Mapping Earthquake Intensity

Lesson Plans and Activities

By Polly R. Sturgeon

Targeted Age:
High school

Activity Structure:
Individual activity

Indiana Standards and Objectives:
9-10.LST.1.1, 9-10.LST.2.3, 9-10.LST.3.1, 9-10.LST.4.1, ES.6.7, 11-12.LST.1.1, 11-12.LST.2.3, 11-12.LST.3.1, 11-12.LST.4.1, Env.3.4

MATERIALS NEEDED

- Pencil
- Colored pencils
- Modified Mercalli Intensity (MMI) Scale

Introduction

In this lesson, students will classifiy and plot historical earthquake reports to produce an isoseismal map. Students will analyze historical isoseismal maps and discuss the response of surficial materials to seismic waves.

Vocabulary

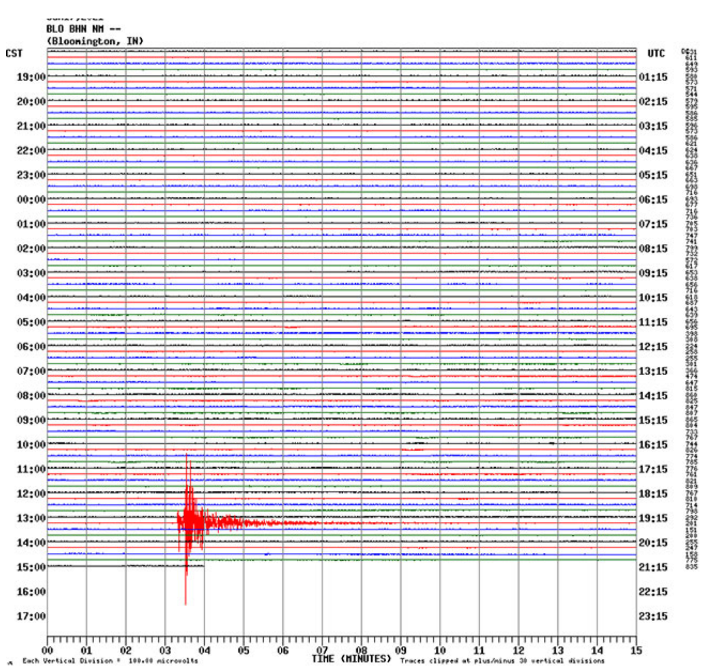
Earthquake – the shaking or vibration of the ground surface in response to the sudden release of energy caused by fault movement
Intensity – a measurement of the severity of shaking during an earthquake and its effects on citizens and structures in and around specific locations
Isoline – a map symbol along which there is a constant value, such as isobars (barometric pressure), isotherms (temperature), or contour lines (elevation)
Isoseism – an isoline that encloses locations with the same level of shaking intensity
Magnitude – a measurement of seismic energy released during an earthquake
Modified Mercalli Intensity Scale – a qualitative ranking system that describes the severity of shaking in specific locations during an earthquake

Background Information

The outer crust of the Earth is divided into several large tectonic plates. Driven by convection currents that permit heat to escape the Earth's interior, these plates move at a rate of 0.5 inch to 4 inches per year. The movement of tectonic plates creates stresses within the Earth's crust and can cause the crust to fracture. The area of contact between two fractured crustal masses is called a fault, and earthquakes occur when a fault suddenly moves and releases energy.

Studies show that the crust under the central United States was torn apart, or rifted, about 600 million years ago. This rift did not completely separate the crust into individual plates, but it did create zones of weakness (faults) in the Mississippi River Valley region. Earthquakes that have occured in Indiana within the past 200 years are caused by these now-deeply buried faults. Most of Indiana's faults are in the southwestern corner of the state. These faults extend into eastern Illinois and northern Kentucky, and are collectively known as the Wabash Valley Fault System. Because the crust is weak in this area, the faults are likely candidates for future movement. Scientists study historical earthquakes that have occurred in the central United States in order to better assess the region's hazards and understand the likelihood of future quakes.

There are two methods of measuring an earthquake: magnitude and intensity. Magnitude (M) is a measurement of the energy released at the source of an earthquake. When a fault suddenly moves, energy is released and radiates through the Earth in a series of waves, much like ripples in a pond. Scientists measure the amount of energy released during an earthquake with sensitive instruments called seismographs. A seismograph records the differential motion between a free mass and a supporting structure that is anchored into the ground. When a seismic wave travels underneath a seismic station, a mechanical or electrical signal is sent to the seismograph, and a recording device produces an amplified record of the horizontal and vertical ground motions. This record is called a seismogram, and scientists use these readings to determine the magnitude of the earthquake at its source, the general direction of the seismic waves, and the nature of the wave motion.



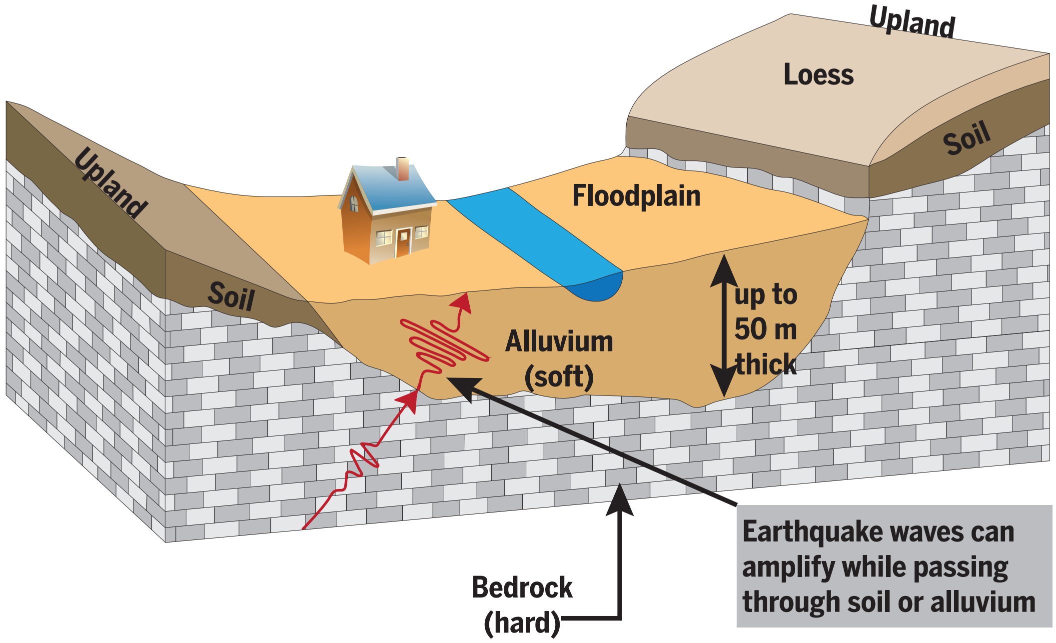
Seismogram showing the M3.8 earthquake that occurred June 17, 2021 near Bloomingdale, Indiana. This seismogram was recorded by the Indiana University seismograph station in Bloomington (BLO).

Intensity is a measurement of the severity of shaking during an earthquake and its effects on citizens and structures in and around a specific location. Unlike the mathematically-derived magnitude scale, intensity is a qualitative measurement that is based upon citizen responses that are matched to the Modified Mercalli Intensity (MMI) Scale. The MMI Scale is composed of increasing levels of intensity that range from imperceptible shaking to catastrophic destruction. In the United States, citizens report their observed effects using the the U.S. Geological Survey's "Did You Feel It?" website. Scientists evaluate these responses and assign an MMI value to a specific site. Because of the localized nature, intensity can be a more meaningful measure of earthquake severity than magnitude because it describes the observed effects experienced in specific areas.

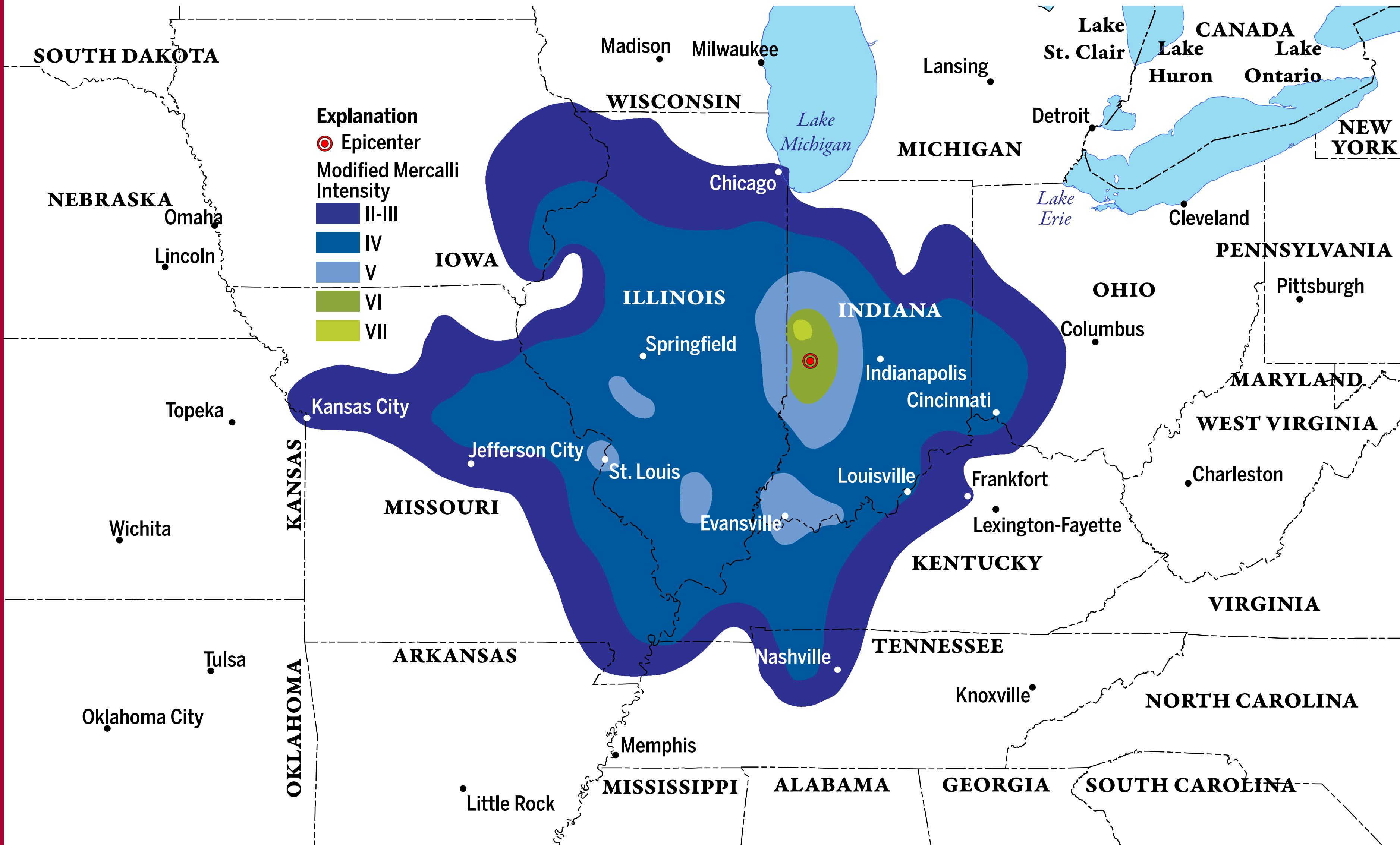
Modified Mercalli Intensity (MMI) Scale		
Intensity	**Shaking**	**Description**
I	Not felt	Not felt by most people.
II	Weak	Felt only by a few people at rest.
III	Weak	Felt by many people indoors, although not often recognized as an earthquake. Vehicles may sway; vibrations felt like that of a passing truck.
IV	Light	Felt by a few people outdoors and most indoors. Vehicles at rest noticeably moving. Dishes, windows, and doors disturbed.
V	Moderate	Felt by nearly all people regardless of location. Some unstable objects may move, dishes and windows break.
VI	Strong	Felt by all. Some heavy furniture moved, damage slight.
VII	Very strong	Damage slight to moderate in well-built structures. Some chimneys broken.
VIII	Severe	Considerable damage in ordinary substantial structures with partial collapse. Heavy furniture overturned, chimneys and walls fall.
IX	Violent	Significant damage to all structures. Buildings shifted off foundations.
X	Extreme	Most masonry and frame structures destroyed, some well-built structures destroyed. Railways bent.

Adapted from The Severity of an Earthquake, USGS General Interest Publication 1989-288-913

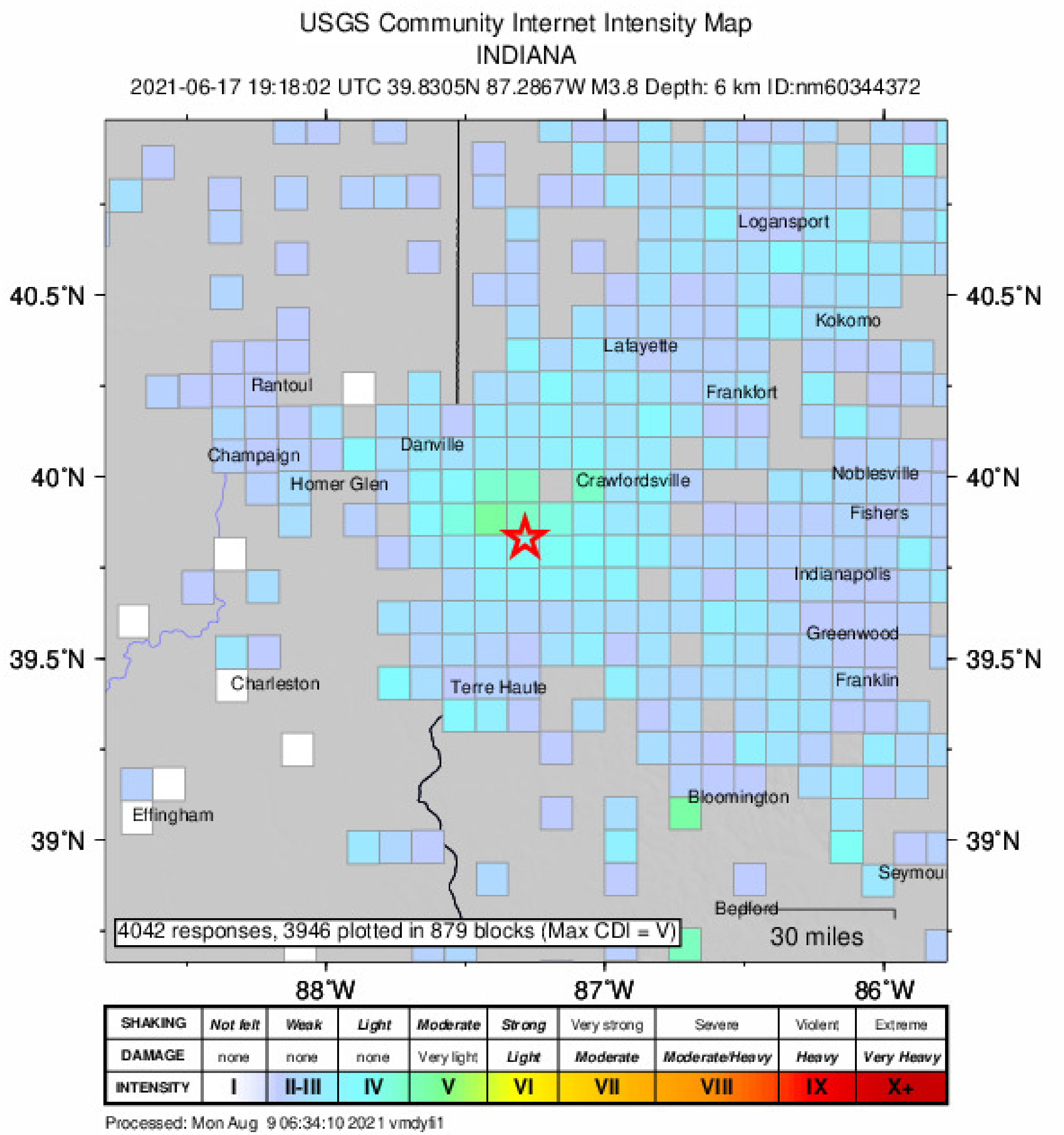
Localized intensity measurements are crucial to understand an earthquake's impact because seismic waves are modified by local geological conditions. Just as water waves can vary due to beach characteristics, the softness, thickness, and structure of ground material can affect the nature and severity of shaking at a specific site. Seismic waves travel faster through hard bedrock than through soft, unconsolidated sediment. When waves pass through soil or alluvium, they increase in amplitude and, therefore, shake more than nearby bedrock. Structures built on soft sediment can experience more intense shaking than those built on harder materials, despite distance to the earthquake's epicenter. Similiarly, seismic waves that enter sediment-filled valleys (such as the Mississippi River Valley) can reverberate within the valley, leading to higher wave amplitudes and longer durations of shaking across a wide area.



Isoseismal maps express the shaking intensity levels experienced during an earthquake. The lines on the map–called isoseisms–connect locations with the same MMI value. The isoseisms typically form a bullseye pattern, where a circle encloses the area of highest intensity near the earthquake epicenter and each band beyond encloses areas with progressively smaller intensity levels. Responses that do not fit this general trend can be attributed to the varying response of ground materials to seismic waves or human reporting error. An excellent example of this can be seen in the isoseismal map from the September 27, 1909 earthquake in the Wabash River Valley (see next page). The earthquake was felt over an area of 30,000 square miles with a maximum MMI of VII (very strong). Predictably, the shaking was reported less intensely further from the epicenter, except in cities underlain by unconsolidated river alluvium. Evansville, Indiana and St. Louis, Missouri reported strong shaking similiar to that of areas significantly closer to the epicenter.



Isoseismal map from the M5.1 earthquake that occurred September 27, 1909 within the Wabash River Valley, Indiana. This map was generated by citizen responses recorded in historical newspapers.



Community intensity map from the M3.8 earthquake that occurred June 17, 2021 near Bloomingdale, Indiana. This map was generated by citizen responses from the USGS "Did You Feel It?" program.

Procedure

1. Review the Modified Mercalli Intensity (MMI) Scale with students. Discuss how citizen responses are qualitatively classified, and how seismic waves respond to different geological materials.

2. Introduce students to the intensity map from the June 17, 2021 earthquake near Bloomingdale, Indiana (provided on previous page, web link at https://igws.indiana.edu/earthquakes/recent). Compare the "Did You Feel It?" responses to the interactive map. Notice how moderate shaking (MMI V) was reported closest to the earthquake epicenter, while weak to light shaking (MMI II-IV) was reported in the surrounding areas. Explain to students that the isolines on the interactive map are called isoseisms because they enclose citizen responses with the same MMI value.

Isoseisms are symbols on a map that connect shaking intensity responses with the same value.

3. Ask students to assign MMI rankings to historical reports from the October 8, 1857 earthquake in southeastern Illinois (see student lesson page 1). Review their responses. What did they find most challenging about the exercise? Discuss how people can be poor indicators of intensity due to varying responses, while damage to structures can be an excellent indicator of shaking intensity.

4. Instruct students to evaluate the isoseismal map from the April 27, 1925 earthquake in Princeton, Indiana (see student lesson page 2). Which cities are located within the MMI VI isoseism? Explain why Indianapolis is within the MMI IV isoseism and Cincinnati is within the MMI V isoseism due to Cincinnati's location along the Ohio River.

5. Ask students to draw isoseisms around the mapped MMI values for the April 30, 1899 earthquake that occurred near Princeton, Indiana (see student lesson page 3). Were there any outliers?

6. Instruct students to combine all of the previous skills to produce an isoseismal map for the September 27, 1909 earthquake that occurred in the Wabash River Valley (see student lesson pages 4-5). Ask them to assign MMI values to historical reports, mark those MMI values on the map, and draw isoseisms around the MMI values.

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Class period: ______________________________

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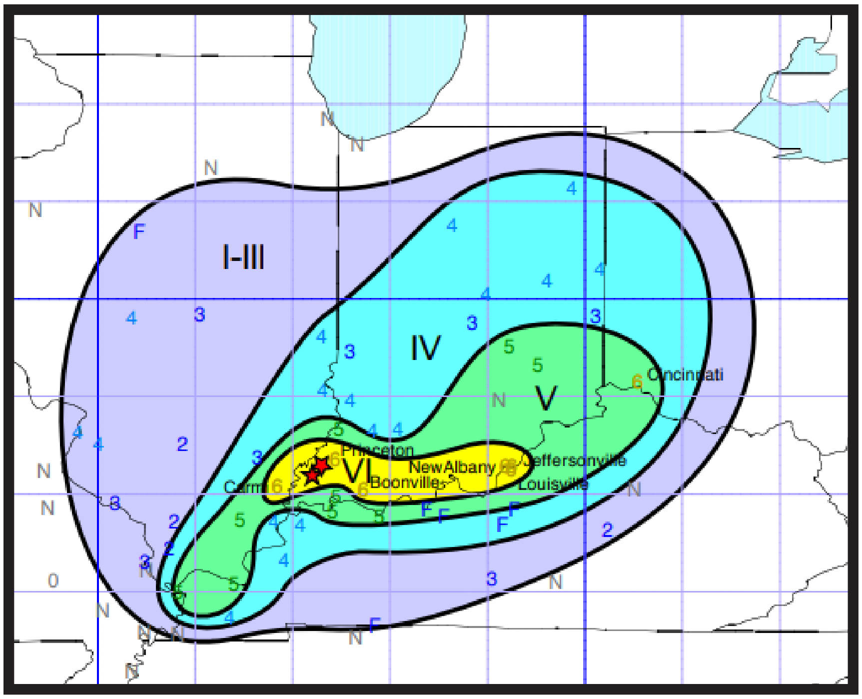
- Modified Mercalli Intensity (MMI) Scale

1. Evaluate the following historical reports from the M5.3 earthquake that occurred in southeastern Illinois on October 8, 1857. Assign each report an intensity value from the Modified Mercalli Intensity (MMI) Scale.

Historical damage report	Intensity assignment
"So violent as to demolish chimneys." Centralia, Illinois	
"Everyone alarmed; doors unlatched and thrown open; glass and crockery broken." Belleville, Illinois	
"Houses rocked like cradles, trees shook and leaves rattled." Alton, Illinois	
"Citizens awakened by shock which lasted perhaps one and a half minutes." New Albany, Indiana	
"A slight shock; a few persons awakened, but generally unnoticed." Evansville, Indiana	
"Slightly felt." Chicago, Illinois	

Data from Catalog of Significant Historical Earthquakes in the Central United States, USGS Open-File Report 2004-1086.

2. Examine the isoseismal map from the April 27, 1925 earthquake in Princeton, Indiana. Answer the questions below.



Data from Catalog of Significant Historical Earthquakes in the Central United States, USGS Open-File Report 2004-1086.

A. What cities are located within the MMI VI isoseism?

B. What do these cities have in common in terms of their geographic location?

C. Cincinatti is an outlier within the MMI V isoseism, and reported experiencing MMI VI shaking despite being 220 miles away from the earthquake epicenter. What geologic conditions could explain this anomaly?

3. Review the MMI values from the April 30, 1899 earthquake near Princeton, Indiana marked on the map below. Draw isoseisms around the responses with the same level of shaking intensity to create an isoseismal map.

Data from Catalog of Significant Historical Earthquakes in the Central United States, USGS Open-File Report 2004-1086.

4. Evaluate the following historical reports from the September 27, 1909 earthquake in the Wabash River Valley. Assign each report an intensity value from the MMI Scale.

Historical damage report	Intensity assignment
"A few chimneys were jarred down and window panes broken out." Covington, Indiana	
"Plaster was cracked, and pictures were shaken from walls." Terre Haute, Indiana	
"Furniture was upset, bottles, and tableware rattled and in many instances broken." Danville, Illinois	
"Vibrations so severe that in some instances sleepers were almost thrown out of their beds; light articles thrown down." St. Louis, Missouri	
"People badly frightened, some ran into the streets; beds, pictures, and furniture were moved." Springfield, Illinois	
"A few old brick buildings cracked, dishes shaken from racks, stove pipes knocked down, doors and windows were opened." Brazil, Indiana	
"Awakened and scared most; tilted a railroad tank so far that several gallons of water spilled out." Henderson, Kentucky	
"Heavy enough to rattle windows and dishes." Edwardsville, Illinois	
"Noticed in several places and great enough to disarrange pictures on walls." Kankakee, Illinois	
"Many residents were so disturbed that they got up; doors and windows rattled, furniture swayed." Kokomo, Indiana	
"A brick chimney was shaken to pieces and fell." Olivette, Missouri	

"Awakened several people, some got up out of bed." Davenport, Iowa	
"Several residents distinctly felt the shocks and were startled." Louisville, Kentucky	
"A number of people felt the earthquake." Dayton, Ohio	

Mark each MMI value on the map below. Then, draw isoseisms around the responses with the same level of shaking intensity to create an isoseismal map.

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"So violent as to demolish chimneys." Centralia, Illinois	VII
"Everyone alarmed; doors unlatched and thrown open; glass and crockery broken." Belleville, Illinois	V
"Houses rocked like cradles, trees shook and leaves rattled." Alton, Illinois	IV
"Citizens awakened by shock which lasted perhaps one and a half minutes." New Albany, Indiana	IV
"A slight shock; a few persons awakened, but generally unnoticed." Evansville, Indiana	III
"Slightly felt." Chicago, Illinois	II

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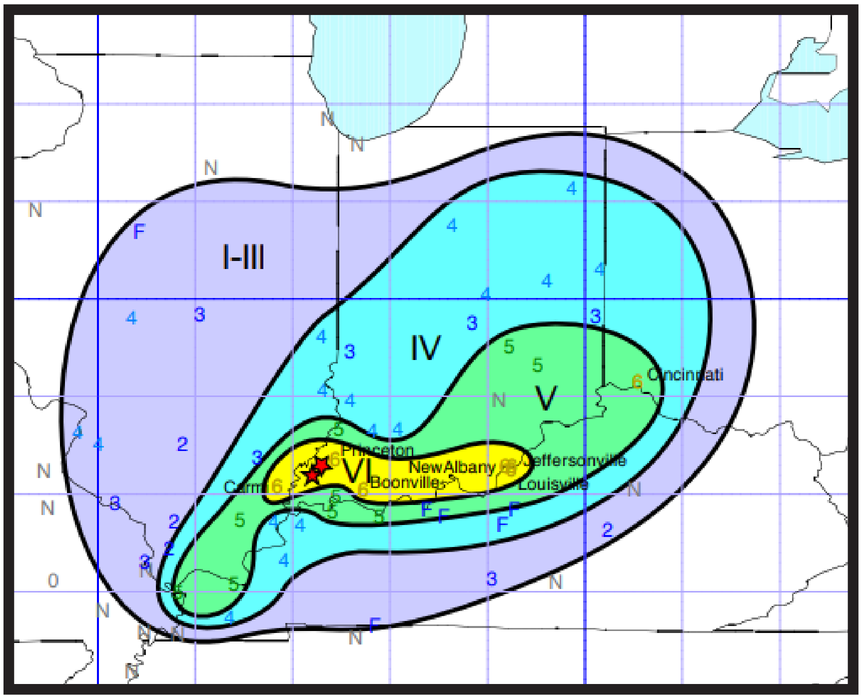


Data from Catalog of Significant Historical Earthquakes in the Central United States, USGS Open-File Report 2004-1086.

A. What cities are located within the MMI VI isoseism?

Carmi (Ill.), Princeton, Boonville, New Albany, Jeffersonville (Ind.), Louisville (Ky.)

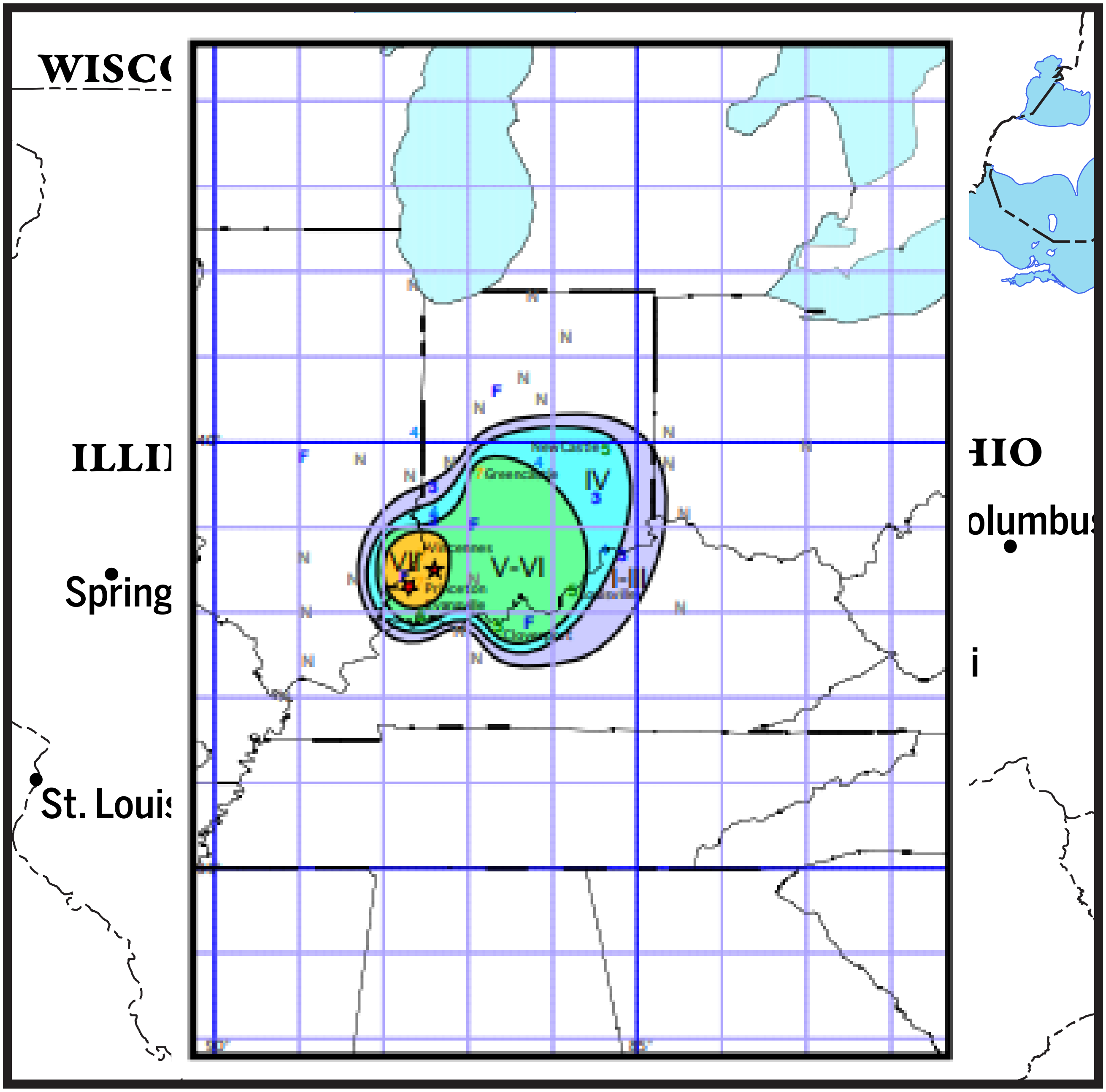
B. What do these cities have in common in terms of their geographic location?

All located along rivers (specifically the Wabash River or Ohio River)

C. Cincinatti is an outlier within the MMI V isoseism, and reported experiencing MMI VI shaking despite being 220 miles away from the earthquake epicenter. What geologic conditions could explain this anomaly?

Located along the Ohio River, where loose, unconsolidated alluvium fills the river valley. This material amplifies shaking.

3. Review the MMI values from the April 30, 1899 earthquake near Princeton, Indiana marked on the map below. Draw isoseisms around the responses with the same level of shaking intensity to create an isoseismal map.



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"People badly frightened, some ran into the streets; beds, pictures, and furniture were moved." Springfield, Illinois	V
"A few old brick buildings cracked, dishes shaken from racks, stove pipes knocked down, doors and windows were opened." Brazil, Indiana	V
"Awakened and scared most; tilted a railroad tank so far that several gallons of water spilled out." Henderson, Kentucky	IV
"Heavy enough to rattle windows and dishes." Edwardsville, Illinois	IV
"Noticed in several places and great enough to disarrange pictures on walls." Kankakee, Illinois	IV
"Many residents were so disturbed that they got up; doors and windows rattled, furniture swayed." Kokomo, Indiana	IV
"A brick chimney was shaken to pieces and fell." Olivette, Missouri	VI

"Awakened several people, some got up out of bed." Davenport, Iowa	III
"Several residents distinctly felt the shocks and were startled." Louisville, Kentucky	III
"A number of people felt the earthquake." Dayton, Ohio	III

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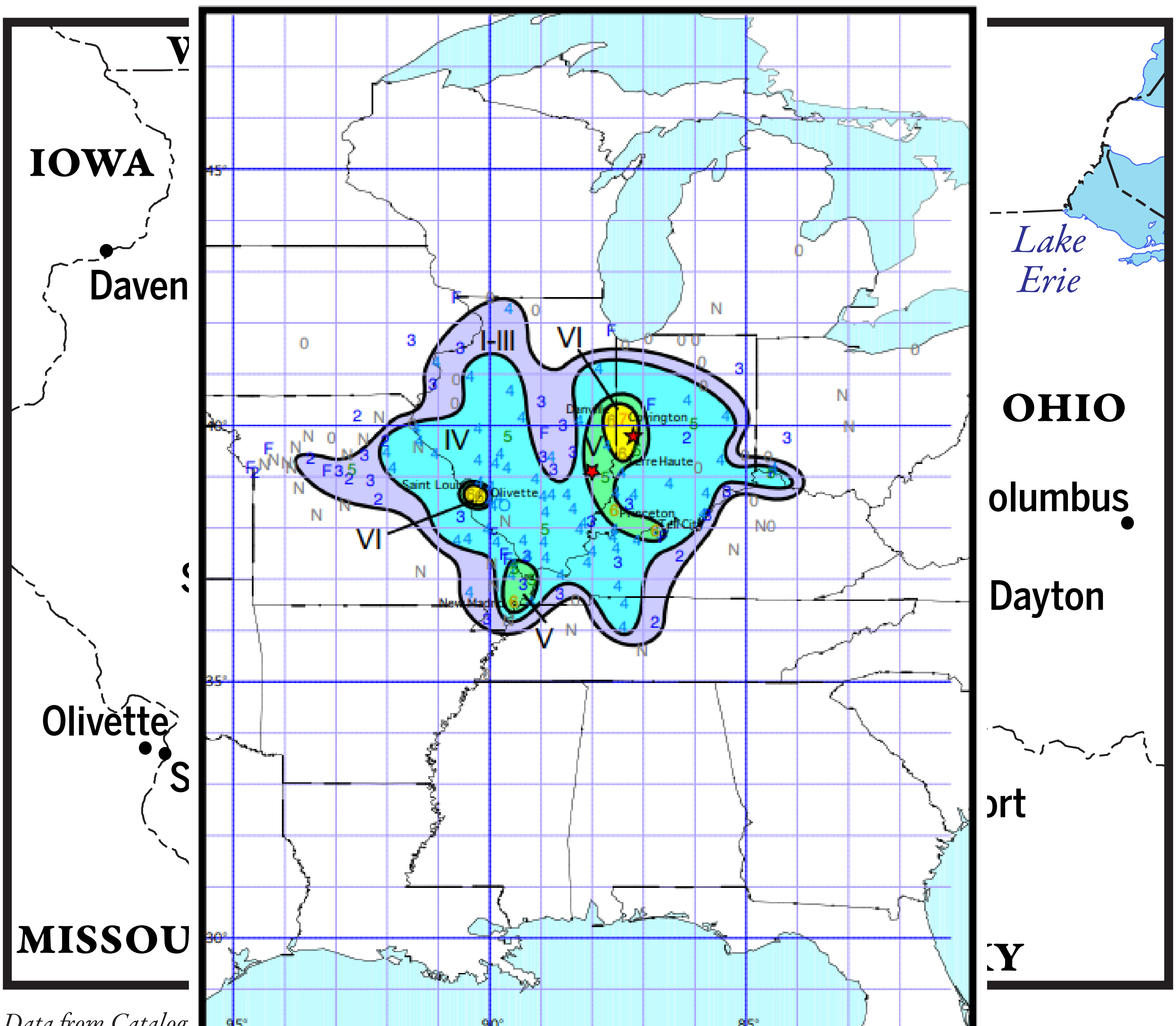

Data from Catalog
USGS Open-File Report 2004-1086.