



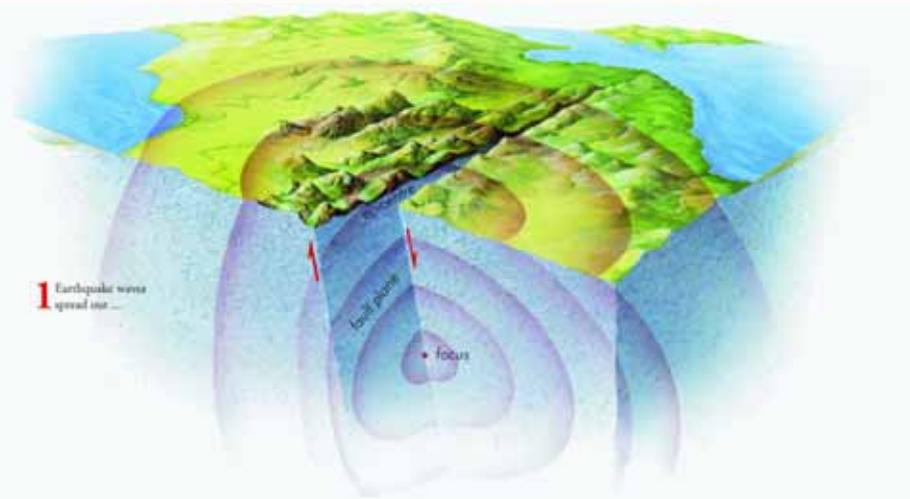
## Seismic waves

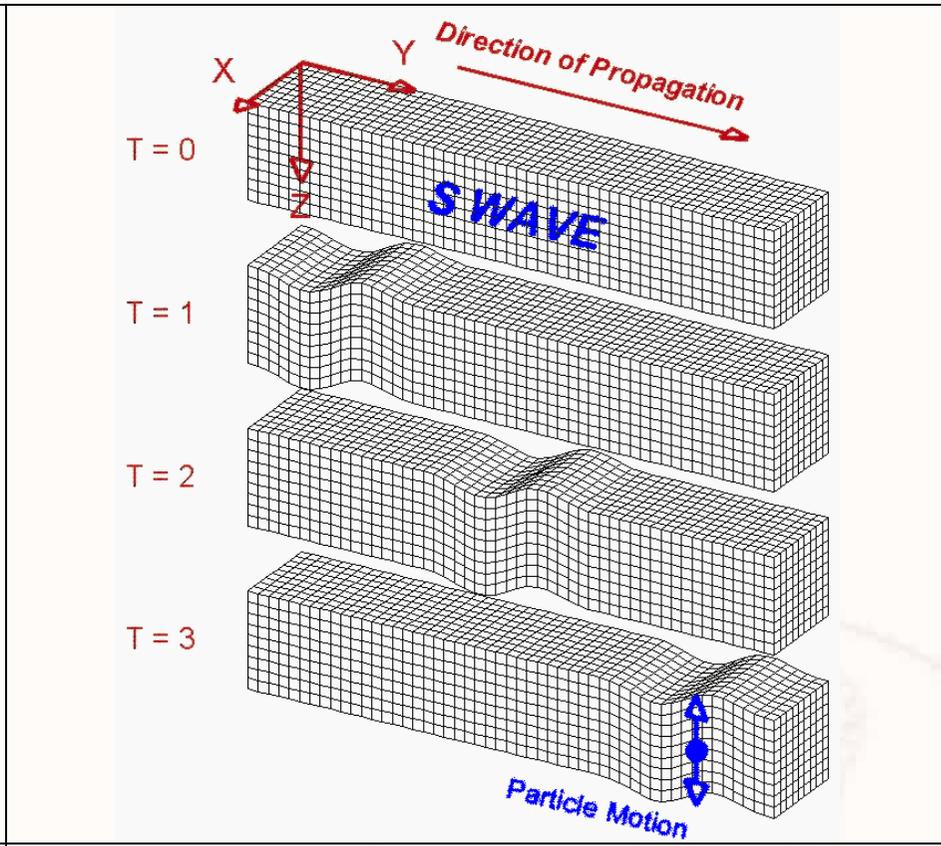
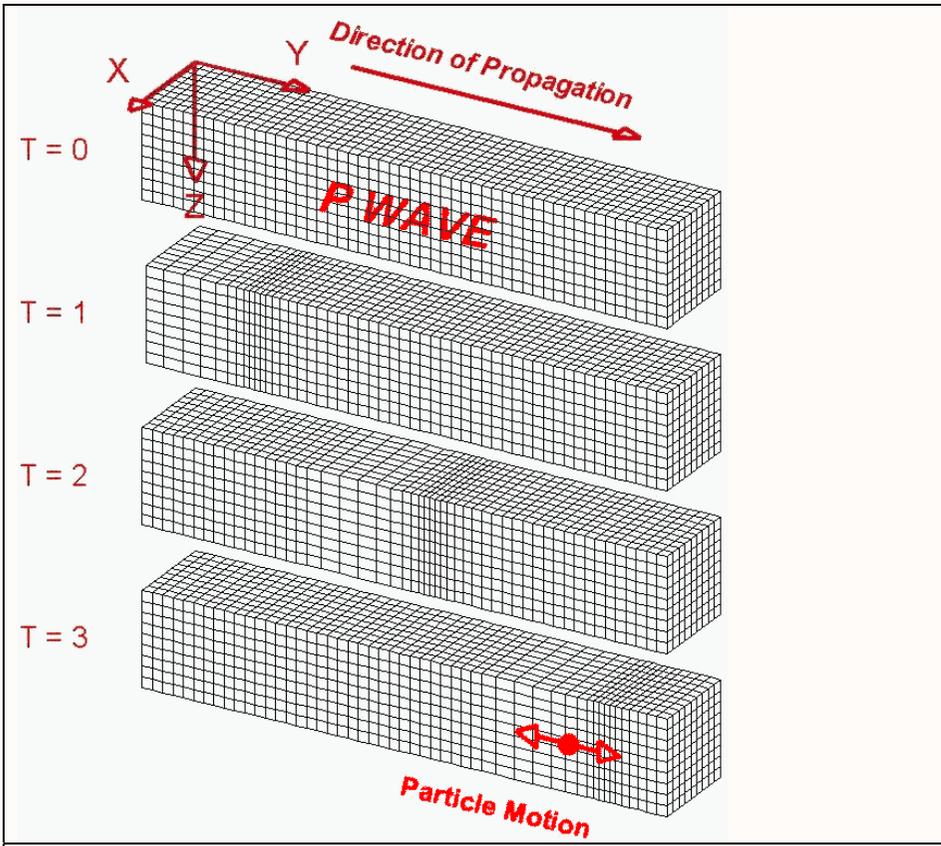
When an earthquake happens deep underground a crack will start to open on a pre-existing line of weakness in the Earth's brittle crust. This crack will then grow larger and larger, relieving built up stress as it goes. The speed at which the crack propagates or grows is 2–3 km/sec. Eventually the rupture will cease to grow and will slow down and stop. The size or magnitude of the earthquake depends upon how much the fault has ruptured (the slip) and also the area over which the rupture has occurred.

This rupturing process creates elastic waves in the Earth which propagate away from the rupture front at a much faster speed than the rupture propagates, the exact speed depends upon the nature of the wave (a longitudinal or P wave is faster than a transverse or S wave), and on the elastic properties of the Earth. As you go deeper into the Earth, the density and pressure increases and so do the velocities of seismic waves.

Seismic waves are fundamentally of two types, compressional, longitudinal waves or shear, transverse waves. Through the body of the Earth these are called P waves (for primary because they are fastest) and S waves (for secondary since they are slower). However where a free surface is present (like the Earth–air interface) these two types of motion can combine to form complex surface waves. Although often ignored in introductory texts, surface waves are very important since they propagate along the surface of the Earth (where all the buildings and people are) and usually have much higher amplitudes than the P waves and S waves. It is usually surface waves which knock down buildings.

Seismic waves, like all waves, transfer energy from one place to another without moving material.





*P-waves are a compression followed by a dilatation. The particle motion is in the direction of propagation. Sound waves are P-waves.*

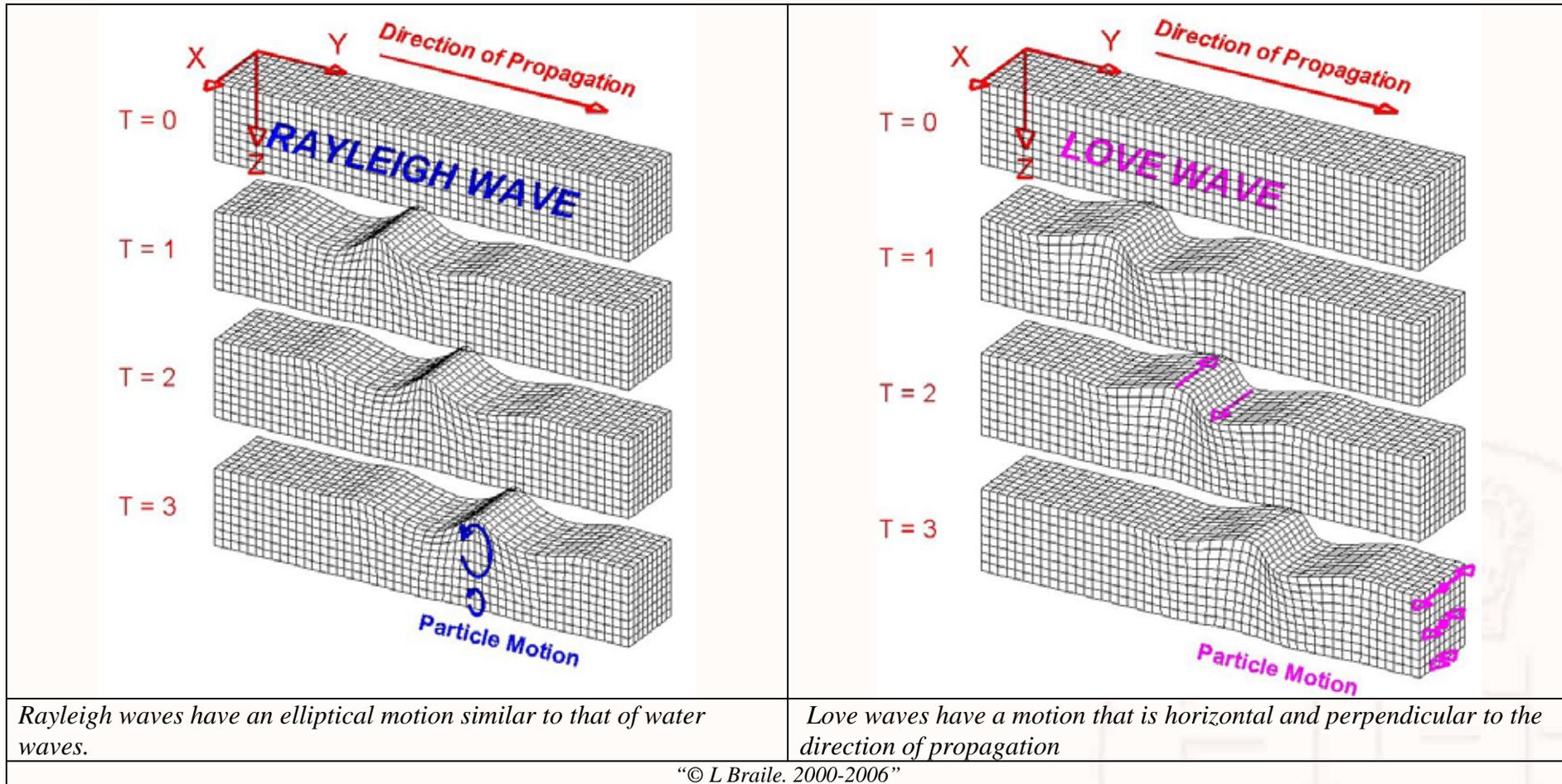
*S-waves have an up motion followed by a down motion. The particle motion is perpendicular to the direction of propagation.*

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Wave propagation through a grid through a grid representing a volume of material. The directions X and Y are parallel to the Earth's surface and the Z direction is depth. T = 0 through T = 3 indicate successive times. The material returns to its original shape after the wave has passed. Animations of these images can be found at <http://web.ics.purdue.edu/~braile/edumod/waves/WaveDemo.htm>



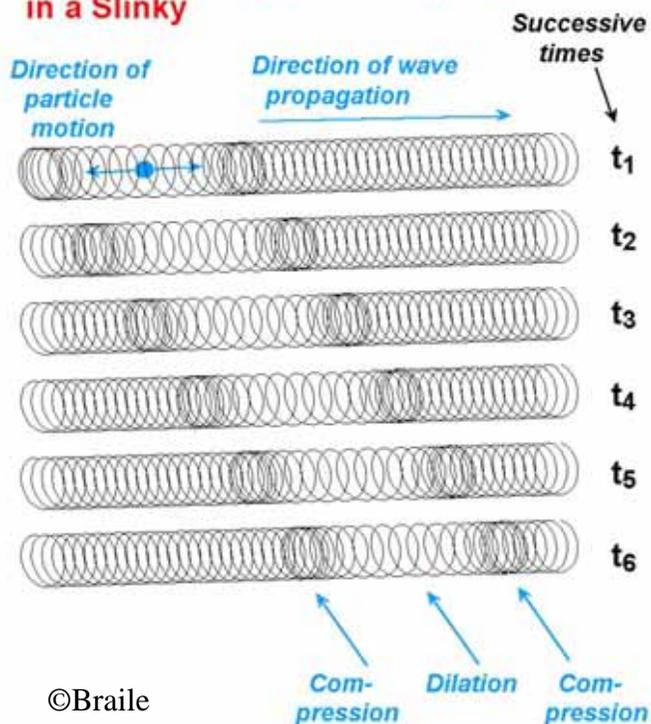
Surface waves have a complex motion that decreases in amplitude with depth, the material returns to its original shape after the wave has passed. Animations of these images can be found at <http://web.ics.purdue.edu/~braile/edumod/waves/WaveDemo.htm>



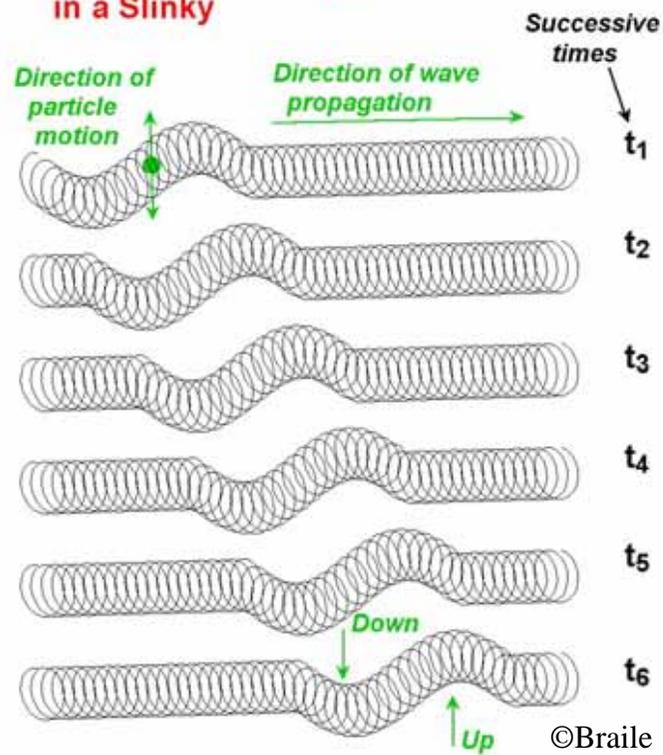


P waves and S waves can be easily demonstrated in the classroom with a slinky.

**Compressional (P) Wave Propagation in a Slinky**



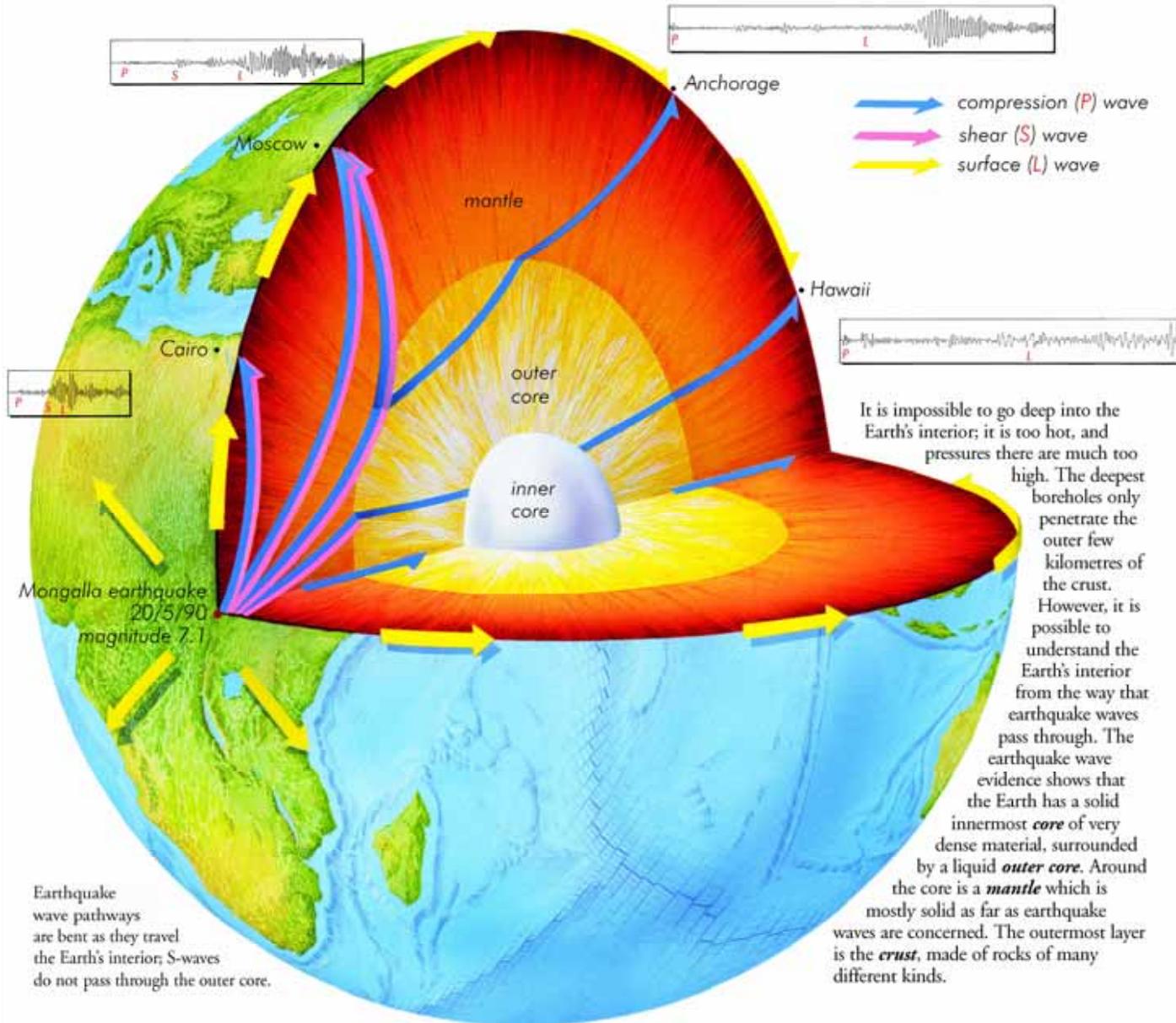
**Shear (S) Wave Propagation in a Slinky**



Hold the slinky stretched across a classroom. Compress 4–5 coils at one end, wait for the slinky to come to a rest and then release the compressed coils.

Hold the slinky stretched across a classroom. Pull the slinky 10 cm perpendicular to the line 4–5 coils from one end. Wait for the slinky to come to a rest and then release the pulled coils

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Earthquake wave pathways are bent as they travel the Earth's interior; S-waves do not pass through the outer core.

It is impossible to go deep into the Earth's interior; it is too hot, and pressures there are much too high. The deepest boreholes only penetrate the outer few kilometres of the crust. However, it is possible to understand the Earth's interior from the way that earthquake waves pass through. The earthquake wave evidence shows that the Earth has a solid innermost *core* of very dense material, surrounded by a liquid *outer core*. Around the core is a *mantle* which is mostly solid as far as earthquake waves are concerned. The outermost layer is the *crust*, made of rocks of many different kinds.

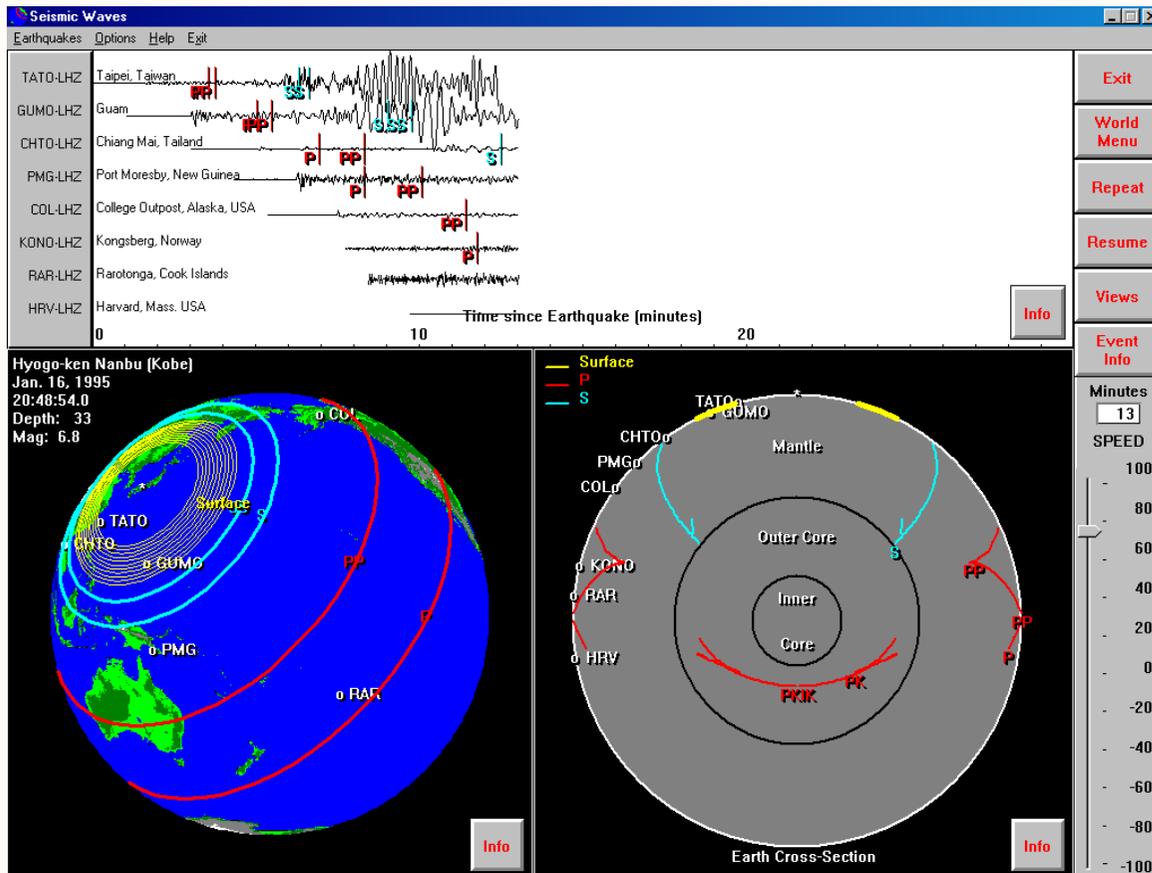
**Seismic waves and the earth**

P waves and S waves travel differently through the Earth., P waves travel faster and S waves cannot penetrate the liquid outer core.



Alan Jones has written a free program to illustrate how seismic waves propagate through the earth called 'Seismic Waves' which is available to download at [www.geol.binghamton.edu/faculty/jones](http://www.geol.binghamton.edu/faculty/jones).

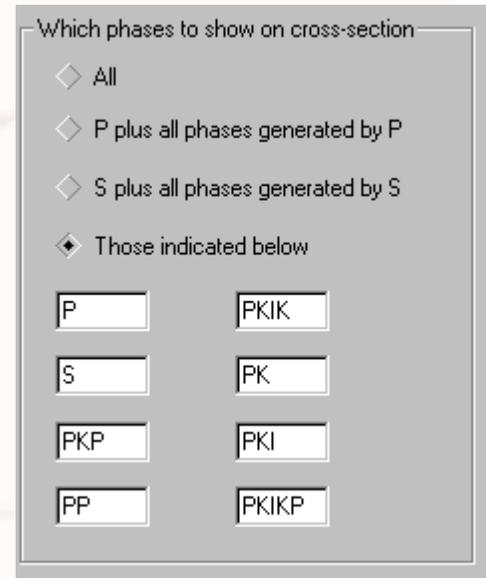
The program contains data from several real earthquakes and shows the wavefronts from these events travelling through and around the earth, including refractions, reflections and conversions at the major velocity discontinuities in the Earth. The views are speeded up records of the wavefronts and every time a wavefront reaches one of the seismic stations around the world the seismogram recorded at that station is played (speeded up) as a sound file. You can choose which earthquakes and which views (cross-section, seismograms or surface) to see.



By default the program shows all possible seismic phases which can produce a cluttered image. To see what happens to the main P and S waves as they travel through the core click



And select only the main phases to view.



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## Summary of seismic wave types and properties

Type (and names)	Particle motion	Typical velocity	Other characteristics
P Compressional Primary Longitudinal	Alternating compressions ('pushes') and dilations ('pulls') in the same direction as the wave is propagating	<b><math>V_P \sim 5 - 7 \text{ km/s}</math> in typical Earth's crust :</b> >~ 8 km/s in Earth's mantle and core; 1.5 km/s in water; 0.3 km/s in air	P motion travels fastest in materials, so the P-wave is the first-arriving energy on a seismogram. Generally smaller and higher frequency than the S and surface waves. P waves in a liquid or gas are pressure waves, including sound waves.
S Shear Secondary Transverse	Alternating transverse motions perpendicular to the direction of propagation.	<b><math>V_S \sim 3 - 4 \text{ km/s}</math> in typical Earth's crust :</b> >~ 4.5 km/s in Earth's mantle; ~ 2.5-3.0 km/s in (solid) inner core	S-waves do not travel through fluids, so do not exist in Earth's liquid outer core or in air or water or molten rock (magma). S waves travel slower than P waves in a solid and, therefore, arrive after the P wave.
L Love Surface waves	Transverse horizontal motion, perpendicular to the direction of propagation and generally parallel to the Earth's surface	$V_L \sim 2.0 - 4.5 \text{ km/s}$ in the Earth depending on frequency of the propagating wave	Love waves exist because of the Earth's surface. They are largest at the surface and decrease in amplitude with depth. Love waves are dispersive, that is, the wave velocity is dependent on frequency, with low frequencies normally propagating at higher velocity. Depth of penetration of the Love waves is also dependent on frequency, with lower frequencies penetrating to greater depth.
R Rayleigh Surface waves	Motion is both in the direction of propagation and perpendicular (in a vertical plane)	$V_R \sim 2.0 - 4.5 \text{ km/s}$ in the Earth depending on frequency of the propagating wave	Rayleigh waves are also dispersive and the amplitudes generally decrease with depth in the Earth. Appearance and particle motion are similar to water waves.

Stated images and text in this document are adapted from those of Larry Braile [web.ics.purdue.edu/~braile](http://web.ics.purdue.edu/~braile).

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