ShakeAlert® activities for formal and informal learning settings

Pasta Quake

Exploring Earthquake Magnitude

Version 03/09/21

Activity modified from Pasta Quake version provided by the Exploratorium.

OVERVIEW

In this activity, learners use uncooked spaghetti noodles to physically demonstrate and experience different earthquake magnitudes (Figure 1). Three options provide opportunities to understand an earthquake's magnitude. The 5-minute demonstration illustrates how an earthquake's magnitude is related to its energy release. A 15-minute activity builds on the 5-minute presentation and allows learners to feel how much more energy is required to break pasta bundles. A 30- to 45-minute activity introduces the important difference between the original (Richter) and the more accurate (moment) magnitude scales. Learners also interact with the computer-based Earthquake Simulator to manipulate key variables that influence the magnitude of earthquakes.

Learners will first explore the concept of an earthquake's magnitude through the Richter scale, which is commonly reported, and then transition into learning about the moment magnitude. Moment magnitude is the scale that seismologists (earthquake scientists) use because it's directly related to physical properties of the earthquake and its source. Appendix A contains the vocabulary needed for this activity.

Why is it important to learn about earthquakes and their magnitude? More than 143 million people are exposed to potential earthquake hazards in the U.S. An understanding of the size of an earthquake and its potential to cause damage is fundamental to earthquake hazard mitigation. An important tool for mitigation is the ShakeAlert® Earthquake Early Warning system for the West Coast of the U.S. which detects significant earthquakes quickly so that alerts can be delivered to people and automated systems often before shaking arrives.

OBJECTIVES

Learners will be able to:

- Demonstrate that an earthquake's magnitude is related to its energy release through the Pasta Quake model.
- Explain the differences between the Richter scale and the more accurate moment magnitude scale.
- Describe that each increase of magnitude by a whole number (**M4** to **M5**) releases 32 times more energy.

Beginner

5 min · 15 min · 30–45 min

Large Group · Small Group

Demo · Materials

Time: 5-, 15- and 30- to 45-minute guided activities that can be adapted for audience and venue.

Audience: This can be done with novice and experienced geoscience learning groups.

Subject: Natural Hazards: Earthquakes, Geoscience.

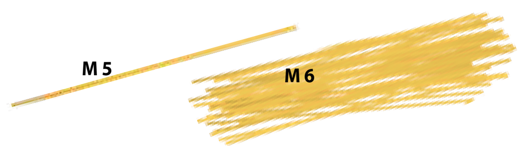

Figure 1. In the Pasta Quake Model, one piece of spaghetti models a magnitude 5 earthquake. A magnitude 6 is represented by 32 pieces.

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MATERIALS

Materials for the 5-minute activity:

- Computer and projection system
- Appendix A—Vocabulary
- Appendix B—Energy of Earthquakes

Materials for the 15-minute activity:

- Computer projection system to show:
    - Energy of Earthquakes (Appendix B)
    - Pasta Quake Math (Appendix C)
    - Photos for demonstrations (Appendix D)
- Scale to weigh pasta (either kitchen or metric)
- One Pasta Quake set up for each learner group
    - 3 lbs. of regular spaghetti for one Pasta Quake set up
    - 34 Rubber bands to hold the 3 lb pasta bundle
    - 15" diameter circles cut from plastic tarps etc. (durable for repeated use)
- 84" diameter round plastic or cloth tablecloth

Materials for 30- to 45-minute activity:

- Computer projection system to show:
    - Energy of Earthquakes (Appendix B)
    - Pasta Quake Math (Appendix C)
    - Photos for demonstrations (Appendix D)
- Print outs of the learner worksheets (Appendix E)

RELEVANT MEDIA RESOURCES

Video

- IRIS video: Moment Magnitude Explained—What Happened to the Richter Scale? (Time: 5:39)

App

- Earthquake Simulator: What does it take to create a big quake?

What is magnitude?

An earthquake's magnitude is a single, numeric value that describes the size of an earthquake. Magnitude, which is denoted by an 'M' in front of a number (like M5), is important because it is one of several factors that contribute to an earthquake's intensity, or the shaking you feel during an earthquake. Earthquake scientists determine an earthquake's magnitude through a recording of earthquake waves on a seismic instrument (or seismogram) or through geodetic instruments.

INSTRUCTOR PREPARATION

We can describe an earthquake's size, or magnitude, in many different ways. There are a variety of magnitude scales that describe what seismologists (earthquake scientists) observe. Some magnitude scales are better for small earthquakes compared to large earthquakes. Media outlets commonly report the magnitude of earthquakes using the term Richter magnitude, or local magnitude scale (M_L). Geophysicists work to provide the best local magnitude scale (M_L) relevant to a particular region for small earthquakes. For larger earthquakes, seismologists use the moment magnitude scale (or M_W, where the w stands for 'work'), which relates to the physics of an earthquake.

The moment magnitude is preferred because it is directly related to the physical properties of an earthquake and its source. Moment magnitude is based on a physics concept called the seismic moment which includes: the rock strength or rigidity; the area of the fault surface that slips; and the distance of fault slip. More details and equations are available in Appendix G (page 19).

The magnitude of an earthquake is larger if:

a) the fault block slipped a long distance,

b) the surface area of the fault block that slipped was really big, and/or

c) if the rocks at the fault were very hard and rigid.

The larger the earthquake, the greater the energy released.

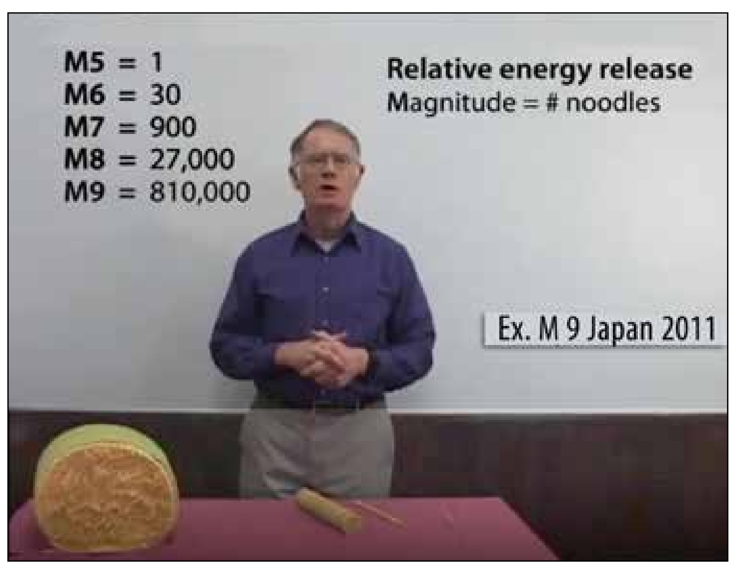


Figure 2. Dr. Robert Butler demonstrates the exponential increase of energy released in the pasta quake activity.

Familiarize yourself with the videos and animations, and with the following before conducting the activities:

- **Appendix A**—Vocabulary
- **Appendix B**—Energy of Earthquakes
- **Appendix C**—Pasta Quake Math
- **Appendix D**—Photos for demonstrations
- **Appendix E**—Learner Worksheet for the 30- to 45-minute activity
- **Appendix F**—Instructor Answer Key to Learner Worksheet
- **Appendix G**—Instructor Background: Understanding the Earthquake Magnitude Scales and Energy
- **Appendix H—**NGSS Science Standards & 3-Dimensional Learning

For the 5-minute activity:

a) Gather the materials listed on page 2

b) Use computer projector to show Appendix B

For the 15-minute activity:

a) Gather the materials listed on page 2

b) Either print the picture of a bundle of 32,768 pieces of spaghetti (Figure 2) or use a computer projector for Figure 2.

c) Use computer projector for Appendix D and optionally show Appendix C.

For the 30- to 45-minute activity:

a) Print copies of the learner worksheet found in Appendix D for each learner

b) Review **Video** resource: *Moment Magnitude Explained—What Happened to the Richter Scale?* (Time: 5:39)

c) Review the **App** resource: *Earthquake Simulator—What does it take to create a big quake?*

d) Review materials in Appendices C–G

NGSS standards for these activities are found in Appendix G.

ACTIVITIES AND DEMONSTRATIONS

IF YOU HAVE 5 MINUTES

Did You Know?

- Did you know that the energy released between different sized earthquakes increases by a factor of 32?

Magnitude is both a scientific and a mathematical concept! Several scales measure earthquake magnitude. In the short graphic Energy of Earthquakes (Appendix B), we will look at the energy released during an earthquake. The energy released increases exponentially based on a factor of 32 (or, more precisely, $10^{1.5}$). This means that a **M6** earthquake releases 32 times more energy than a **M5** earthquake, and that a **M7** earthquake releases 1000 times more energy than a **M5** earthquake!

Directions:

1. Show the graphic Energy of Earthquakes (Appendix B) either on a computer projection system, on a large print-out, or with handouts for learners.
2. Point out how the diameter of the circles dramatically increases. The area of the circles increases by a factor of 32. Compare the size of the 2011 **M9** earthquake in Japan with the M7 earthquake in Haiti.
3. Emphasize the surprising and striking human impact. The 2011 **M9** Japan earthquake and resulting tsunami took 20,000 lives, while the 2010 **M7** Haiti earthquake took 150,000 lives. The Haiti earthquake was much more damaging than the 2011 Japan earthquake, despite the fact that the seismic energy release was 1000 times less than that of the 2011 Japan earthquake.

Questions for Discussion:

Although both earthquakes were devastating, why was the Haiti earthquake so much more deadly than the Japan earthquake while being significantly smaller? (*Haiti was especially destructive because its epicenter was close to a major city and its hypocenter, or focus, was close to the Earth's surface. The majority of the unreinforced masonry buildings collapsed.*)

What else did you find interesting or surprising in the graphic? (*Answers will vary, but you can mention that an understanding of the size of an earthquake and its potential to cause damage is fundamental to earthquake hazard mitigation. Discuss local earthquakes and compare their energy release to that during the 1700 M9 Cascadia earthquake, and the 2019 M7 Ridgecrest, CA earthquake.*)

IF YOU HAVE 15 MINUTES

Did You Know?

- Did you know that we can simulate the energy released in an earthquake with pieces of spaghetti?

Pasta provides a physical model to help us understand the energy released in incrementally larger earthquakes. As pasta is bent and broken, we can see, feel and hear the effects of energy release which simulates an earthquake.

The Pasta Quake activity should follow the 5-minute activity which explains the exponential progression of energy release in earthquakes. As an extension, the instructor can incorporate Pasta Quake Math into the activity found in Appendix C. The math allows learners to discover the increasing area of circles with each magnitude which corresponds to the increase in energy release.

Directions:

Provide one Pasta Quake set up for each group of learners. The images in Appendix D are available to use in place of the actual bundles.

1) Prepare Pasta Quake sets for learner groups (Figure 1).
   Instructor needs:
   - All the items listed for the learner group
   - Optional: You could actually create a bundle of 32,768! If you do, keep it hidden under a box or towel until it is revealed in the activity!

   Each learner group needs:
   - Single strands of spaghetti for each learner (**M5** earthquake)
   - One bundle of 32 strands of spaghetti bound on each end with a rubber band (**M6** earthquake). Prepare additional bundles if you want each learner to break their own bundle. Note: This bundle will be broken!
   - One bundle of 1,024 strands of spaghetti or 2½ lbs (**M7** earthquake). Note: this bundle will be handled by learners, but will not be broken so the bundle can be reused!
   - All the assembled pieces can be rolled and wrapped in the folded tablecloth to contain the Pasta Quake set.
2) Distribute one Pasta Quake set up to each group of learners. The interactive demonstration begins with one piece of spaghetti. Ask learners to pick up one piece of spaghetti.
3) Bend the single strand slowly until it breaks. Notice the work it takes to break the spaghetti. Call this a Magnitude 5 on the Pasta Magnitude scale.
   Have the learners bend the single strand until it breaks.

   Questions for Discussion:

   Describe how the energy was transformed from stored (potential) to moving (kinetic). (*The bending pasta stored elastic potential energy until it snapped, which releases kinetic energy*.)

   What did you notice when the piece of spaghetti broke? (*You can hear a snap, feel the release of energy in vibrations and see the break*.)

   If breaking this single strand of spaghetti represents a Pasta Magnitude 5, what factor would you need to multiply this single piece of spaghetti by to equal a Pasta Magnitude 6? (*Answer: 32, because the M6 Pasta Quake releases 32 times more energy than a M5 Pasta Quake and is represented by 32 pieces of spaghetti*.)

   Optional Pasta Quake Math for M6:

   A 32-strand bundle of spaghetti = an area of 1.14 cm^2.

   To determine the diameter of the bundle, divide the area by π (3.14159) = .36 cm^2.

   Next, take the square root of the product to determine the radius $\sqrt{.36\ cm^2}$ = .6 cm.

   And finally multiply by 2 to determine the new diameter .6 cm x 2 = 1.2 cm (2.67 in).
4) Let's make an **M6** earthquake! Hold up the smallest bundle with 32 strands of spaghetti (Figure 3). Ask learner groups to notice what it feels like to bend the bundle of 32 strands.
   Bend the bundle until it breaks. Notice the work it takes to break the bundle. If the pasta magnitude scale were like the earthquake magnitude scale, this would be a Pasta Magnitude 6.

Figure 3: Magnitude 6 pasta bundle of 32 spaghetti strands breaking.

Note: If there are enough bundles of pasta for each learner, they can bend and break their own bundle. If you have only one bundle per group, have the learners pass the bundle around, flexing the bundle then observe as one person breaks the bundle.

Questions for Discussion:

What did you notice? Was the **M6** Pasta Quake still fairly easy to break? How did the bundle break...all at once or a strand at a time? (*Observations will vary, sometimes it's a single strand, and at times multiple strands will break together. Earthquakes can also grow! At times, an earthquake will only break parts of the fault and then will 'grow' and continue to break other parts of the fault, with time.)*

5) Pick up the next larger bundle of spaghetti. If a **M6** earthquake had 32 strands, how many pieces of spaghetti do you think will be in this bundle representing a **M7** earthquake? (*The M7 Pasta Quake is represented by 32 X 32 = 1,024 pieces of spaghetti.*) *Note:* Since we will *NOT* break this larger bundle of spaghetti, have learners pass the bundle around the group. Try to bend the large bundle without breaking it!

Optional Pasta Quake Math for M7:

1,024-strand bundle. Area = 36.32 cm^2.

To determine the diameter of the new bundle, divide the area by π (3.14159) = 11.56 cm^2

Next, take the square root of the product to determine the radius √ 11.56 cm^2 = 3.4 cm.

And finally multiply by 2 to determine the new diameter 3.4 cm x 2 = 6.8 cm (2.67 in).

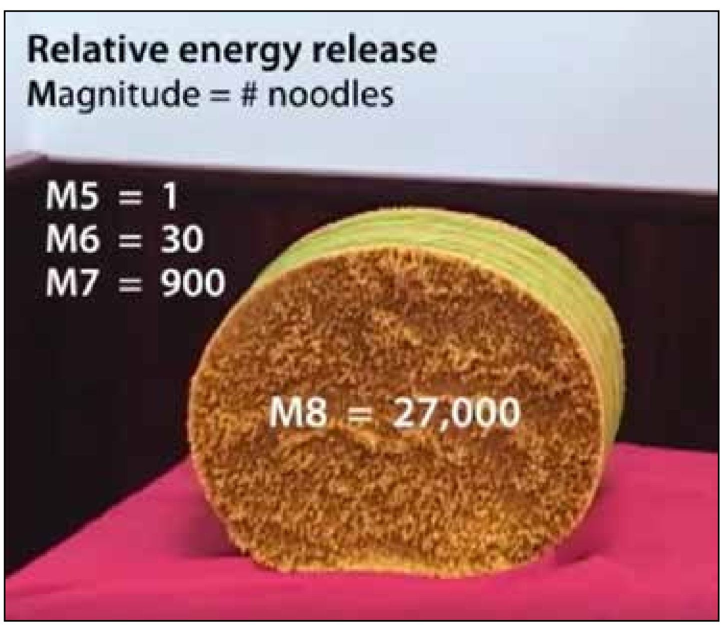


Figure 4. Magnitude 8 pasta bundle of 27,000 strands of spaghetti (15-inch diameter circle) (Larger image available in Appendix D.)

Question for Discussion:

What did you notice about the difference in energy it took to try to bend the larger bundle that represents an **M7** earthquake? (*Observations will vary.)*

6) Pick up the smaller, circle of plastic. This circle represents the cross-sectional area of a **M8** bundle of pasta. How many pieces of spaghetti do you think this circle represents? Hint, if an **M7** had 1,024 pieces of spaghetti, what number would we use to increase the energy to represent a Pasta Magnitude 8? (32) Ask learners to use a calculator to multiply 1,024 by 32. (32,768 pieces) Another way of describing this, a **M8** earthquake is an energy increase of 32 x 32 x 32 (or 32,768) times more energy release than a **M5** earthquake.

Optional Pasta Quake Math for M8

32,768-strand bundle of spaghetti (Figure 4) Area = 1,162.24 cm^2.

To determine the diameter of the new bundle, divide the area by π (3.14159) = 369.95 cm^2.

Next, take the square root of the product to determine the radius √ 369.95 cm^2 = 19.23 cm.

And finally multiply by 2 to determine the new diameter 19.23 cm x 2 = 38.46 cm (15.14 in).

Question for Discussion:

How much force do you think it would take to break a bundle of 32,768 pieces of spaghetti? How much energy would be released by this bundle of spaghetti breaking? Show the image in Figure 4 which shows the actual size of the bundle! (*Answers will vary.*)

Figure 5. Instructor Bonnie Magura demonstrates pasta quake magnitudes: M8 15-inch blue circle and M9 84-inch diameter blue tarp circle. (Optional: larger image available in Appendix D.)

7) Now let's consider an M9 Pasta Quake. How big do you think this bundle of spaghetti will be? Suggest learners stretch their arms to indicate how big the circle will be. How many pieces of spaghetti will this represent? Hint: If there are 32,768 pieces of spaghetti in a **M8** Pasta Quake, and we multiply that number by 32, how many pieces will there be? Learners can use a calculator to find the answer which is 1,048,576 pieces of spaghetti. Now ask learners to open up the folded tablecloth. Remind them that this is the cross-sectional area of a **M9** bundle of pasta. *Optional:* Display Figure 5 in Appendix D before the discussion.

Optional Pasta Quake Math for M9:

32,768-strand bundle of spaghetti. Area = 1,162.24 cm^2.

To determine the diameter of the new bundle, divide the area by π (3.14159) = 369.95 cm^2.

Next, take the square root of the product to determine the radius $\sqrt{369.95 \text{ cm}^2}$ = 19.23 cm.

And finally multiply by 2 to determine the new diameter 19.23 cm x 2 = 38.46 cm (15.14 in).

Questions for Discussion:

Could you break this bundle with your hands? (*No.*)

How much energy do you think it would take to break a bundle of spaghetti this large? (*Answers will vary.*)

What type of earthquake is capable of producing a **M9** earthquake? (*Only subduction zones, with a vast area of contact along their megathrust boundary, are capable of generating a Great (M9) earthquake.*)

What impressed you most about this activity? (*Answers will vary.*)

Why is it important to learn about earthquakes and their magnitude? (*Answers will vary. Remind students that understanding the magnitude of an earthquake and its potential to cause damage is fundamental to earthquake hazard mitigation.*)

8) Ask learner groups to clean up broken spaghetti. Refold the tablecloth, the smaller plastic circle and wrap around the **M7** bundle of unbroken spaghetti. Return supplies.

IF YOU HAVE 30 to 45 MINUTES

Did You Know?

- Did you know that seismologists now use the moment magnitude scale to compute earthquake magnitude rather than the original Richter scale?

Moment magnitude provides a more uniform extension of the magnitude scale, particularly for large earthquakes. The moment magnitude scale provides the most reliable estimate of earthquake size.

This activity can be used in either a classroom with computers or assigned as distance learning. A worksheet accompanies the activity in Appendix D. An instructor answer key follows in Appendix E.

The activity has two parts: In Part 1, the activity features a short 5:39 minute video that explains why the original Richter scale is no longer used to measure earthquake magnitude, particularly for larger earthquakes. In Part 2, learners use the interactive Earthquake Simulator to investigate factors that control the size of an earthquake's magnitude. These factors define the seismic moment used to calculate moment magnitude.

Directions:

Part A:

1. Tell learners that we are going to explore what happened to the Richter scale of earthquake magnitude.

Questions for Discussion:

Have you ever felt an earthquake? What did it feel like?

What was the largest earthquake you have ever heard about? Where did it happen?

The term magnitude refers to size, but what is the size measuring? (*The magnitude measures the amount of energy released in an earthquake.*)

2. Distribute the learner worksheet (Appendix D) and suggest they read over the questions related to the video. That way, learners can take notes or answer the questions while they watch the video.
3. Discuss the answers to the questions before moving on to Part 2. See Appendix E for answers.

Part B:

1. Ask learners to log on to the Earthquake Simulator: What does it take to create a big quake?
2. Continue with the second page of the worksheet. Allow learners to explore the Earthquake Simulator and then answer questions.
3. Briefly review the different factors available on the simulator. Point out that the slider scale must be moved off of 0 for each factor before you can run a calculation.
4. Point out that the Earthquake Simulator was designed to model strike-slip earthquakes which could potentially reach a magnitude of 8.6. However, larger M9+ megathrust earthquakes only occur on subduction zone plate boundaries.

Note: Encourage students to estimate the magnitude before they hit the calculate key!

5. Discuss the answers and share new insights from the activity.

APPENDIX A — VOCABULARY

Elastic: the property of any deformed object (stretched or compressed) to return back to its original shape and size after deformation.

Elastic potential energy: the energy that an object has during deformation.

Epicenter: the point (map location) on the Earth's surface directly above the hypocenter.

Exponential: an increase that grows more and more rapidly, e.g. multiplying by n orders of magnitude (10^n).

Hypocenter: point within the earth that an earthquake starts. The hypocenter is defined by its geographic coordinates (latitude and longitude) and depth.

Kinetic energy: the energy that an object has in motion

Logarithmic scale: way to describe numerical data for a very wide range of values in a compact way. Typically, the largest numbers in the data are hundreds or even thousands of times larger than the smallest numbers and the resulting scale is nonlinear determined by a fixed factor.

Magnitude: a number that characterizes the relative size of an earthquake. Magnitude is based on measurement of the maximum motion recorded by a seismograph.

Moment Magnitude (M_W): the preferred measure of earthquake size (***magnitude***) in which takes into account the stiffness of the rock, the average slip on the rupture plane, and the area of the rupture plane in addition to the maximum motion (amplitude) recorded by a seismograph (the "moment" of the earthquake). See ***Magnitude***. www.iris.edu/hq/inclass/animation/205

Richter Scale (M_L): a logarithmic earthquake magnitude scale first developed by Charles Richter in the 1930s. The scale measures the size of earthquakes occurring in southern California using relatively high-frequency data from nearby seismograph stations. For seismic waves, the scaling factor is 32 times or a 32-fold increase in energy

Rock rigidity: the resistance of rock to bending. Rigidity is a constant for a given rock material.

Seismic moment (M_O): the area of rupture along a fault multiplied by the average displacement multiplied by the rock rigidity.

$$M_O = \mu * A * D,$$

(μ = rock rigidity, A = area of the fault surface that slipped, D = distance of offset)

Seismogram: the real-time record of earthquake ground motion recorded by a seismograph. Seismograms are the records (paper copy or computer image) used to calculate the location and magnitude of an earthquake.

Seismograph: an instrument that records vibrations of the Earth, especially earthquakes. Seismograph generally refers to the seismometer plus a recording device as a single unit.

Seismologist: scientists who study earthquakes and their phenomena.

Seismometer: a sensitive instrument that can detect waves emitted by even the smallest earthquakes.

Subduction zone: a convergent plate tectonic boundary, where one tectonic plate is forced underneath another. Subduction zones produce the largest earthquakes in the world (M8.5+).

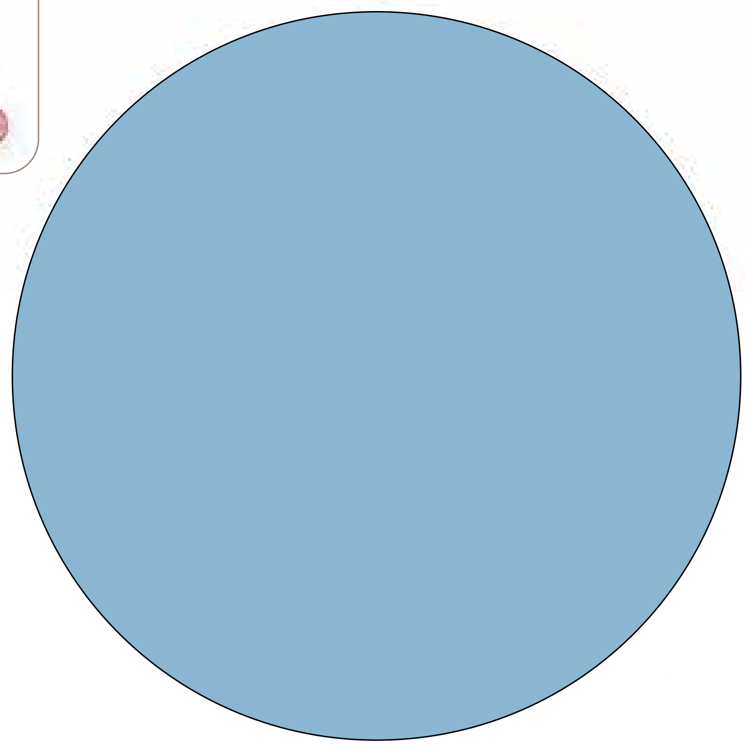
APPENDIX B—ENERGY OF EARTHQUAKES

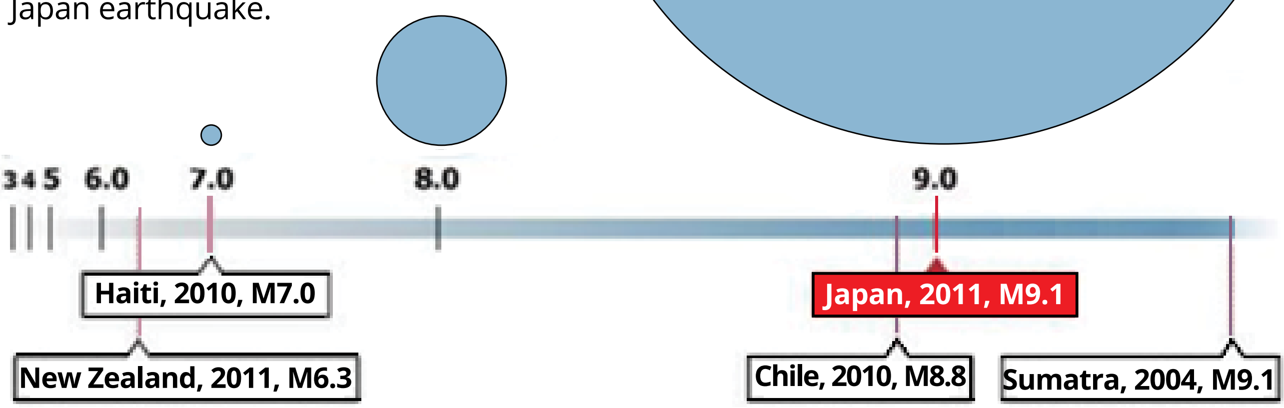
Energy of Recent Earthquakes

According to the US Geological Survey, the 2011 magnitude-9.1 earthquake off the east coast of Honshu, Japan's largest island, was the fifth largest earthquake recorded worldwide and the largest ever recorded in Japan. Locations of notable recent earthquakes (2000-2010) are shown on the map below.

Seismic Energy

For each unit increase in earthquake magnitude, the seismic energy released goes up by a factor of 32. The areas of the blue circles represent the comparison of seismic energies released by the 2010 magnitude-7 Haiti earthquake and the 2011 magnitude-9 Japan earthquake.





Human Impact

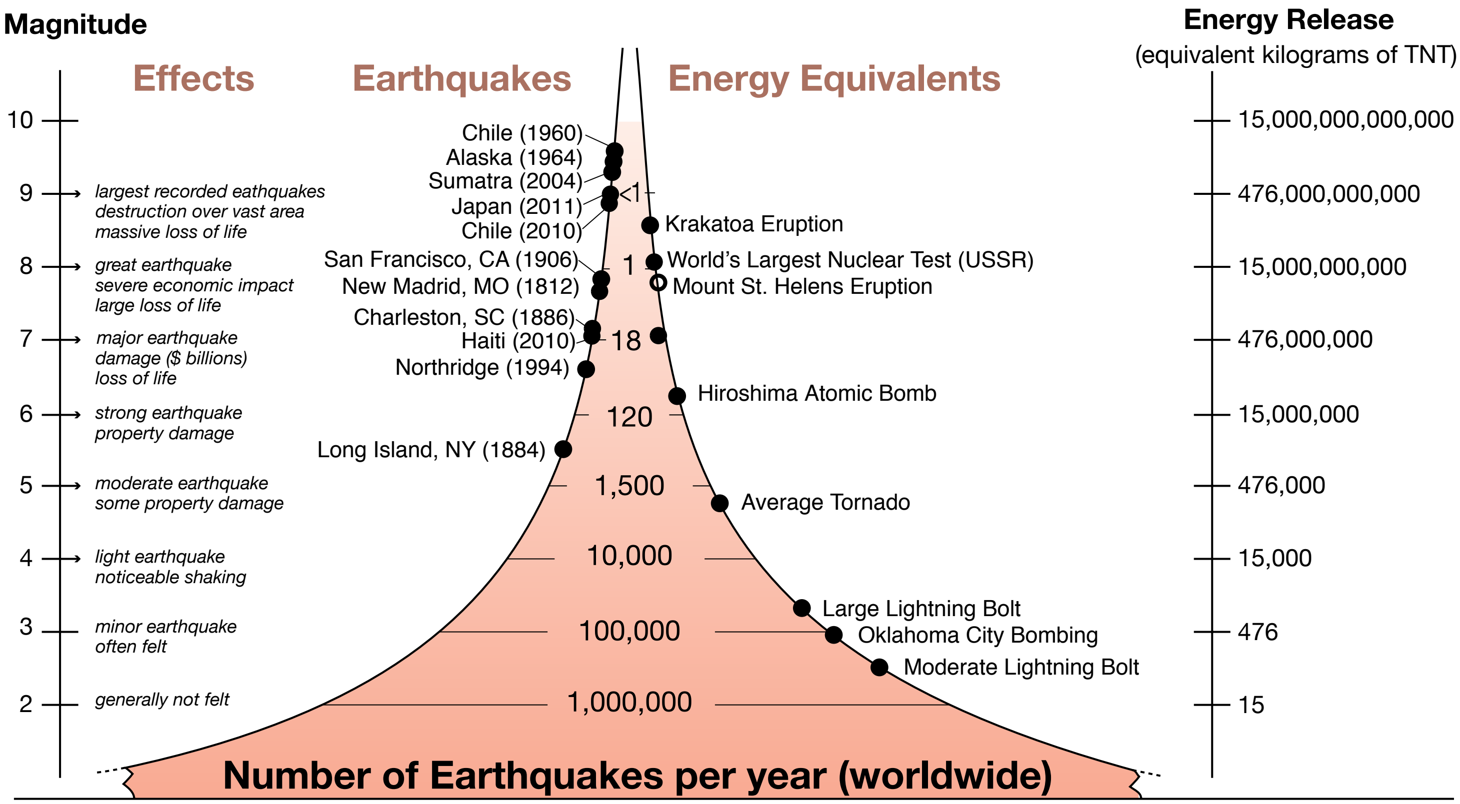
The 2011 Japan earthquake and resulting tsunami took ~20,000 lives.
The 2010 Haiti earthquake took ~150,000 lives, despite the seismic energy being more than 1000 times less that the seismic energy of the 2011 Japan earthquake. So the human impact of earthquakes is controlled by many factors in addition to earthquake energy. Distance of the earthquake from large cities and the strength of buildings and infrastructure are very important.

Adapted from Magnitudes of Recent Earthquakes graphic by LiveScience (Ross Toro, www.ouramazingplanet.com): www.livescience.com/13773-japan-earthquake-triggered-smaller-quakes.html

The average number of earthquakes per year, and their relative sizes.

The left side of the figure describes the effects of an earthquake by magnitude. The larger the number, the bigger the earthquake.

- Significant earthquakes are noted on the left side of the shaded tower.
- The shaded area indicates how many earthquakes of each magnitude occur every year.
- The events on the right side of the tower show equivalent energy release.



From the IRIS fact sheet, "How Often Do Earthquakes Occur?"

APPENDIX C—PASTA QUAKE MATH

An earthquake's magnitude is a measure of the amount of energy released. The Richter (M_L) and moment (M_w) magnitude scales both use the seismogram, or recording of seismic waves, to determine the magnitude. While the Richter scale primarily uses the maximum amplitude of the seismic waves, the moment magnitude is based on the seismic moment. The seismic moment is the rock rigidity times the distance the fault moved times the area of the fault that ruptured. Although the student worksheets do not address the area of a fault surface, for a more advanced class you might include a variation on these calculations.

Doing the math:

To calculate increasing magnitudes, we will work with the cross section area of bundles of spaghetti.

To increase the magnitude, the cross section area in cm^2 is multiplied by 32 (the log factor representing the energy released for each level). We will also find the diameter of the bundle to see how the size of the bundles of spaghetti increases with each magnitude.

Magnitude 6:

A 32-strand bundle of spaghetti = an area of 1.14 cm^2.

To determine the diameter of the bundle, divide the area by π (3.14159) = .36 cm^2.

Next, take the square root of the product to determine the radius √ .36 cm^2 = .6 cm.

And finally multiply by 2 to determine the new diameter .6 cm x 2 = 1.2 cm (2.67 in).

To increase a **M6** to **M7**:
multiply the area of **M6** 1.14 cm^2 by 32 = 36.32 cm^2

Magnitude 7:

1,024-strand bundle. Area = 36.32 cm^2.

To determine the diameter of the new bundle, divide the area by π (3.14159) = 11.56 cm^2

Next, take the square root of the product to determine the radius √ 11.56 cm^2 = 3.4 cm.

And finally multiply by 2 to determine the new diameter 3.4 cm x 2 = 6.8 cm (2.67 in).

To increase a **M7** to **M8**:
multiply the area of **M7** 36.32 cm^2 by 32 = 1,162.24 cm^2

Magnitude 8:

32,768-strand bundle of spaghetti. Area = 1,162.24 cm^2.

To determine the diameter of the new bundle, divide the area by π (3.14159) = 369.95 cm^2.

Next, take the square root of the product to determine the radius √ 369.95 cm^2 = 19.23 cm.

And finally multiply by 2 to determine the new diameter 19.23 cm x 2 = 38.46 cm (15.14 in).

To increase a **M8** to **M9,** multiply the area of M8:
1,162.24 cm^2 by 32 = 37,191.68 cm^2

Magnitude 9:

1,048,576-strand bundle. Area = 37,191.68 cm^2.

To determine the diameter of the new bundle, divide the area by π (3.14159) = 11,838.49 cm^2.

Next, take the square root of the product to determine the radius √ 11,838.49 cm^2 = 108.81 cm.

And finally multiply by 2 to determine the new diameter 108.81 cm x 2 = 217.62 cm (85.68 in which also equals *7.14 feet!!*)

Table 1: *The number of strands of spaghetti needed to represent each step-wise increase in magnitude beginning with M5. If you gather enough spaghetti for a M9 earthquake, the diameter would be over 7 feet across!!!*

Magnitude	Strands of Spaghetti	Area of the bundle	Diameter of the bundle
5	1		
6	32	1.135 cm^2	1.2 cm or 0.47 in
7	1,024	36.32 cm^2	6.8 cm or 2.67 in
8	32,768	1,162.24 cm^2	38.46 cm or 15.14 in
9	1,048,576	37,191.68 cm^2	217.62 cm or 85.68 in or 7’ 2”

APPENDIX D—PHOTOS FOR DEMONSTRATION

Figure 2

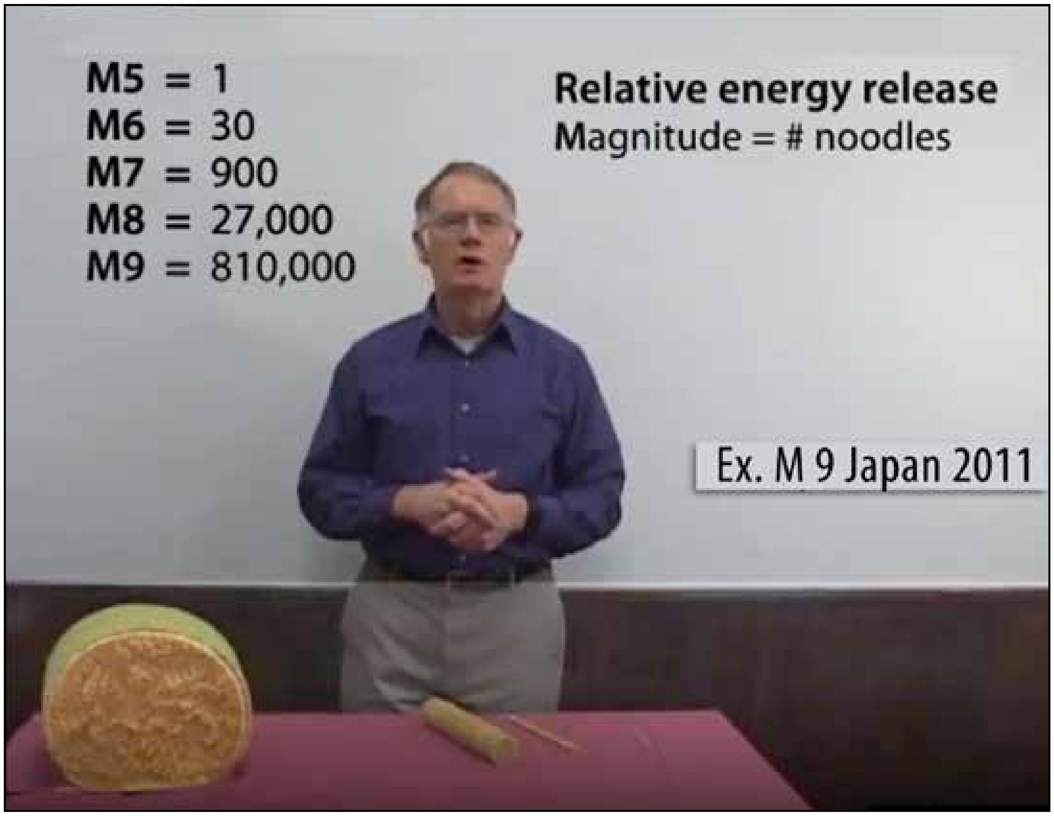


Figure 3

Figure 4

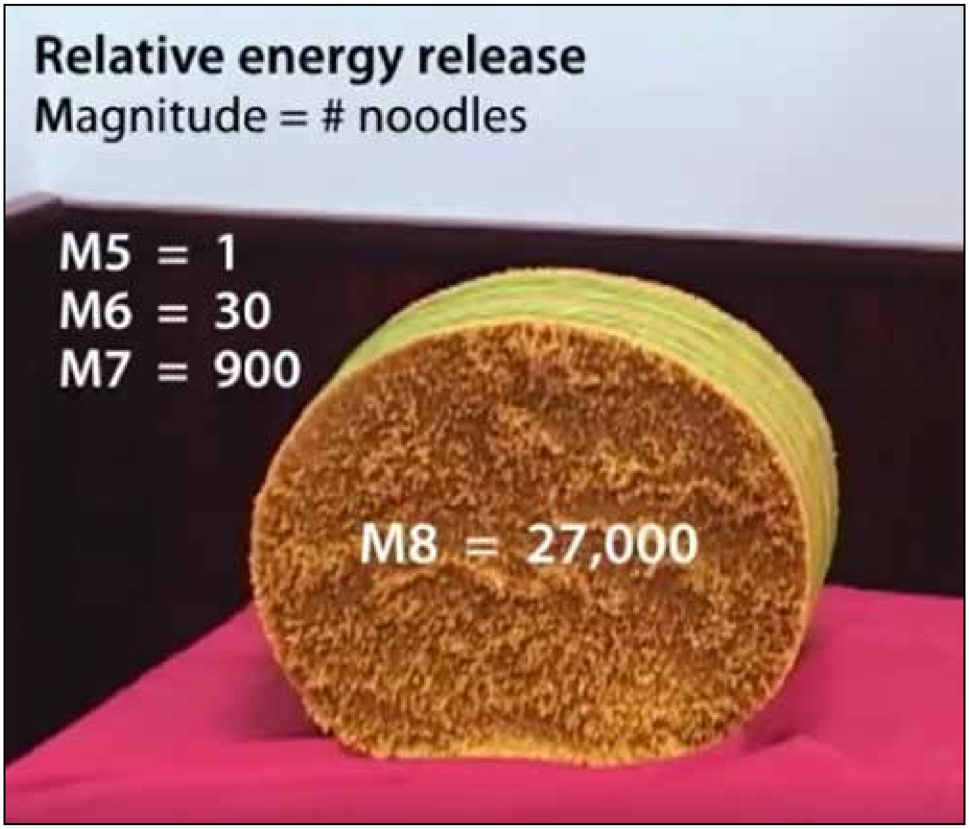


Figure 5

APPENDIX E: LEARNER WORKSHEET (30 - 45 min activity)

Name: ______________________

Per. _______

Date: _________

Exploring Earthquake Magnitude

Part A. Watch this video, then answer the questions below:

Moment Magnitude Explained—What Happened to the Richter Scale? (Time: 5:39)

Charles Richter and Beno Gutenberg first developed the Richter scale of earthquake magnitude in the 1930s. Since that time, significant advancements have been made to more accurately measure earthquake magnitude.

1. Describe the limitations of the original Richter scale.

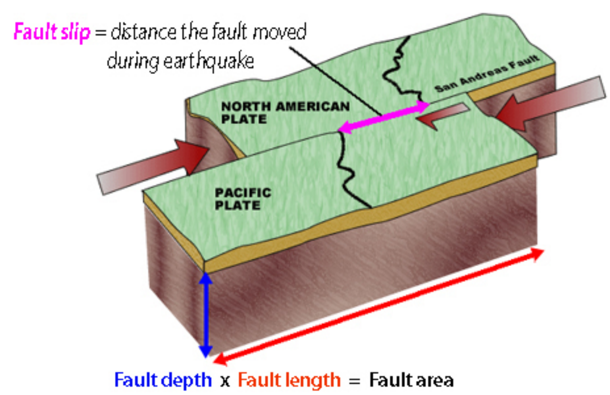
2. In 1979, seismologists were able to connect the more sensitive seismograph recordings with the physics of an earthquake. The result is the moment magnitude scale. The moment magnitude is based on the seismic moment, which is a function the area of slip (fault depth times fault length), the fault slip, and the rock rigidity.

   What does each factor mean and why is it important?

   a. Fault area (fault length x fault depth) of the slipped block?'

   b. Fault slip (Offset)?

   c. Rock rigidity (Mu; μ)?



Seismic Moment (M_o)= Fault length × Fault depth × Fault slip × Rigidity

Seismic Moment (M_w) = log M_o/1.5 - 10.7

3. The Richter scale is based on the amplitude of the recorded waves and the moment magnitude scale is based on the energy released. At what end of the magnitude scales are they similar—the lower end or the higher end of the scale?

Part B: Log on the **Earthquake Simulator**: What does it take to create a big quake? www.iris.edu/app/10.5/

The magnitude of an earthquake describes the amount of energy released from a given earthquake. The **Earthquake Simulator** models how the four factors contribute to the moment magnitude. The moment magnitude is related to the amount of energy released from an earthquake. Explore the Earthquake Simulator on your own, then answer the following questions. Tip: The Earthquake Simulator provides great "*Did You Know?*" facts, as you explore.

1. For the four factors used in the **Earthquake Simulator**, what is the minimum (above 0) and maximum possible scale used for each? Name one cool fact you gained from each factor?

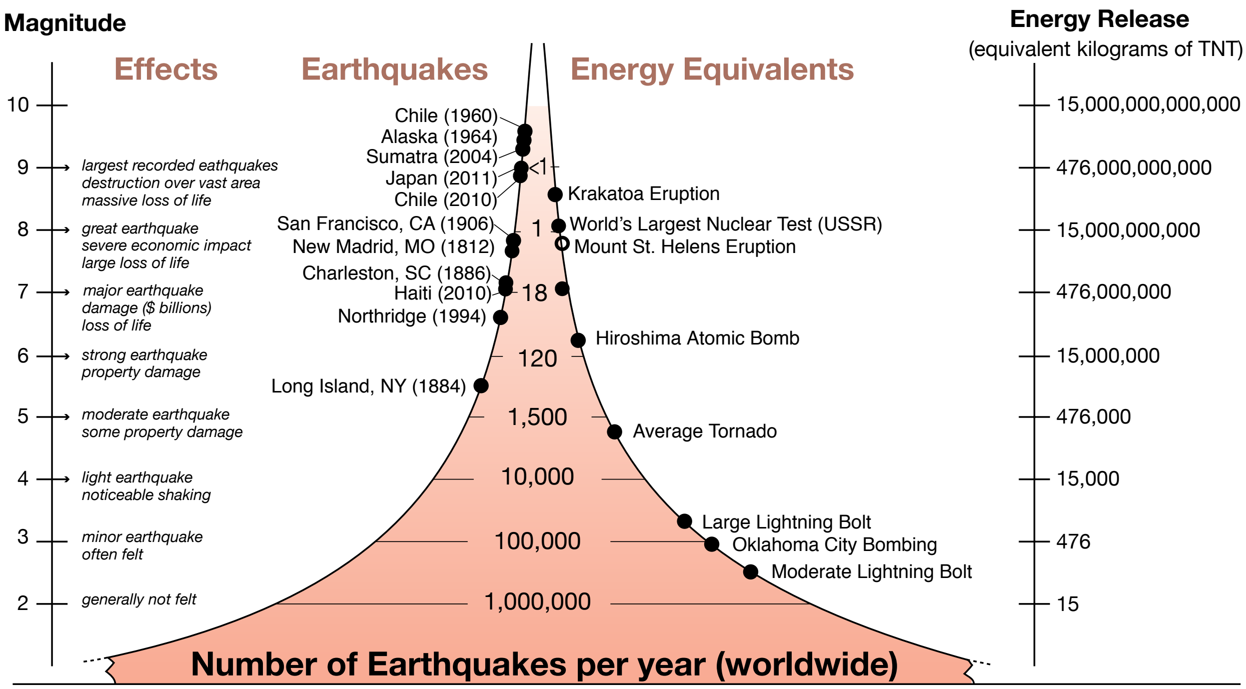
	Min	**Max**	**Cool Fact**
Length			
Depth			
Slip			
Rigidity			

2. What is the smallest earthquake you can create with the simulator?

3. Can earthquakes this size cause damage? Explain your answer.

4. How likely are large earthquakes to occur each year?

5. Study the graph below. Describe the relationship between magnitude, energy release and number of earthquakes occurring per year worldwide. Hint: Focus on the number of earthquakes per year and the shape of the orange graphic.



Earthquake magnitudes and energy release, and comparison with other natural and man-made events.

Optional questions for learners with greater earthquake knowledge.

6. Another type of fault poses tremendous earthquake hazard and risk. This fault extends 600 miles from northern California through Oregon and Washington, to British Columbia.

   a. What is this type of fault and resulting earthquake called?

   b. What magnitude of earthquakes are possible with a full rupture?

   c. Name at least three risks from this type of earthquake:

7. How can an earthquake early warning system, like the ShakeAlert® system for the West Coast of the U.S., address earthquake risks to help create safer and more resilient cities and communities?

Appendix F: Instructor Answer Key to Learner Worksheet

Name: ______________________

Per. _______

Date: _________

Exploring Earthquake Magnitude

Part A. Watch this video, then answer the questions below:

Moment Magnitude Explained—What Happened to the Richter Scale? Time: 5:39

Charles Richter and Beno Gutenberg first developed the Richter scale of earthquake magnitude in the 1930s. Since that time, significant advancements have been made to more accurately measure earthquake magnitude.

Answers below expand on the video narration:

1. Describe the limitations of the original Richter scale.

The Richter scale underestimates the size of large earthquakes because seismometers at that time (1930s) were not sensitive enough to capture the full spectrum of seismic signals. This means that during larger earthquakes the seismic signals would be 'clipped' or cutoff.
Video 37 sec. – 53 sec.

2. In 1979, seismologists were able to connect the more sensitive seismograph recordings with the physics of an earthquake. The result is the moment magnitude scale. The moment magnitude is based on the seismic moment, which is a function the area of slip (fault depth times fault length), the fault slip, and the rock rigidity.

   What does each factor mean and why is it important?

   a. Fault area (fault length x fault depth) of the slipped block?

   The estimated area of the fault zone along which the fault slipped.
   It defines the area that actually ruptured during the earthquake.
   Video 1:10 – 2:48

   The greater the fault area that slips, the larger the earthquake.

   b. Fault slip (Offset)?
   Distance that one block slips along one side of the fault zone relative to the other side. The larger the fault slip, the larger the earthquake.

   c. Rock rigidity (Mu; μ)?
   Rock rigidity is a constant for a given rock material. It describes the resistance of rock to bending. More energy is stored in rocks of high rigidity than rocks of low rigidity. Rock rigidity is lower in the crust than it is in the mantle. (More rigid rocks release more energy during an earthquake, and this energy can travel farther distances. For the same magnitude, east coast (old, cold, more rigid rock) earthquakes are felt further away, compared to the west coast (young, hot, less rigid rock)).
   Video 1:44

3. The Richter scale is based on the amplitude of the recorded waves and the moment magnitude scale is based on the energy released. At what end of the magnitude scales are they similar--the lower end or the higher end of the scale?
   The moment magnitude scale is calibrated so that smaller magnitude earthquakes match the Richter scale.
   Video 3:20 – 3:43

Part B: Log on the Earthquake Simulator: What does it take to create a big quake? www.iris.edu/app/10.5/

The magnitude of an earthquake describes the amount of energy released from a given earthquake. The Earthquake Simulator models how the four factors contribute to the moment magnitude. The moment magnitude is related to the amount of energy released from an earthquake. Explore the Earthquake Simulator on your own, then answer the following questions. Tip: The Earthquake Simulator provides great *"Did You Know?"* facts, as you explore.

1. For the four factors used in the Earthquake Simulator, what is the minimum (beyond 0) and maximum possible scale used for each? Name one cool fact you gained from each factor? *Answers may vary*

	Min	Max	Cool Fact
Length	*The length of the fault - 40km to 40,000km*		
Depth	*The depth of the fault – 5km to 35 km*		
Slip	*The distance one side of the fault moved relative to the other— 2m to 350m*		
Rigidity	*The strength of the rock 20 = sandstone, 50 = granite, 32 = Average of many rock types that make up Earth's outer shell, and 1,200 = diamond.*		

2. What is the smallest earthquake you can create with the simulator?

M6.6

3. Can earthquakes this size cause damage? Explain your answer.

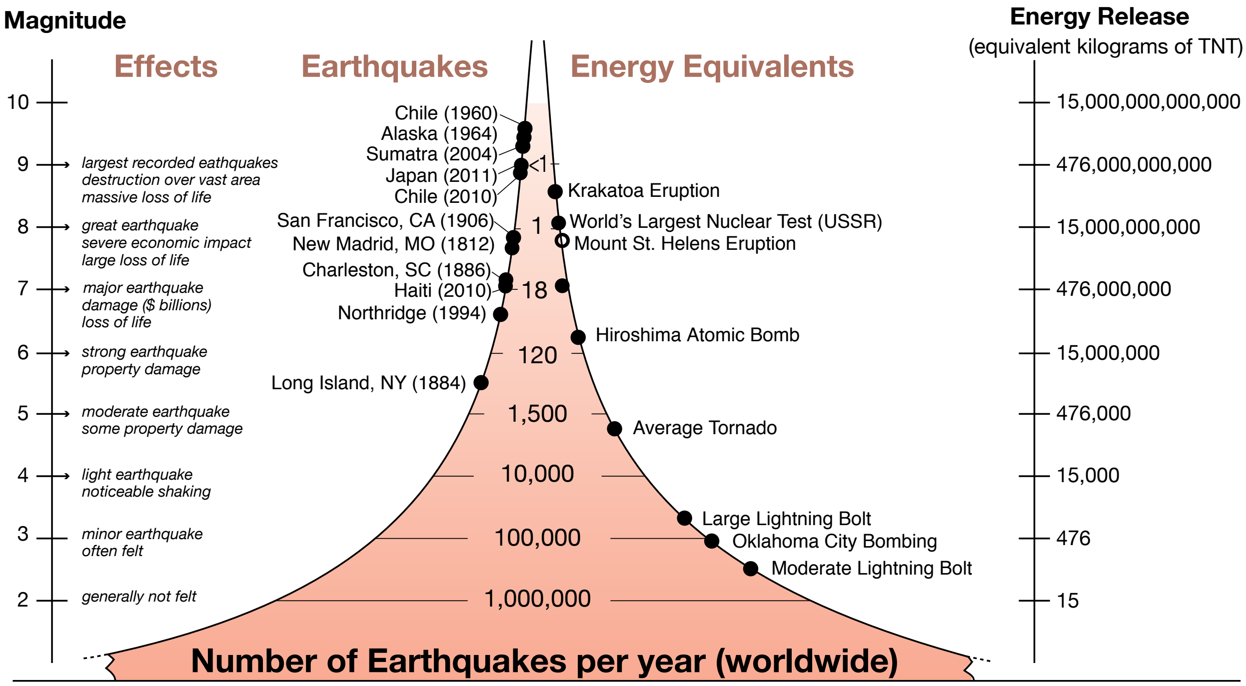
On average, more than 150 earthquakes between magnitude 6 and 6.9 occur each year. Earthquakes of this magnitude can cause significant damage to poorly engineered structures. Example: 1989 Loma Prieta, CA earthquake - M6.9.

4. How likely are large earthquakes to occur each year?

Only about 1-2 earthquakes between magnitude 8 and 8.9 occur each year somewhere in the world. Such earthquakes can cause destruction over a wide region if they occur near populated areas, and in some cases significant damage can occur even 400 km away, such as in the M8 Michoacan, Mexico earthquake in 1985.

5. Study the graph below. Describe the relationship between magnitude, energy release and number of earthquakes occurring per year worldwide. Hint: Focus on the number of earthquakes per year and the shape of the orange graphic.

There is a pattern to magnitude and earthquake frequency distribution. As earthquake magnitude and energy release increase, the number of earthquakes decrease.



Earthquake magnitudes and energy release, and comparison with other natural and man-made events.

Optional questions for learners with greater earthquake knowledge.

6. Another type of fault poses tremendous earthquake hazard and risk. This fault extends 600 miles from northern California through Oregon and Washington, to British Columbia.

a. What is this type of fault and resulting earthquake called?

This subduction-zone fault is a thrust or reverse fault, called a megathrust fault because of the scale. The resulting earthquake is called a megathrust earthquake.

b. What magnitude of earthquakes are possible with a full rupture?

M9

c. Name at least three risks from this type of earthquake:

Coastal tsunamis, prolonged shaking with increased damage due to geologic hazards from landslides, liquefaction, increased ground shaking and widespread damage to infrastructure, to include water, sewage, power, fuel, and transportation.

7. How can an earthquake early warning system, like the ShakeAlert® system for the West Coast of the U.S., address earthquake risks to help create safer and more resilient cities and communities?

Earthquake alerts allow users and automated systems to begin or take actions to protect themselves, equipment, and/or delicate operations from injury or damage during shaking. An alert powered by ShakeAlert® may be received before, during, or after shaking arrives at a particular location. When an alert powered by ShakeAlert® is received depends on the distance from the quake and how they receive the alert so that a protective action can be taken, such as Drop, Cover, and Hold On.

APPENDIX G—The Relationship between Earthquake Magnitude Scales and Energy

About energy transformations

The force of friction keeps faults locked, or stuck. During this time, the fault stores potential energy. When the force of friction is overcome, an earthquake occurs. The potential energy stored along a fault is released through movement, as in an earthquake. The stored potential energy along the fault is transformed during an earthquake to kinetic energy (when the fault moves in an earthquake), wave energy (in the form of seismic waves), and thermal energy (in the form of heat along the fault). The magnitude, or size of an earthquake, is determined based on the recorded seismic waves. From seismographs, scientists can get a sense of how much energy was released during an earthquake.

Seismic waves may increase or decrease in amplitude because of how far they travel through the Earth before they reach a recording station (or seismometer), the type of soil and rock conditions that the seismometer sits on, and the type of seismometer that records the seismic waves. Even the type of fault that the earthquake occurred on can affect the amplitude of seismic waves! Scientists keep these different factors in mind when they calculate the magnitude, or the size of an earthquake.

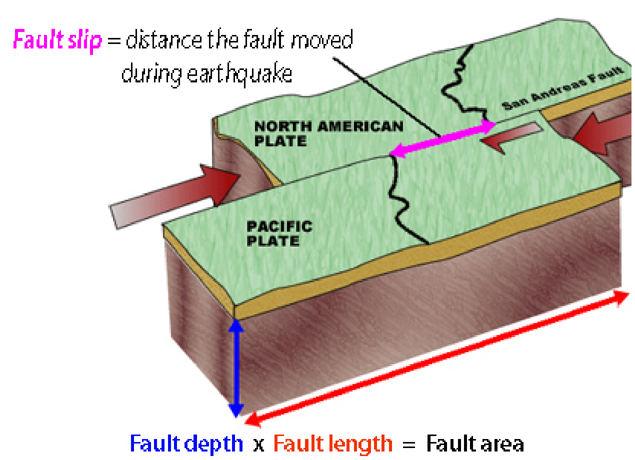
About earthquake magnitude scales

Let's discuss two well-known magnitude scales: the Richter scale (M_L, where M stands for magnitude and the L stands for 'local') and the moment magnitude scale (M_w, where M stands for magnitude and the w stands for 'work', or a physical measure of energy transfer).

In the 1930s, Charles Richter developed a logarithmic scale based on his earthquake observations in southern California (hence, the 'local' designation). Each unit increase on the scale represents a ten-fold increase in the size. Richter based his measurements on shallow earthquakes, recording at distances of about 100-600 km away, and recorded by a Wood-Anderson seismograph, which is no longer in use today because of improvements in technology. However, at greater depths, distances, or magnitudes, the local magnitude scale underestimates the size of an earthquake because the seismic waves have greatly decreased in amplitude.

In the 1970s, seismologists developed a more uniform magnitude scale based on the physical parameters of the earthquake, the moment magnitude scale. Similar to the Richter scale, the moment magnitude is also logarithmic. Each unit increase on the scale is based on a $10^{1.5}$ or ~32 times increase in the size. The moment magnitude provides the most reliable estimate of earthquake size, especially for very large earthquakes.

Moment magnitude is based on a physics concept called the seismic moment (M_O). The seismic moment (M_O) helps us understand how much energy was released during an earthquake. The seismic moment (M_O) takes into account: the rock strength or rigidity (μ), which is how much the fault resists slip; the area of the fault surface that slips or offset (depth * length = A); and the distance of slip on the fault's offset area (D). Taken together, the seismic moment (MO) is represented by this equation: $M_O = \mu AD$.



Seismic Moment (M_o)= Fault length × Fault depth × Fault slip × Rigic

Seismic Moment (M_w) = log M_o/1.5 - 10.7

About the energy released in an earthquake

In terms of moment magnitude, each magnitude unit represents a 32-fold increase in energy release during an earthquake. What this means is that a M6 earthquake will release 32x more energy than a M5 earthquake, and that a M7 earthquake will release 1000x (32x32) more energy than a M5 earthquake!

This activity will focus on understanding the moment magnitude, since most seismologists use this magnitude scale for larger earthquakes that can cause the most shaking and damage (see Appendix B).

For more information, the video, "Moment Magnitude Explained—What Happened to the Richter Scale?" (Time: 5:39) provides a thorough explanation of the differences between estimating earthquake magnitude using the Richter and moment magnitude scales

APPENDIX H— NGSS Science Standards & 3 Dimensional learning

Earth and Human Activity

MS-ESS3-2 Performance Expectation:

Analyze and interpret data on natural hazards to forecast future catastrophic events and inform the development of technologies to mitigate their effects. MS-ESS3-2

Science and Engineering Practices

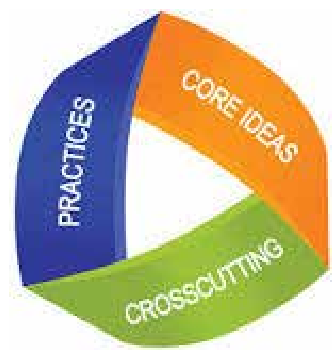
Analyzing and Interpreting Data
Analyzing data in 6–8 builds on K–5 experiences and progresses to extending quantitative analysis to investigations, distinguishing between correlation and causation, and basic statistical techniques of data and error analysis

Disciplinary Core Ideas

ESS3.B: Natural Hazardss
Mapping the history of natural hazards in a region, combined with an understanding of related geologic forces can help forecast the locations and likelihoods of future events. (MS-ESS3-2)

Crosscutting Concepts

Patterns
Graphs, charts, and images can be used to identify patterns in data.(MS-ESS3-2)



Incorporated Research Institutions for Seismology

IRIS

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