Shadowlands

Simulating the effect of the Earth's core on earthquake waves

When earthquake waves (both primary P-waves and S-waves or shear waves) move through rocks of different compositions and elastic properties, they change direction (refract) as they speed up or slow down. Earthquake waves travelling through the deep Earth are continuously refracted along curved paths, as changes in these properties with depth are gradual, and they are eventually refracted back to the surface where they are recorded. (Fig.1)

After a surface distance of about 11,000 km from an earthquake epicentre, (representing an epicentral angle measured at the centre of the Earth of 103°) no direct S-waves are recorded at all. This results in an **S-wave shadow zone** around the Earth; a direct result of a major seismic boundary (the Gutenberg Discontinuity) at a depth of 2,900 km. This boundary, between the mantle and the Earth's liquid outer core, stops S-waves travelling further as liquids cannot shear.

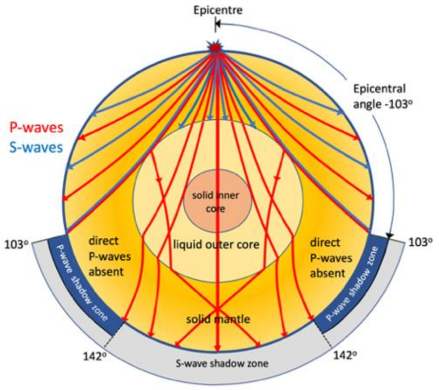

Fig.1 – The earthquake shadow zones associated with the pathways of P- and S-waves through the Earth © *Pete Loader*

Between epicentral angles of 103° and 142° no direct P-waves are recorded either, forming a **P-wave shadow zone**, but they are recorded once again after 142°, to focus on the opposite side of the Earth from the earthquake. However, these waves arrive later than expected indicating they have been refracted by the Earth's core.

Simulating earthquake shadow zones

- Draw two circles on white paper: one with the diameter of a glass beaker (to represent the Earth's outer core) and another, twice the size (to represent the Earth's surface).
- Draw a line from a point on the surface (an epicentre located directly above an earthquake) along its radius, to the centre of the Earth.
- Place an empty glass beaker in the centre circle. Using a light source (such as a mobile phone torch), shine a light through the beaker from just below the epicentre (along the radius line) and observe the shadow created on the opposite side (Fig 2a). (Note: although this is produced by light refracting through the glass alone, it serves to illustrate the extent of the S-wave shadow zone in the real Earth).
- Add water to the beaker and observe the focussing effect of the light to simulate the P-wave shadow zone (Fig 2b).
- Demonstrate that the shadow zones move when the light source is moved around the simulated Earth to represent the locations of different earthquakes.

Presented with this simulation, either as a class activity or a demonstration, students are asked to:

- mark on the outer circle the extent of the shadow zones.
- compare the measured epicentral angles of the shadow zones in the simulation with that of the real Earth in Fig 1.
- suggest reasons why the epicentral angles for the shadow zones in the simulation might be different from those found in the real Earth.
- discuss how the simulation helps explain the scientific reasoning for shadow zones in the real Earth.

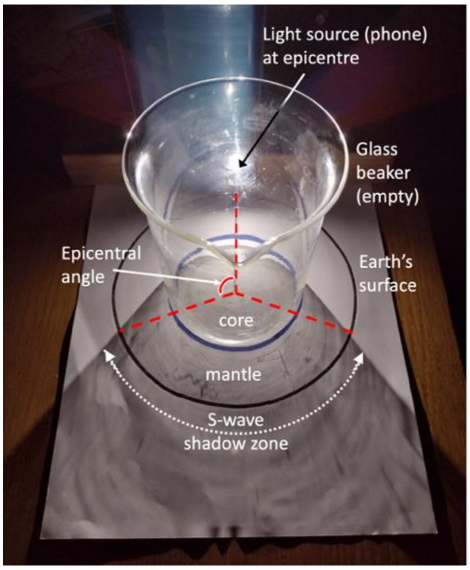

Fig 2a: The principle of the epicentral angle and the extent of a simulated S-wave shadow zone in the real Earth

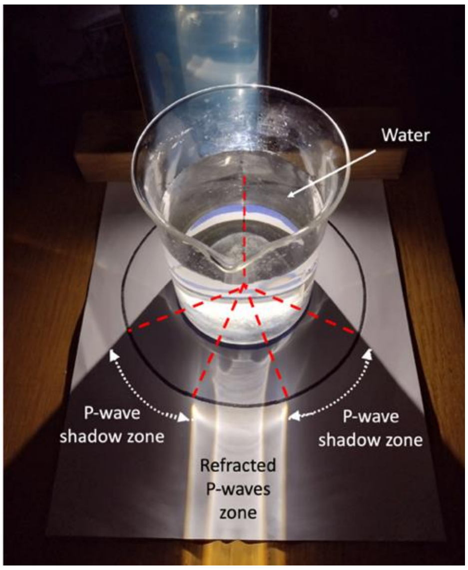

Fig 2b: The principle behind the formation of the P-wave shadow zone in the real Earth

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The back up

Title: Shadowlands

Subtitle: Simulating the effect of the Earth's core on earthquake waves.

Topic: A simulation exercise to demonstrate that the shadow zones created by earthquake waves are affected by the size and physical properties of the Earth's liquid outer core.

Age range of pupils: 15+ years

Time needed to complete activity: 15 minutes

Pupil learning outcomes: Pupils can:
- describe the shadow zones associated with earthquake waves passing through the Earth;
- explain the factors causing shadow zones associated with P- and S-waves in the Earth;
- explain the effect of a liquid in refracting light waves;
- evaluate why the simulation differs from real earthquake waves travelling through the deep Earth.

Context:
P-waves are 'pressure' waves that vibrate rock in the direction in which they travel so are transmitted by solids, liquids and gases. S-waves are 'shear' waves and vibrate rock at right angles to the direction in which they travel so are not transmitted through liquids, which are not able to shear. The depth and size of the Earth's outer core and the refraction of earthquake waves provide limits as to where P- and S-waves are recorded on the Earth's surface following an earthquake. These lead to the formation of shadow zones where no direct earthquake waves travelling through the Earth are recorded. Those of the simulation will be;
- different in size and scale compared to the real Earth as the simulation uses light waves through air and water and not earthquake waves through rock of different compositions and physical properties (density, incompressibility and rigidity);
- the effect of the solid inner core has not been considered in this simulation;
- the simulation is only in 2D and the core is a sphere, not a cylinder.

Following up the activity: Use the internet to trace the shadow zones of a recent large earthquake.

Underlying principles:
- Earthquake waves are refracted by the Earth to travel along curved paths depending upon physical properties.
- S-wave are 'shear' waves and are not transmitted though the Earth's liquid outer core.
- Shadow zones occur for every earthquake, but their position depends upon the earthquake's location.

Thinking skill development:
Moving the light source establishes a pattern of shadow zones linked to the position of the source. Adding water to the beaker changes the pattern causing cognitive conflict. Explaining and discussing the results of the simulation involves metacognition. Applying the simulation to the real Earth involves bridging.

Resource list:
- paper
- drawing instruments (compass, protractor, ruler)
- glass beaker (500 ml used in Fig 2)
- light source
- water

Useful links:
https://www.earthlearningidea.com/PDF/304_Slinky_seismic_waves.pdf
https://www.earthlearningidea.com/PDF/76_Slinkies.pdf
https://www.earthlearningidea.com/PDF/77_Human_molecules.pdf

Source: From an idea by Dr Chris Bedford (Radley College) published in TES Vol. 41 No.1 2016 and developed by Pete Loader of the ELI Team. Photos by Pete Loader.