

Structure of the Earth: the story of the waves

Learning objectives:

- written communication skills
- data analysis skills
- revision of content relating to seismic waves

Timing: 20 minutes

Introduction:

This exercise focuses on the indirect evidence for the Earth's internal structure from earthquake waves.

Students are asked to use their prior knowledge of the properties of seismic waves to interpret a graph showing how the velocities of **P-waves** and **S-waves** change with depth in the Earth.

Earthquakes produce P- and S-waves which pass through the Earth. Table 1 summarises the properties of P-waves and S-waves.

Earthquake wave	Other names	Mode of propagation	Properties
Surface waves	Love (L) and Rayleigh	Movement of the surface of the Earth	Reduce in intensity more quickly than other waves; these 'ground moving' waves cause the majority of earthquake devastation
Primary waves (body waves)	P-; push; pressure; compression; longitudinal	Compression and rarefaction of particles within the Earth	The faster of the two types of body waves; they travel through solids and liquids but travel more slowly through liquids than solids
Secondary waves (body waves)	S-; shear; transverse	Movement of the particles by shear, or motion at right angles to the wave travel direction	The slower of the two types of body wave; not transmitted by liquids (or other fluids)

Table 1 Properties of P-waves and S-waves

P-waves pass through both **mantle** and **core**, but are slowed and refracted at the mantle / core boundary at a depth of 2900 km.

S-waves passing from the mantle to the core are absorbed because shear waves cannot be transmitted through liquids. This is evidence that the outer core does not behave like a solid substance.

S-waves are not transmitted through the liquid outer core. This produces a 'shadow zone' on certain parts of the Earth's surface where S-waves are not recorded, and this is used as the main piece of evidence to deduce the size of the core. The core has a radius of 3470 km.

The main properties of the layers of the Earth are summarised in Table 2.

Layer	Properties
Crust	A thin outer layer with a mean density of about 2.8 g cm^{-3} . It is solid and consists of continental crust (mainly of granitic and sedimentary rocks) and oceanic crust (mainly of basaltic rocks). Oceanic crust has an average thickness of 6 km whereas continental crust has an average thickness of around 35 km. It can not easily be seen on the graph due its small scale.
Lithosphere	The solid crust and upper mantle material that may be up to 200 km thick in places.
Asthenosphere	The layer beneath the lithosphere, not synonymous with the low velocity zone. A zone of ductile behaviour that can accommodate movement.
Low velocity zone	A zone within the asthenosphere in the upper mantle that is defined on seismic criteria. It varies in depth between 50 and 250 km and represents part of the mantle that may be about 5% liquid. It transmits S-waves but both S- and P-wave velocities are reduced.
Mantle	A layer about 2885 km thick with density increasing with depth from $3.3 - 5.4 \text{ g cm}^{-3}$. It is solid and is thought to consist of peridotite (an iron / magnesium-rich silicate rock).
Outer core	A layer 2255 km thick which is very dense, increasing with depth from $9.9 - 12.3 \text{ g cm}^{-3}$. It is liquid and probably consists of an iron and sulfur mixture.
Inner core	This has a 1215 km radius and is very dense, with a maximum density of 13.5 g cm^{-3} . It is solid, and is thought to consist of an iron and nickel mixture.

Table 2 The main properties of the layers of the Earth

Students complete written answers to the worksheet *Waves in the Earth*.

Answers to questions:

- Q 1. (a) Lines drawn at a little more than 0 km, at 2900 km and at about 5100 km.
 (b) In the zone between 0 km and 2900 km wave velocity is increasing. In the zone between 2900 km and 5100 km the wave velocity is zero
- Q 2. Wave velocity drops to zero at 2900 km depth, as this is where liquid core starts, and S- (shear) waves cannot travel through liquids.
- Q 3. (a) P-wave velocity has a higher value and a greater gradient than the S-wave velocity plot. P-wave velocity reduces sharply at 2900 km depth but not to zero as S-wave velocity does.
 (b) Both P- and S-waves show rapid increase in velocity just below the surface (beneath the crust), varying but rising velocities to almost 1000 km depth then slowly increasing velocities to 2900 km. S- and P-wave velocities drop significantly between about 100 and 250 km depth.
 (c) A line drawn on graph to show P-wave velocity changing near 5100 km
 (d) Labels: Wave velocity increases gradually from 2900–5100 km, wave velocity increases suddenly at 5100 km and then remains fairly steady to the centre of the Earth.
- Q.4 (1) crust labelled at 20 km, (2) mantle labelled from 20–2900 km, (3) outer core labelled 2900–5100 km, (4) inner core labelled at 5100–6500 km.

- Q 5. (2) P-waves travel faster through mantle than S-waves. Mantle is solid
(1) S-waves cannot travel through outer core so it is liquid
(3) P-and S-waves travel through inner core so it is solid.

Acknowledgement:

This exercise is taken directly from the Earth Science Teachers' Association series of teaching materials entitled *Investigating the Science of the Earth* It is from *SoE2: Geological changes – Earth's structure and plate tectonics*, Activity E3. [1996. ISBN 1 873266 12 X, Available from: Dave Williams, Corner Cottage, School lane, Hartwell, Northants, NN7 2HL]