"I feel the Earth move under my feet..."
—CAROLE KING

INVESTIGATING THE MERCALLI INTENSITY SCALE THROUGH "LIVED EXPERIENCE"

BY RICHARD JONES

Shortly after almost any perceptible earthquake, the news reports the magnitude of the event based on the Richter scale. While this measure is specific and has deep meaning to most seismologists, the public has very little understanding of how this exponential energy measurement scale relates to the destruction they see via the media or firsthand. Most people understand that a Richter magnitude 7.0 quake will do more damage than a magnitude 6 quake, but they are often puzzled by the variation in damage they see between earthquakes of the same magnitude. (For example, the difference between the Haiti and New Zealand earthquakes that both had magnitudes of 7.0 on the Richter scale.) In addition, there is only one Richter magnitude for each earthquake, which makes no reference to distance from the epicenter. Richter magnitudes are absolute measures of the energy released by an earthquake; geologists also measure an earthquake's intensity, or its effect on the Earth's surface (USGS 2012). There are many intensities for an earthquake, and this scale does not have a mathematical basis. Instead, it is based on recording physical damage and qualitative observations made during or shortly after an earthquake.

As early as 1883, Michele Stefano De Rossi and François Alphonse Forel developed a 10-step scale to quantify the intensity of earthquakes based on observed ground motion, destruction, and personal accounts (Bolt 1999). In 1902, the Italian volcanologist Giuseppe Mercalli developed the 12-step Mercalli scale as an improvement to the 10-step Rossi-Forel scale (Musson 2009). In 1931, Mercalli's scale was modified by Harry Wood and Frank Neumann (USGS 2012) into the scale we currently use in the United States. The modified Mercalli (MM) intensity scale is composed of 12 increasing levels of intensity that range from imperceptible shaking to catastrophic destruction and is designated by Roman numerals I through XII. Although qualitative in nature, it can provide a more concrete model for middle and high school students striving to understand the dynamics of earthquake behavior. In Europe, seismologists have continued to refine the Mercalli scale (see generalized time line, Figure 1) and have used the European macroseismic scale since 1992 (Musson 2009).

FIGURE 1 Time line for the development of earthquake intensity scales

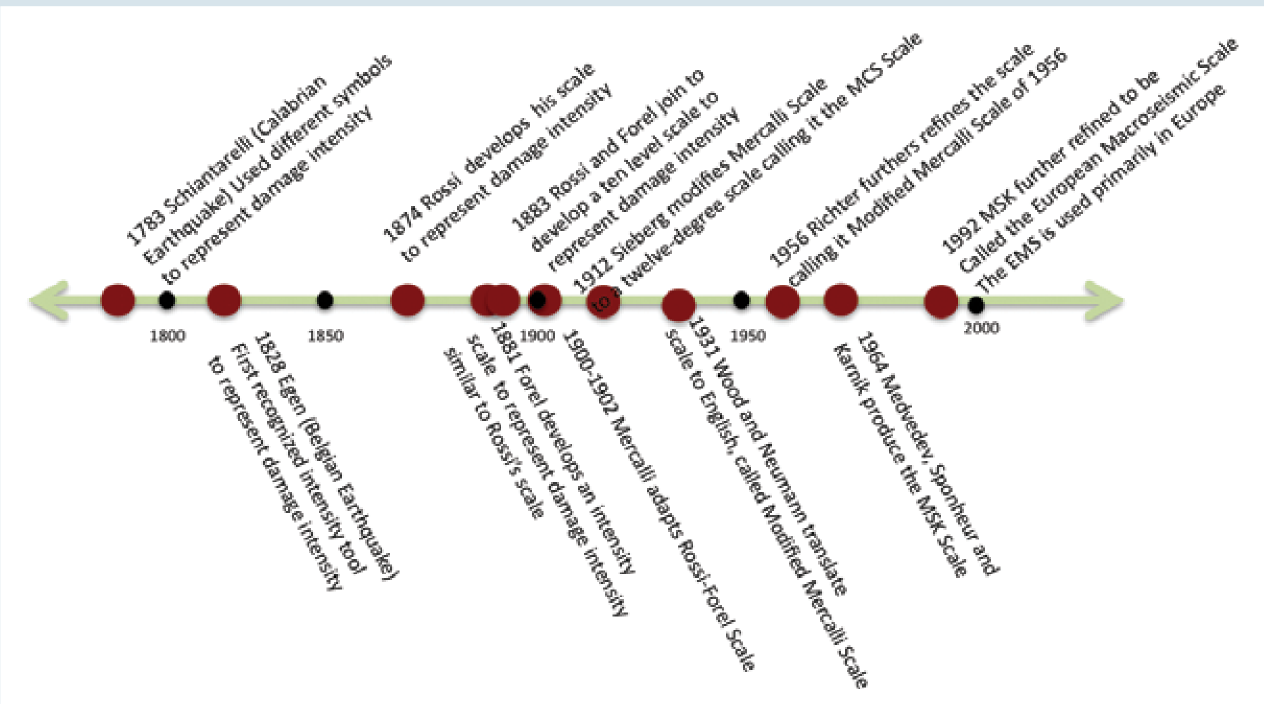
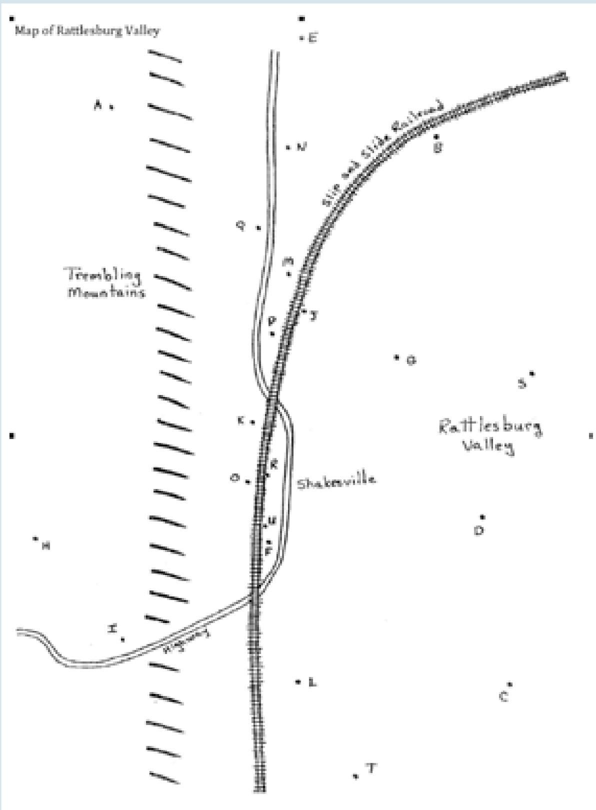


FIGURE 2 Map of Rattlesburg Valley



These observations and various degrees of destruction are evaluated according to their positions on the modified Mercalli intensity scale and plotted very carefully on a map of the affected area. The points of equal Mercalli intensity are then connected to from isoseismal lines (lines of equal seismic intensity). What commonly occurs is a relatively simple pattern of concentric "contours," with the greatest intensity at the epicenter of the earthquake and progressively lesser intensities at greater distance from the epicenter. Frequently, the pattern of isoseismal lines is elongated along the trace of the fault that caused the earthquake. This allows geologists to deduce the approximate position of the fault and locate it on the map, and is something students will do as part of this activity. Drawing contours should be familiar to students who have previous experience drawing contour maps. For students without previous experience, it is best for the teacher to demonstrate how the position of these lines is estimated from the data and how they can never cross.

How is the scale used?

Immediately after an earthquake, trained observers go into an earthquake-affected area and note the degree of physical destruction and record the observations of eyewitnesses. For example, this is an eyewitness account of the 2010 Christchurch, New Zealand, earthquake:

> "The building started to shake, my computer screen started to flicker and then the books started to fly off the shelves so I just dived under my desk. I have experienced a few aftershocks before this, but this was totally different. When I came outside the city looked like a bomb had hit it. There was dust and smoke in the air and bits of glass and rubble falling from the tops of buildings. People were walking around covered in blood and in tears—it was just shocking."
> —Christopher Ratcliffe, 27 (*Birmingham Post 2010)*

Engagement

Ask students if they have ever been in an earthquake. If they have, have them write down what they remember from the experience. These memories can be evaluated with the MM intensity scale to help students understand how to use the scale. If your students have never experienced an earthquake, there are many good video resources. For example, they can watch a video of the 2010 earthquake in New Zealand (*http://youtu.be/-Q7hzKcON8k*) or another short video of a more recent or more geographically appropriate earthquake to set the tone of the activity and provide reference for whole-class discussion related to fitting the reports to the MM scale. It is often helpful to discuss the concept of scales and measurement and allow students to determine their own class intensity scale. The class scale is generally similar to the MM scale, because students judge their scale based on their own experiences rather than a measure of energy released.

The activity

The scenario

Provide students with the following hypothetical scenario:

> The hypothetical town of Shakesville in the Rattlesburg Valley in northeastern California is reported to have had a large earthquake. Travel to this area of the

FIGURE 3 **Hypothetical eyewitness reports**

(see the online version of this article at *www.nsta.org/middleschool* for all of the reports)

A. According to Lloyd Boyd, a night watchman at the mill east of Shakesville, "The whole place was shakin'. Mr. Grossman's desk seemed have a mind of its own. It darn near chased me out of the place."

B. Reverend Father Tim reported that the Bells of St. Bartholomew of the Valley rang for several minutes, and the chimney at the rectory had fallen into Mrs. Dillingham's strawberry patch.

C. Via Twitter: "Weirdest thing ever! House looks fine, but it moved about 6" to the east. Furniture is all over the place and chimney is in the yard." @stanearthquake

D. Chip Tobin, night clerk at Wally's Gasamat, said that he was just about knocked off his feet by the shaking: "Man, I had a heck of a time getting out from behind the counter with candy bars coming down and the slushy machine trying to fall on me. What was really eerie was that once the shaking stopped and the building stopped creaking, I could still hear bells clanging from the old school across the highway."

E. KPIX reporter Mac McNelly, via Skype, said, "Good morning, Erica, I am just west of downtown Shakesville, and as you can see from these images, the earthquake early this morning has caused considerable damage, and many of the people displaced by the loss of their homes are distraught. Rescue and recovery efforts are slowly getting under way after being hampered by some street flooding caused by broken water mains in this area."

state is cost prohibitive, due to the distance from major urban centers and possible earthquake damage to roads, rail lines, and the regional airport. You will have to rely on hypothetical eyewitness damage reports that have been collected via phone, e-mail, and Twitter to construct an isoseismal (lines of equal seismic intensity) map of the earthquake-affected area.

Procedure

Each student will need a map of the Rattlesburg Valley (Figure 2), copies of the eyewitness reports (Figure 3), and the MM intensity scale (Figure 4), along with the following instructions:

1. Read the hypothetical eyewitness reports.
2. Evaluate each report in teams of two to four the MM intensity scale and then plot the intensity at the appropriate location on the map. (This may be done as a whole group.)
3. Draw isoseismal lines on the map to produce concentric bands of varying intensity. Each band should contain stations of the same intensity.
4. Based on your isoseismal map, you should be able to predict and draw the trace of the fault that is responsible for this hypothetical earthquake.

Instructional advice

Sometimes you will find that watching the video segment as a class and reading the levels of intensity on the MM together, followed by discussion and consensus, will help students understand the task of interpreting the hypothetical eyewitness reports; this takes 20 to 30 minutes. The video only lasts a few minutes and is well worth the time. Reading the intensity levels will take about seven minutes unless there are a few questions from students. The majority of the remainder of the time allotted for these activities is dependent on the level of student discussion, on the level of student engagement and interest, and whether students can come to a consensus on intensities. Additionally, you may want to modify steps 1 through 3 based on students' ability. For example, students could be asked to read and discuss several of the hypothetical eyewitness reports as a class to establish inter-rater reliability, just like real teams that go out into the field after an earthquake must do.

Inter-rater reliability is simply how closely each of the raters agrees on the intensity. For example, three students may feel that the report indicates an intensity of IV, while six students feel that the report describes an intensity of V. Establishing inter-rater reliability provides a good opportunity for students to share their reasons for selecting a specific intensity and compare their reasons to those of students who had a different interpretation of the witness report. The more students who agree that a specific eyewitness report represents a specific intensity, the higher the inter-rater reliability of the determination. This process should only take 10 to 15 minutes. If not done previously, you may now want to model drawing one of the isoseimal lines using a transparency on an overhead, a hard copy with a document camera, or a similar device, so students have a better understanding of why the lines should not cross and how they can estimate the location of the line based on the available data.

Evaluation

Once students have completed their isoseismal maps (see Figure 5 for an example), it is recommended that they compare and contrast their maps with other students' by simply placing one map over the top of another. Another option is to have students trace their isoseismal lines on a transparency and then place all of the transparencies over one another. Using an overhead and a hard copy with a document camera, the teacher

FIGURE 4 **Modified Mercalli intensity scale (modified from Feldman, pers. comm.)**

I. Not felt except by a very few under especially favorable conditions or by delicate instruments.

II. Felt only by a few persons at rest, especially on upper floors of buildings.

III. Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motorcars may rock slightly. Felt as light vibrations, similar to the passing of a truck. Duration can be estimated.

IV. Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Heavy vibration, a sensation like a heavy truck striking building. Standing motorcars rocked noticeably.

V. Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.

VI. Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Ground moves so strongly that it is difficult to walk. Damage slight, weak masonry may be cracked.

VII. Very difficult to stand. Large bells (church or school) ring. Damage negligible in buildings of good design and construction; slight to moderate in well-built, ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.

VIII. Damage slight in specially designed structures; considerable damage in ordinary, substantial buildings, with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Houses may be moved off their foundations and branches may be broken off trees.

IX. General panic; many people run screaming into the street. Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations. Water mains are likely to be broken.

X. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails somewhat bent. Many landslides, damage to dams; water sloshes out of ponds and reservoirs.

XI. Few, if any, (masonry) structures remain standing. Bridges destroyed. Rails bent greatly. All underground pipelines broken.

XII. Damage total. Lines of sight and level are distorted. Objects thrown into the air while quake is in progress.

FIGURE 5 Sample student map

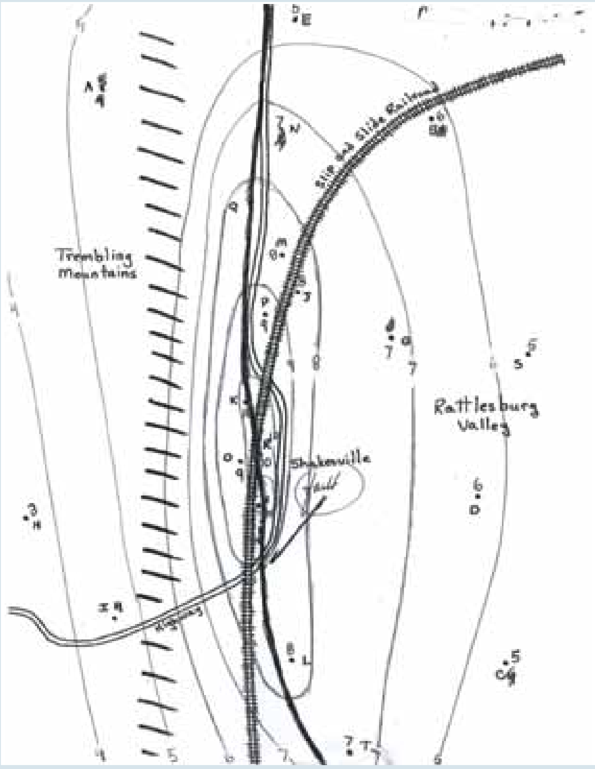
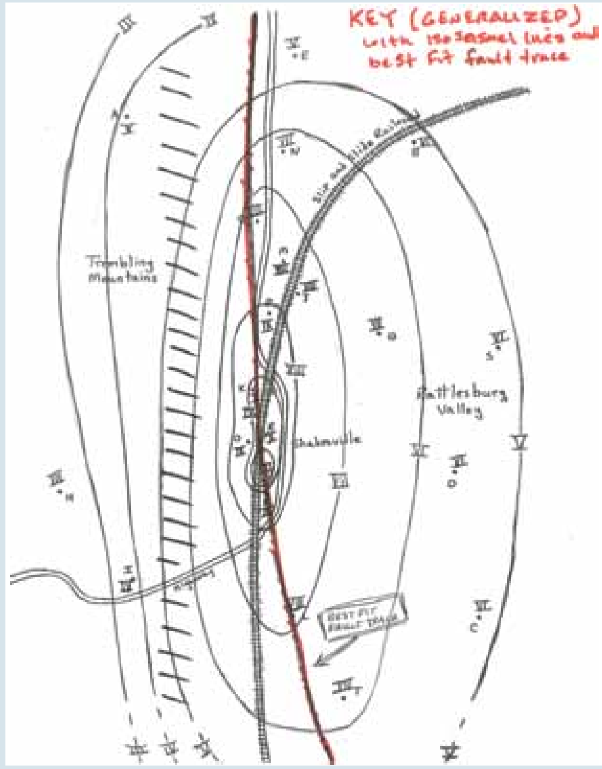


FIGURE 6 Generalized map and fault trace



can show the class how similar or different the interpretation from each group or student is. This aspect of the activity should take no more than 10 minutes and provides numerous opportunities for students to discuss the reasoning they used to draw their maps. This is also an excellent opportunity for students to collaborate with peers and will help them refine their interpretation of the hypothetical eyewitness reports and how these reports fit the generic descriptors on the MM intensity scale. Depending on their grade level and ability, you may want to have students work in collaborative groups to come to a consensus regarding both the isoseimals and the fit of the fault trace. However you do the initial evaluation of their isoseismal maps, students will have some variation in their interpretation of the hypothetical eyewitness reports, but the general pattern of isoseismal maps will be similar, and students should be able to plot the hypothetical fault with sufficient certainty. If you wish to have a more formal evaluation of students' interpretations, use an overlay of the generalized isoseismal lines and best-fit fault trace (Figure 6) or one you have created, along with a rubric designed to measure how well students meet the target expectations (Figure 7).

Extensions

There are many possible extensions to this activity. Students could use online sources that compare the MM and Richter scales (*www.geography-site.co.uk/pages/physical/earth/richt.html*) to determine the likely Richter magnitude of the hypothetical Rattlesburg Valley earthquake. However, there are two extensions that have proven especially beneficial to my students. First, the variability in student interpretation of the hypothetical eyewitness reports has helped students to understand the need for standardization in interpretation. As mentioned previously, students may work in teams of two to four or as a whole class to evaluate each of the reports and come to a consensus on the specific fit to the MM intensity scale. This exercise underscores the value of inter-rater reliability and consistent training for observers. Second, students can overlay their isoseismal maps with an Excel spreadsheet grid, filling the cells based on the value of the hypothetical MM

FIGURE 7 Rattlesburg isoseismal map rubric

Item evaluated	Unacceptable = 0	Acceptable = 1	Target = 2
Plotting of hypothetical eyewitness reports	Missing data points and/or interpretation of intensity from report off by two or more orders of intensity.	No missing data points and interpretation of intensity from report off by no more than one order of intensity on the majority of points.	No missing data points and interpretation of intensity from report off by no more than one order of intensity on all points.
Drawing of isoseismal lines, including labels of intensity	Missing and/or crossing isoseismal lines. Isoseismal intensity lines not labeled. Some intensity points not contained within correct isoseismal bands.	No missing or crossing isoseismal lines. Isoseismal intensity line labels incomplete. Few intensity points not contained within correct isoseismal bands.	No missing or crossing isoseismal lines. Isoseismal intensity line labels complete. All intensity points contained within correct isoseismal bands.
Placement of isoseismal lines compared to generalized location on overlay (Figure 4)	Few, if any, of isoseismal lines agree with generalized location on overlay.	Few isoseismal lines do not agree with generalized location on overlay.	Isoseismal lines on student map are all reasonably close to generalized location on overlay.
Predicted fault trace on student map compared to generalized location on overlay (Figure 4)	No attempt to locate fault trace and/or fault trace is more than four centimeters away from generalized location on overlay.	Fault trace is between two and four centimeters away from generalized location on overlay.	Fault trace is less than two centimeters away from generalized location overlay.

intensity for each. Once the cells are filled, students can produce a color 3-D surface or contour map that should resemble their hand-drawn isoseismal map.

Final thoughts

This activity is easily modified to meet the needs of your curriculum and students. It can be used for enrichment, as a supplement, or as a stand-alone activity that will help students to better understand the Mercalli scale. The activity also provides a more concrete explanation of the variation in the destruction students see via the media or that they have experienced firsthand in an earthquake. ■

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