "Why do you think that?" "What's your evidence?" "How did you arrive at that conclusion?"	
☐ **6. Challenge or Counterexample** "Does it always work that way?" "How does that idea square with Sonia's example?" "What if it had been a copper cube instead?	
Goal Four Help Students Think With Others	
☐ **7. Agree/Disagree and Why?** "Do you agree/disagree? (And why?)" "What do people think about what Ian said?" "Does anyone want to respond to that idea?"	
☐ **8. Add On:** "Who can add onto the idea that Jamal is building?" "Can anyone take that suggestion and push it a little further?"	
☐ **9. Explaining What Someone Else Means** "Who can explain what Aisha means when she says that?" "Who thinks they could explain why Simon came up with that answer?" "Why do you think he said that?"	

**Source: visit The Inquiry Project at TERC (https://inquiryproject.terc.edu/).*

ADI Laboratory Investigation Proposal C

The Guiding Question…

How could oil and natural gas production in Oklahoma alter the rate and size of earthquakes in Oklahoma?

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What data will you collect?

- The rate and size past earthquakes in OK
- The rate and size of current earthquakes in OK
- A description of how oil and natural gas is produced in OK
- Details on any changes to the production of oil and gas in OK
- Locations of oil and gas production in OK
- Locations of faults in OK

↓

How will you collect your data?

Your Procedure

- Search the USGS Earthquake Hazards Program website
- Explore the IRIS Earthquake Browser (Rate and size of earthquakes)
- Search for news relevant stories on oil and gas production in OK in the library
- Search for new relevant to possible increases in seismicity in OK in the library
- Search Oklahoma Geologic Survey website

What safety precaution will you follow?

Follow classroom and school policies regarding the use of the internet.

↓

How will you analyze your data?

- Create a frequency graph of earthquakes both before and after the oil production started.
- Create a graph of the magnitudes of the quakes both before and after the oil production started.
- Overlay the locations of the quakes with the locations of the both the production well locations and the injection well locations.

↓

Your actual data

I approve of this investigation. ______________________ Instructor's Signature ____________ Date

APPENDIX E: TARGETING 3D-NGSS LEARNING

Students who demonstrate understanding can:

MS-ESS3-4. Construct an argument supported by evidence for how increases in human population and per-capita consumption of natural resources impact Earth's systems.

Science & Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
• Asking questions • Planning and carrying out investigations • Analyzing and interpreting data • Constructing explanations • Engaging in argument from evidence • Obtaining, evaluating and communicating information	**MS-ESS3A Natural Resources** - Humans depend on Earth's land, ocean, atmosphere, and biosphere for different resources, many of which are limited or not renewable. Resources are distributed unevenly around the planet as a result of past geologic processes. **MS-ESS3B Natural Hazards** - Some natural hazards, such as volcanic eruptions and severe weather, are preceded by phenomena that allow for reliable predictions. Others, such as earthquakes, occur suddenly and with no notice, and thus they are not yet predictable. However, mapping the history of natural hazards in a region, combined with an understanding of related geological forces can help forecast the locations and likelihoods of future events. **MS-ESS3C Human Impacts on Earth Systems** - Human activities have altered the biosphere, sometimes damaging it, although changes to environments can have different impacts for different living things. Activities and technologies can be engineered to reduce people's impacts on Earth.	**Cause and Effect**: Mechanism and Explanation Events have causes, sometimes simple, sometimes multifaceted. A major activity of science is investigating and explaining causal relationships and the mechanisms by which they are mediated. Such mechanisms can then be tested across given contexts and used to predict and explain events in new contexts. **Stability and Change.** For natural and built systems alike, conditions of stability and determinants of rates of change or evolution of a system are critical elements of study

NAME: ______________________________

DATE: ______________________________

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CAN HUMANS CAUSE EARTHQUAKES?

An investigative study

BACKGROUND

On Saturday, September 3, 2016, Oklahoma experienced the largest earthquake ever recorded in the state. A M5.8 earthquake occurred approximately 9 miles (15 km) northwest of the town of Pawnee, Oklahoma. Residents within 30 miles of the epicenter experienced moderate to strong shaking, which damaged roads, broke windows, and damaged masonry on residences and historical buildings (Figure 1). In fact, the quake was large enough that many in the neighboring states of Texas, Arkansas, Kansas and Missouri also felt the earthquake.

***Figure 1**. The sandstone façade of this 100-year-old historic building in Pawnee, OK was damaged due to a M 5.8 earthquake that occurred nearby on Saturday, September 3, 2016. (Photo: Oklahoma Channel 9 News)*

While Oklahoma is not a region of the U.S. that we traditional think of as having a significant earthquake hazard, earthquakes have occurred there in the past. For instance, this earthquake is only the largest in a sequence of earthquakes that began in 2009. Moreover, it punctuates reports from residents of northwest Oklahoma that the number of earthquakes they feel seems to be increasing rapidly. What could be going on? Could these earthquakes be the result of the effort to extract natural gas from Oklahoma that also increased in 2009?

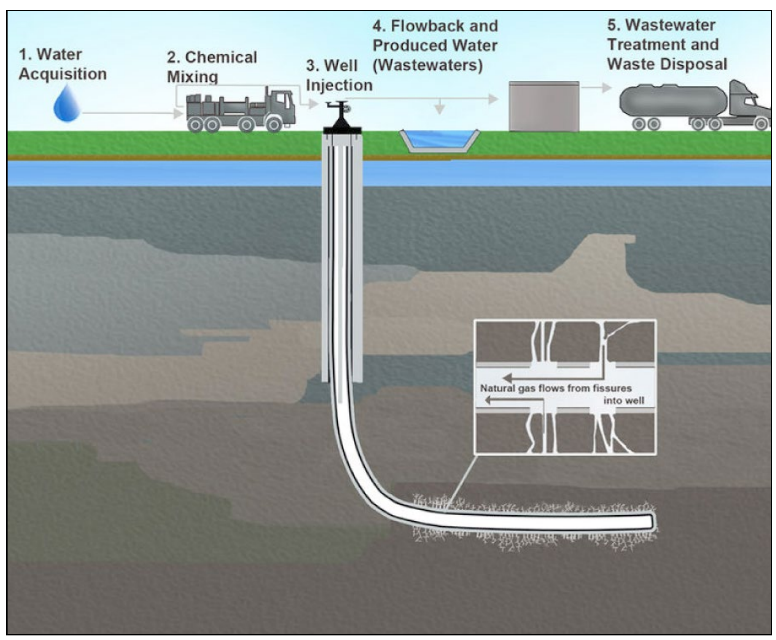

***Figure 2.** Illustration of the water cycle of hydraulic fracturing (Environmental Protection Agency).*

Natural Gas Extraction in Oklahoma

The process of removing hydrocarbons from Earth's crust has become an essential activity for humankind. However, major challenges arise during oil and gas production that have the potential to affect the natural and built environments in a variety of ways.

One newer approach is known as the production of ***unconventional gas resources***, through a process known as high volume-hydraulic fracturing ("***hydrofracking***"; Figure 2). Hydrofracking involves injecting large volumes of water (3-5 million gallons/ well), sand and chemicals into the rock under high pressure to create cracks through which the gas may escape the rock formation and then be collected. Hydrofracking most commonly takes place in gas fields found in shales.

In addition, water is also trapped in the same pore space as oil and natural gas and is recovered during conventional oil and gas production. In some places, this flowback water is estimated to be between 9 and 35% of the water injected into the well. This suggests that between 387,000 gallons and 1,505,000 gallons of fluid will return to the surface. The disposal of naturally produced water and/or hydraulic fracture fluid presents major challenges, since the wastewater is frequently injected back into Earth's crust.

Some states, such as Oklahoma and Ohio, allow hydrofracking and wastewater injection (Figure 3), while other states such as Pennsylvania, allow hydrofracking but require wastewater to be transported out of state for disposal. In Oklahoma, hydrofrac fluid represents only 10% or less of the fluids disposed of in wastewater injection wells.

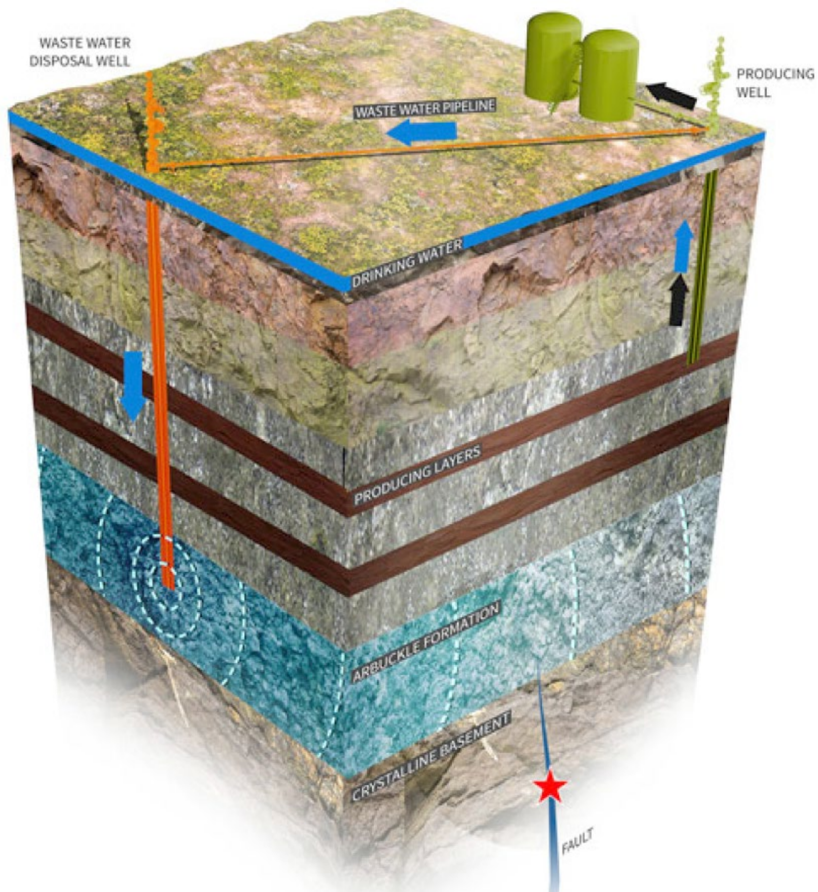

Figure 3. *Diagram of deep wastewater injection well and production well. (Image credit: Steven Than, Courtesy Stanford University)*

STAGE 1: IDENTIFICATION OF THE TASK AND THE GUIDING QUESTION

Collect evidence to support or refute the claim that the unconventional gas production process in Oklahoma has resulted in an increase in earthquakes within the state.

Then, explain a mechanism by which this process could alter the natural occurrence of earthquakes. The guiding question of this investigation is *"How could oil and natural gas production in Oklahoma alter the rate and size of earthquakes in Oklahoma?"*

Before you can design and carry out your investigation, you must determine what type of data you need to collect, how you will collect it, and how will you analyze it. To help you make this determination, it will be useful to consider what type of data you need to collect.

Think about the following questions:

- What is an earthquake?
- What processes cause earthquakes to occur naturally?
- Has seismicity in Oklahoma changed over time?
- In what ways might unconventional gas production influence earthquake occurrence?

To determine how you will collect your data, think about:

- Where might you find the sort of data you need to evaluate this question?
- Are all online sources of data equal to one another?
- What might be some differences between sources?

In order to determine how you will analyze your data think about:

- What will be the best way to display/visualize your data?
- What are the benefits of averaging your data?
- Could there be any value in not averaging your data?
- Could past events be useful for describing the future?

STAGE 2: DESIGN A METHOD AND COLLECT DATA

Before you can design and carry out your investigation, you must determine what type of data you will need to collect, how you will collect it, and how will you analyze it. "Investigation Proposal"

Connections to Crosscutting Concepts and the Nature of Science and Scientific Inquiry

As you work through your investigation, be sure to think about:

- How scientists ask and/or evaluate questions that challenge the premise(s) of an argument
- How scientists identify inputs and outputs of systems
- Ways that graphs, charts, and images can be used to identify patterns in data
- How empirical evidence is required to differentiate between cause and correlation, and make claims about specific causes and effects
- Ways the stability of a system might be disturbed either by sudden events or gradual changes that accumulate over time

STAGE 3: ANALYZE DATA AND DEVELOP A TENTATIVE ARGUMENT

Once your group has finished collecting and analyzing your data, you will need to develop an initial argument.

- Your argument must include a claim. The claim is your answer to the guiding question.
- Your argument must also include evidence in support of your claim. The evidence is your analysis of the data and your interpretation of what the analysis means.
- Finally, you must include a justification of the evidence in your argument. You will therefore need to use a scientific concept or principle to explain why the evidence that you decided to use is relevant and important.

You will create your initial argument on a whiteboard. Your whiteboard must include all the information shown in Figure 4.

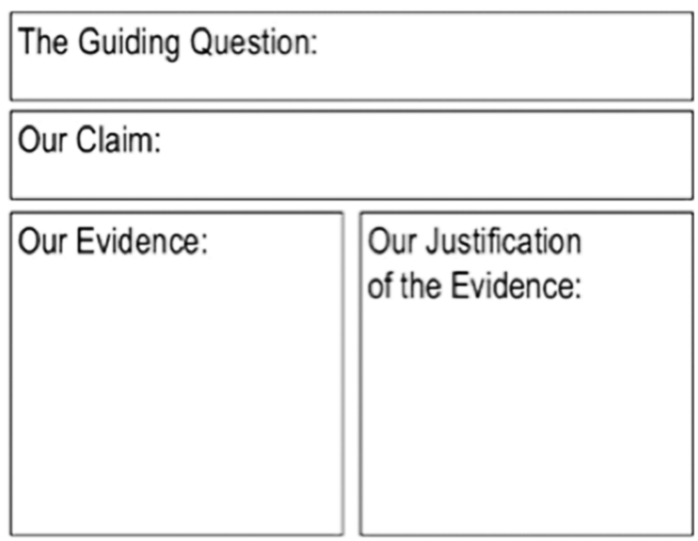

Figure 4. Argument presentation on a whiteboard

STAGE 4: ARGUMENTATION SESSION

The argumentation session allows all of the groups to share their arguments.

- One member of each group will stay at the lab station to share that group's argument, while the other members of the group go to the other lab stations to listen to and critique the other arguments. *The goal of the argumentation session is not to convince others that your argument is the best one. Rather, the goal is to identify errors or instances of faulty reasoning in the initial arguments so these mistakes can be fixed.*

- *When you visit each groups presentation, you* will need to evaluate the content of the claim, the quality of the evidence used to support the claim, and the strength of the justification of the evidence included each argument that you see.

ADI Laboratory Investigation Proposal

The Guiding Question…	
What data will you collect?	
How will you collect your data?	Your Procedure
How will you analyze your data?	
Your actual data	

I approve of this investigation. ______________________ Instructor's Signature ____________ Date

STAGE 5, EXPLICIT AND REFLECTIVE DISCUSSION

In order to critique an argument, you might need more information than what is included on the whiteboard. You might need to ask the presenter one or more follow up questions such as:

- How did your group collect the data? Why did you use that method?
- What did your group do to make sure the data you collected are reliable? What did you do to decrease measurement error?
- What did your group do to analyze the data, and why did you decide to do it that way? What did you do to make sure that your calculations are correct?
- Is that the only way to interpret the results of your group's analysis? How do you know that your interpretation of the analysis is appropriate?
- Why did your group decide to present your evidence in that manner?
- What other claims did your group discuss before deciding on that one? Why did you abandon those alternative ideas?
- How confident are you that your group's claim is valid? What could you do to increase your confidence?

Once the argumentation session is complete, you will have a chance to meet with your group and revise your original argument. Your group might need to gather more data or design a way to test one or more alternative claims as part of this process. Remember, your goal at this stage of the investigation is to develop the most valid or acceptable answer to the research question!

STAGE 6: WRITE AN INVESTIGATIVE REPORT

Once you have completed your research, you will need to prepare an ***investigative report*** that consists of three (3) sections. Each section should provide an answer for the following questions:

- What question were you trying to answer and why?
- What did you do during your investigation and why did you conduct your investigation in this way?
- What is your argument?

Your report should answer these questions in two (2) pages or less. This report must be typed and any diagrams, figures, or tables should be embedded into the document. Be sure to write in a persuasive style; you are trying to convince others that your claim is acceptable or valid!

STAGE 7: PEER REVIEW

Peer review is an important part of the scientific process. All investigative reporting is subject to scrutiny by other scientists who are "experts" in the same field to determine the validity of the findings.

STAGE 8: FINAL REPORT

Use the feedback that you have received from the peer review process to modify and improve your report. Your final report will be submitted to the teacher.

OPTIONAL DATA

EVIDENCE: PART I—SEISMICITY 01/01/1984 - 12/31/2008

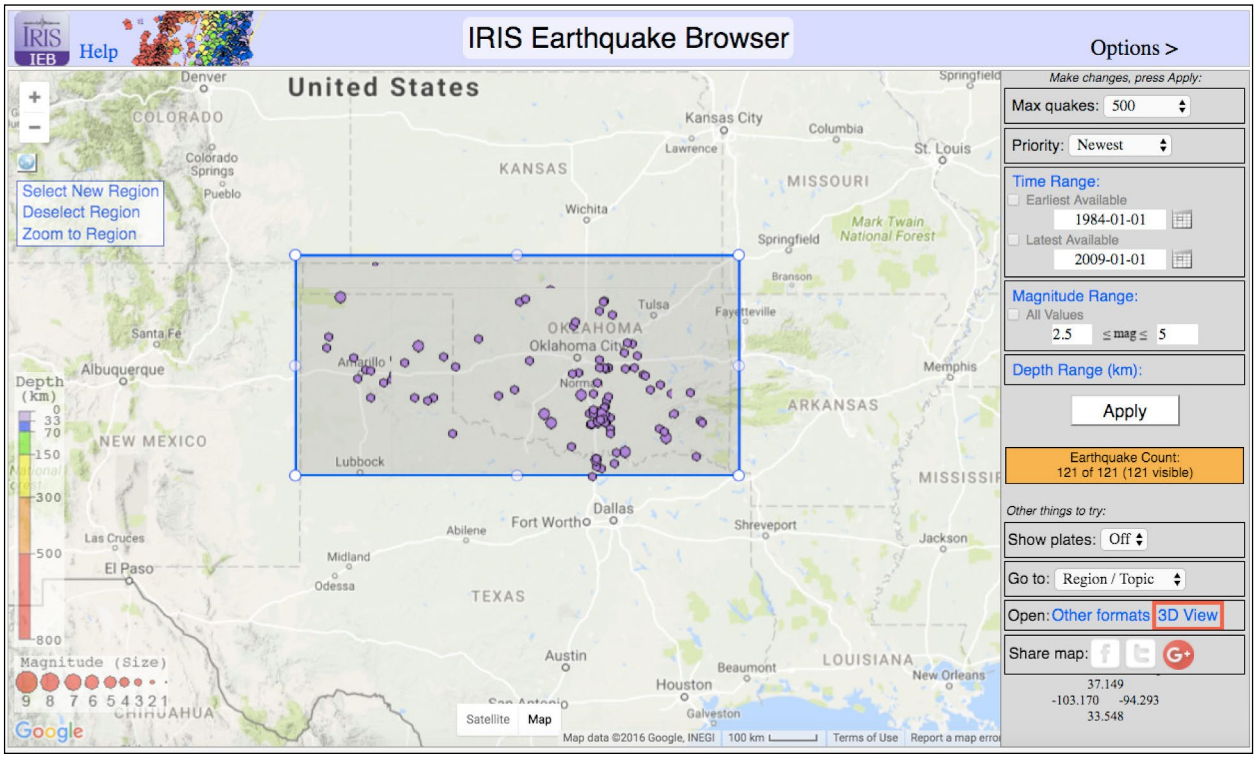

Figure 1: *For the given region, between 01/01/1984 and 12/31/2008 (~25 Years) there were 121 earthquakes between M2.5 to M4.5. View the interactive map of this data in IRIS's Interactive Earthquake Browser: http://bit.ly/2hm9xCb*

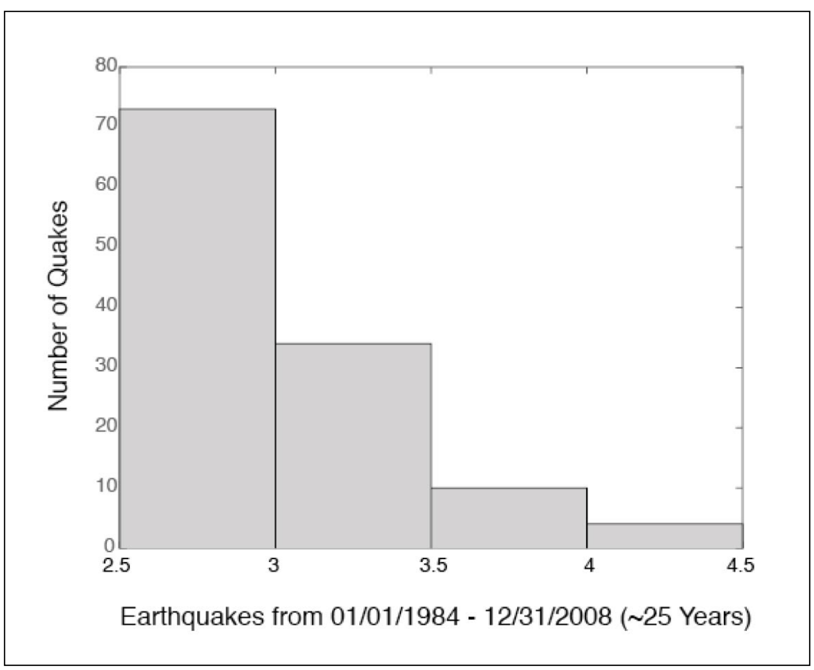

Figure 2: *Graph of Earthquakes from 01/01/1984 – 12/31/2008 (~25 Years).*

EVIDENCE: PART II—SEISMICITY 01/01/2009 - 04/01/2017

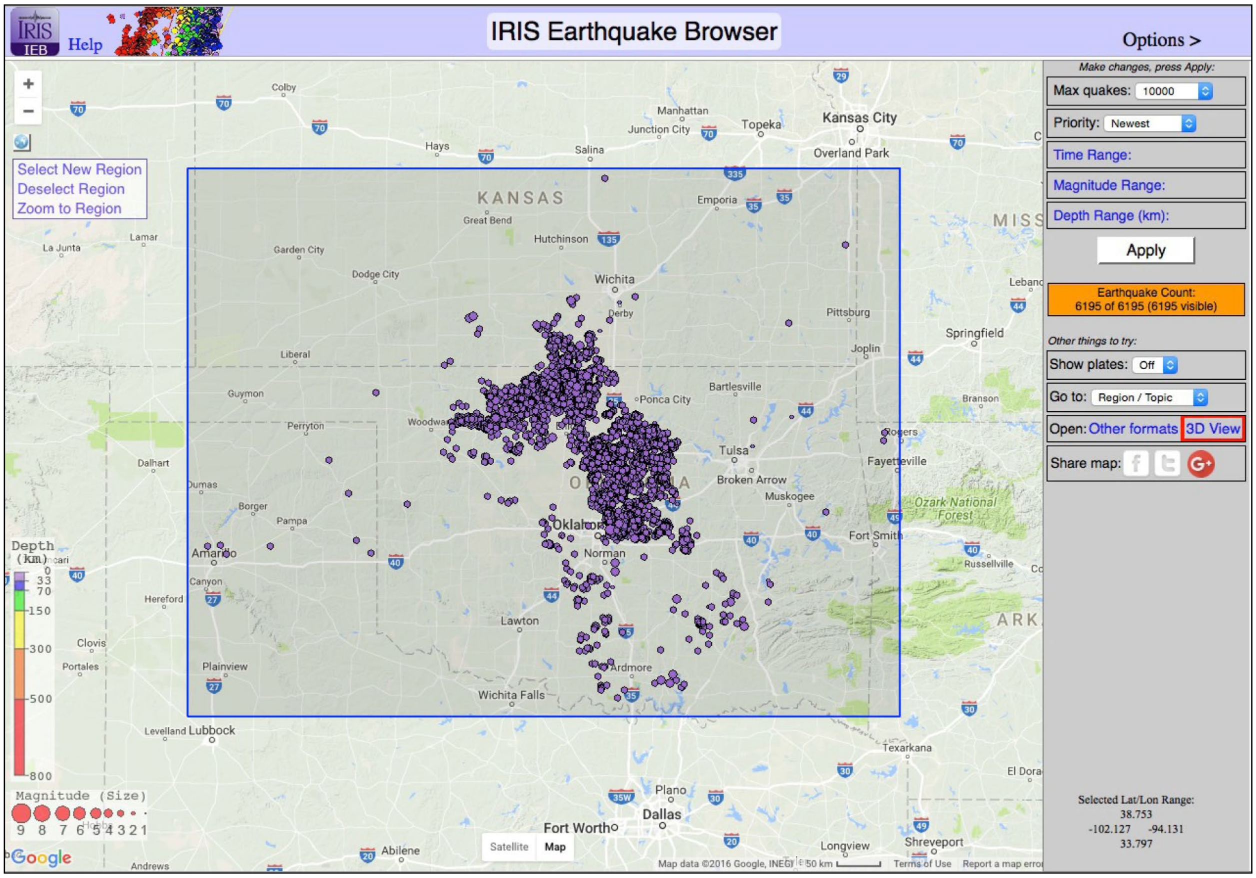

Figure 3: *For the given region, between 01/01/2009 – 04/01/17 (~7 Years) there were 6195 earthquakes. The magnitude range for these quakes was M0.8 to M5.8. View the interactive map of this data in IRIS's Interactive Earthquake Browser: http://bit.ly/OK_Gas_Boom*

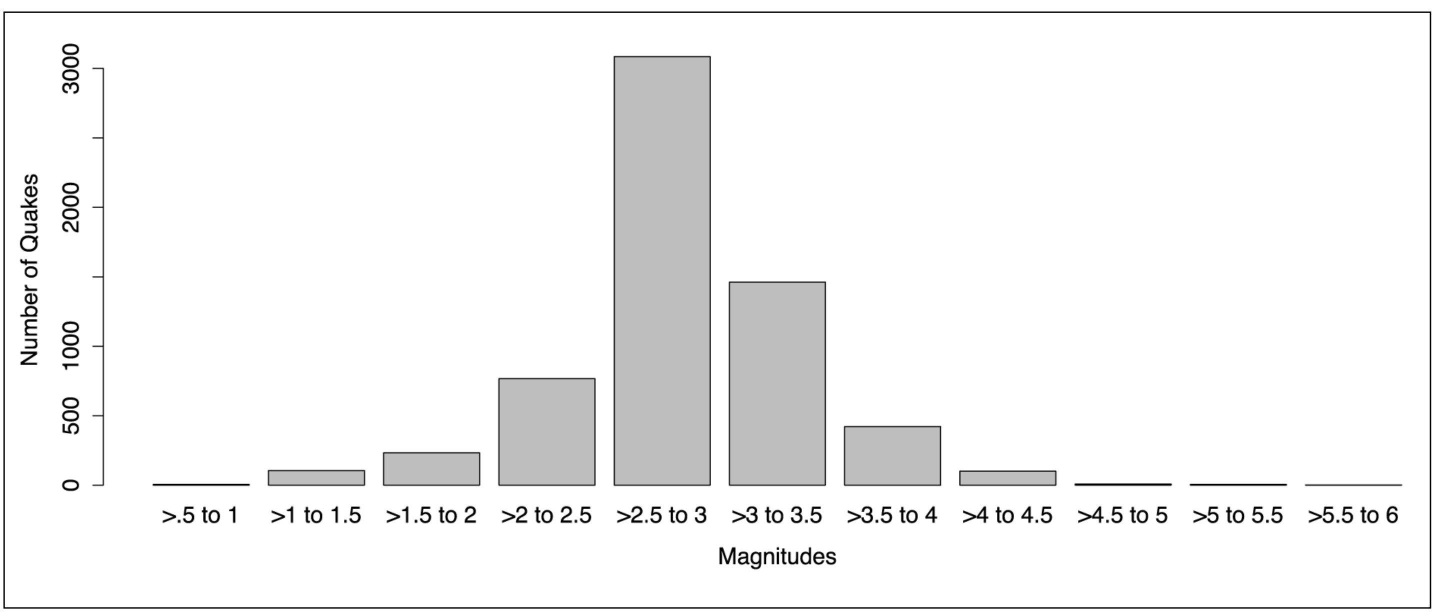

Figure 4: *Graph of Earthquakes from 01/01/2009–04/01/2017 (~7 Years).*

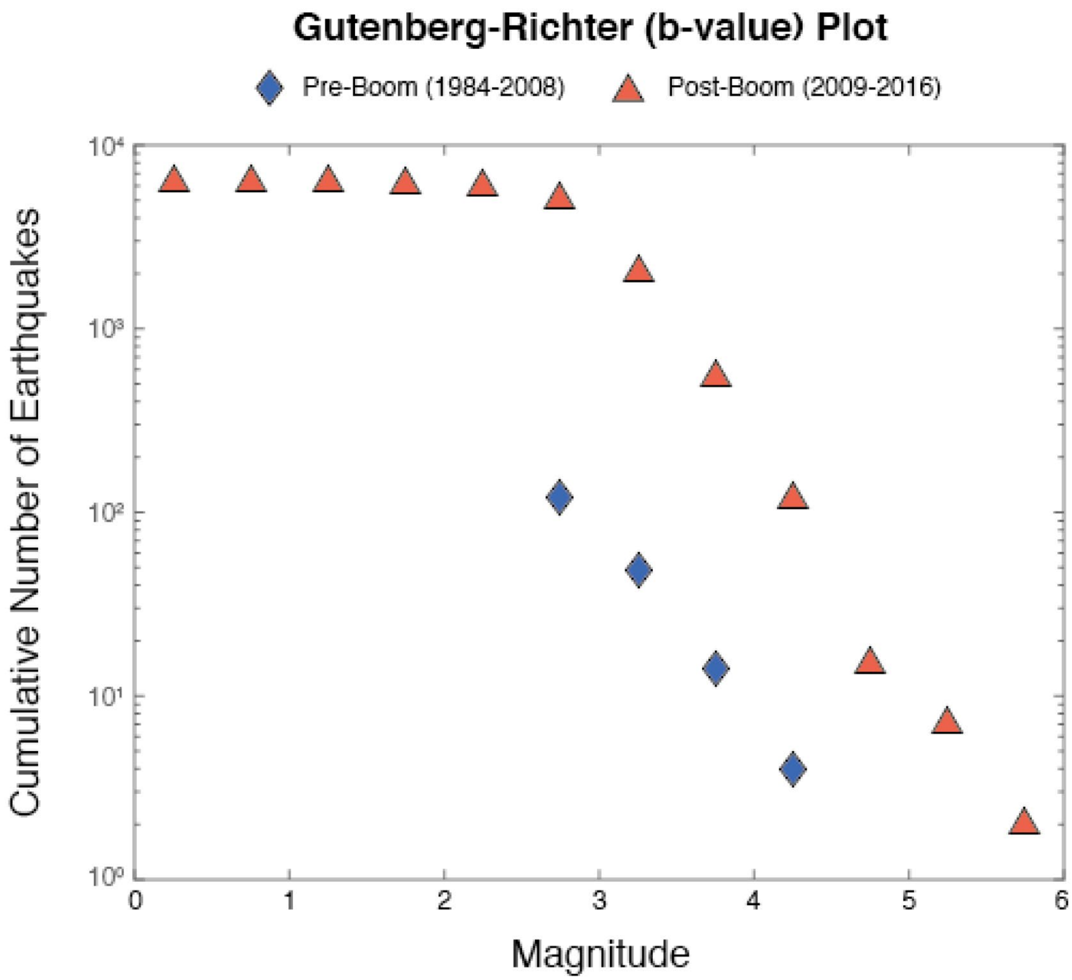

Figure 5: *The Gutenberg-Richter plot is a logarithmic graph that plots the cumulative number of earthquakes greater than or equal to a given magnitude in a set period of time (y) against that magnitude (x), to determine a basic characteristic of the seismicity rate in any given region and defined time period. The blue diamonds plot the magntude and number of background earthquakes before the drilling boom beginning in 2009.*

Note that for the x-axis data, the magnitudes, are linear in scale (though not energy output). However, the y-axis numbers change enormously, as you can see on the graph on the previous page! If we used a proportional linear scale for each axis, the y-axis would be huge, while the x-axis would be miniscule! Thus if you plan to graph your data, you will need a log-linear graphing template.

EVIDENCE: PART III—HYDROFRACKED WELLS IN OKLAHOMA FROM 2009 TO 2012

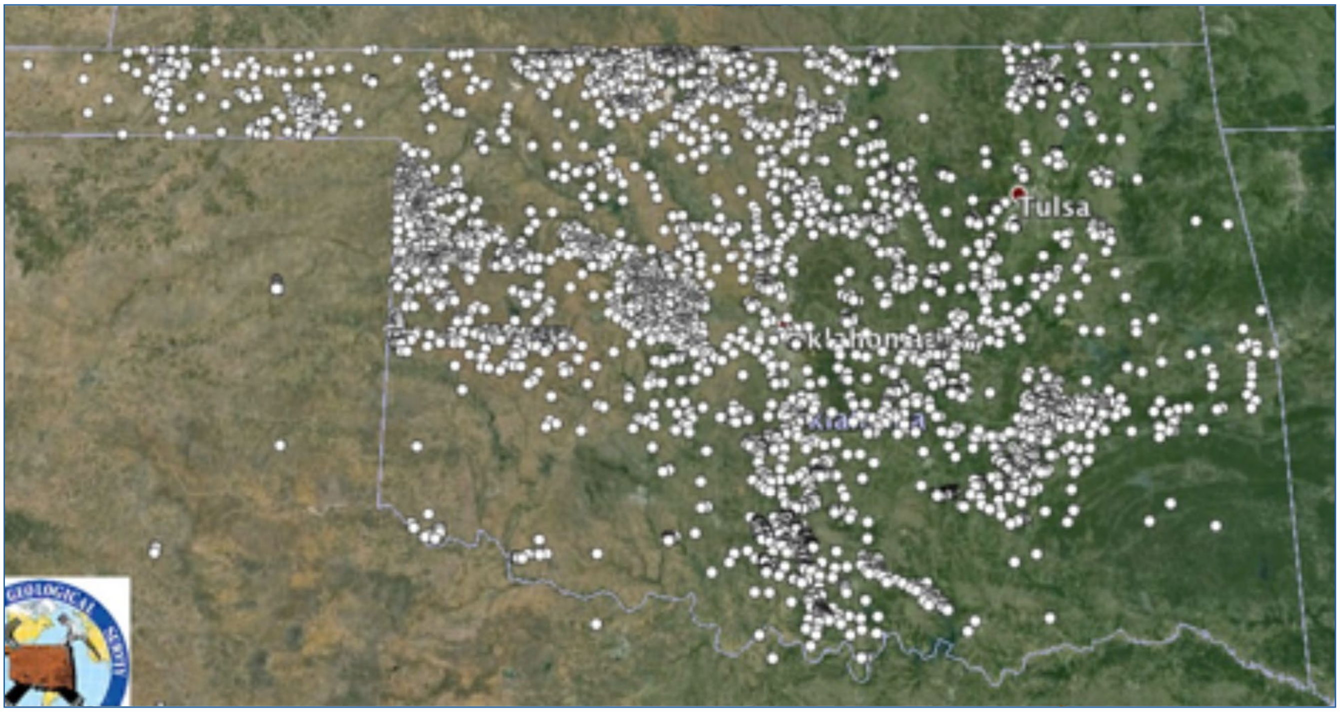

Figure 6: *Hydrofracked well sites in Oklahoma from 2009 to 2012.*

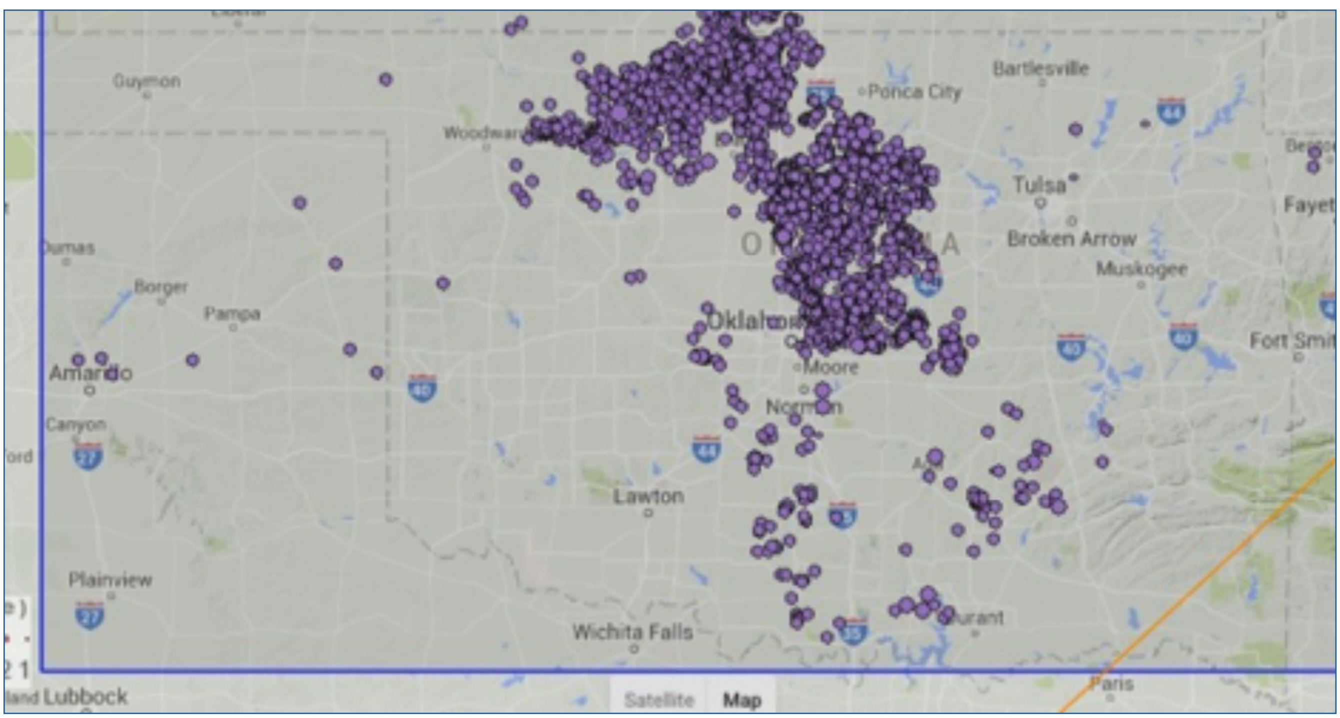

Figure 7*: Earthquakes from 2009 to 04/01/2017.*

EVIDENCE: PART IV—DEEP INJECTION WELLS OF WASTEWATER IN OKLAHOMA FROM 2010 TO 2012

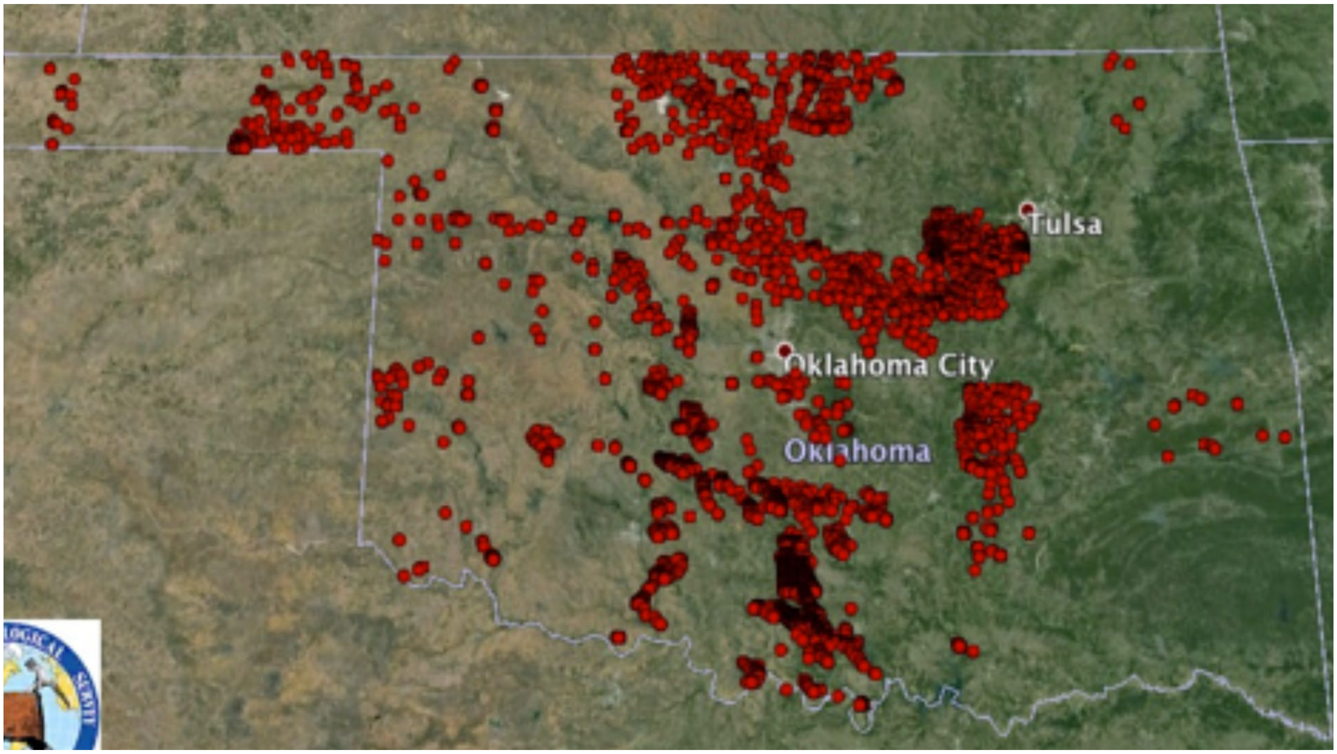

Figure 8*: Wastewater Injection wells from 2010 - 2012.*

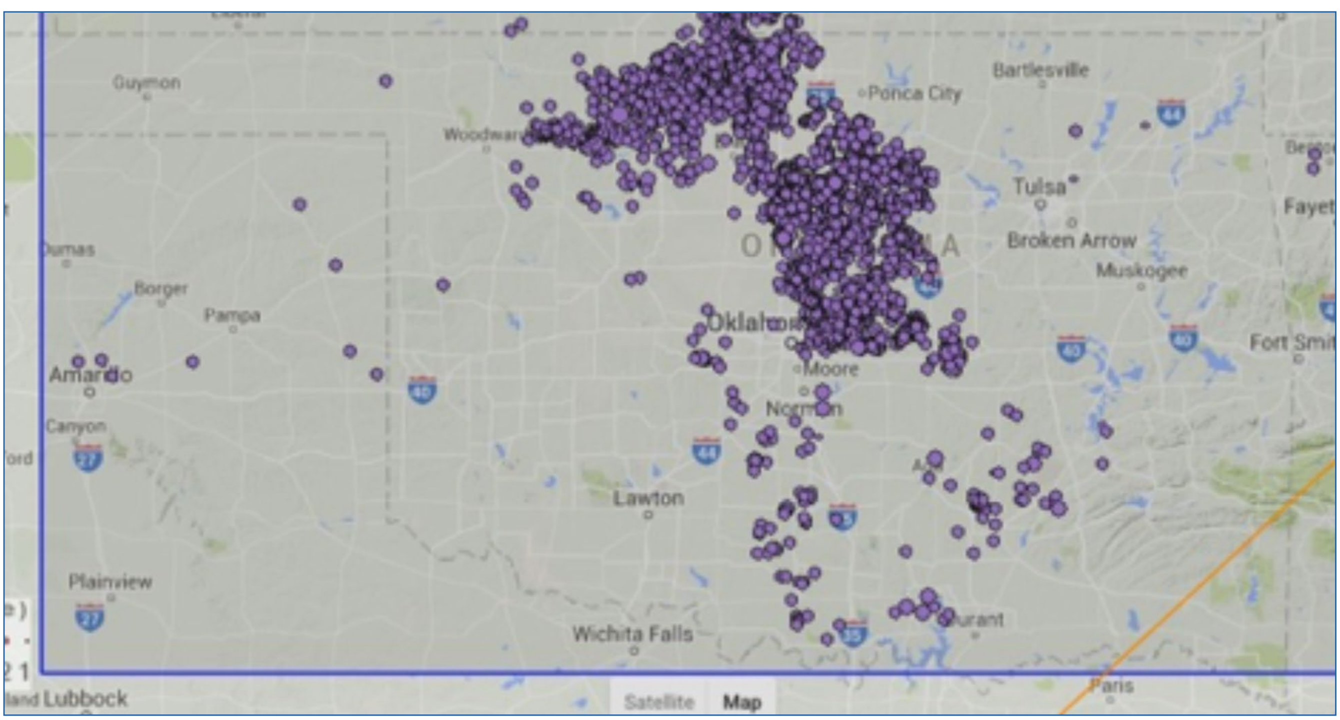

Figure 9: *Earthquakes from 2009 to 04/01/17.*

EVIDENCE: PART V—OKLAHOMA POPULATION DENSITY

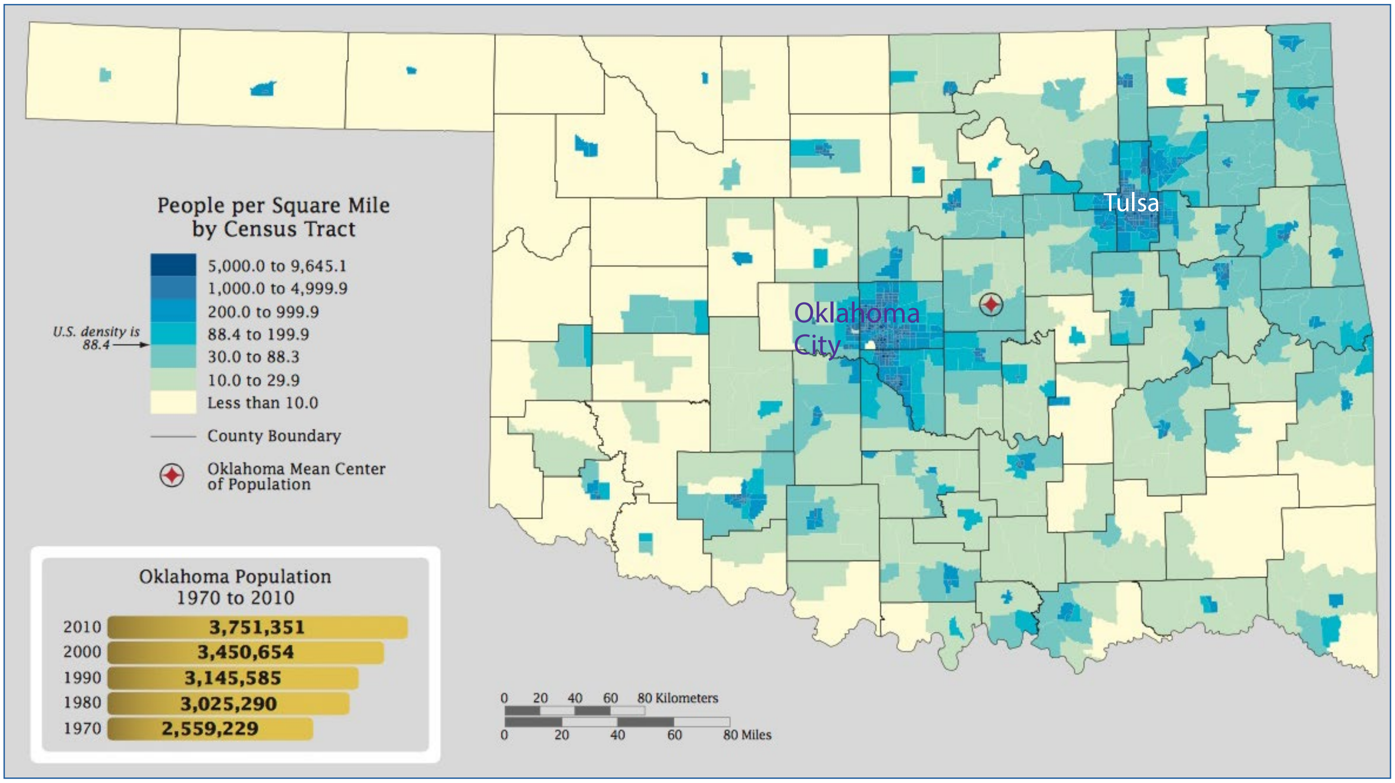

Figure 10: *Oklahoma population density based on 2010 census data. Modified from:*
http://www2.census.gov/geo/maps/dc10_thematic/2010_Profile/2010_Profile_Map_Oklahoma.pdf

EVIDENCE: PART V—INTERPRETIVE FAULT MAP OF OKLAHOMA

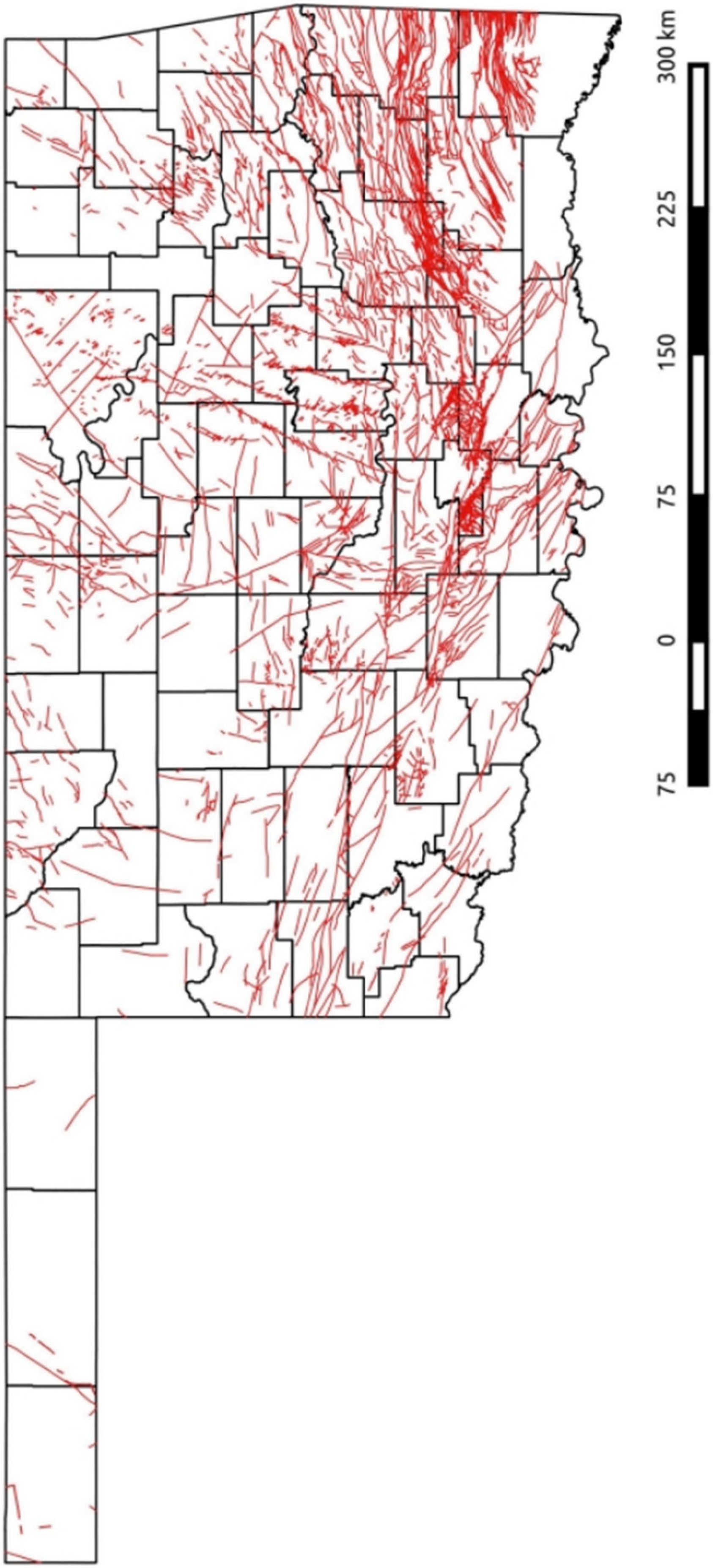

Figure 11: *Source: OF2-2016. Comprehensive Fault Database and Interpretive Fault Map of Oklahoma, by Stephen Marsh and Austin Holland. 2 plates with supplement. 15 pages. 2016.* [*http://www.ou.edu/content/ogs/data/fault.html*](http://www.ou.edu/content/ogs/data/fault.html)