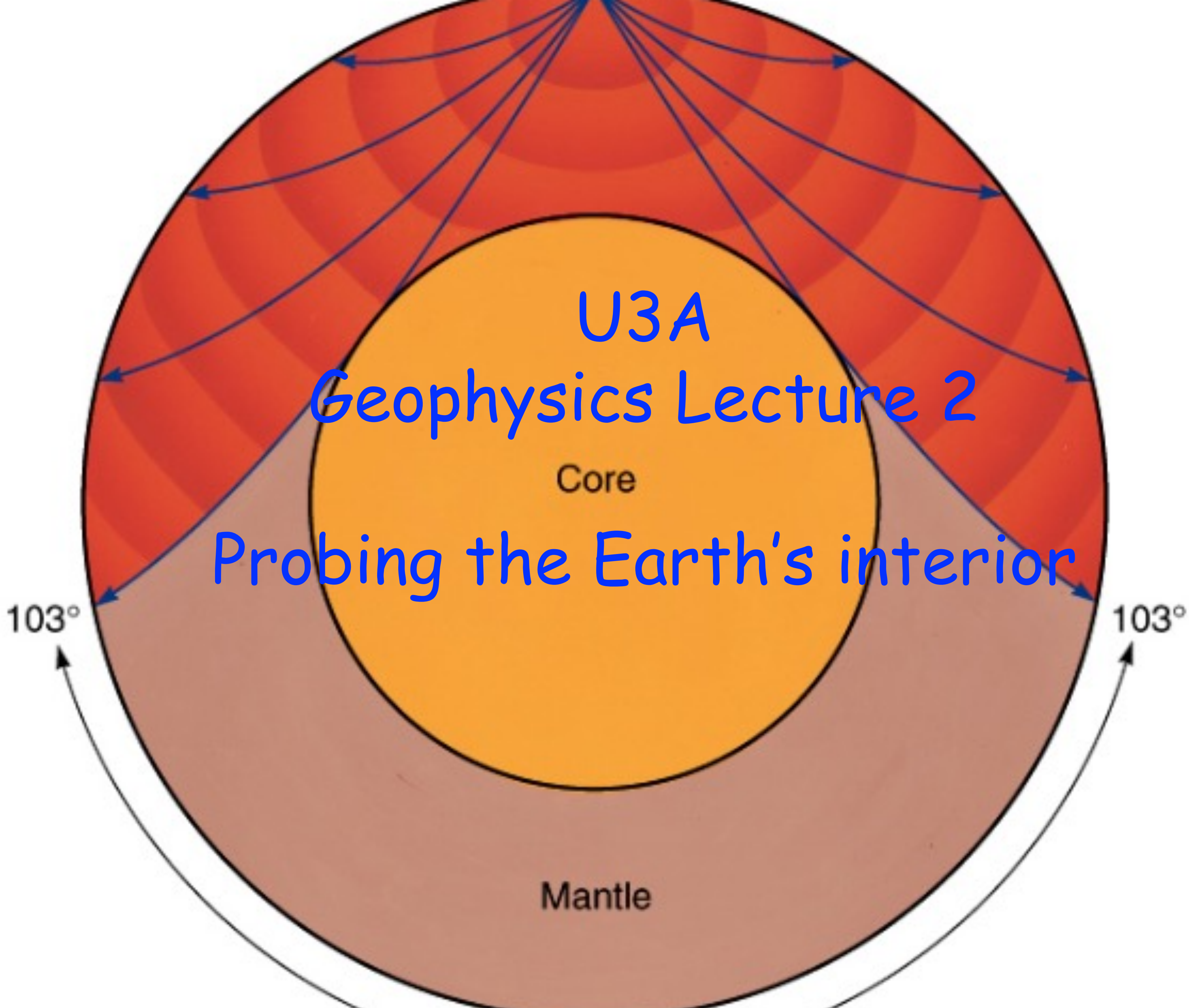
U3A
Geophysics Lecture 2

Probing the Earth's interior

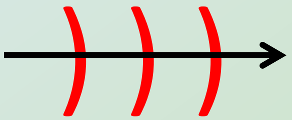


Introduction

- Most of what we know about the Earth's interior comes from the study of variations in velocity of seismic waves
- seismic rays travel in a straight line when travelling through an homogenous medium of constant temperature and pressure
- data from seismic stations indicate that the velocity of seismic waves is not constant when passing through the Earth
- P-waves accelerate when passing through solids of increasing elasticity and slow down in liquid media
- S-waves are not transferred through liquid media

Body waves and seismic fronts

- We can analyse the behaviour of body waves (P and S waves) passing through the Earth to investigate the Earth's interior
- seismic body waves radiate from the focus in all directions
- they migrate outwards from the focus in ever expanding spheres known as wave fronts

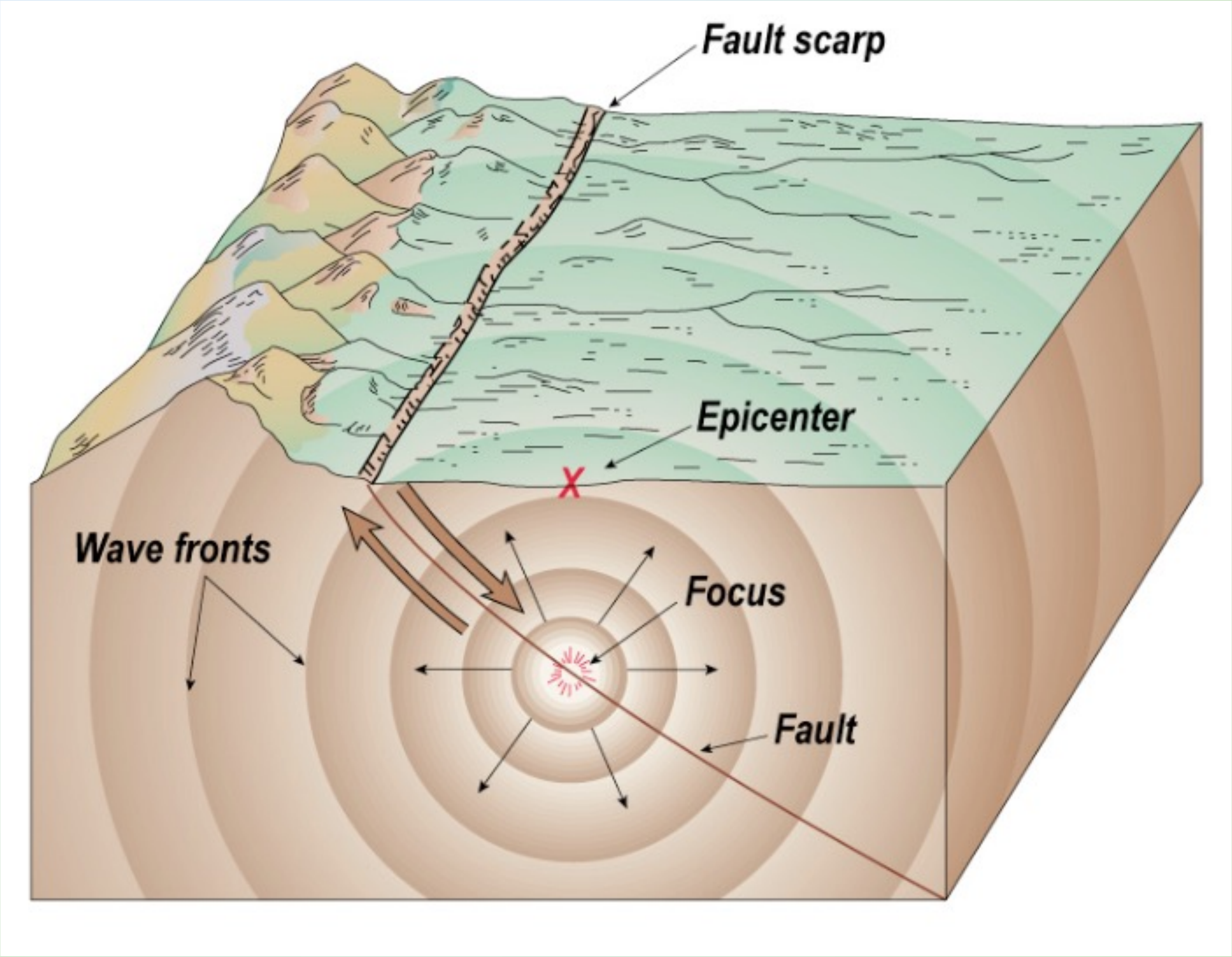


- the direction of wave front movement is represented by arrows or rays drawn perpendicular to the wave front
- A ray represents the direction in which a packet of energy of that wave is migrating

Seismic rays

- If a wave front is spherical, then the rays are a series of radial lines emanating from a focus
- waves will refract when there is a change in their velocity → wave fronts lose their sphericity
- even when the wave fronts are not spherical, rays are nevertheless always perpendicular to the wave front
- this means that rays are not always straight, they can bend due to changes in velocity of the propagating wave front

Propagation of earthquake energy



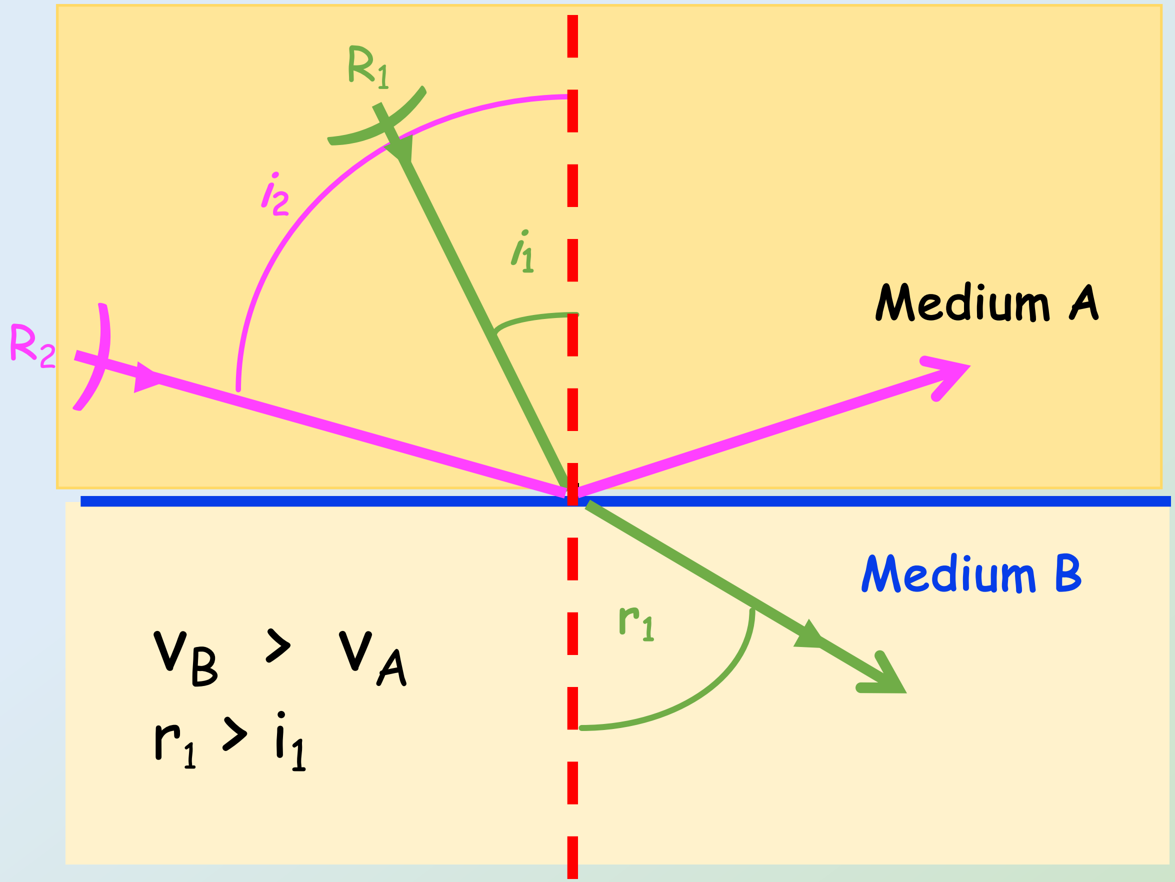
Factors controlling speed of seismic waves

- The speed at which waves travel depends on nature of the medium transmitting the waves
- rigidity and density of a medium control the speed → tendency for rigidity and density to increase with depth
- seismic waves travel through poorly compacted soil at ~300metres/sec
- through denser underlying rock, they travel much faster (kms/sec)

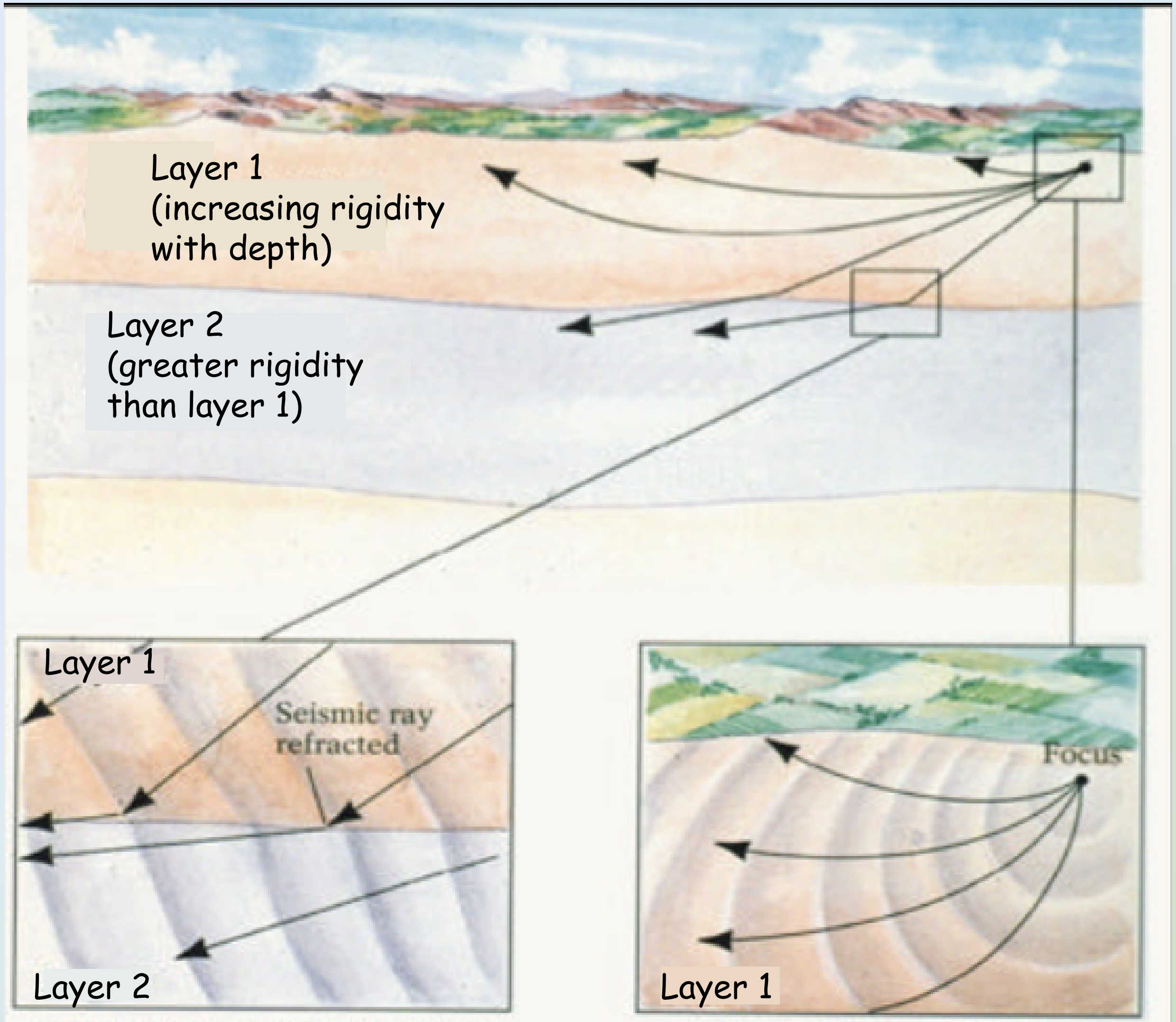
Seismic refraction

- If seismic waves approach a boundary between media of different density in the Earth's interior → undergo change in velocity on crossing the boundary → causing them to bend or refract
- refraction is where a wave changes its direction and velocity when crossing the boundary between two contrasting media
- if seismic waves approach the boundary between adjacent media at a low angle, they may reflect off the surface
- if they approach at a somewhat greater angle, they may enter the new medium changing velocity and causing them to bend or refract

Critical angle and ray refraction



Seismic refraction

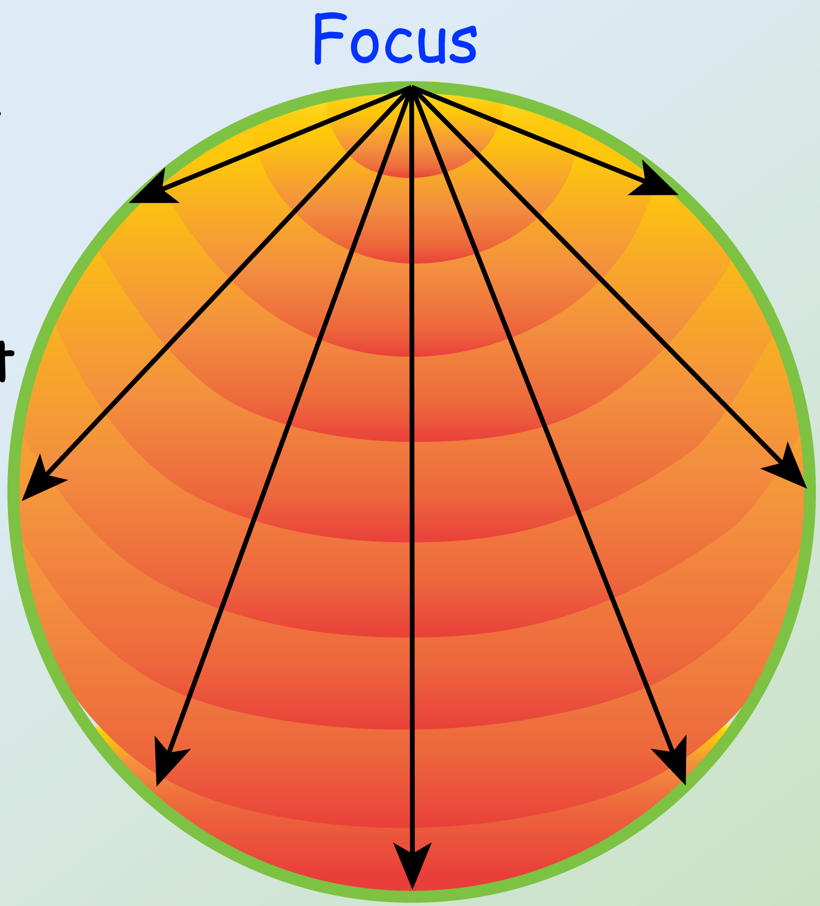


Velocity change between layers

Velocity change within layer

Seismic waves – uniform density

- In an homogenous planet with uniform density, seismic waves are neither refracted nor reflected
- they would propagate with constant velocity through the whole planet
- seismic rays drawn perpendicular to the wave fronts would follow straight lines
- seismic observations show that the Earth does not behave like this

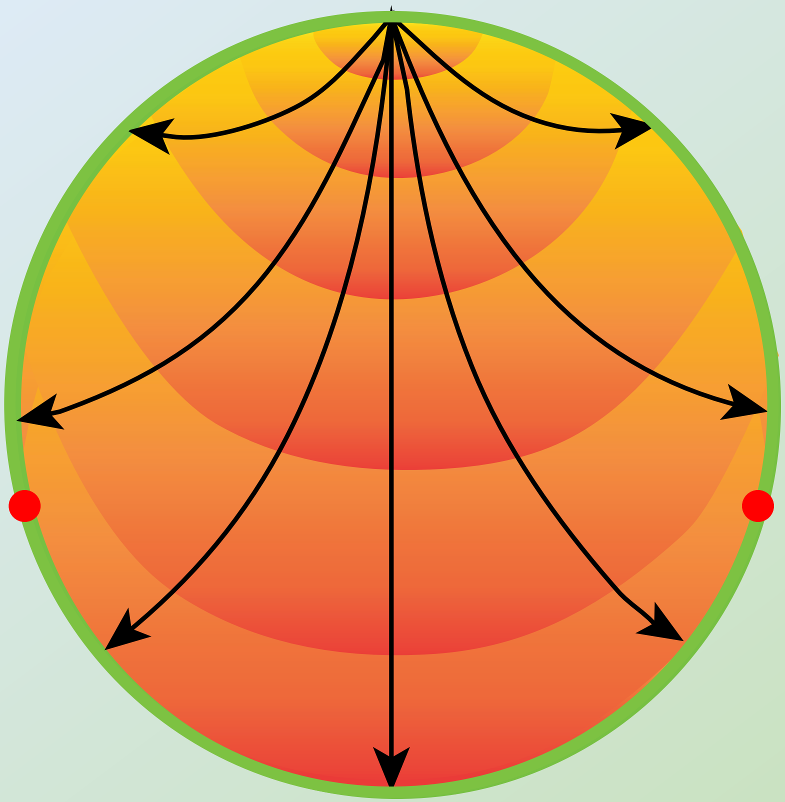


Evidence for seismic refraction

- Earthquake waves travel large distances and travel deep into the Earth → behave differently to that of planet of uniform density
- studies on earthquake waves indicate → waves arrive sooner than expected at seismographs at large distances from the epicentre
- the further the waves travel from the epicentre the shorter are the travel times when compared to those expected from an Earth of uniform density, uniform rigidity and uniform velocity
- it is clear therefore, that the density of the Earth's interior is not uniform → there is an overall increase with depth

Seismic waves - increasing density

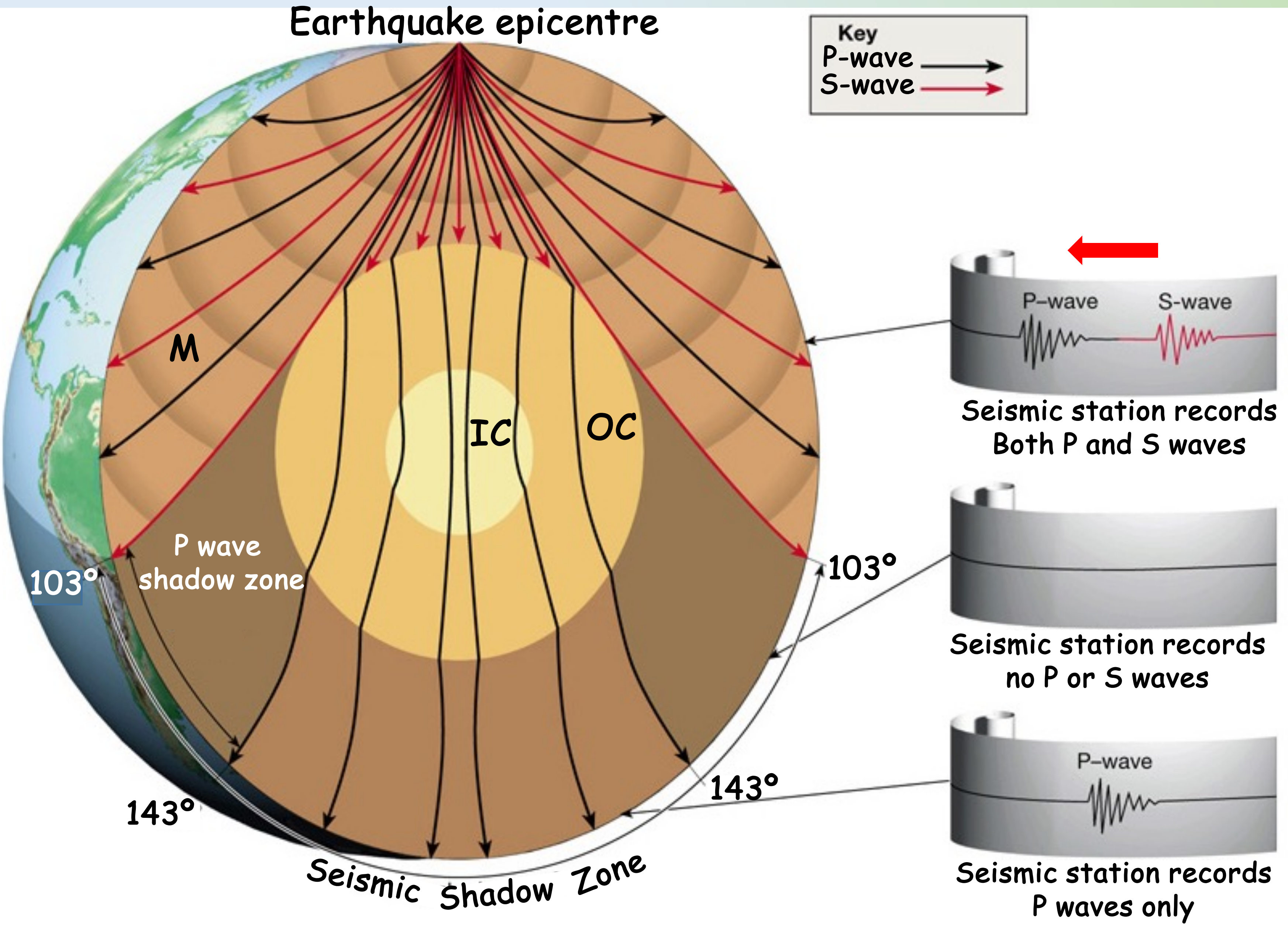
- In a planet where density and rigidity increase gradually with depth, seismic waves are refracted
- seismic velocities would increase steadily with depth and waves would follow a curved path
- this is similar to known paths of seismic waves in the Earth up to about 11,000 km from the epicentre



Seismic shadow zone

- In 1906, it was discovered that earthquake wave detection stopped abruptly about 103° from the epicentre (about 11,000km away)
- beyond this was a broad zone where no seismic waves were detected → the Shadow Zone
- at distances beyond 143° from the epicentre, seismic P-waves reappear
- S-waves are totally extinct beyond 103°
- these P-waves on the opposite side of the Earth from the epicentre (>143°) travel through the Earth much slower than predicted

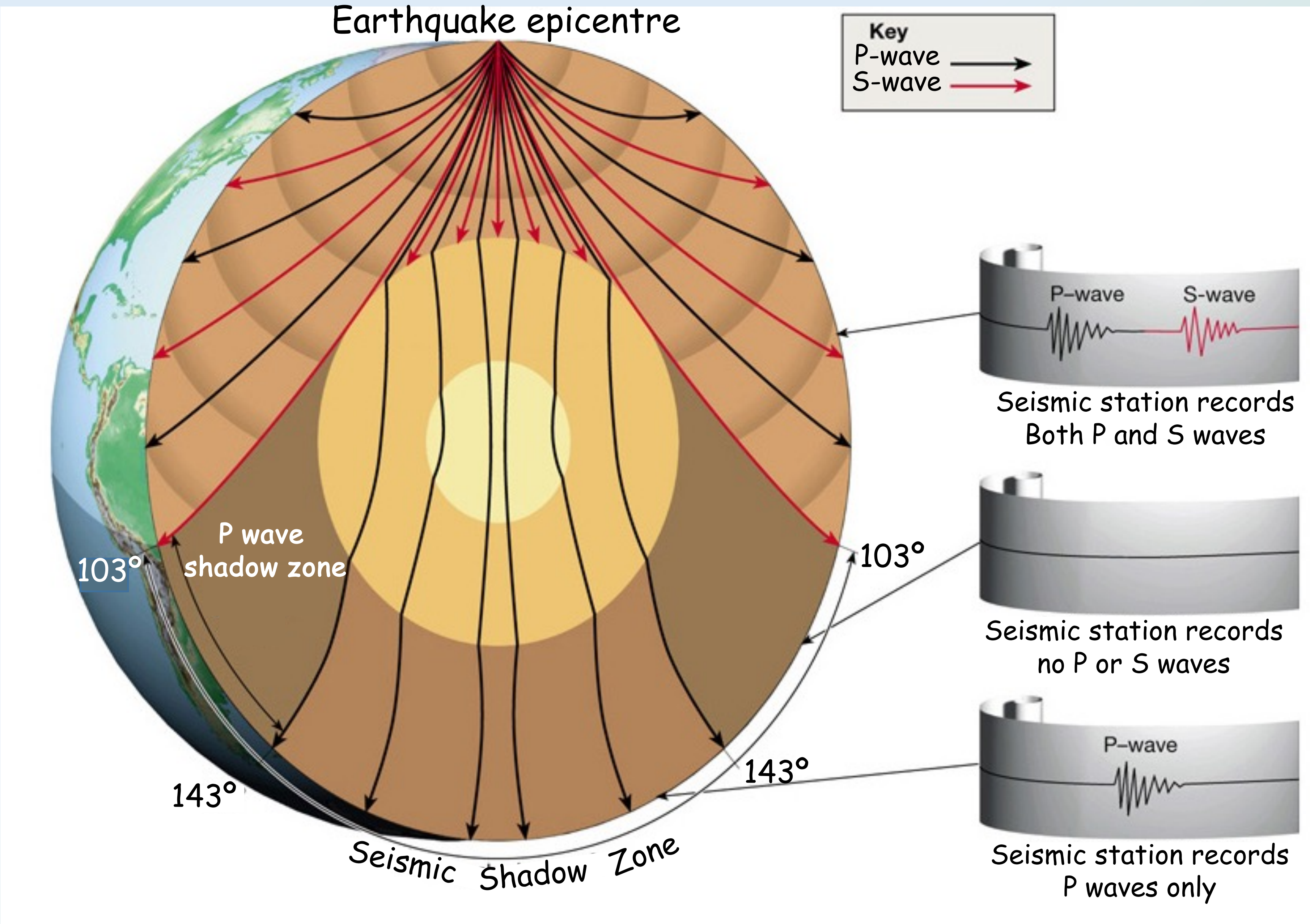
Seismic shadow zone



Seismic shadow zone

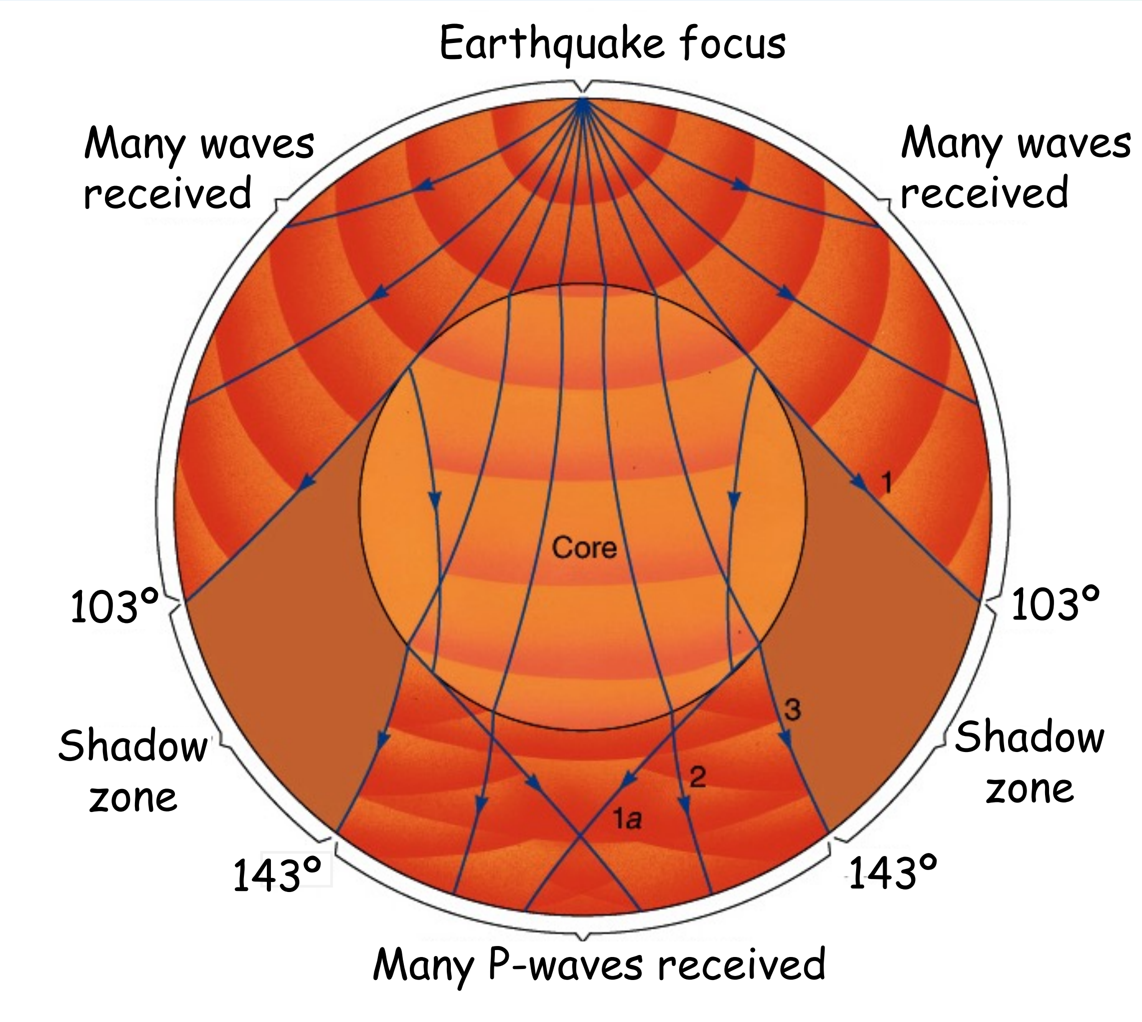
- The shadow zone implies that refraction bends the waves away from the zone
- if there is an increase in velocity with depth, the waves bend towards the surface
- if there is a decrease in velocity, then waves bend the other way
- this can be explained by there being a spherical region within the Earth in which the velocity is lower than spherical shell above
- knowing the two angles, 103° and 143° we can predict size of the shell of low velocity and its velocity from the angle of refraction

Seismic shadow zone



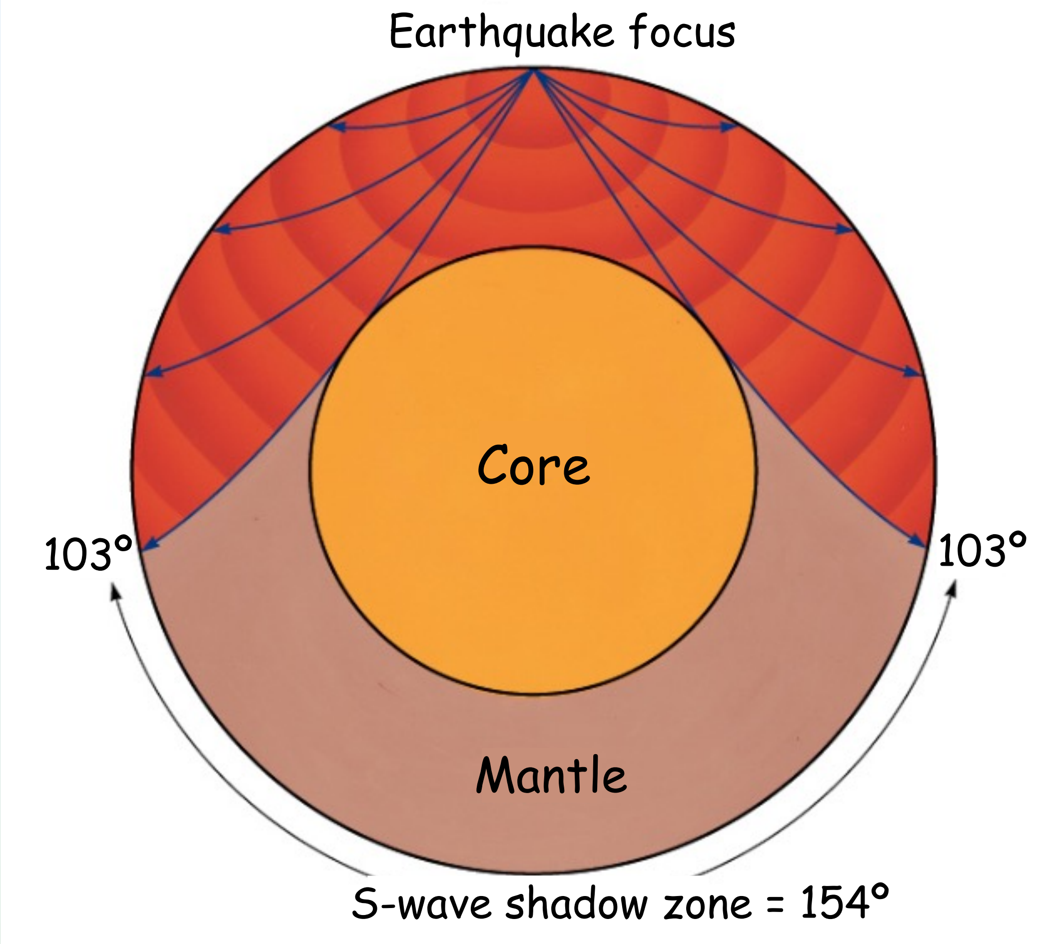
The P-wave Shadow zone

- The shadow zone indicates that the Earth has a central core that deflects the P-waves
- P-waves travel more slowly through the core, so they are refracted inwards
- we can determine the size of the core from the refraction → top of core is 2,900km deep



The S-wave Shadow Zone

- The effect on S-waves is even more striking
- no S-waves are found at any distance beyond 103° from the epicentre
- this produces a large S-wave shadow zone covering nearly half of the Earth
- interpretation → core does not transmit S-waves at all



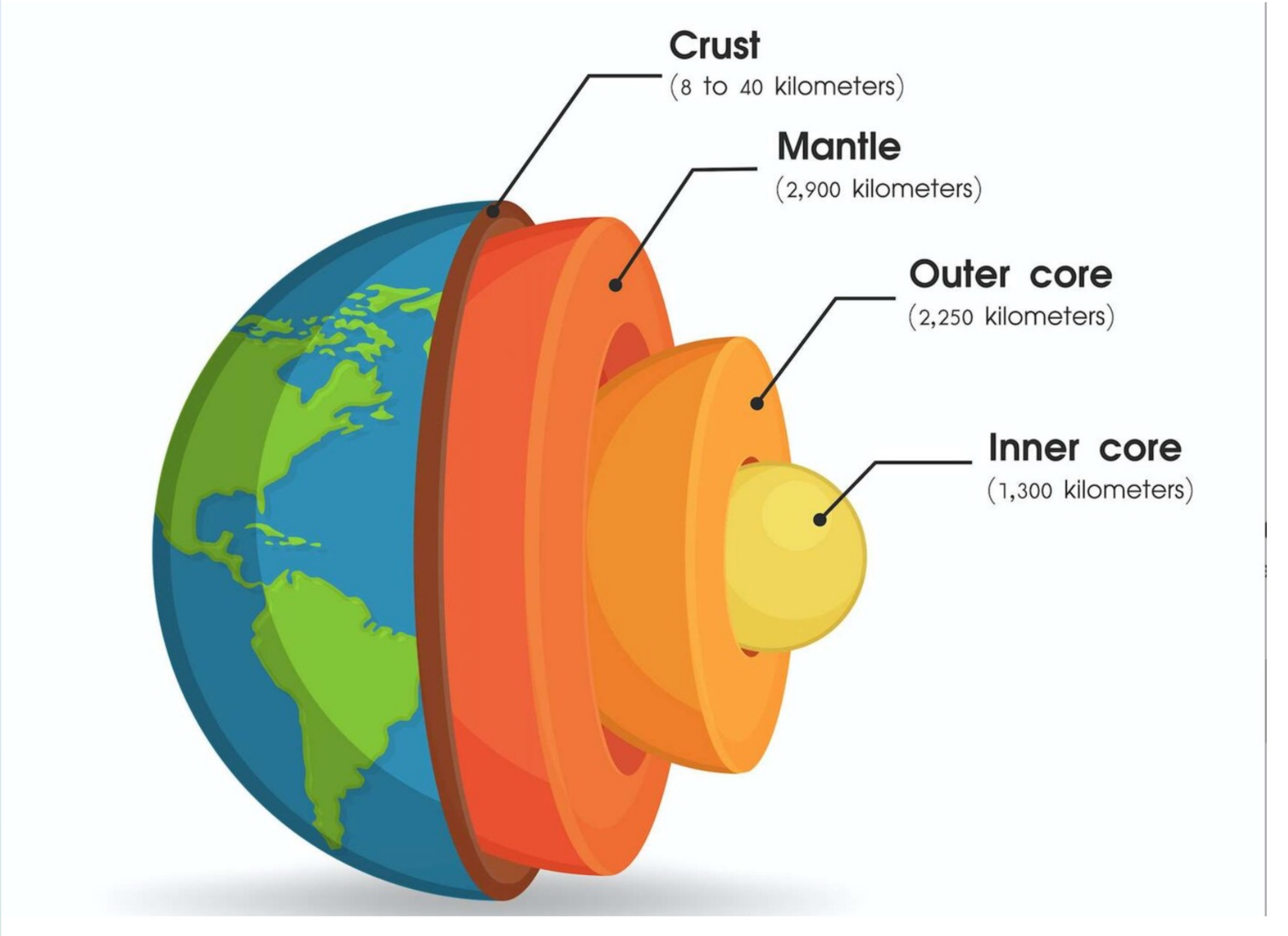
The properties of the core

- P-waves are transmitted by solids, liquids and gases → more slowly in liquids than in solids
- S-waves are shear waves and can only be transmitted by solids and cannot be transmitted by a liquid medium
- the behaviour of the S-waves therefore implies that at least the outer part of the core is liquid
- the Earth's mass and volume show that core must be very dense, 10-13gm/cm^3 (contrasts with mantle → made of rock (~3.5gm/cm^3)
- together this property (and meteorite composition and magnetism) provide evidence consistent with a composition of molten Fe-Ni

The inner core

- The core is complex and has a number of internal subdivisions
- detailed observations show that some very weak P-waves are actually observed within the shadow zone at about 120° from the epicentre
- these are thought to be reflected upwards by an inner core thought to be solid → not possible to occur by refraction
- when there is a sudden change in velocity → reflections can occur → boundary between outer and inner core
- the top of the inner core is at a depth of about 5,100metres from the surface

Layers of the Earth (Getty images)



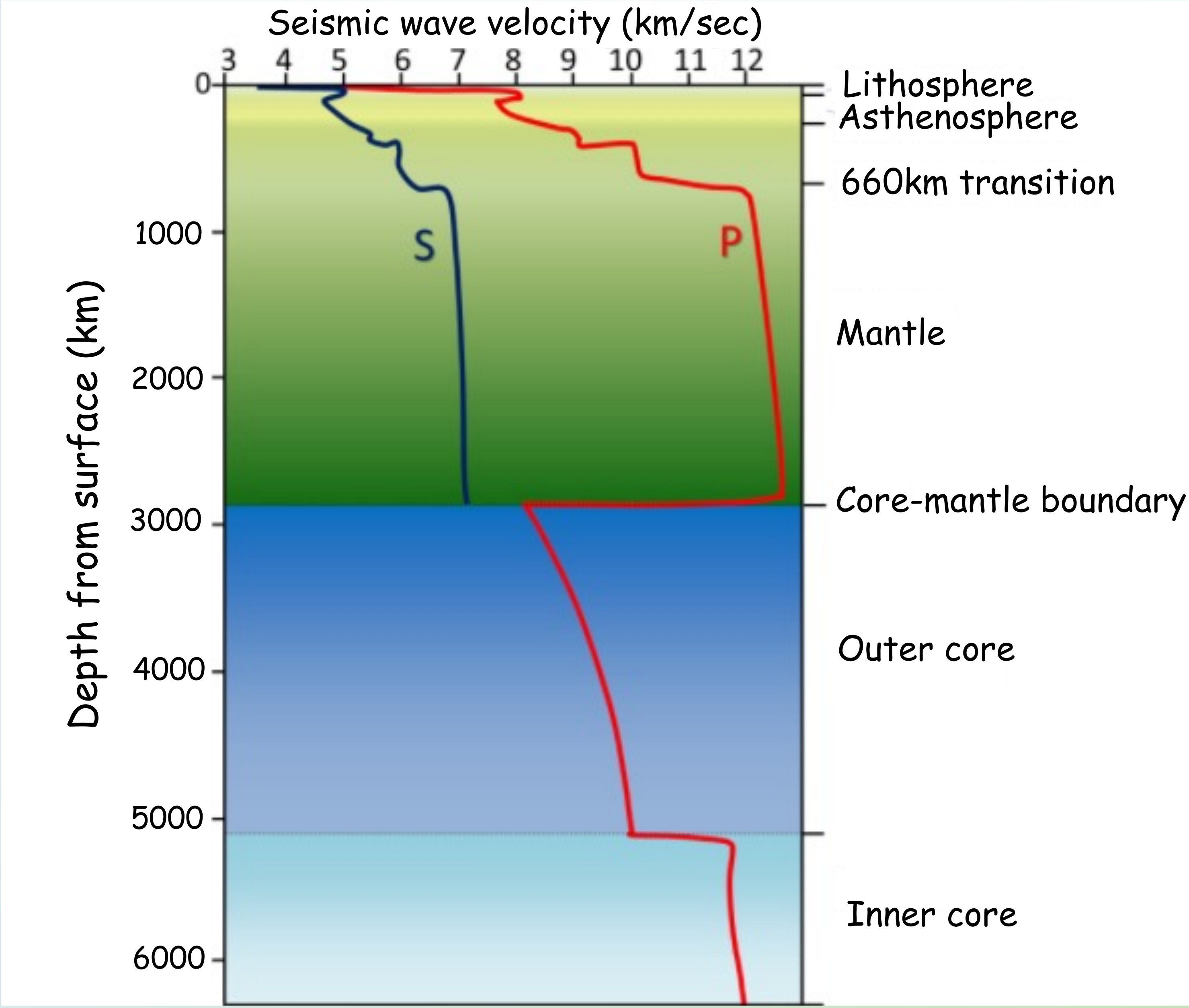
The outer core

- No direct S-waves appear within an arc of 154° lying directly across the globe from the earthquake epicentre → S-wave shadow zone
- S-wave shadow zone must exist because of S-wave's inability to penetrate intervening materials
- as S-waves do not travel through liquid media it is concluded that a liquid region surrounds the Earth's centre

Seismic velocity structure in the Earth

- The structure of the Earth consists of a series of shells
- these shells are defined by the speed at which seismic waves are transmitted through the Earth
- this includes the speed at which P-waves are transmitted and whether or not S-waves are transmitted at all
- by examining where P and S waves are detected and by the time it takes them to reach seismographs located at varying distances from the epicentre, we can deduce the velocity structure of the Earth

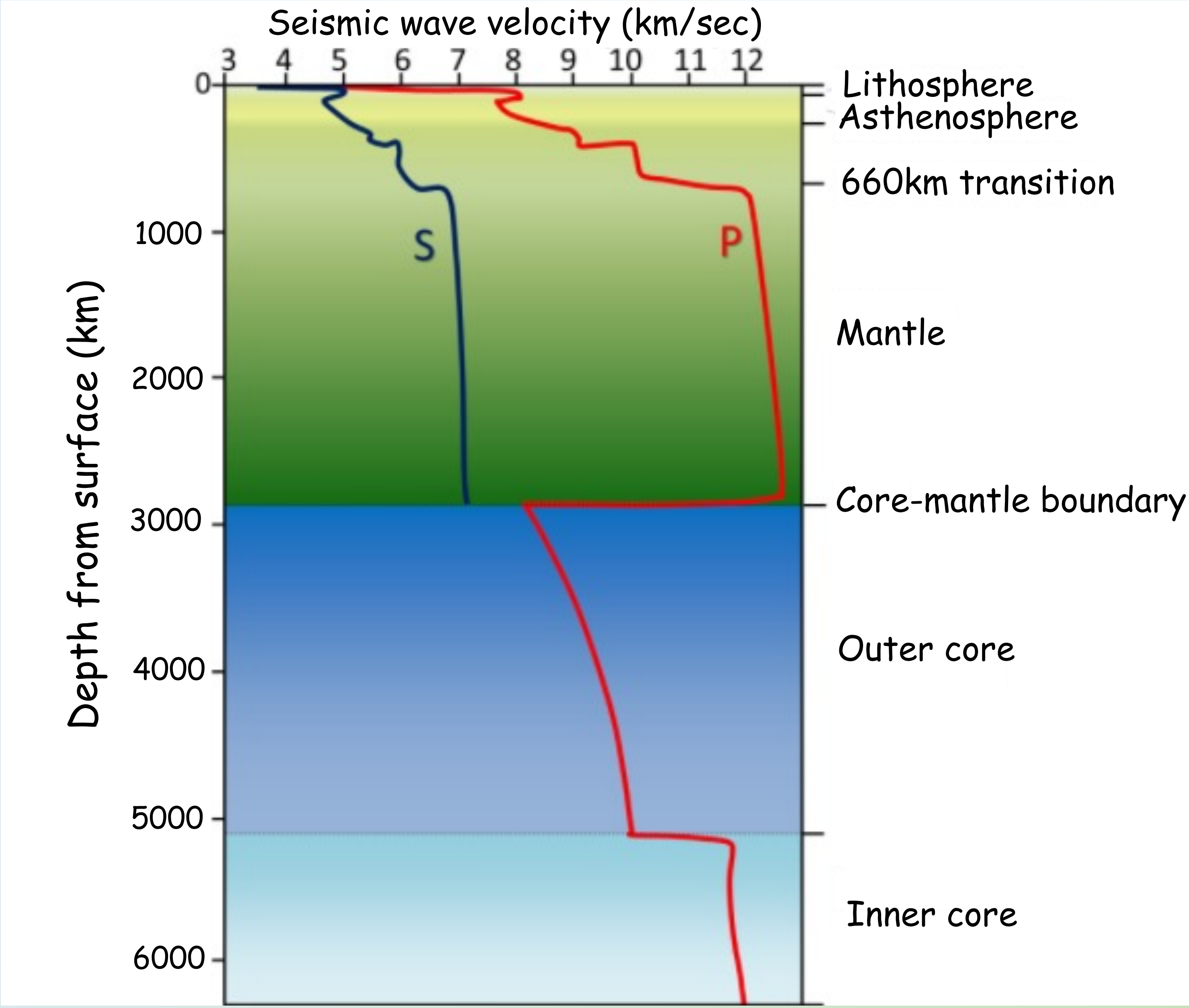
Seismic velocity structure in the Earth



Seismic discontinuities

- At certain levels in the Earth's interior seismic velocities change abruptly → seismic discontinuities
- the core-mantle boundary is a major example of a seismic discontinuity i.e. rapid change in seismic velocity within Earth
- other seismic discontinuities occur at the outer core-inner core boundary and also in the upper mantle
- within the upper mantle, velocity changes are caused by phase changes → denser polymorphs
- a significant seismic discontinuity defines the base of the crust at about 15km (oceanic) and 70km (continental) depth
- this is called the Mohorovicic discontinuity, or simply the Moho

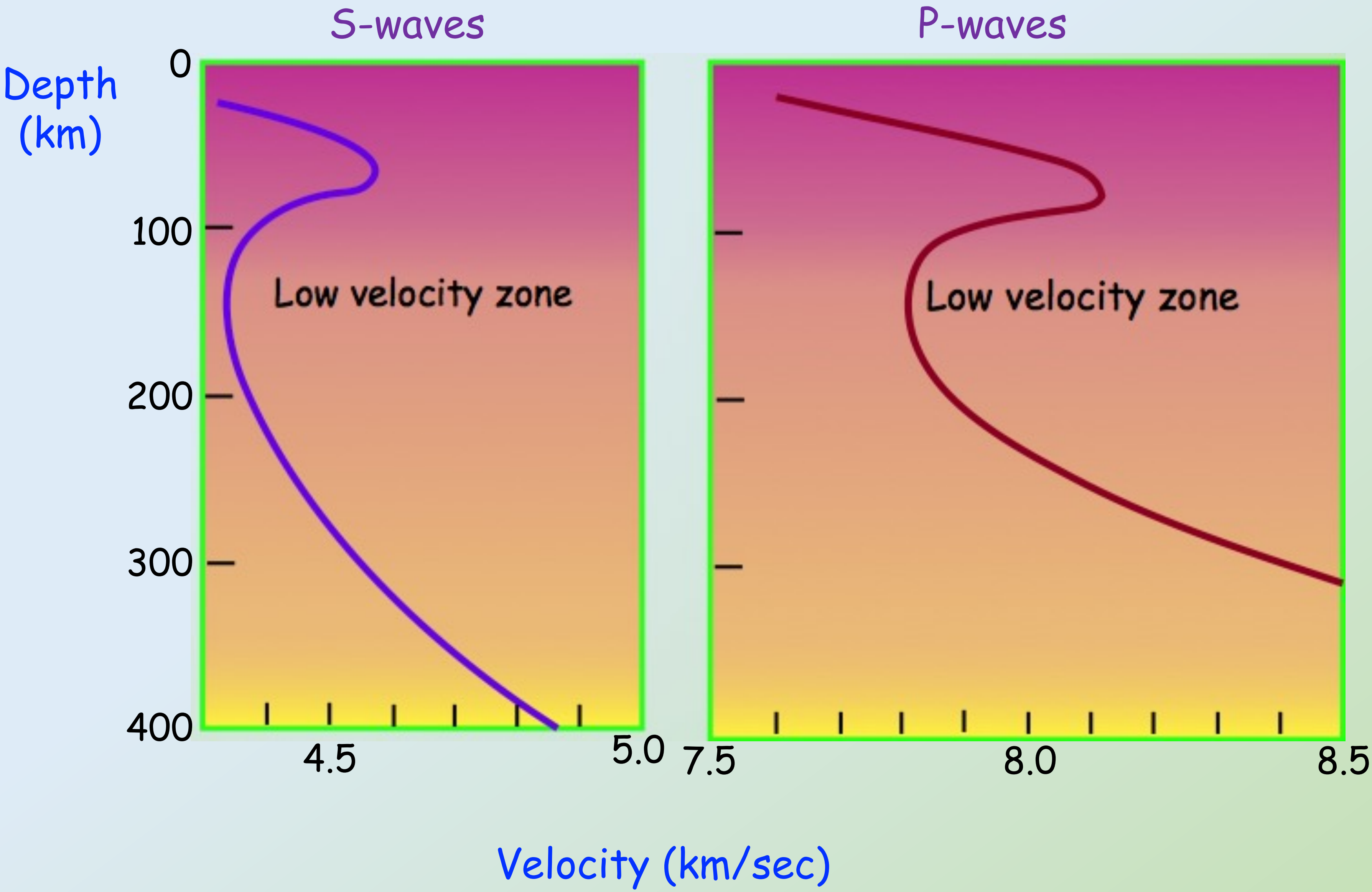
Seismic discontinuities in the Earth's interior



The low velocity zone

- The most important seismic discontinuity occurs as a low velocity zone in the upper mantle
- this low velocity zone is called the asthenosphere
- it is not sharp but extends from a depth of about 100km to 250km below the surface; in some regions it may extend to 350km
- P and S-wave velocities are sharply reduced within the asthenosphere
- the asthenosphere is believed to be partly molten (1 to 10% melt) that accounts for its low velocity → most basalt magmas originate from the asthenosphere

Seismic velocities in upper mantle



Relationships in the upper mantle