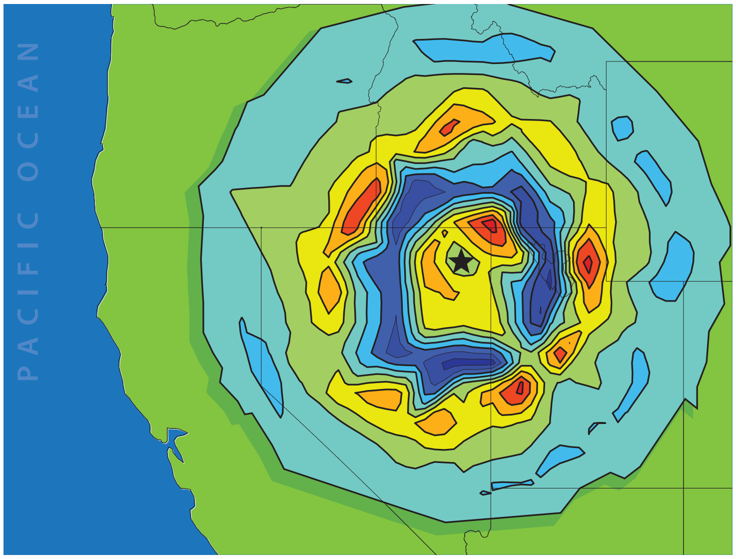
EARTHQUAKES...LIKE RIPPLES ON WATER?

Instructors' Guide | REVISED: March 2013 | **VERSION: 1.0** | ***http://www.iris.edu/hq/inclass/lesson/EQ_like_ripples/***



WHAT'S INCLUDED:

See this activity as part of one or more learning sequences at:

www.iris.edu/hq/inclass/sequences

OVERVIEW

In this activity, students investigate the classic Earth science analogy; "Seismic waves radiate outward from an earthquake's epicenter like ripples on water". Instruction begins as student examine a discrepant, thought-provoking image that connects the unfamiliar concept of the spreading out of seismic wave to the more familiar scenario of ripples on water radiating outwards in all directions after a droplet falls onto a pool. After students have recorded their initial thoughts regarding the image, they collect observational data from experimentation with water droplets falling into a pool to either support or refute their initial ideas. As a whole class, students then watch a visualization of ground motion at various points in the US and attempt to conceptually map this visualization to relevant features from their experiments. Students reflect on seismic wave propagation by constructing an argument (claim, evidence and explanation) that either supports or refutes the initial analogy "Earthquakes... like ripples on water?"

60 min | Beginner | Demo | Whole Class | Materials Required

IRIS InClass

CONTENT OBJECTIVES

Students will be able to:

1. Explain that seismic waves propagate outwards as wave fronts from the source in 3-dimensions (X, Y, & Z axes) and have a velocity
2. Explain that the amplitude of seismic waves is related to the amount of energy released from the source and decreases with distance from the source
3. Compare and contrast seismic waves to ripples on water.

MATERIALS & PREP

Teacher Materials:

- Overhead projector
- Small cup of water
- Eyedropper (if unavailable a straw, used like a pipette may be substituted)
- 9”x13” clear-glass baking dish with ~5 cm of water
- Thin, clear ruler (Optional but helpful if available)
- Flex Cam (Optional but helpful if available)
- Image: “Earthquakes… like ripples on water?”
- Videos/Animations/Data Visualizations
    - “How is an earthquake is LIKE ripples on water?”
    - “How is an earthquake is UNLIKE ripples on water ?”
    - “Earthquakes… like ripples on water?”
    - “Pebble into a pond”
    - Ground Motion Visualization for Wells, NV quake
    - Ground Motion Visualization for Mid-Indian Ridge Quake

Small group investigations (per group of 2–3 students):

- Clear or translucent container with 2–3cm of water (4” in diameter or larger is best as water waves travel very quickly)
- Small cups of water
- Eye dropper (if unavailable a straw, used like a pipette works well)
- Student worksheet for each student

Note1: *To provide context for this lesson students should already know that Earth materials are elastic and understand the Elastic Rebound Theory.*

Note2: *This activity has lots of places where optional instructions can either expand or reduce the duration of the activity. We present a "middle of the road" option but, where possible, alternatives as well.*

1) Open

Hang the poster prominently in the classroom several days prior to the lesson. Alternatively, show the poster image on the screen as students enter the classroom. Be sure to discuss the color scale of the image.

2) Prior Knowledge

a) Students describe what they "see" in the image using a Think-Write-Pair-Share strategy in #1 on the student worksheet.

b) Students record any questions that the images generates in #2 on the student worksheet. Emphasize that there are no right or wrong answers, or silly questions.

c) Elicit additional questions by showing students the animated version of the poster. Students should add these questions to their list.

3) Explore/Explain

a) Assign students into pairs or small groups.

b) Provide each group with a small dish filled with several centimeters of water, an eyedropper or a straw, and a small cup of water.

Tip – **To reduce the duration of this activity, the small-group work could be completed as a teacher-lead, whole-class investigation.**

c) Groups should test the analogy (Earthquakes… like ripples on water) by completing questions #3–5 on their worksheet.

d) Explore students' experiences in a whole-class discussion. Discussion can be facilitated by placing a 9"x13" clear-glass baking dish filled with several centimeters of water on an overhead projector. Slip the thin, clear ruler under the dish to provide scale. In this way you can demonstrate the following concepts students observed in their experimentation.

- The amplitude of the waves is related to the energy of the source (controlled by the mass and the drop height);
- Waves expand outward, or propagate, in circular wave-fronts
- Wave height decreases and eventually dies out with distance away from the source (or with time after the source) due to spreading out of the wave energy over a larger and larger area (or volume);

VOCABULARY

Amplitude- *The maximum displacement of a particle from a point of equilibrium.*

Propagate- *To cause a wave to move through a medium.*

Seismic Waves- *An elastic wave in the Earth generated by an earthquake or other large source.*

Wave- *A regular, rhythmic disturbance in time and space that transfers energy.*

- Waves have a speed (velocity) of propagation that can be measured. During this discussion emphasize how the ripples are 3-D in the dish but when projected on the screen become a 2-D, gray-scale representation of 3-D phenomena. In this case, darker gray represents a wave peak. This projection is similar to the process of converting ground displacement, a 3-D phenomena, into the color-coded image on the image, a 2-D representation where the peaks are represented by red/orange.

Tip – The data shown in the clip moves very quickly. Playing the clip at half speed or repeating multiple times is very useful.

e) Show the visualization, "Earthquakes… like ripples on water?" animation. Students, working in pairs or small groups, should identify relevant features of the analogy (e.g. what they saw at their desks (the analog) compared to the visualization (the target).

f) Encourage students to map the similarities between the relevant features they have identified. Asking them to create a table, similar to the analogy map (provided in the teacher background for your reference) may be useful to guide students. Once students have created their lists, review the similarities as a class.

g) Show the animation "How is an earthquake is LIKE ripples on water?" and have students update their tables.

h) Next, repeat the mapping procedure but this time encourage students to indicate or map the limitations of the analogy. (Note: Skipping this step when presenting analogies to students opens the door for misconceptions and misunderstandings). Once students have created their lists, review the similarities as a class.

i) Show the animation "How is an earthquake is UNLIKE ripples on water?" and have student update their tables.

4) Reflect

Student should complete #6 on the student worksheet.

5) Apply

Show students the "Ground Motion Visualization for Mid-Indian Ridge Quake". Before playing it, the visualization will need a brief introduction. It also shows ground motion like the drip animation, but in a different way. Key points include:

- Circles—Each circle represents a seismometer
- Yellow Circle—This is the station that recorded the seismogram shown below the map.
- Color—When the circle is red the motion is up and when it is blue, the motion is down.
- Seismogram—This is what a recording of the ground motion at the yellow station looks like. Although there is interesting information in it, this can be ignored for this activity.

Start the clip at 15 seconds in and only let it run until 23 seconds into the clip.

- Ask students to use their understanding of both the ripples on water and the prior visualization to explain what is occurring in the clip. (This works well as an "Exit-Ticket" type question)

ANSWER: *The earthquake occurred almost at the antipode, or a point on the Earth's surface that is diametrically opposite to the position, of the array of seismometers shown. Thus, after radiating out in all directions from the earthquake, the seismic energy is now coming back together (because Earth is a sphere) to a point just east of the array.*

TEACHER BACKGROUND

Using an analogy—Analogies are a useful instructional strategy, especially in the science classroom. They can serve both to motivate student interest while also developing a conceptual understanding of topics that can't be easily explored through direct experiences, such as labs and demonstrations. The classic Earth science analogy "Seismic waves radiate outward from an earthquake's epicenter like ripples on water" is an excellent example. Here the familiar concept of ripples on water (analog) is connected to the unfamiliar idea of seismic waves (target). For the purpose of enhanced engagement, this activity starts with a visual image of a drop hovering above and then falling into what appears to be ripples in the Western U.S. Thus, the image not only conveys the analogy but its discrepant nature also invites student inquiry.

To be instructionally effective, analogies must be familiar to the learner, and their features/functions must be congruent with those of the target. To ensure students are familiar with the analog, this activity provides small groups of students an opportunity to carefully view the phenomena from various angles. In this case, this functional analogy works because there are a number of similarities between the operation of the target and the analog. The mapping of these shared attributes should be made explicit to students. Likewise, it is also important to explicitly indicate the limitations of the analogy for students.

Analog (Familiar Situation)	Target (Science Concepts)
Dripping water and ripples	Earthquakes
is (are) like	
A water droplet suspended above a pool of water	Potential energy is stored elastically in rocks beneath Earth's surface as they deform due to plate motion
The water droplet grows from the slow leak. Eventually it becomes too heavy and overcomes the forces suspending it.	Potential energy builds in rocks as plate motion continues. Eventually it overcomes the strength of the rock.
The water droplet falls, striking and temporarily deforming the surface of the water	The rock suddenly slips/breaks (potential energy is converted to kinetic energy). Earth materials temporally deform as the waves pass through it.
Because water is an elastic medium, the particles in water are deformed, physically interact with their neighbors and return to their original position. Thus, energy is transported; the water is not	Because Earth is an elastic medium, the particles in Earth are deformed as they physically interact with their neighbors, and return to their original position. Thus, energy is transported, Earth material is not.
Via the process above, energy propagates outward from the source across the surface as ripples. *Note: In this example, an unseen pressure wave propagates through the water ahead of the ripple shown.*	Via the process above, energy propagates outward in all directions from the earthquake hypocenter as body waves. When this energy reaches the surface, surface waves are generated. The image shows the surface effects of both body and surface waves propagating outward from the epicenter.
Ripples in water travel along the phase boundaries between water/air and decrease in amplitude with depth	Surface waves travel along the phase boundary between Earth/atmosphere and decrease in amplitude with depth
As a ripple propagates, water particles have both longitudinal and transverse motion	As a Rayleigh wave (one type of surface wave) propagates particles have both longitudinal and transverse motion

Analog (Familiar Situation)	Target (Science Concepts)
Dripping water and ripples	Earthquakes
is (are) *NOT* like	
A water droplet grows from a slow leak over a relatively short time period, perhaps over the course of seconds or minutes.	Potential energy builds very slowly in rocks as Earth's tectonic plates move ~3-5 cm/year.
Ripples are most like surface waves as both travel along the phase boundary.	Ripples are not like body waves (Primary and Secondary waves). These seismic waves radiate outwards in all 3-dimensions and travel through Earth.
Particle motion for water ripples is prograde	Particle motion for Surface waves is retrograde for Rayleigh waves and perpendicular to the direction of wave propagation for Love waves. Particle motion for Body waves is parallel to the direction of wave propagation for Primary waves and perpendicular to the direction of wave propagation for Secondary waves.
Ripples expand in nearly concentric rings because water is essentially homogeneous	Seismic waves expand in only roughly concentric rings/spheres. This velocity of the seismic waves, and in turn the shape of the rings/spheres, is influenced by the geology of the Earth materials the waves are traveling through. Waves speed up in some materials, and slow down in others.
Ripples are relatively slow	Seismic waves in Earth travel approximately 100 times faster than water waves
A falling droplet of water strikes the surface of the water to create ripples	Earthquakes occur below the surface at the hypocenter and propagate outwards. Surface waves are generated when body waves interact with the surface of Earth
Other general differences: Physical scale, scale of the energy released, material/composition (water & Earth), Earthquakes are not generated from falling water on Earth, a water droplet may build up in seconds while the stress for an earthquake can accumulate for hundreds or thousands of years, stresses for earthquakes are built up from within Earth.	

The above activity is an excellent activity to lead students, from a familiar and accessible visual of ripples on water, into and exploration of seismic waves. Once hooked, learning can be extended to additional explorations of seismic waves using Slinkys™ to learn how various seismic waves propagate. In addition, the following sequence is useful strategy to transition students' mental models of seismic waves propagation from one of wavefront to ray-path.

About Seismic Waves and the Visualizations - The energy from an earthquake radiates outwards in all directions. Because of the elastic properties of Earth materials (rocks) and the presence of the Earth's surface this energy propagates as four main types of seismic waves. Compressional or Primary (P) and Shear or Secondary (S) waves propagate through the Earth's interior and are known as body waves. Love and Rayleigh waves propagate primarily at and near the Earth's surface and are called surface waves. As when any type of seismic wave encounters Earth's surface, it causes the ground to move (Figure 1). Unless the earthquake is nearby, the scale of these motions are generally too small, perhaps only 0.001mm (a fraction of the diameter of a human

Activity	Seismic wave mental model	Learning
"Earthquakes... like ripples on water?" poster and water waves	Wavefront	Seismic waves propagate outward from the hypocenter in all directions
Seismic Waves (Free PC only software)	Wavefront	Seismic waves propagate through Earth as well as across its surface
5-slinky model (shown above)	Wavefront & Ray paths	Seismic waves propagate outward from the hypocenter in all directions Seismic waves have a travel time
Single slinky & slinky attached to house	Ray Paths	Seismic waves transfer energy not material Mechanism of seismic wave propagation (P, S and Surface waves)
Human waves	Ray Paths	Kinesthetic review of P & S wave motion

hair), and occurs over a time scale, 100s of seconds, that is too long for humans to "feel" or detect. However, sensitive instruments such as seismographs are able to discern such changes and record them as seismograms. The visualization on the front of this poster uses a color scale to indicate the change in amplitude of the ground through time as recorded at nearly 400 seismic stations that make up USArray [http://www.usarray.org]. Because the seismometers are distributed in a grid with a spacing of approximately 70km, unprecedented density, the collective display of the ground motion across the array is particularly informative both for teaching and scientific research.

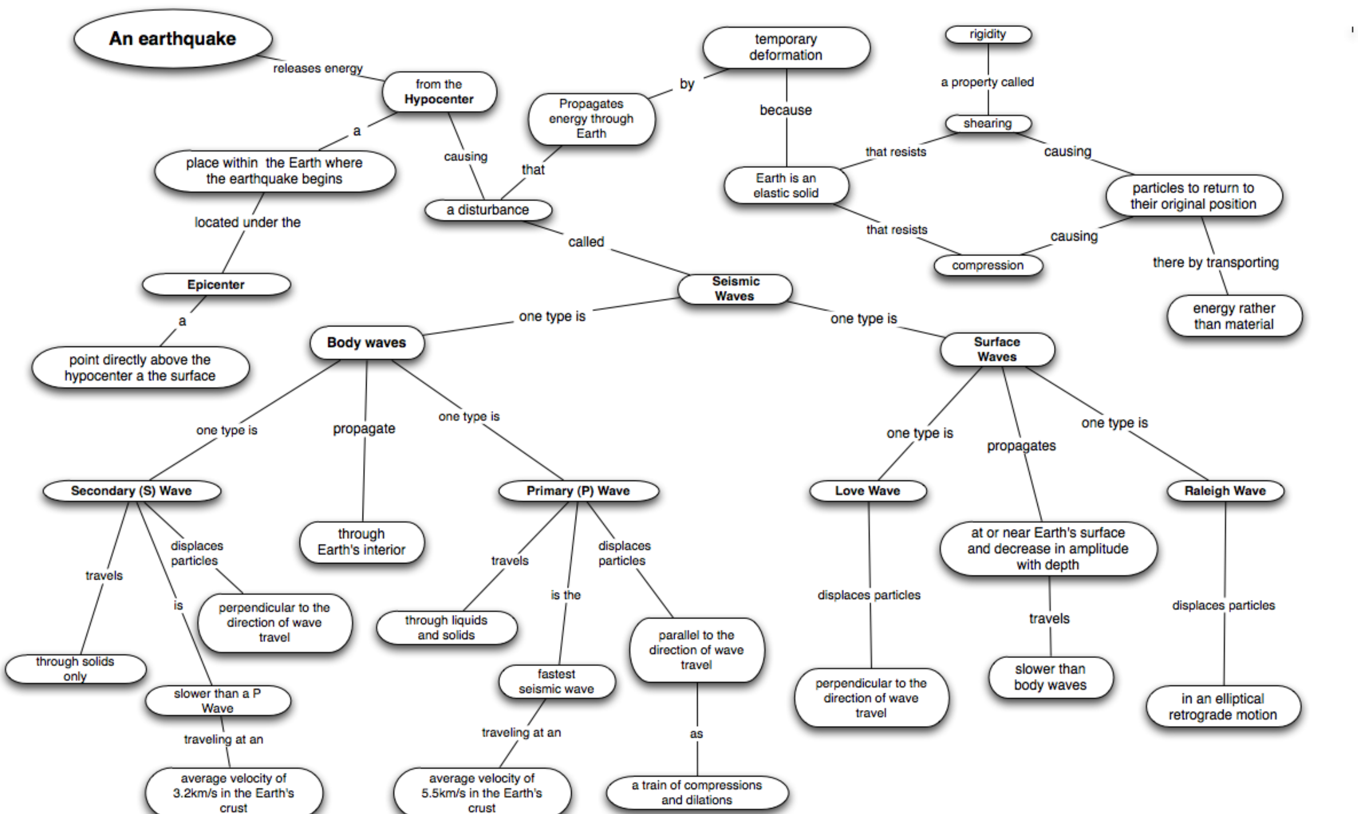


Figure 1. A concept map of seismic waves

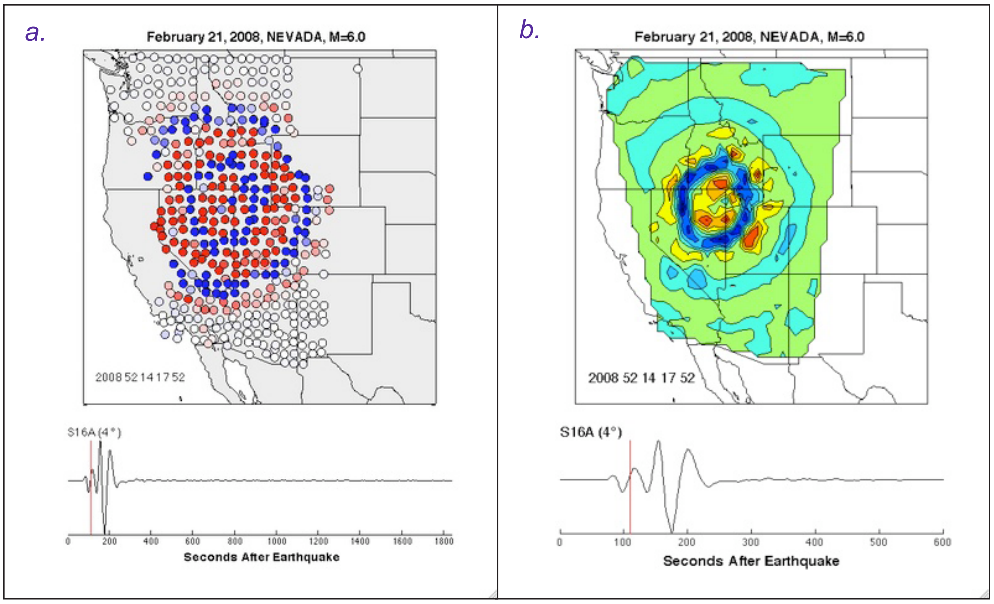


Figure 2. Visualizations of ground displacement from an earthquake. (a) Individual station response is shown as red = up and blue = down. (b) In a contoured visualization, warmer colors like yellow, orange and red indicate positive displacement, while cooler colors from pale to dark blue indicate negative displacement.

collecting the individual responsresented by a circle. The color of the station, indicates the ground displacement at that individual station (e.g. red = up and blue = down).

Next, using a computer, the individual responses from each station (figure 2a) are combined to create contours or connections between points of a constant value (figure 2(b).

By analyzing how these contours change through time (below), we see how seismic energy radiates outwards from the epicenter and spreads across the array. If the continent were homogenous, the pattern on the front of the poster would be perfectly concentric like the ripples on water. However, since Earth's crust is not homogeneous we see many subtle anomalies to the pattern. Scientists study these anomalies to infer structure and composition of the ground in which the waves are traveling to help them answer geologic questions. For example: What causes earthquakes to occur far from the edges of tectonic plates? What happens to plates after they have been subducted? What is the role of hotspots in evolution of the continents?

When examining this data, it is important to note that the visualizations play 75x faster than actual speed. The visualizations used on the poster have also been slightly altered artistically. This was necessary to smooth out anomalies generated from the process used to create the colored data contours; a process combining data from over 400 stations. However, the video clips and still images captured from the videos (Figure 3) have not been altered in this way. As a result, this data appears much more "complex". For example, background "noise" can be seen as random blobs when the clip opens. Also, watch the upper right corner of the field in the clip to see a prominent example of an "edge effect". It is important to remember that they are artifacts of the process used to generate the visualization rather than actual data representing geologic features of Earth.

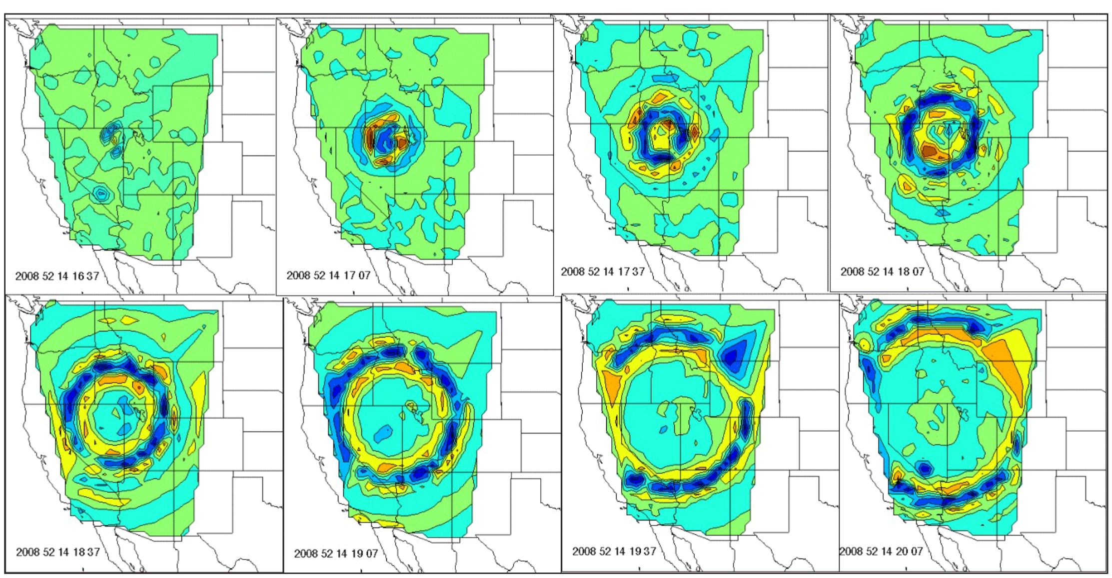


Figure 3. Time-step visualizations of ground displacement from an earthquake.

REFERENCES, ACKNOWLEDGEMENTS & FURTHER READING

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Name:

Period:

Date:

EARTHQUAKES...LIKE RIPPLES ON WATER? WORKSHEET

1 Describe what you “see” when you look at the image.

My Ideas	*Paired Ideas*

2 What questions does the image generate for you?

3 Develop and describe a procedure that uses the materials provided to explore the analogy “Earthquakes… like ripples on water”. Conduct and repeat the procedure several times and carefully view the phenomena from various angles to discover the 3-D nature of ripples (e.g. birds-eye as well as edge on). Record your observations, both text and sketches, in the space below.

Procedure	*Observations*

4 How do the ripples change as you move the position of the eyedropper (e.g. higher or lower)?

5 How long does it take for a wave to reach the edge of the container?

6 Question: Are earthquakes like ripples on water?

a) Your Claim:

b) Your Evidence:

d) Your Explanation:

ANSWER KEY

Student Worksheet – Earthquakes…Like Ripples On Water?

1 Describe what you "see" when you look at the image.

My Ideas	*Paired Ideas*
Student responses will vary	*Student responses will vary*

2 What questions does the image generate for you?

Student responses will vary

3 Develop and describe a procedure that uses the materials provided to explore the analogy "Earthquakes… like ripples on water". Conduct and repeat the procedure several times and carefully view the phenomena from various angles to discover the 3-D nature of ripples (e.g. birds-eye as well as edge on). Record your observations, both text and sketches, in the space below.

Procedure	*Observations*
Student responses will vary somewhat but students should use the eyedropper to add drops to the pool of water.	*Student responses will vary but students should note the following…* • *Ripples propagate outward from the sources of the disturbance.* • *The ripples transmit energy but do not transmit material.* • *The surface of the water is displaced vertically as the waves pass (floating something on the water can make this more obvious)* • *If your dish is large enough, students may notice that they waves become smaller as they move away from the source do to attenuation.*

4 How do the ripples change as you move the position of the eyedropper (e.g. higher or lower)?

As you increase the height of the eyedropper you increase the kinetic energy of the falling drop. As a result, the amplitude of the ripples will also increase. Conversely as you lower the eyedropper, the falling drop will have less kinetic energy at impact and the amplitude of the ripples will be smaller. The kinetic energy of the drop could be compared to the magnitude of an earthquake.

5 How long does it take for a wave to reach the edge of the container?

This will vary depending on the size of the container you are. The point to emphasize is that the wave does have a measureable speed and it does take time for the energy to propagate from the source to a distant point.

6 Question: Are earthquakes like ripples on water?

a) Your Claim:
Student responses will vary

b) Your Evidence:
Student responses will vary

d) Your Explanation:
Student responses will vary