



# Defining an Earthquake and Exploring Earthquakes far from Plate Boundaries



?

?

?

?

?

# ***What is an Earthquake?***

?

?

?

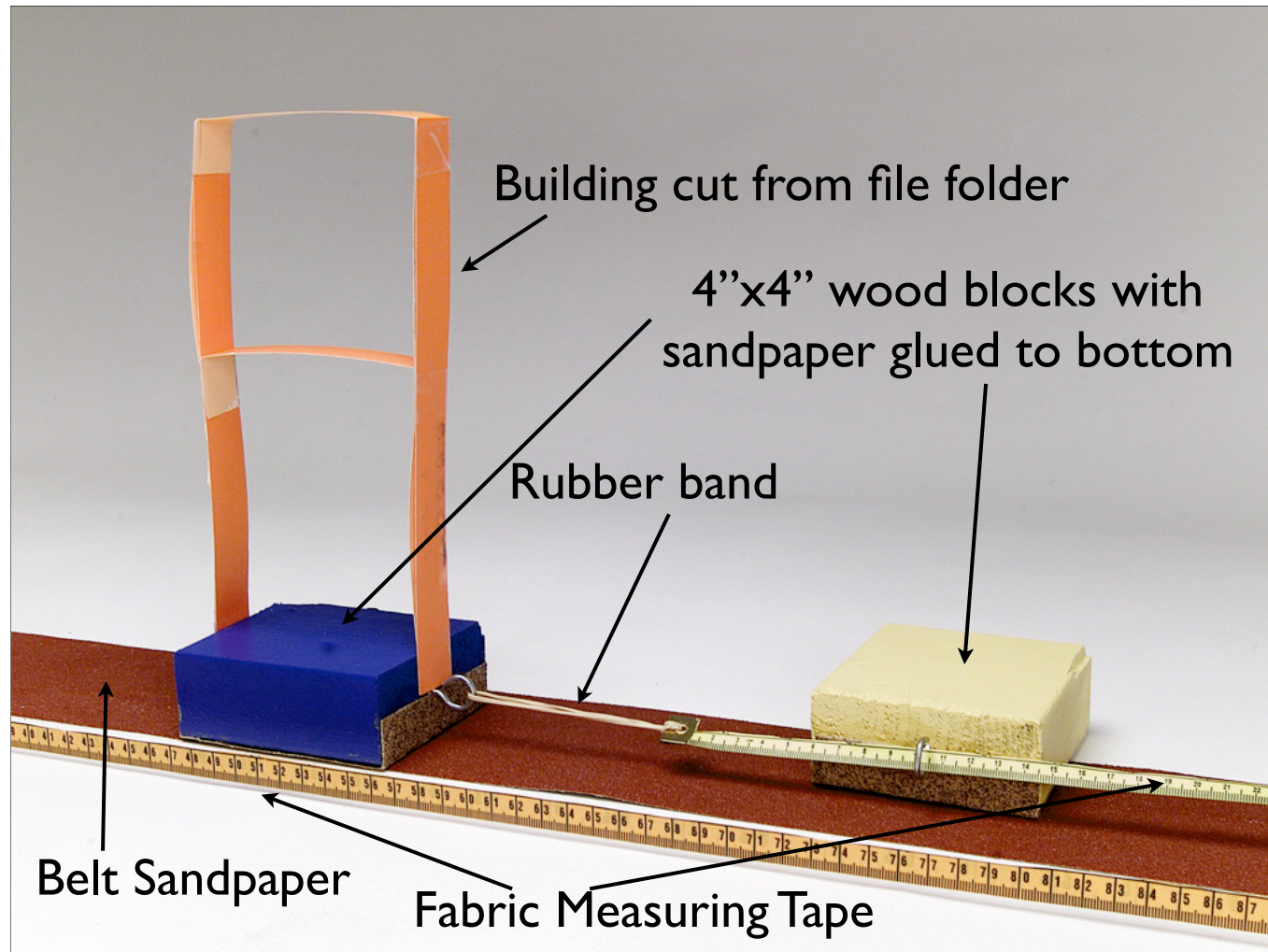
?

?

Create a description with a partner

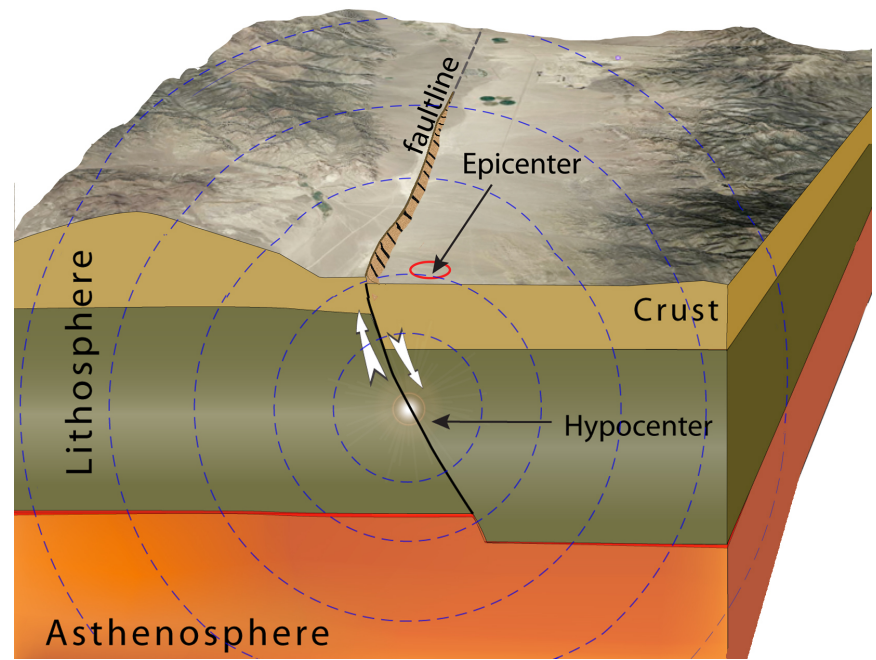
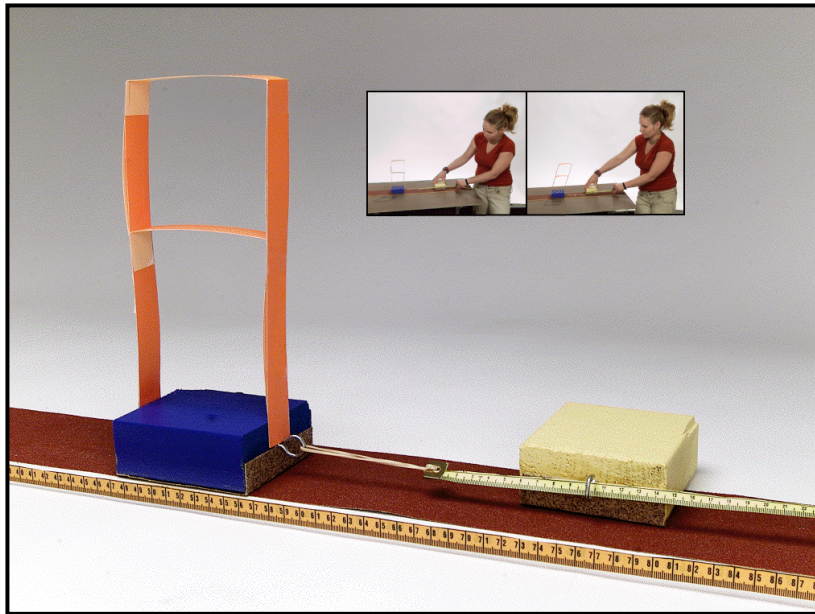


# Earthquake Machine



# Like and Unlike

An earthquake is the sudden motion of rocks within the Earth as stored elastic energy is released.



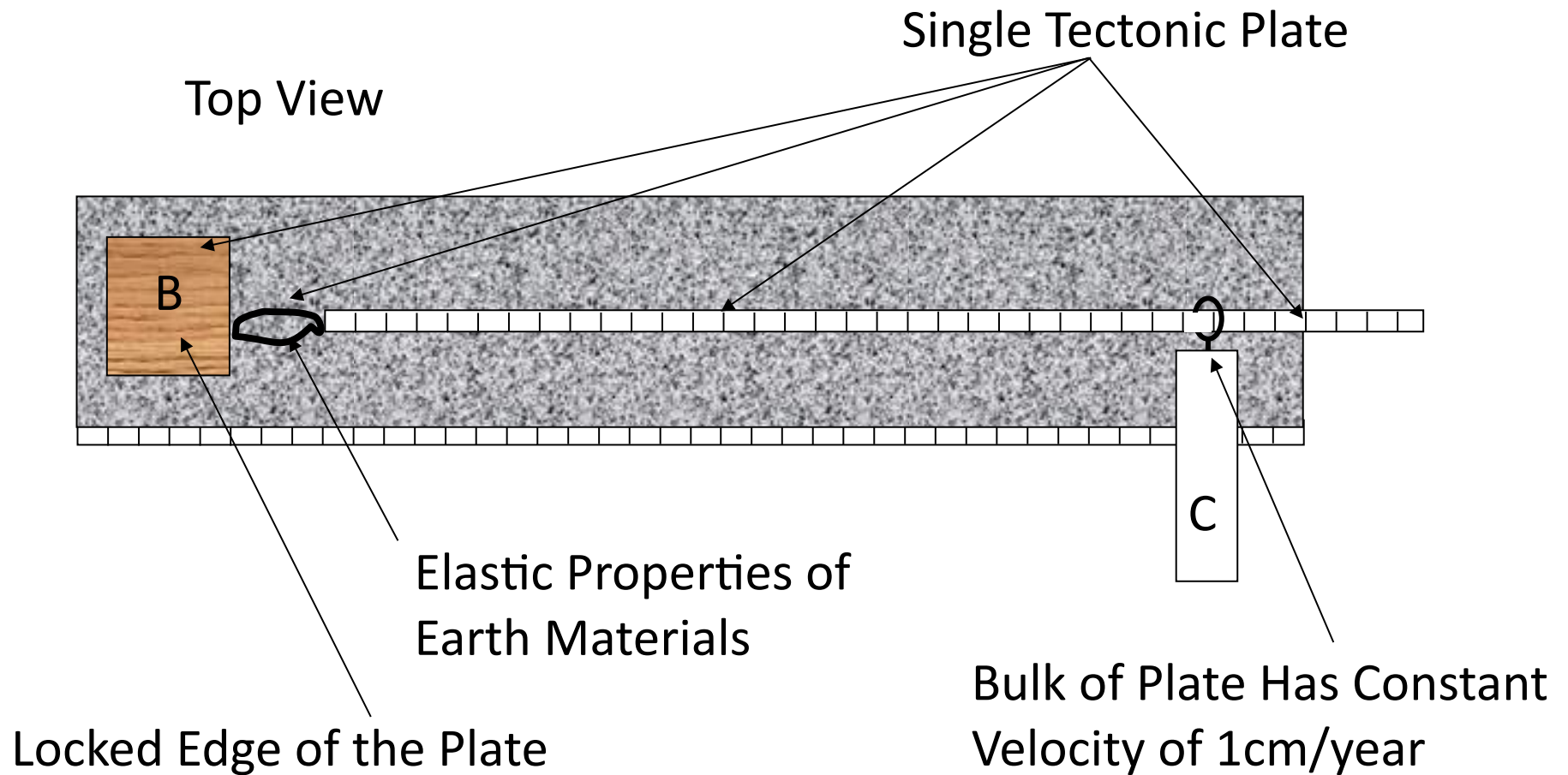


Energy in the model comes from you.

*Where might this same energy come from  
in the Earth system?*

Think - Pair - Share

# Earthquake Machine Properties



# Elastic Rocks

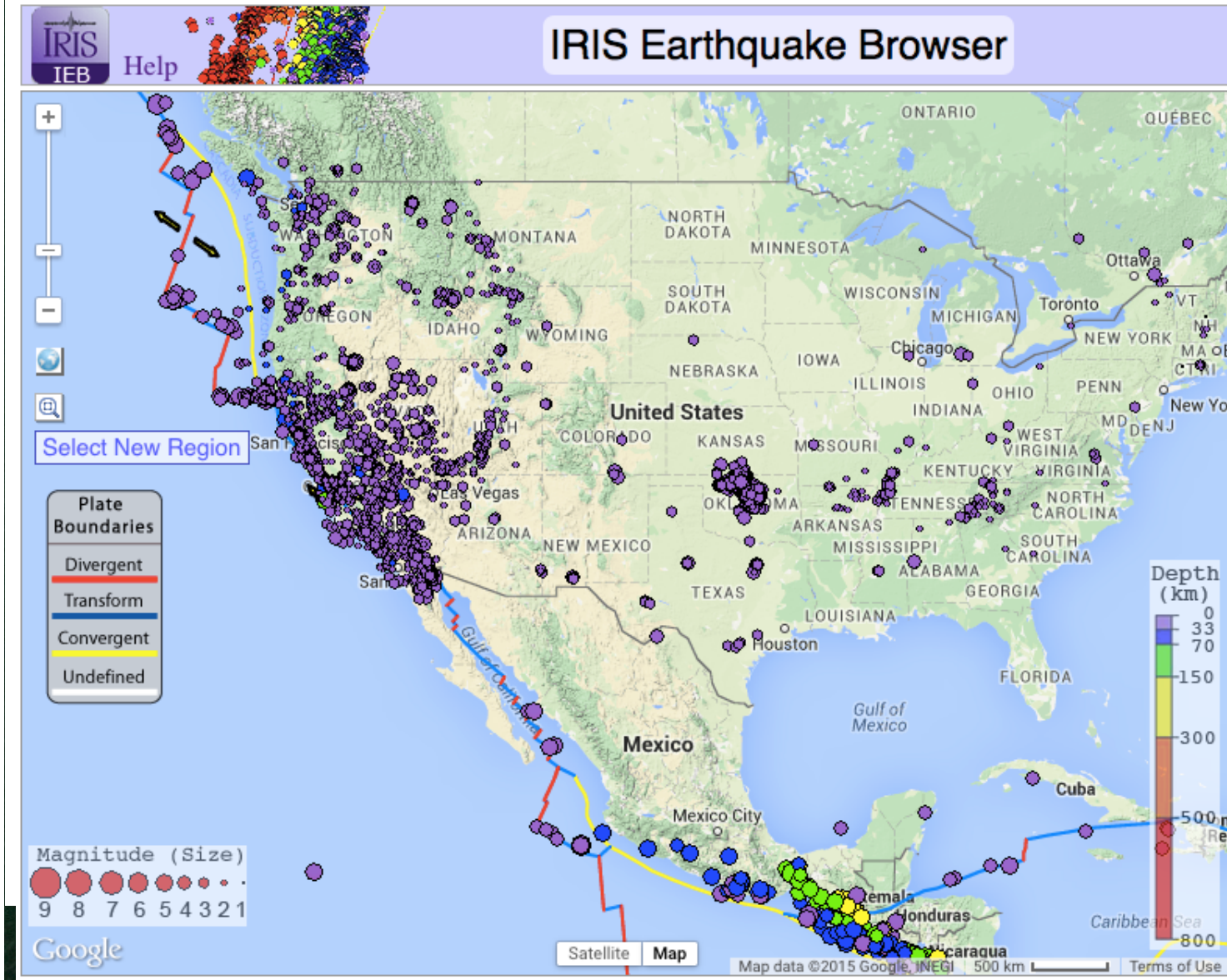
- Already talked about rocks being elastic for seismic waves to travel through them
  - Small quick motions
- How can energy be stored in rocks?
- How does energy released relate to earthquake magnitude?
  - [http://www.iris.edu/hq/programs/education\\_and\\_outreach/animations/26](http://www.iris.edu/hq/programs/education_and_outreach/animations/26)

*How could you modify the model so that it no longer stored energy?*

*Based on this (and assuming superhuman powers, perhaps) what would you change about Earth to prevent all future earthquakes?*



# Exploring earthquakes away from a plate boundary



[ds.iris.edu/ieb/](https://ds.iris.edu/ieb/)

# Exploring earthquakes away from a plate boundary

- *Use the Earthquake Browser to look for evidence to answer the question: Do earthquakes occur in Minnesota?*
  - First look at US as a whole, then zoom into Minnesota
  - Look at both the map view, 3D view, and the table list
  - What is the biggest event in the catalog?
  - Could some or all of the events on the map and in the table be something other than earthquakes?
  - Why or why not?

# Oklahoma earthquakes

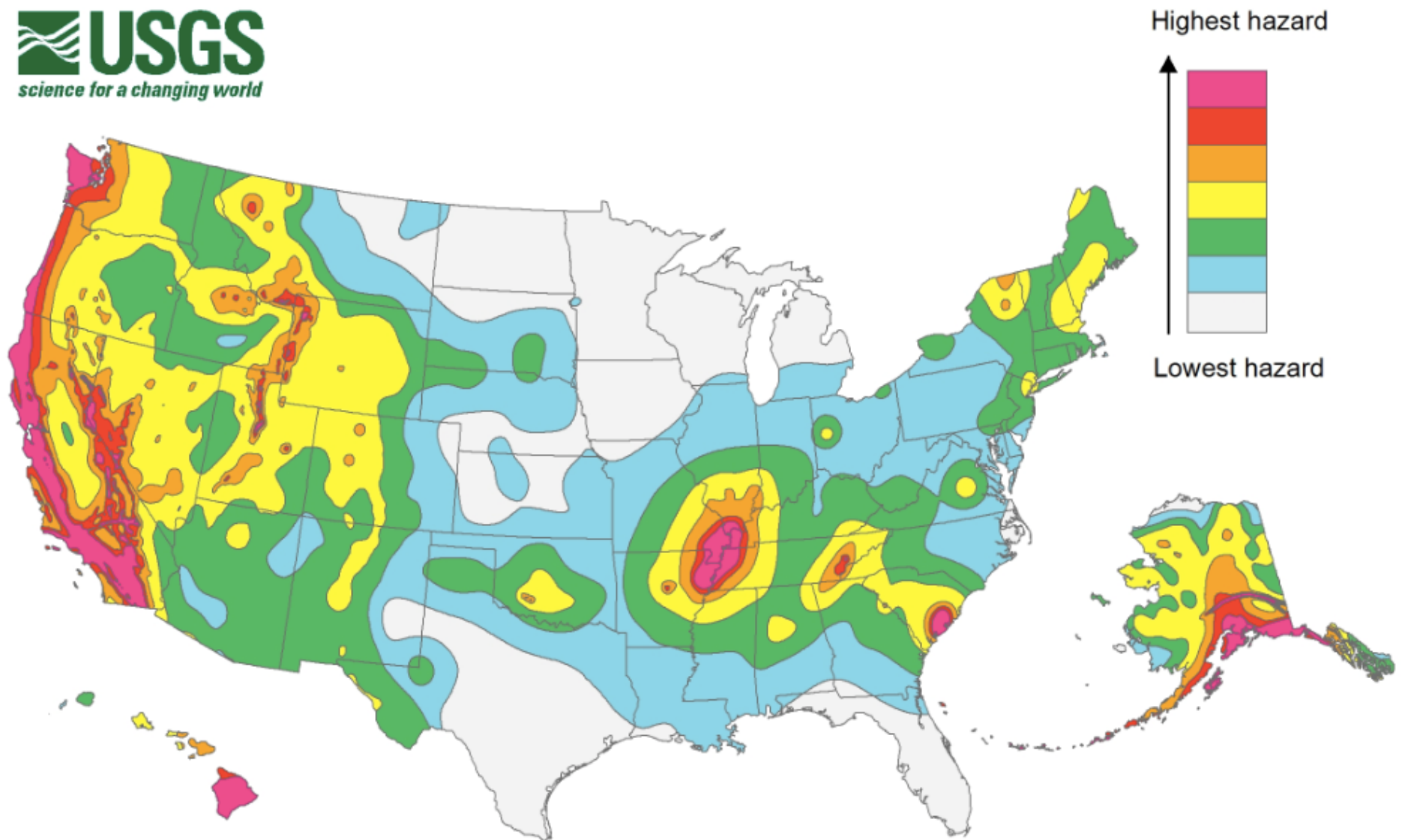
- *How do the events on the map in Oklahoma compare to the events in Minnesota?*
  - Look at both the map view and the table list
  - Could some or all of the events on the map and in the table be something other than earthquakes?
  - Why or why not?
  - Now compare the time periods
    - 1995-01-01 to 2005-01-01
    - 2005-01-01 to 2015-01-01
  - What might explain the difference?

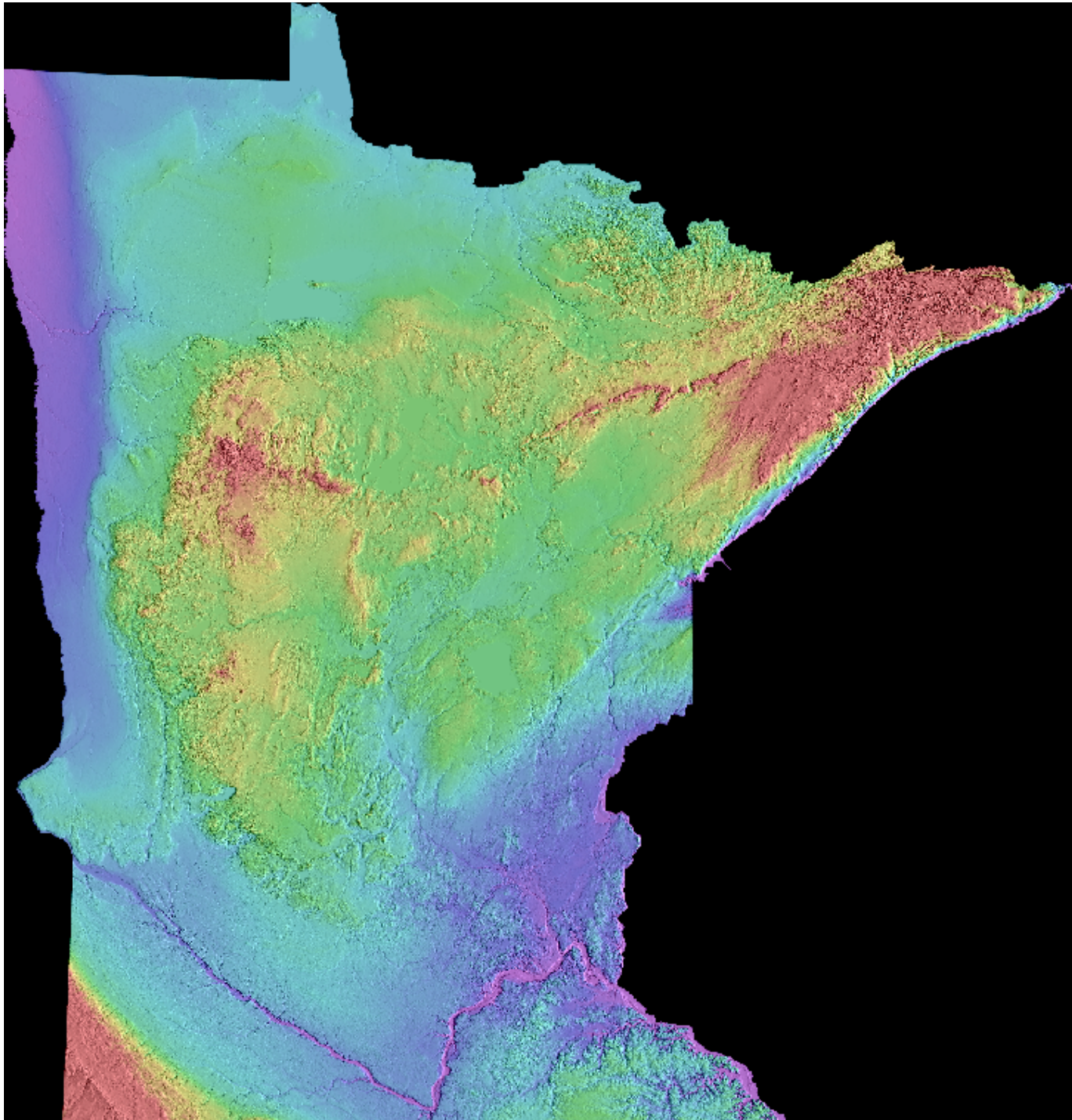


# Oklahoma earthquakes

- *Most recent earthquakes have probably been induced by injection of waste water into deep wells*
- *However most waste water disposal wells don't cause earthquakes*
- *90% of injected waste water in Oklahoma comes from unconventional wells with a high water/oil ratio*
- *Only 10% comes from disposal of hydrofracking fluids*

# Seismic hazard in the US

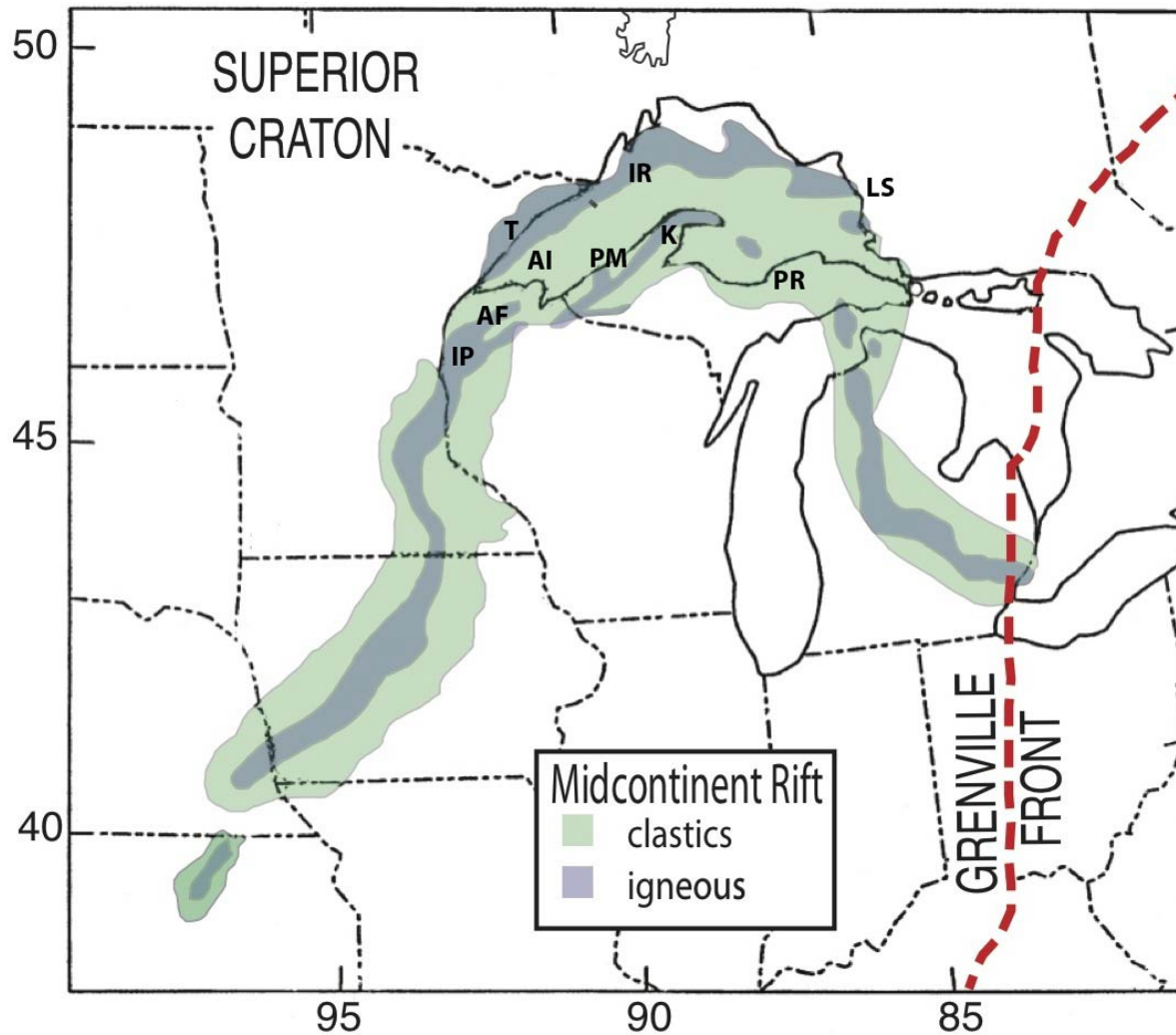




Topography  
controlling  
iron deposits



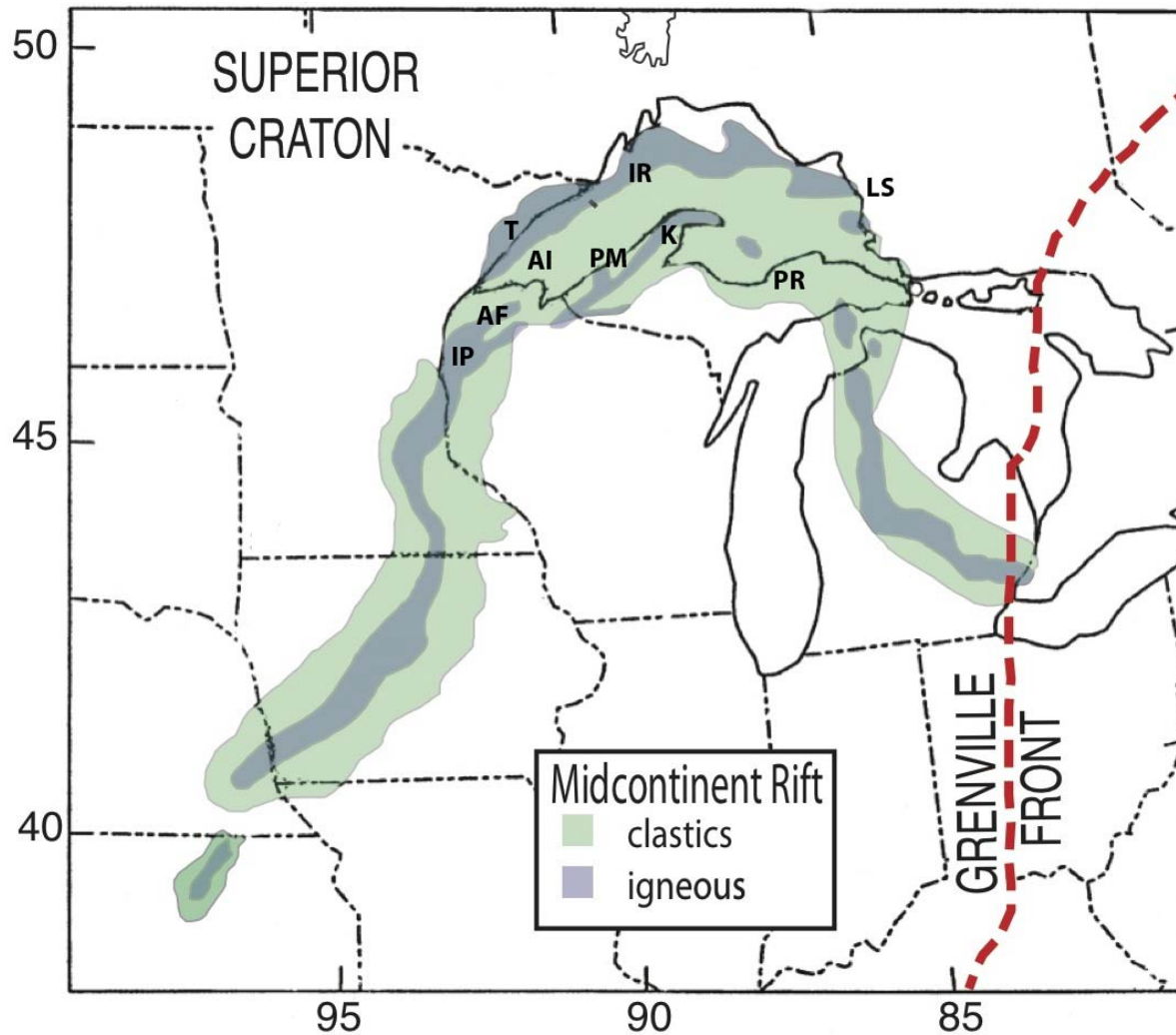
# Mid Continent Rift



The Midcontinent Rift System (MCRS), is a 1.1 billion year old 3000 km (1800 mile) long scar along which the North American continent started to tear apart, just as Africa is splitting today along the East African Rift, but for some reason failed to form a new ocean.

The MCRS also provided mineral deposits that shaped the region's settlement and growth.

# Mid Continent Rift

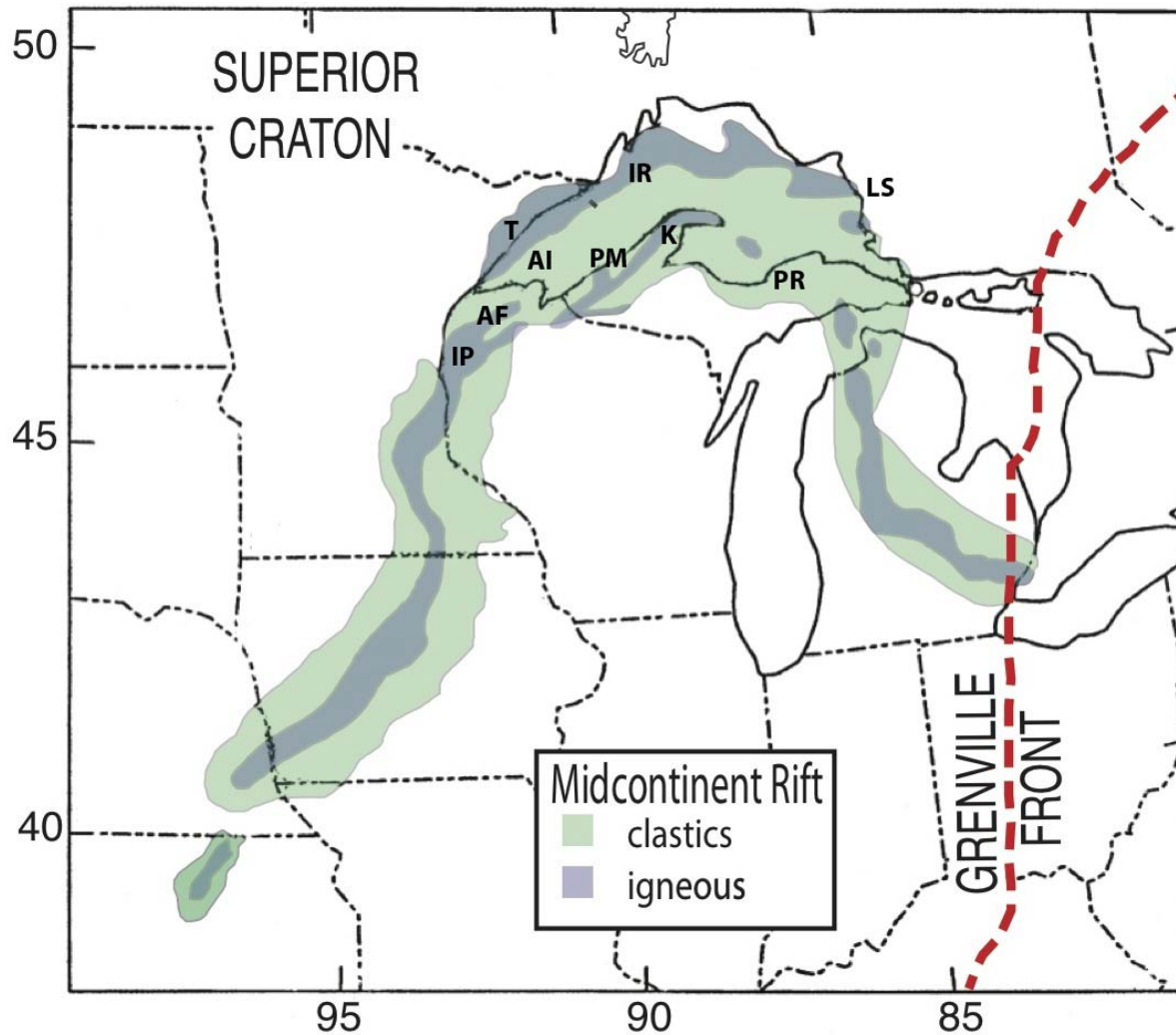


The Midcontinent Rift System (MCRS) or the Keweenaw Rift is a 1800-mile (3000-kilometer) long belt of igneous (volcanic) and sedimentary rock).

The rift system has two major arms meeting in the Lake Superior region (Hinze et al., 1997; Ojakangas et al., 2001).

One extends southwestward at least as far as Oklahoma, and the other extends southeastward through Michigan to Alabama

# Mid Continent Rift



Despite the rift's size, most visitors don't know about it, because these rocks are mostly covered by sediments and sedimentary rocks younger than those of the rift. They appear at the earth's surface only near Lake Superior.

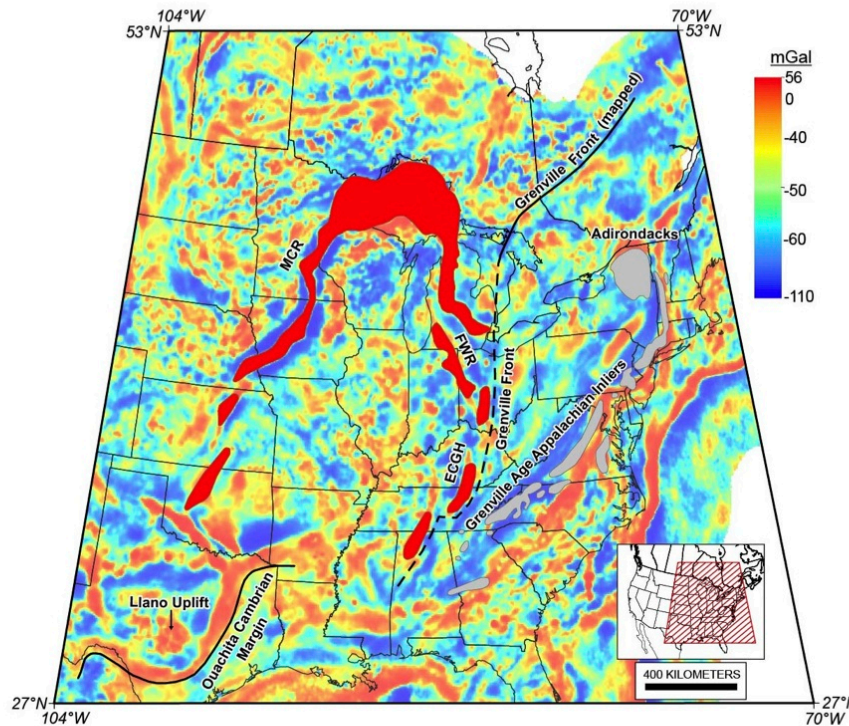


## Gravity studies

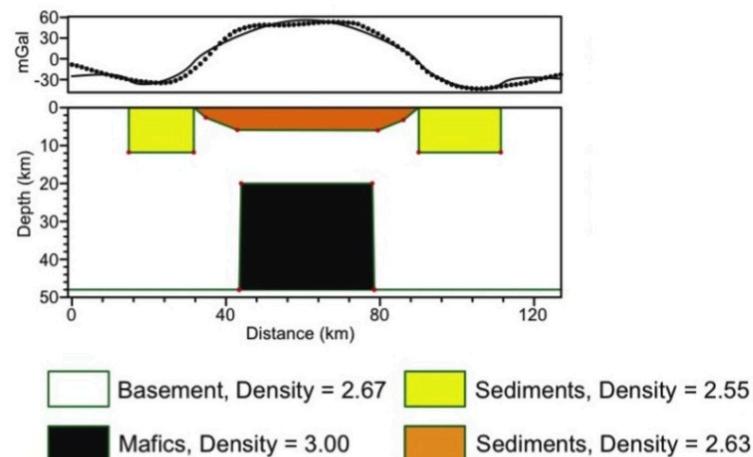
Geologists combine what they learn from the exposed rocks with clever techniques that “see” the hidden parts of the rift. One technique uses very accurate measurements of gravity and magnetism. The buried volcanic rocks contain lots of iron, and so are denser and more magnetic than the surrounding rocks.

Gravity and magnetic surveys have mapped a huge thickness – up to 15 miles or 25 km - of volcanic rocks, so the entire rift system has about 240,000 cubic miles (a million cubic kilometers) of volcanic rocks. This is 44 times the volume of all the Great Lakes combined!

Stein et al.,  
2014a



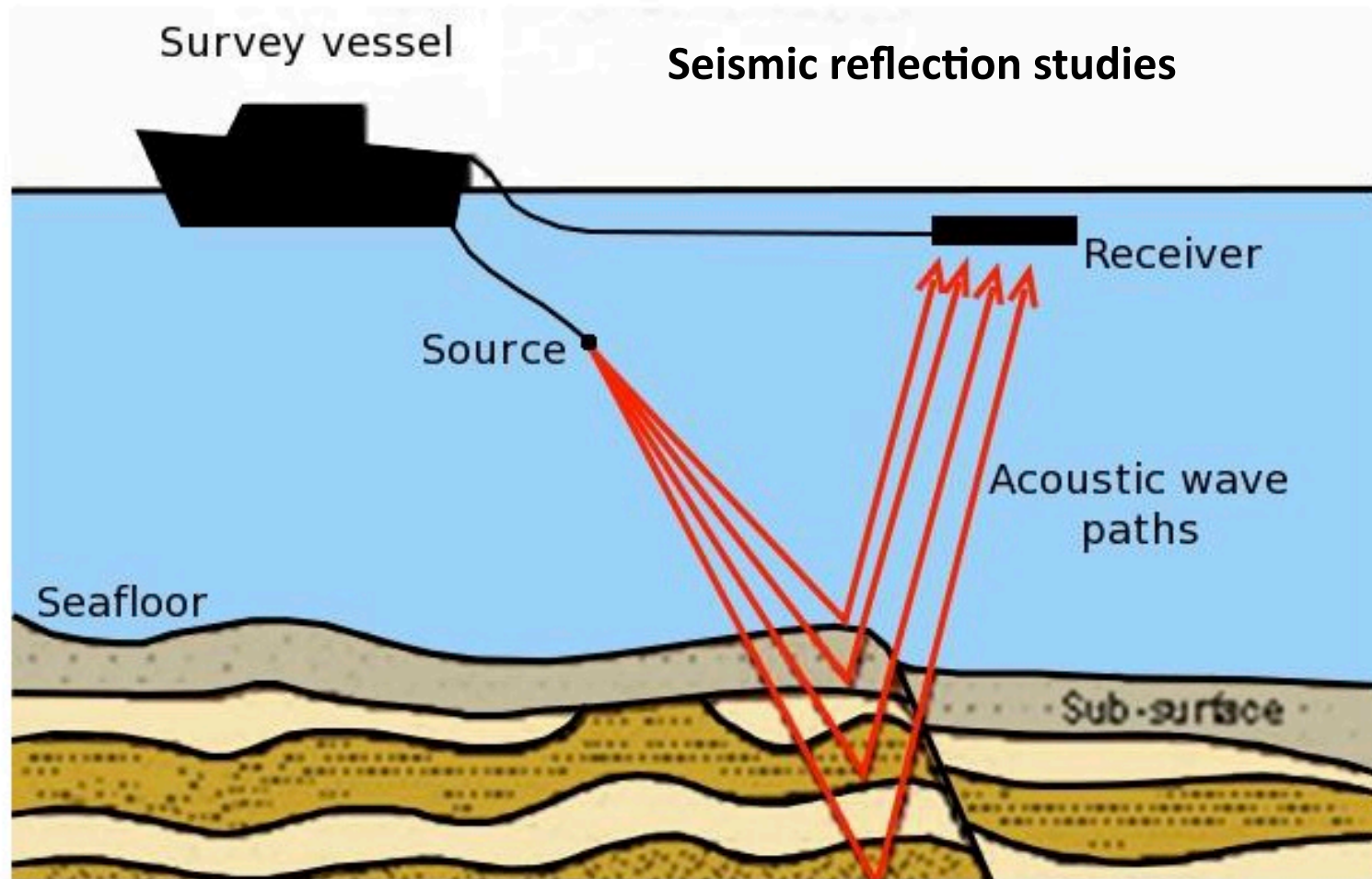
Merino  
et al.,  
2013



Stein et al: MCR for interpreters

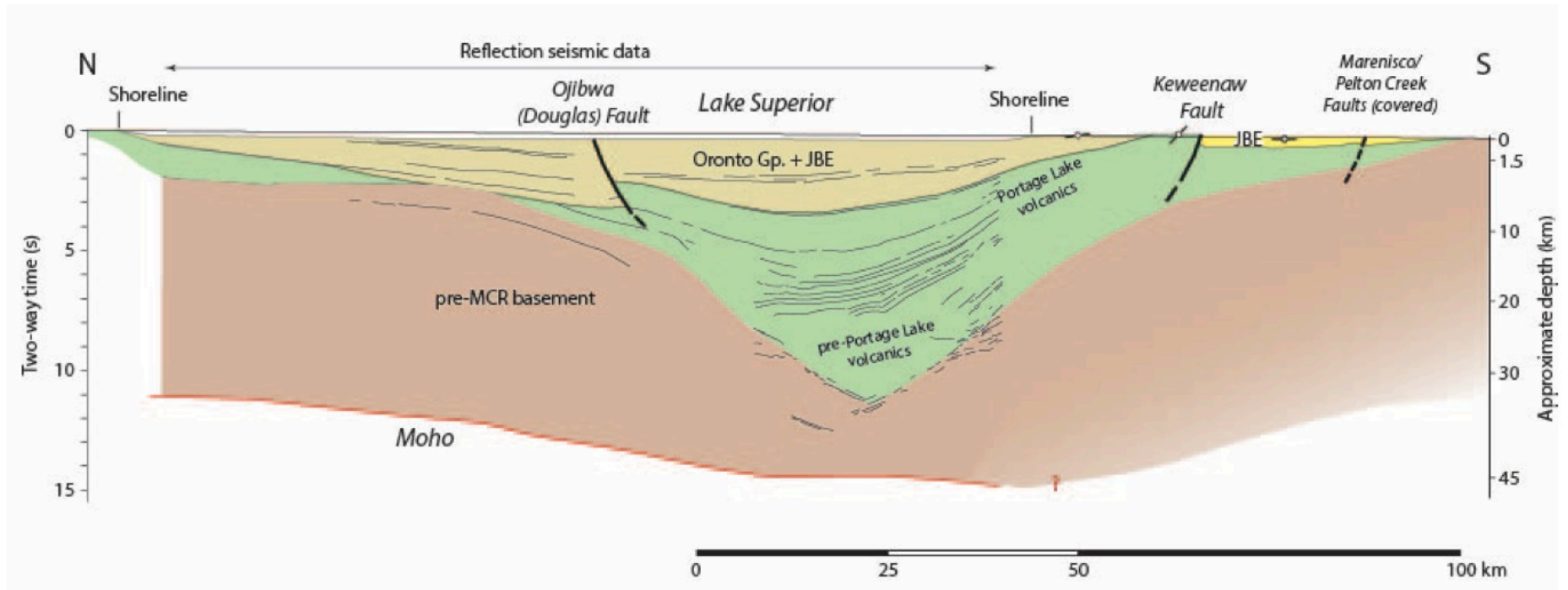
## Seismic reflection studies

Univ. of  
Southampton



Other methods use seismic waves to “see” at depth. This method, which is also used to find oil and natural gas deposits, is like the way doctors use X-rays. Surveys across Lake Superior used waves generated by a towed sound source that traveled downward, reflected off interfaces at depth between different rocks, and were detected by seismometers. The resulting seismograms were used to generate an image of the rocks at depth.

## Geology under Lake Superior from seismic section



A north-south cross section shows a deep depression under Lake Superior filled by layers of volcanic rocks and overlying sediments to a depth of 30 km (18 miles), which is much deeper than Lake Superior's average depth of about 150 m (500 feet).

This structure is called a syncline, in which the volcanic rocks on the north side – as seen at Isle Royale – dip southward toward the center of the lake, whereas those on the south side – as seen at Porcupine Mountains - dip to the north.