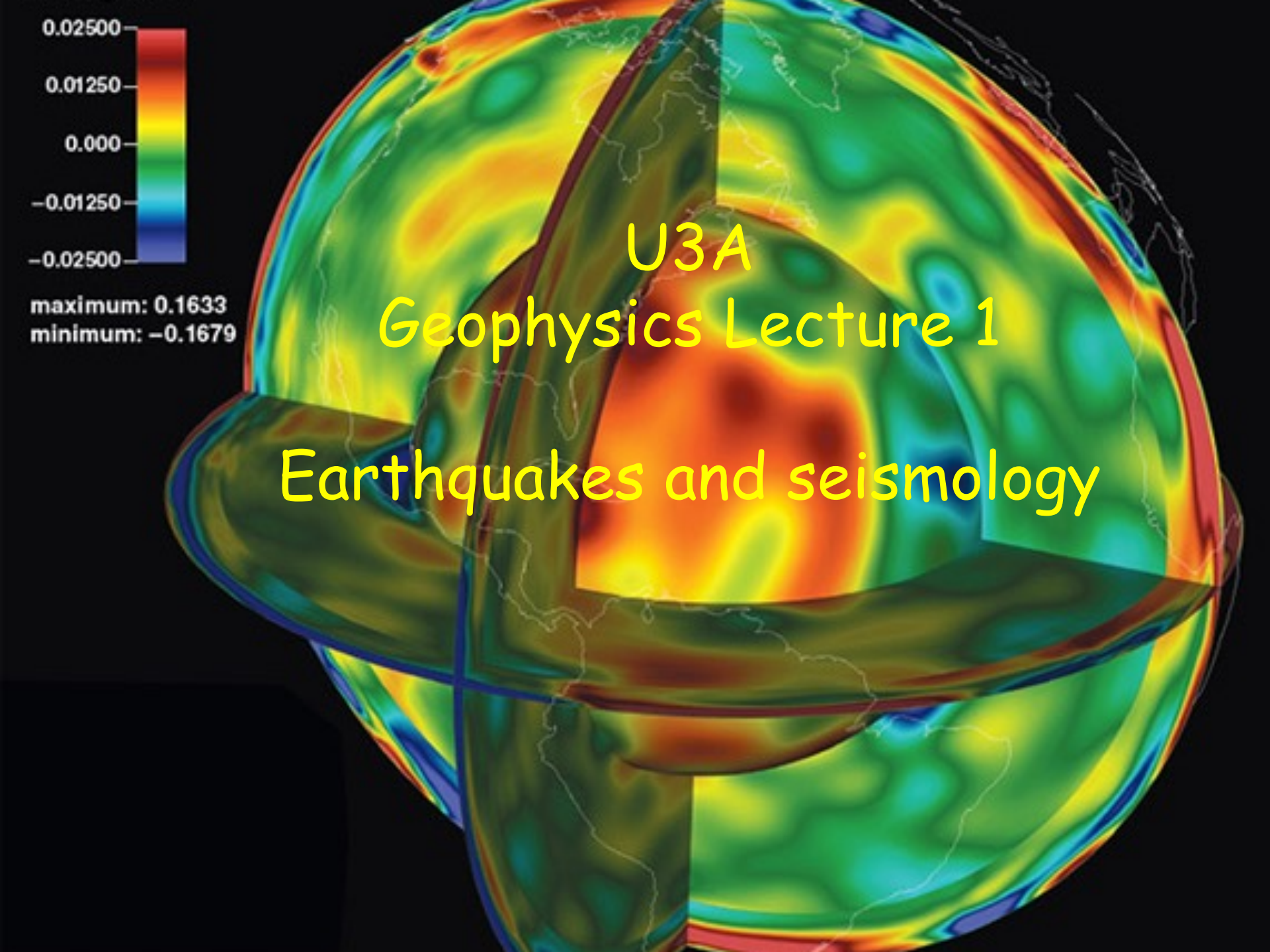


U3A
Geophysics Lecture 1

Earthquakes and seismology

Introduction

- Most of the Earth lies well beneath the surface, too deep for conventional geological exploration
- depth of deepest drill holes into continental crust <13km and 2km into oceanic crust
- our direct information about the Earth is limited to near surface
- knowledge of Earth's interior comes from geophysics
- most of what we know of the Earth's interior is derived through the study of seismic waves generated by earthquakes

Earthquakes

- Earthquakes are shock waves radiating outwards from some dislocation at depth within the Earth
- they are a mechanical vibration that we can observe at the surface
- energy transferred by earthquakes involves waves
- earthquake waves are called seismic waves and the study of earthquakes is called seismology
- seismology is important because:
  - → understanding earthquakes allows us to minimise damage and loss of life
  - → provides us with clues as to the nature of the Earth's interior

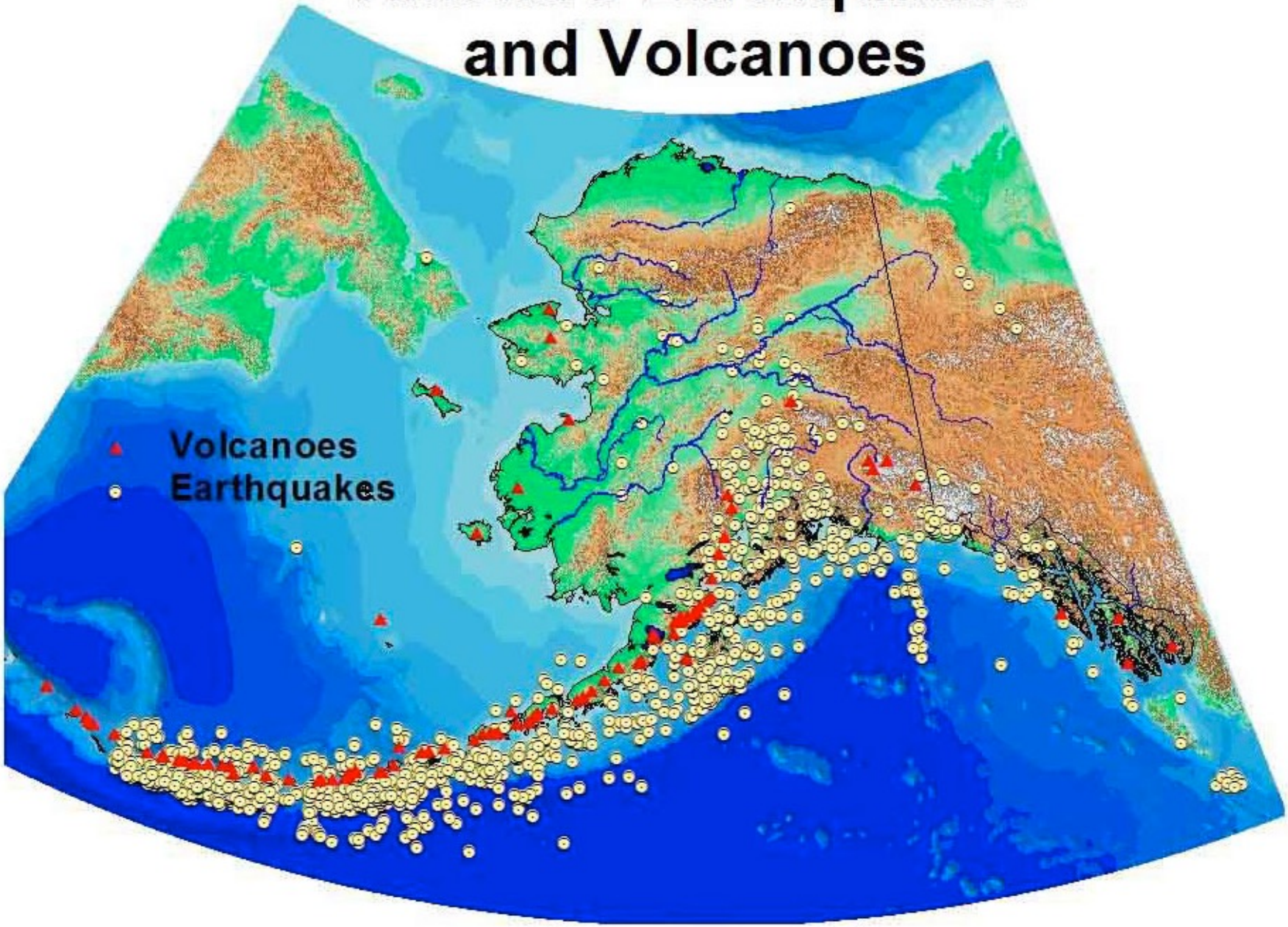
Earthquakes

- There are ~150,000 earthquakes each year strong enough to be detected by seismic recording stations
- on average, only ~100 are large enough to cause significant damage and loss of life
- earthquakes need to be understood to mitigate their effects e.g. design of buildings to survive earthquake damage
- also to enable earthquake prediction
- earthquake recording also provides us with details of the Earth's interior

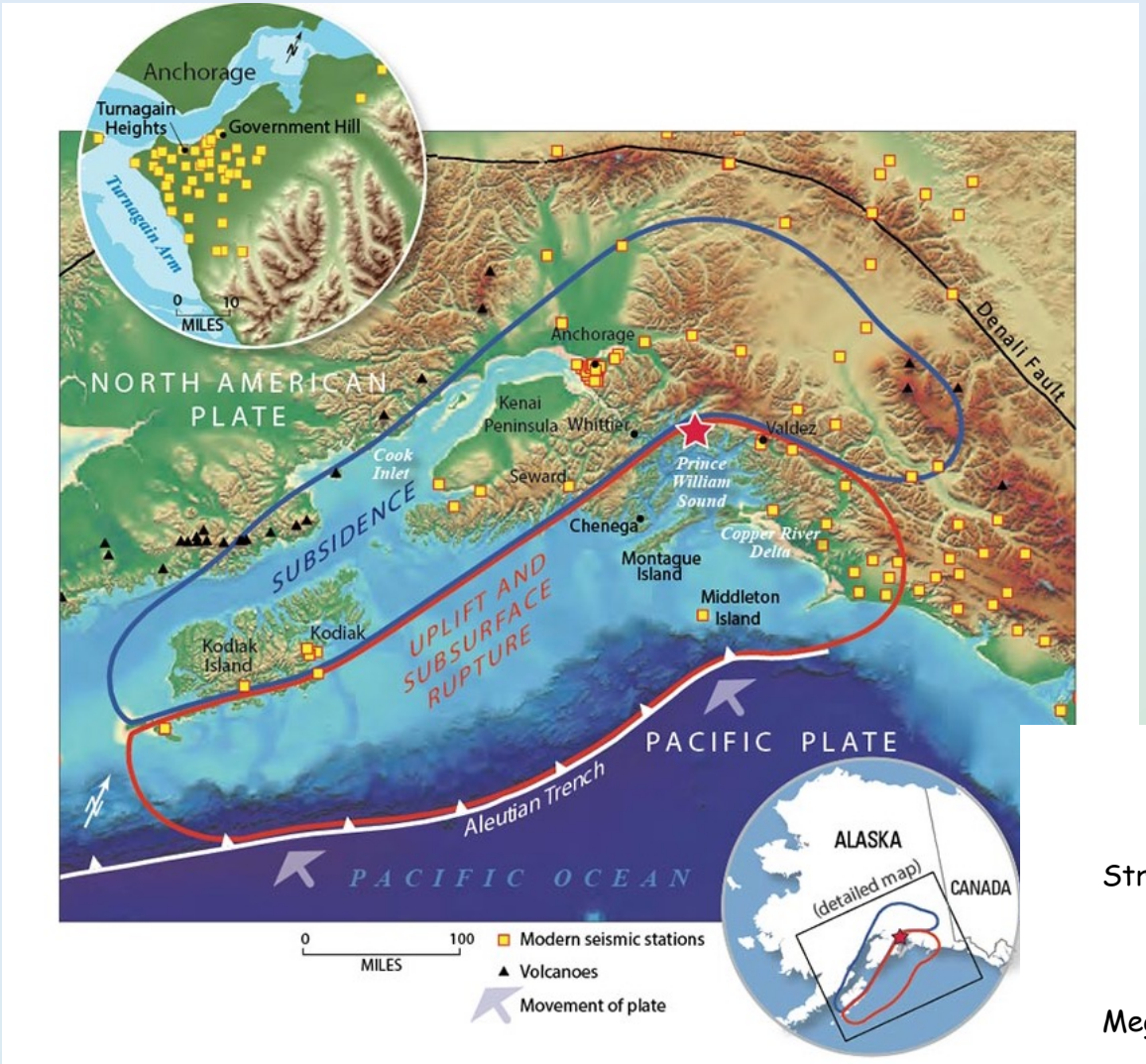
Great Alaskan earthquake 1964

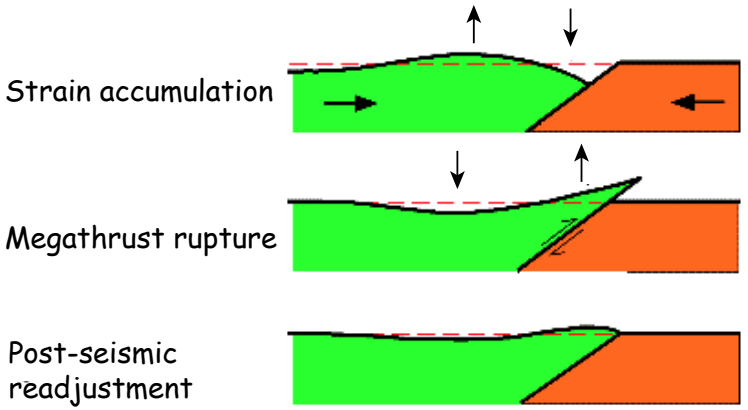
- Occurred 27th March 1964, lasted 4 minutes
- megathrust rupture with Pacific plate subducted beneath North American plate
- epicentre → Prince William Sound 100km southeast of Anchorage, Alaska. Depth of focus → 125km
- magnitude 9.2 on Richter scale (second strongest recorded)
- damage caused by by ground rupture, severe ground shaking, liquefaction, tsunami, ocean floor shift → 11.5 metres
- created large tsunamis (up to 67m in height)

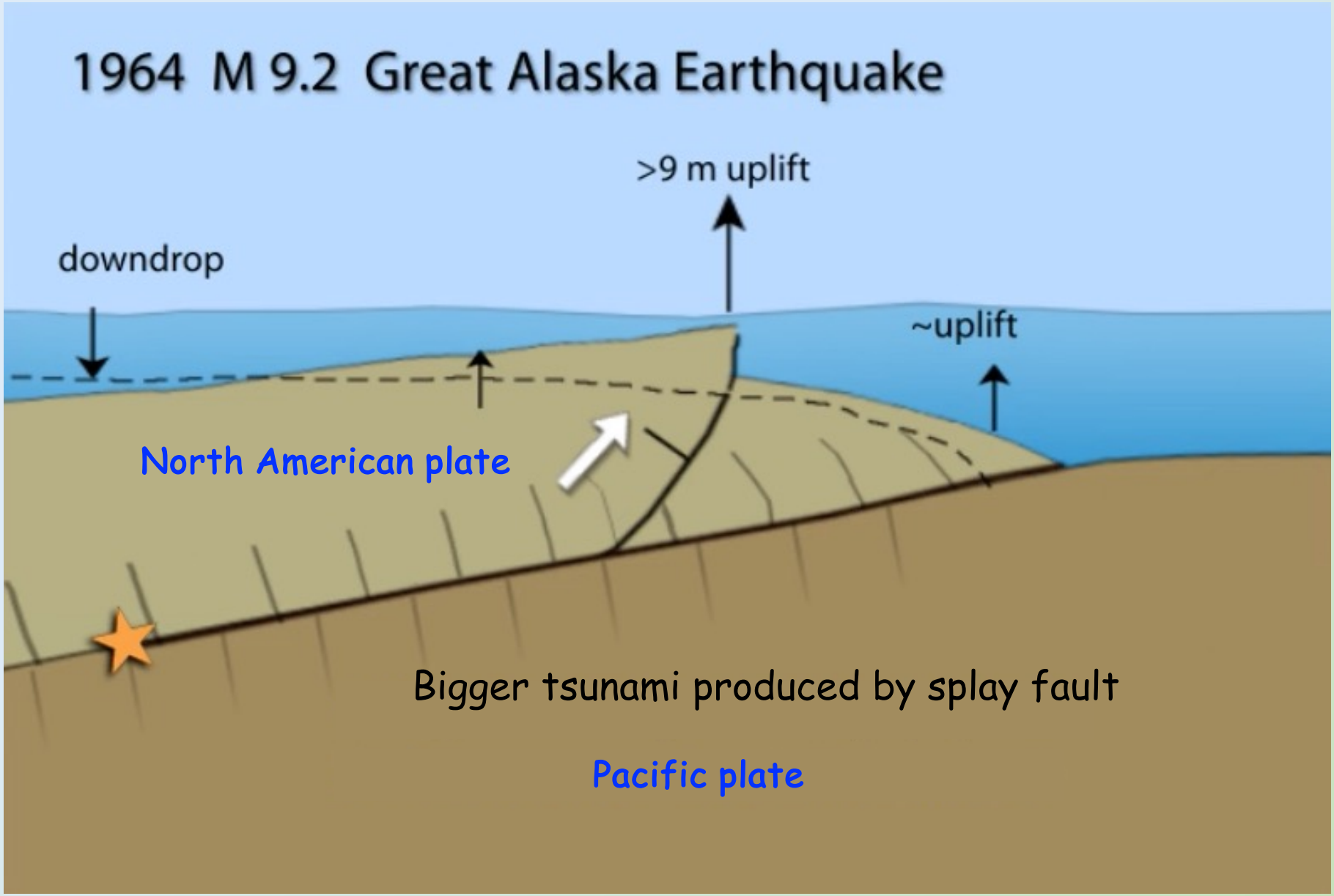
Alaska's Earthquakes and Volcanoes



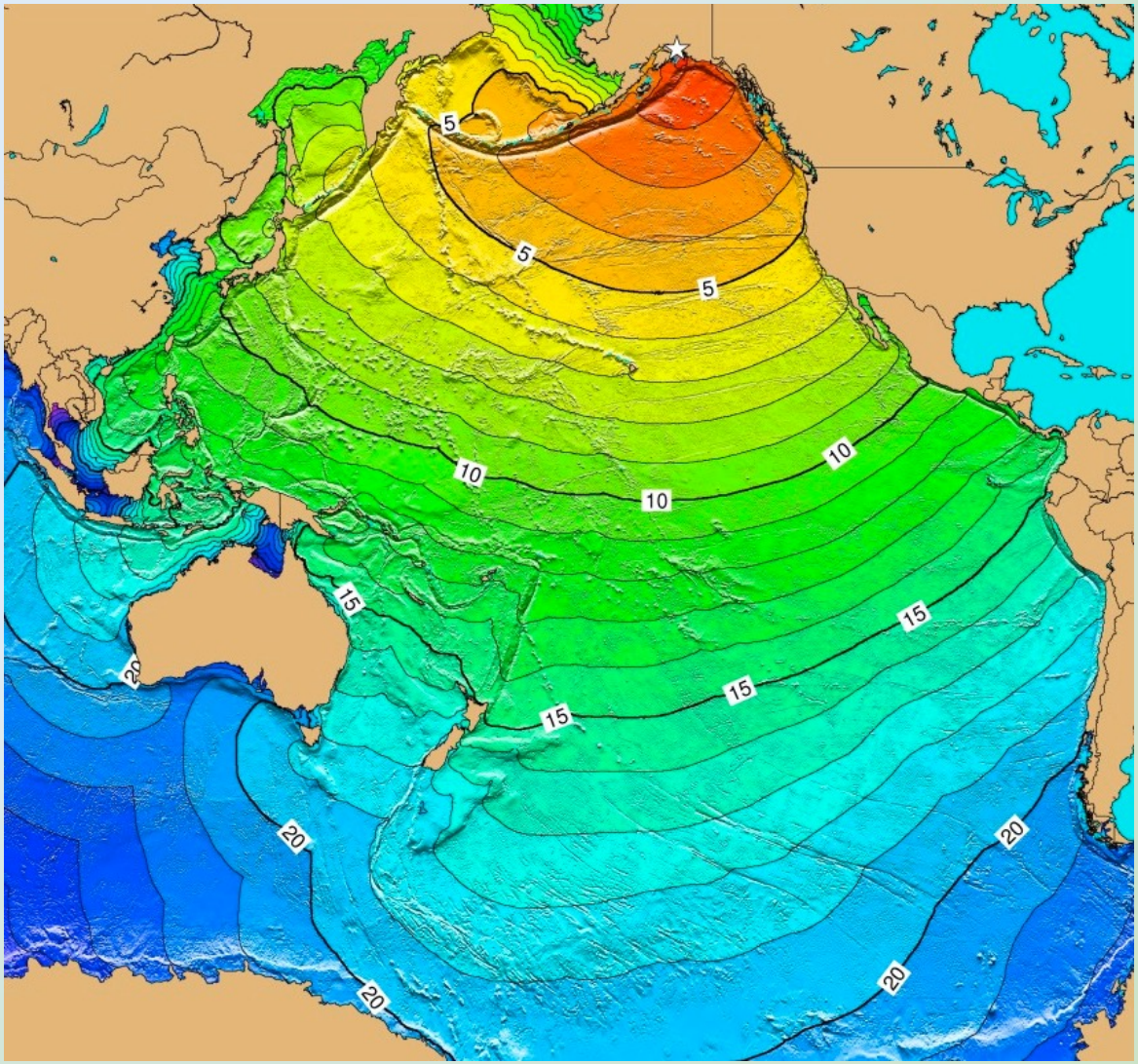
Megathrust


Anchorage
Turnagain Heights
Government Hill
Turnagain Arm
0
10
MILES
NORTH AMERICAN PLATE
Anchorage
Kenai Peninsula
Whittier
Valdez
Seward
Cook Inlet
Prince William Sound
Chenega
Copper River Delta
Montague Island
Middleton Island
Kodiak
Kodiak Island
SUBSIDENCE
UPLIFT AND SUBSURFACE RUPTURE
Denali Fault
PACIFIC PLATE
Aleutian Trench
PACIFIC OCEAN
0
100
MILES
Modern seismic stations
Volcanoes
Movement of plate
ALASKA
(detailed map)
CANADA


Strain accumulation
Megathrust rupture
Post-seismic readjustment


1964 M 9.2 Great Alaska Earthquake
>9 m uplift
downdrop
~uplift
North American plate
Bigger tsunami produced by splay fault
Pacific plate

Great Alaskan earthquake 1964



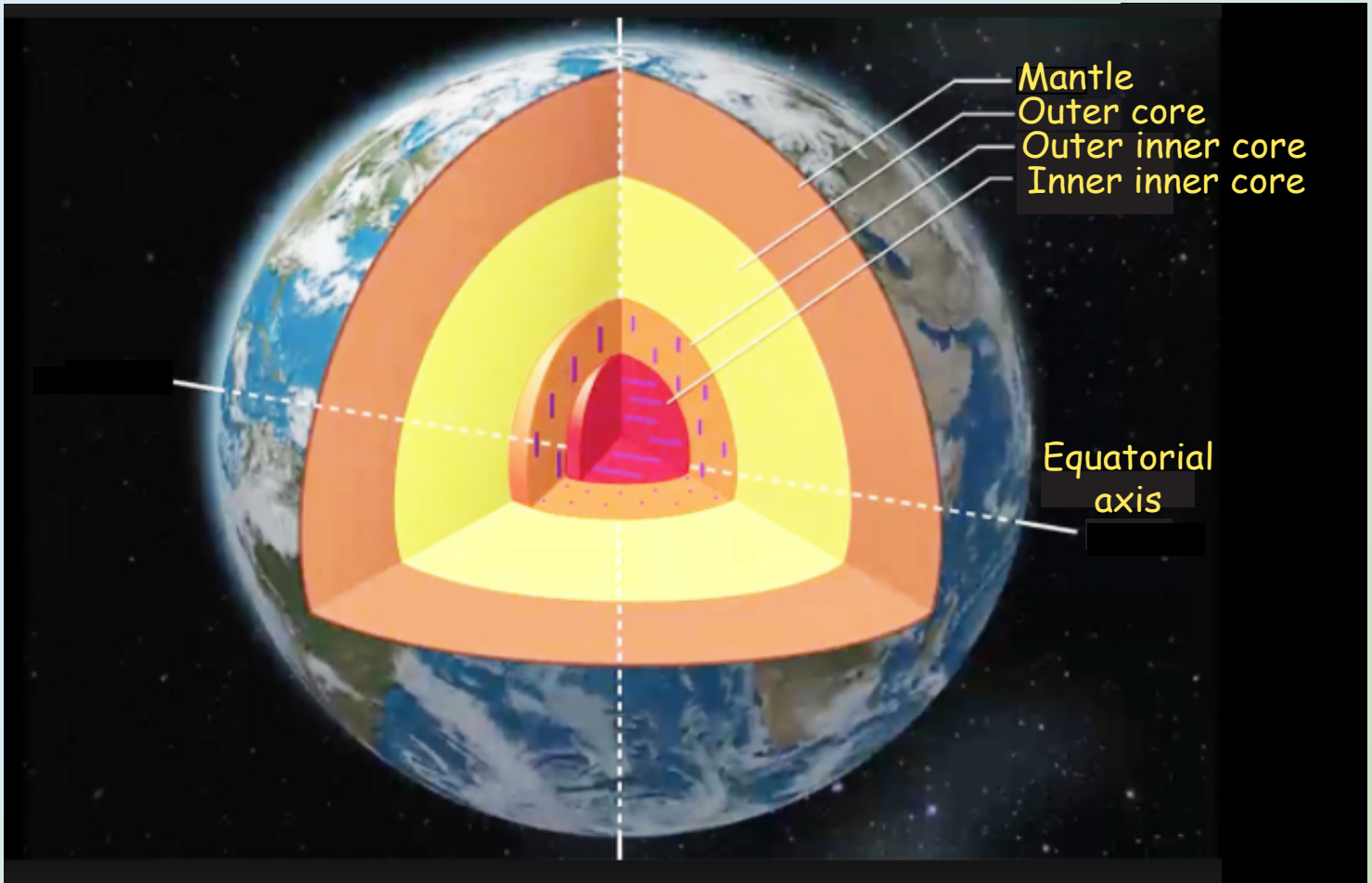
Tsunami travel times (hrs) Alaskan earthquake 1964

Alaskan earthquake 1964

Some of the severe damage caused by the quake

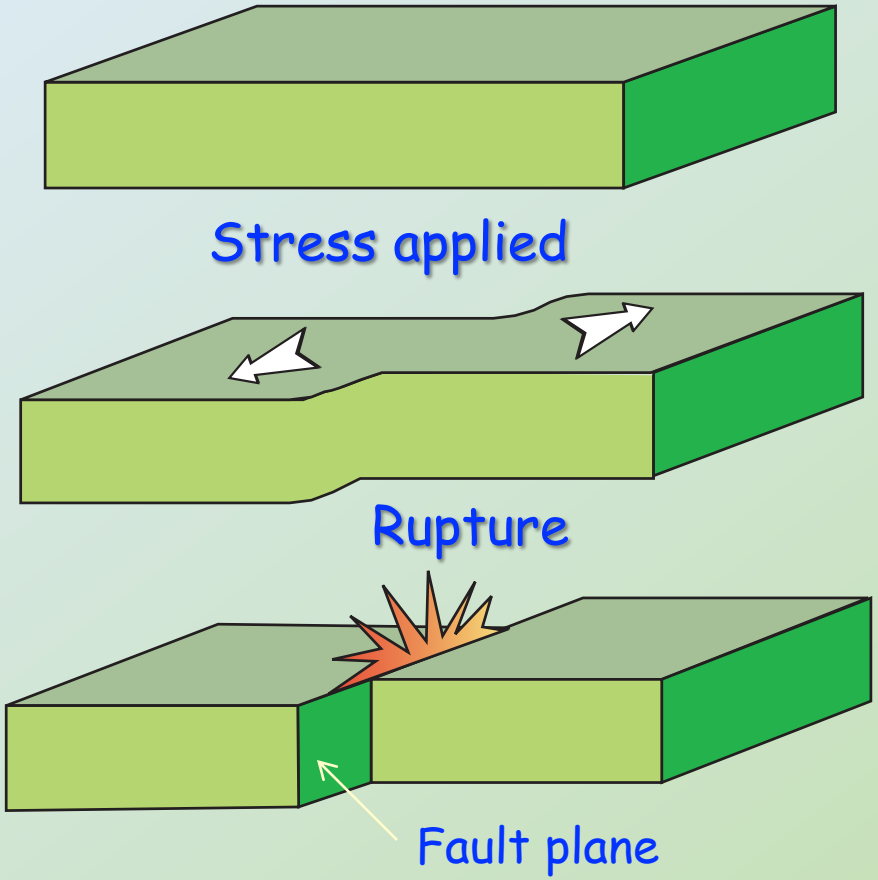
Earth's interior

- The Earth's interior is composed of a series of concentric shells
- each shell has distinctive physical properties, composed of different materials

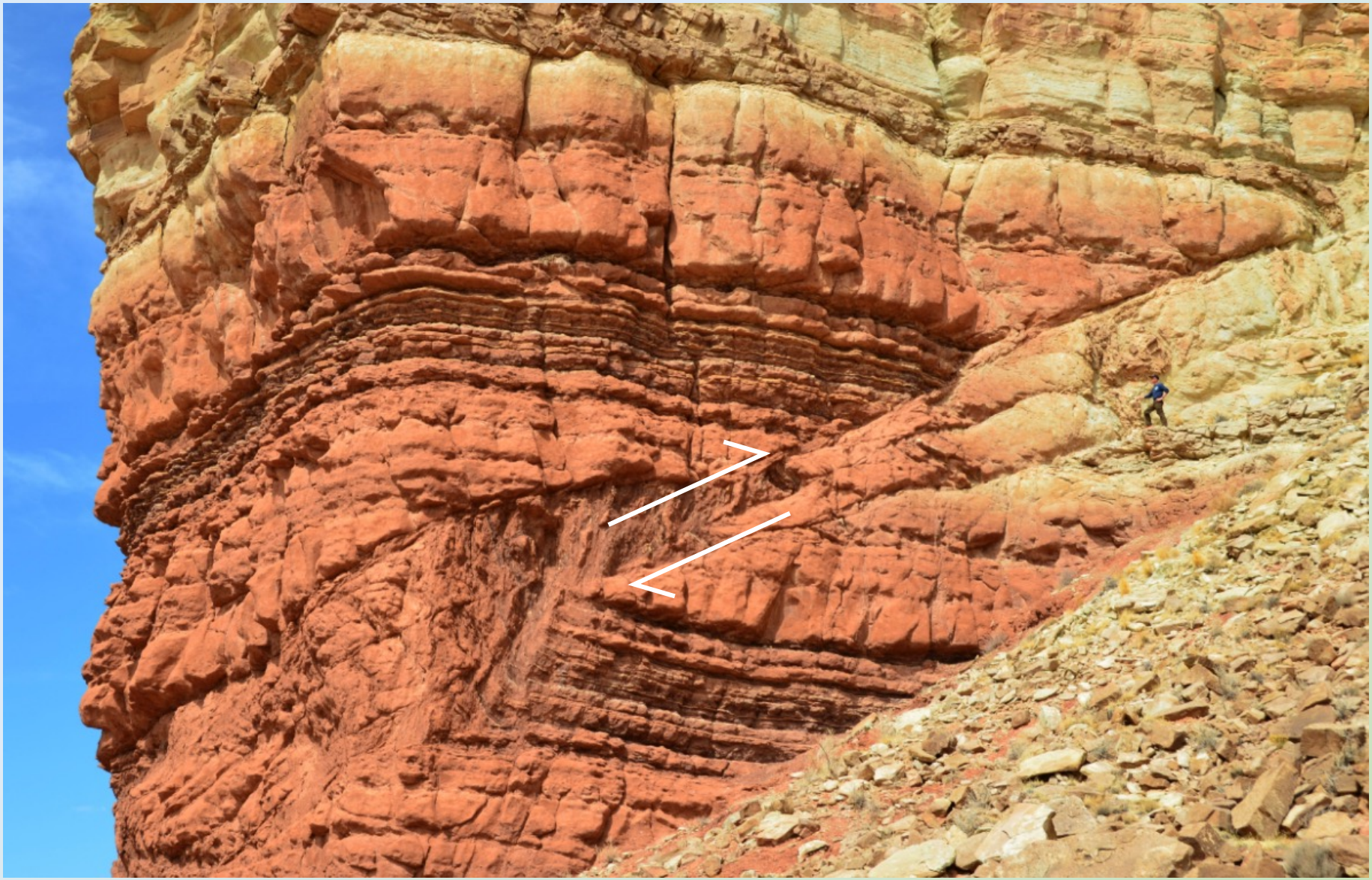


Causes of earthquakes

- Earthquakes are produced by sudden movement in Earth's crust.
- The sudden movement propagates along a fault
- when rocks are subjected to stress they deform elastically up to a point called the elastic limit
- when this limit is reached, the rocks yield by brittle fracture
- the stored strained energy is released as seismic waves



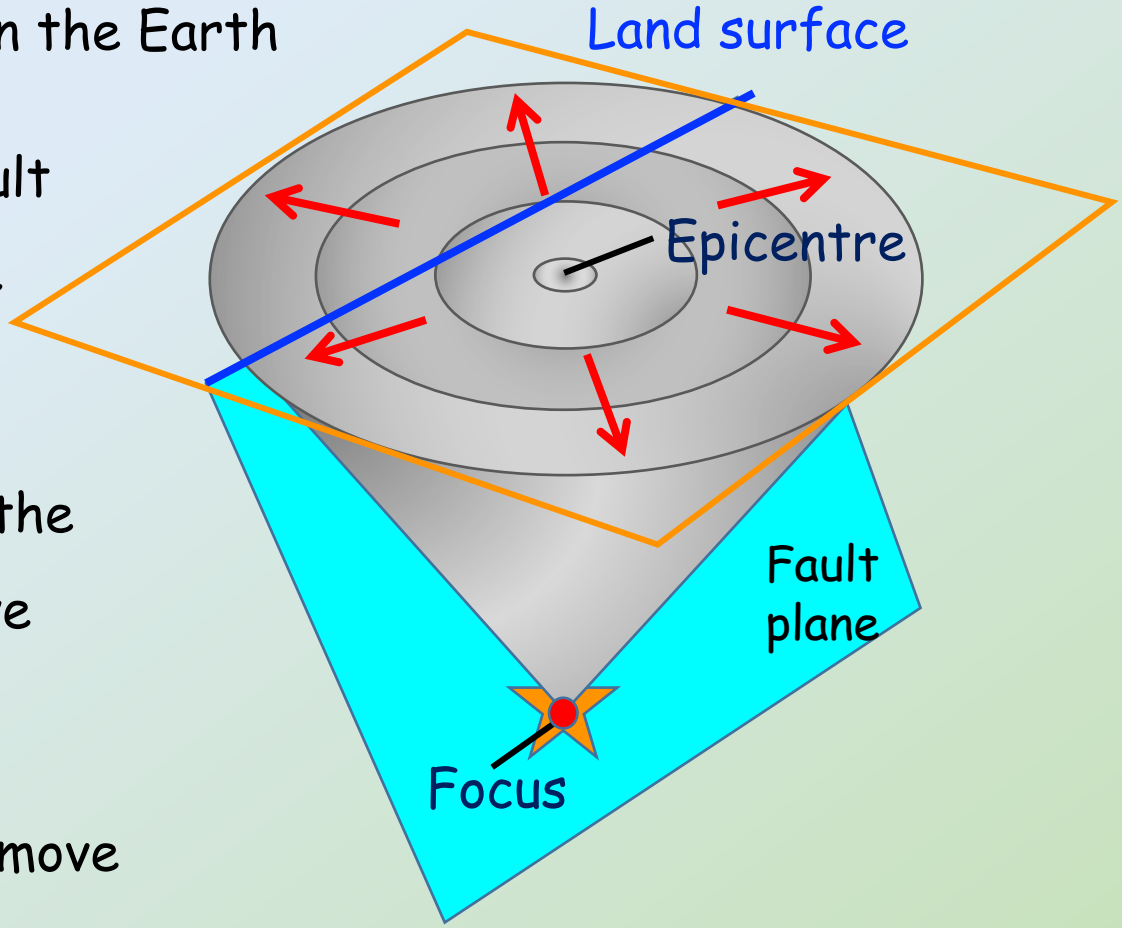
Faulted sedimentary layers



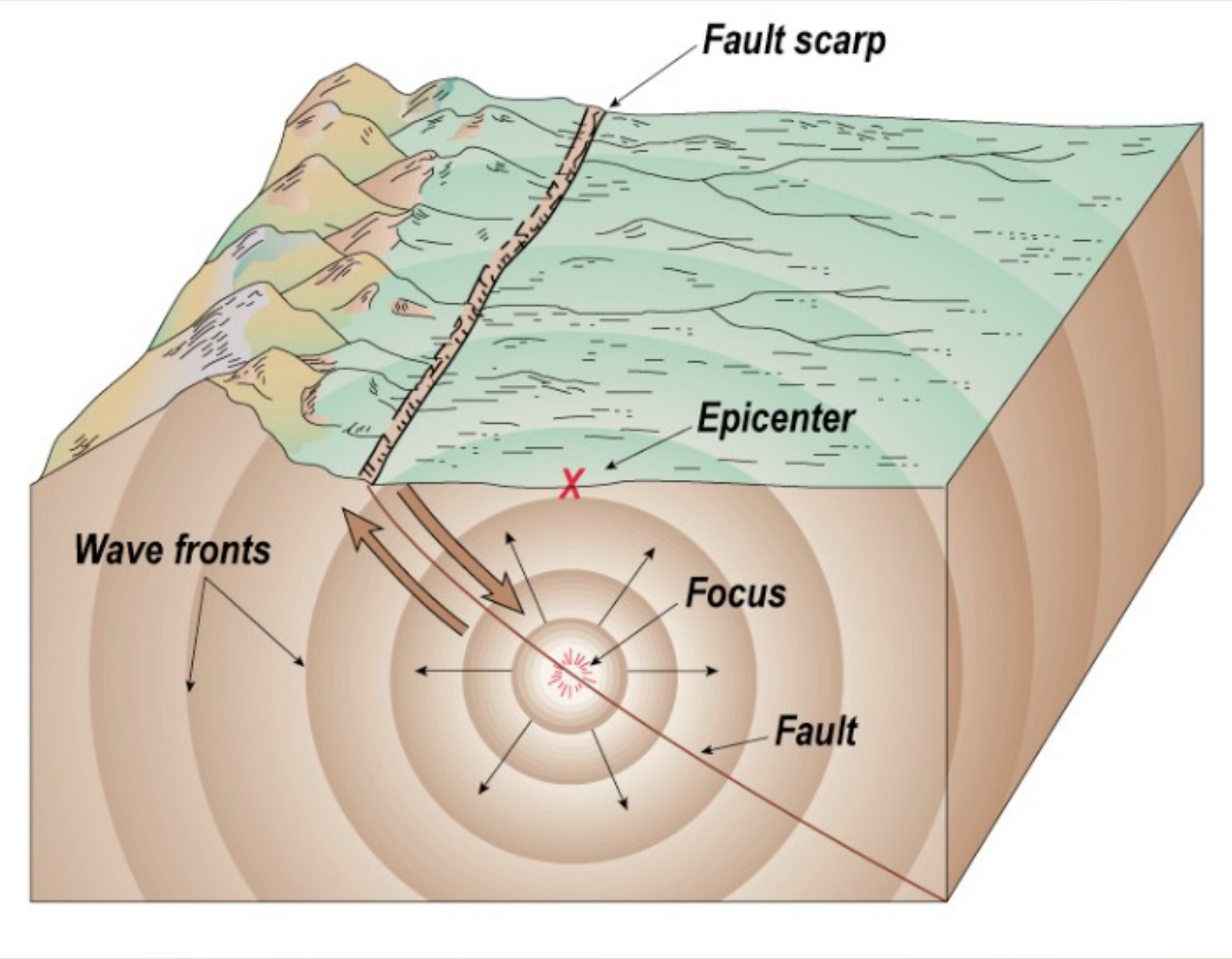
Thrust fault, San Raphael Swell, Utah

Source of an earthquake

- Earthquakes occur where there is a sudden mechanical failure in the Earth
- the focus is the point on a fault where rocks begin to rupture (always sub-surface)
- the epicentre is the point on the Earth's surface directly above the earthquake's focus
- seismic waves at the surface move radially out from the centre



Propagation of earthquake energy

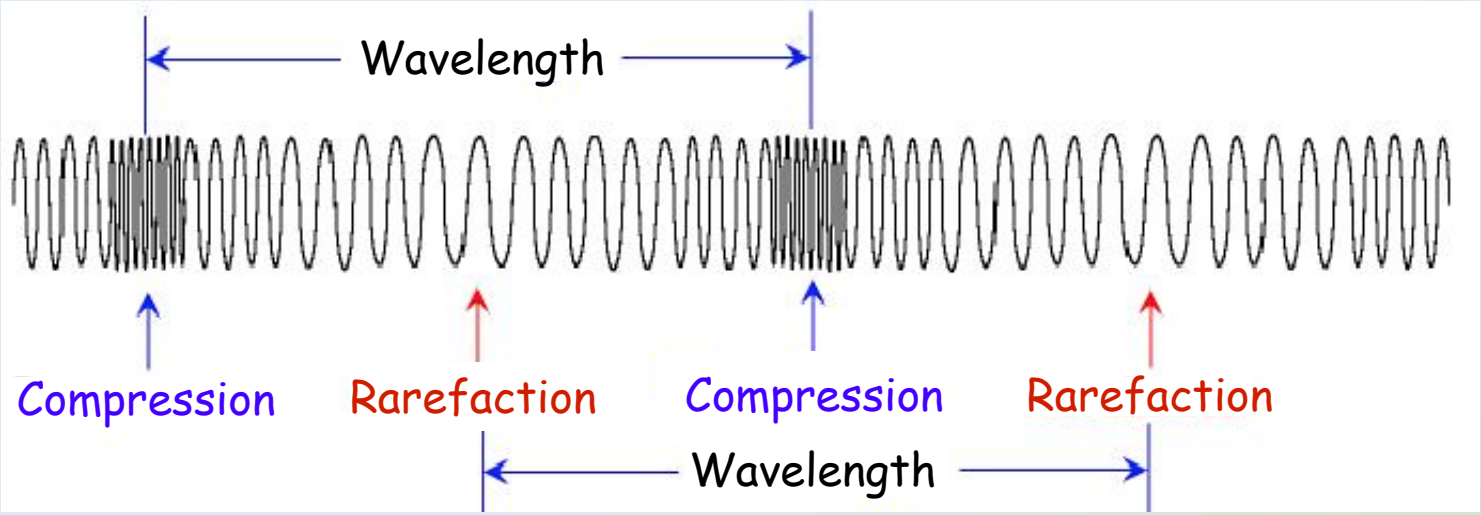


Types of seismic waves – body waves

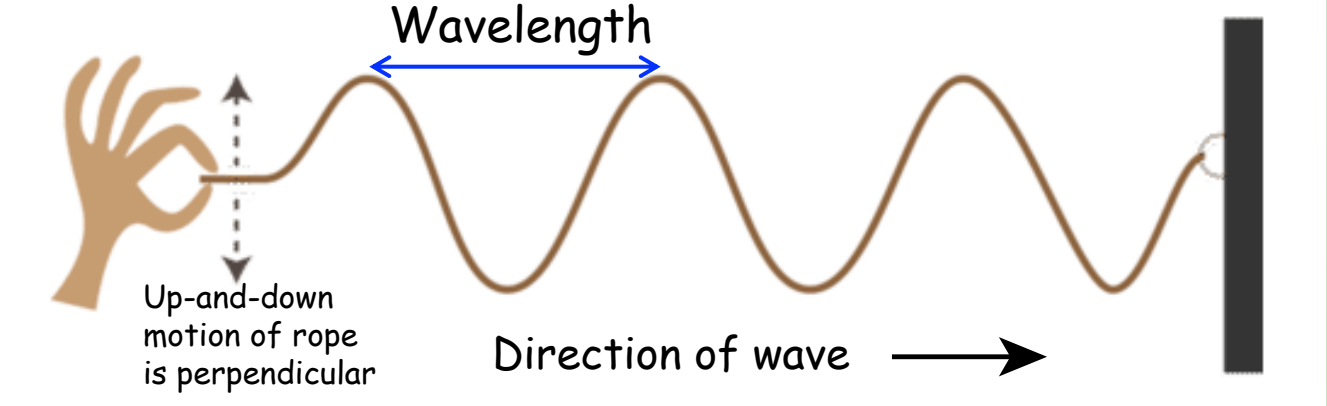
- Body waves
  - move through the Earth (not restricted to surface)
  - two kinds of body waves → P and S waves
- P-waves (primary waves)
  - compression waves (alternate compressions and rarefactions)
  - movement back and forth in direction of propagation
  - travel very fast → 6 to 7 km/sec in Earth's crust
  - can travel through any sort of medium (gases, liquids, solids)
- S-waves (secondary or shear)
  - transverse waves, shear type motion
  - movement is perpendicular to the direction of propagation
  - travel much more slowly → 3 to 4km/sec in the crust
  - cannot travel through liquids or gases, only through solids

Seismic body waves

P-waves (compression waves)

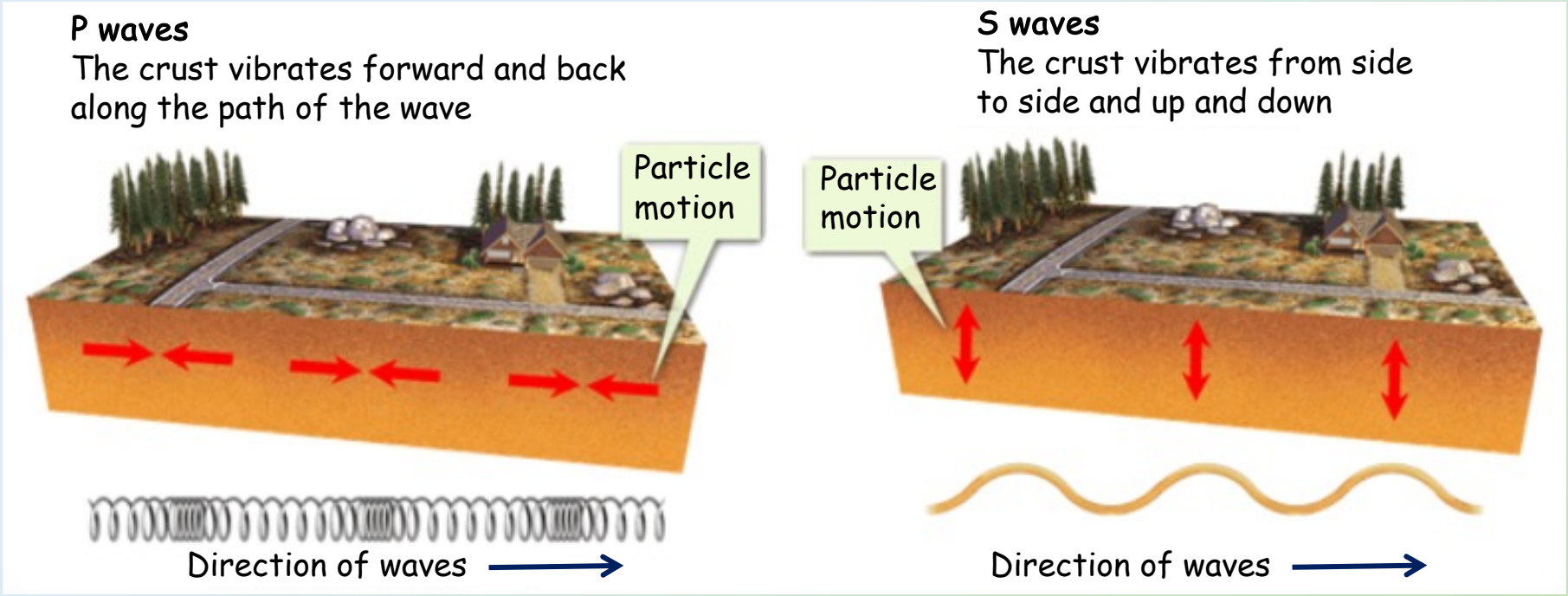


S-waves (transverse waves)

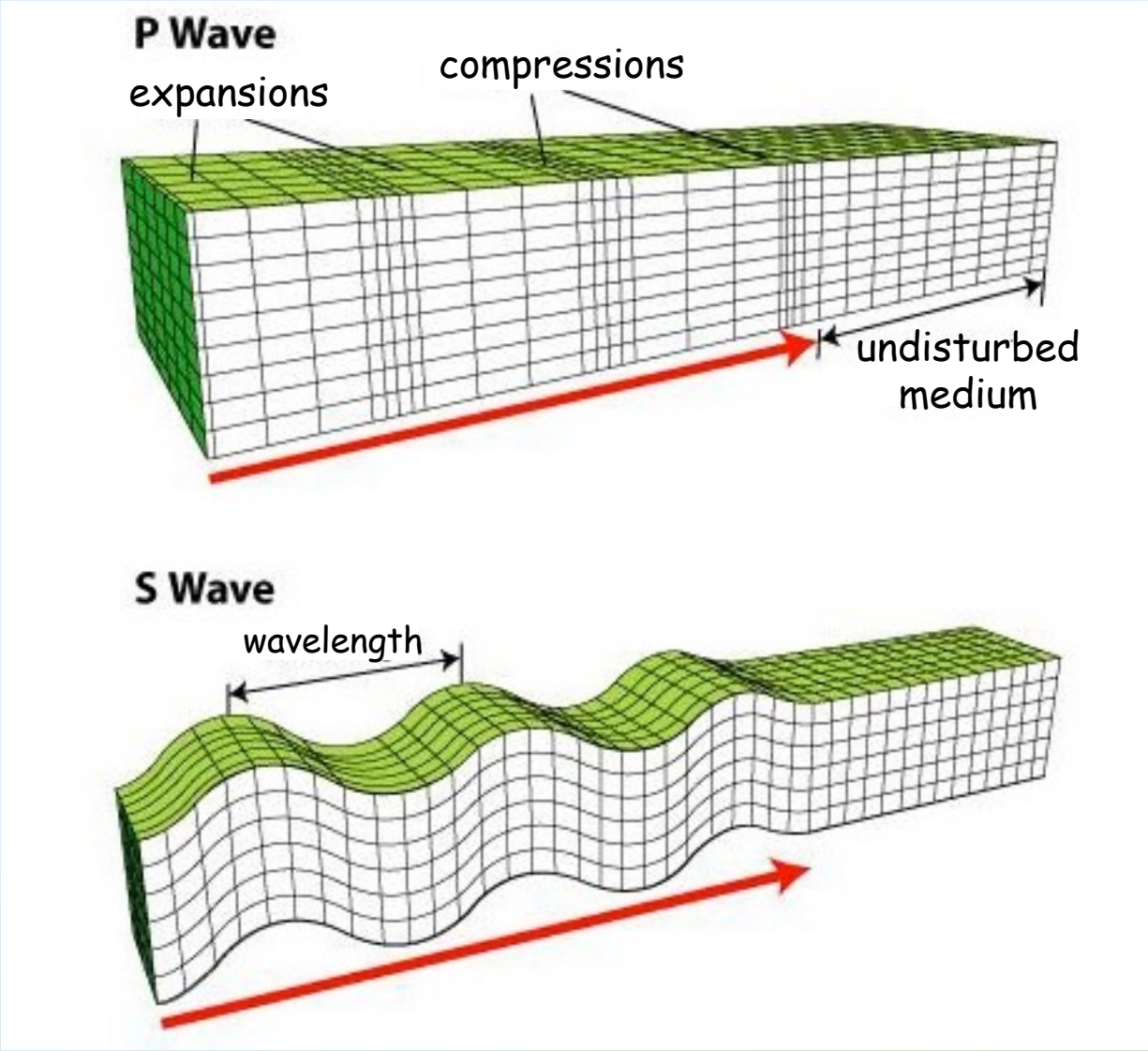


Seismic waves

- P waves are seismic waves that compress and expand the ground like an accordion
- S waves are seismic waves that vibrate up and down as well as from side to side



Body waves


P Wave
expansions
compressions
undisturbed
medium
S Wave
wavelength

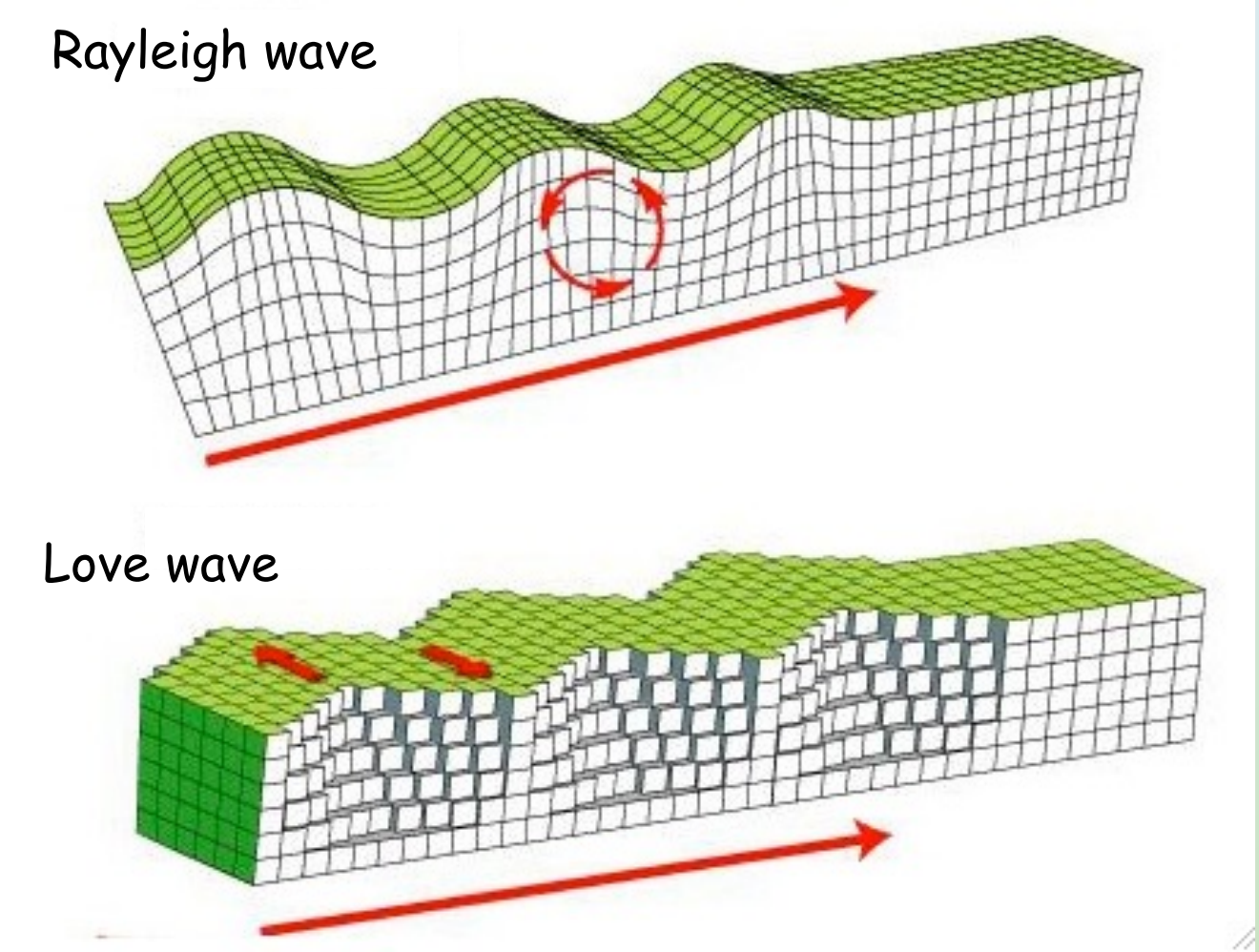
Types of seismic waves – surface waves

- Surface waves
  - propagate out from the epicentre (analagous to ripples on a pond)
  - travel around the surface of the Earth
  - surface waves cause most damage in earthquakes (large displacements)
  - the slowest waves → travel at 2.5km/sec
  - two kinds → Rayleigh and Love waves

- Rayleigh waves
  - rolling up and down motion (like sea waves)

- Love waves
  - nastier motion than Rayleigh waves
  - side-to-side motion (like a snake) highly damaging to most buildings
  - produce large displacement

Seismic surface waves



Measuring earthquakes

- Earthquakes have a very wide range in magnitude
- absolute magnitude of an earthquake depends on how much of the strain energy is instantaneously released
- intensity of earthquake is a measure of how much damage it produces → varies with amount and type of infrastructure affected, ground conditions, also depth and distance from epicentre
- absolute energy release measured on Richter scale
- intensity is estimated from human observation using 12 point Mercalli scale

Measuring earthquakes

- Energy of an earthquake described by magnitude and intensity

- Two scales commonly used:
  (1) Richter magnitude scale
  (2) Mercalli intensity scale

- Richter scale based on logarithmic scale → whole number increment → 10X increase in magnitude

- Earthquakes with magnitude >7 → major earthquakes

- Mercalli scale describes observations of an earthquake's effects on man-made objects

Mercalli scale

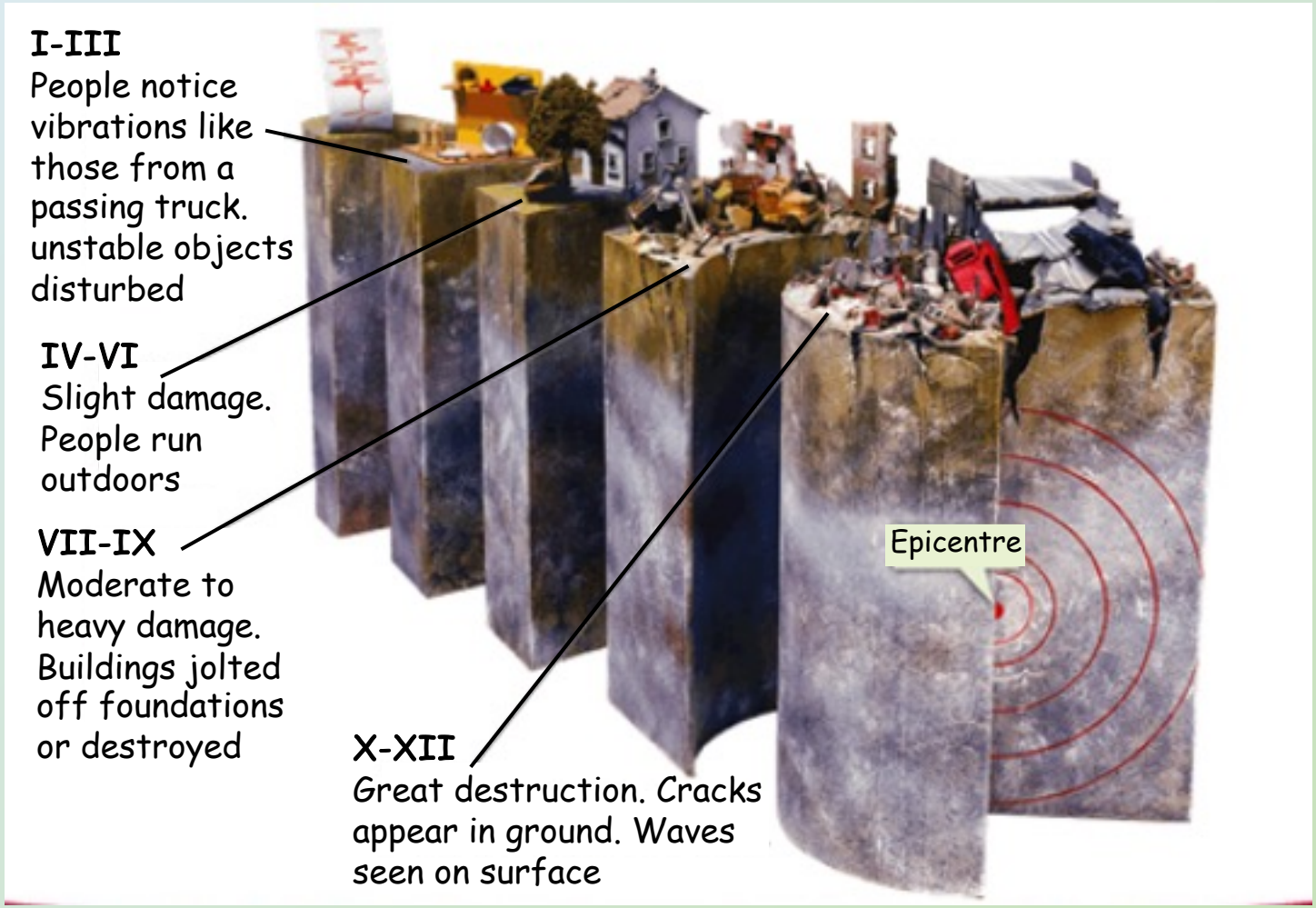
- Guiseppe Mercalli (1902) developed a standard scale based on increasing levels of earthquake damage
- intensity is estimated from human observation using 12 point Mercalli scale
- Could you sea any ground motion? Did plaster drop from walls or ceiling? Was there minor damage to houses? Was there significant structural damage to buildings ? Did trees shake? Could you hear crockery rattle etc.
- scale based on increasing amount of damage

Mercalli scale

- Not directly related to the energy of the earthquake → other factors involved e.g. distance from epicentre, depth of focus, nature of surface material e.g. Mexico City built on reclaimed mud → becomes thixotropic when shaken

Mercalli scale

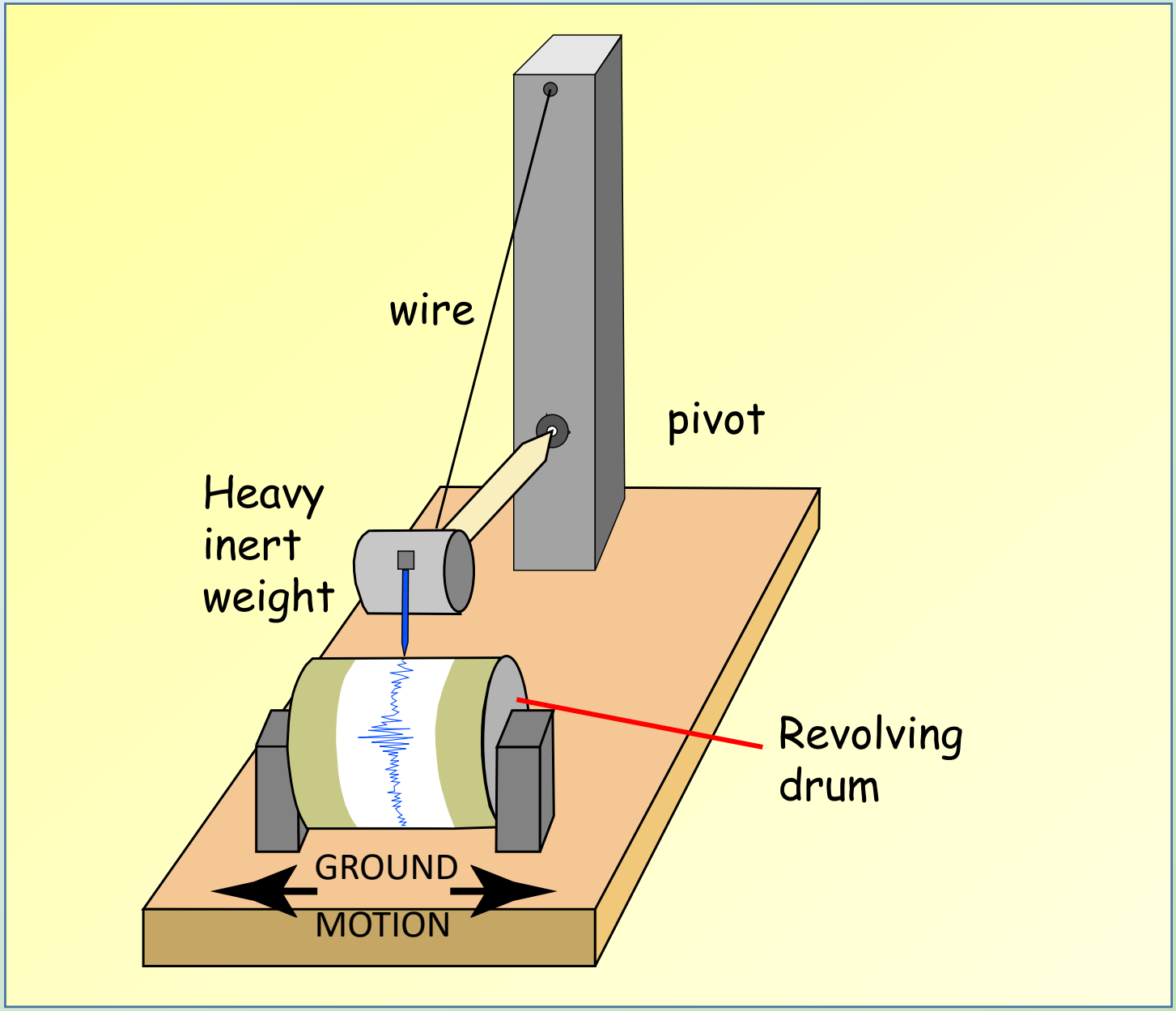
The Mercalli scale was developed to rate earthquakes according to the amount of damage at a given place



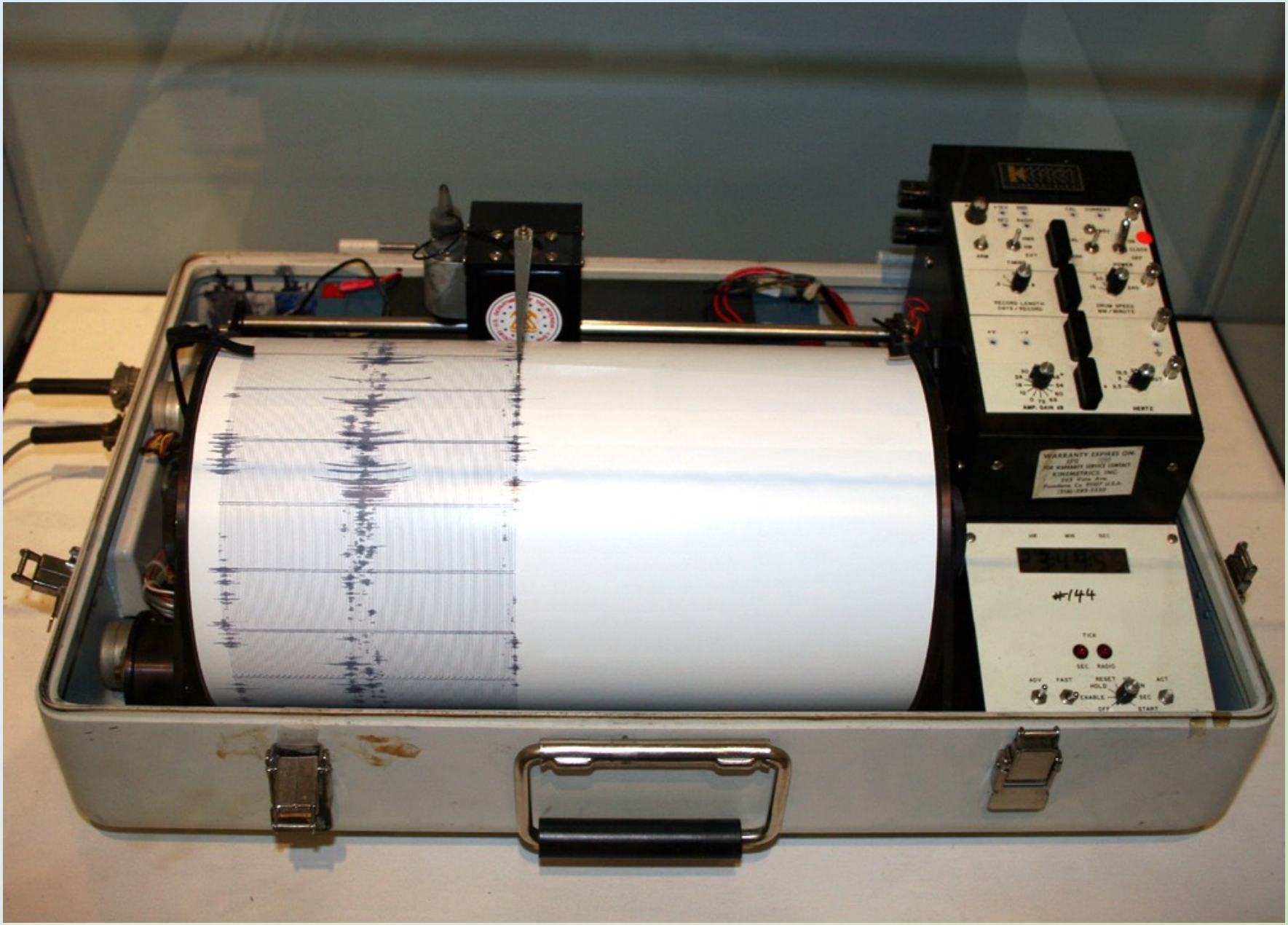
Seismographs

- Seismographs are instruments used to measure earthquake activity quantitatively (irrespective of damage caused)
- a seismogram is the record that seismographs produce of the arrival times and magnitude of seismic waves
- modern seismometers amplify the wave motion electronically and can detect even very weak signals
- does not have to be located in immediate vicinity of quake → can be remote
- seismographs enable us to measure the size of earthquakes and locate them accurately from the arrival time of seismic waves

Mechanical seismograph

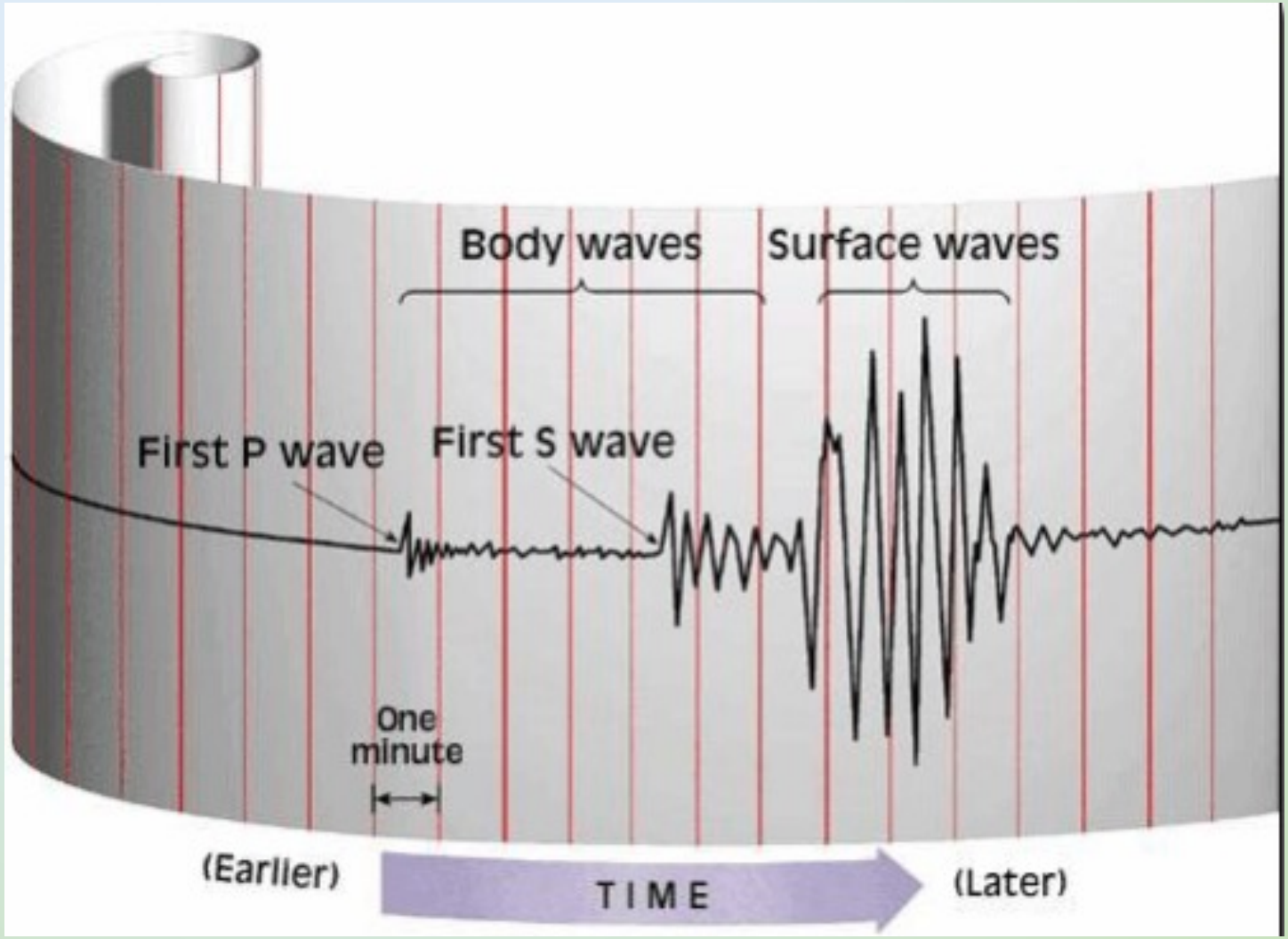


Electronic seismograph



Seismogram

- Seismogram – graph produced by a seismograph
- modern seismograms are commonly electronic



Earthquake magnitude

- The magnitude of an earthquake is a measure of the amount of energy released by it
- the Richter Scale relates the amplitude of the largest peak on a seismograph to the amount of energy released
- the Richter Scale is logarithmic, each point producing a ten-fold increase in amplitude on the seismograph
- each point corresponds to a 30-fold increase in the amount of energy produced e.g. energy released by magnitude 6 earthquake is 30 x magnitude 5; 900 x magnitude 4

Earthquake magnitude

- Earthquake magnitude → amount of energy released
- Richter scale correlates largest amplitude peak on a seismogram to the amount of energy released during the quake
- The Richter scale is open-ended → no maximum number
- largest possible earthquake is about magnitude 9 to 9.5
- it is possible to have earthquakes with negative numbers
- earthquakes not usually reported if they are less than 1

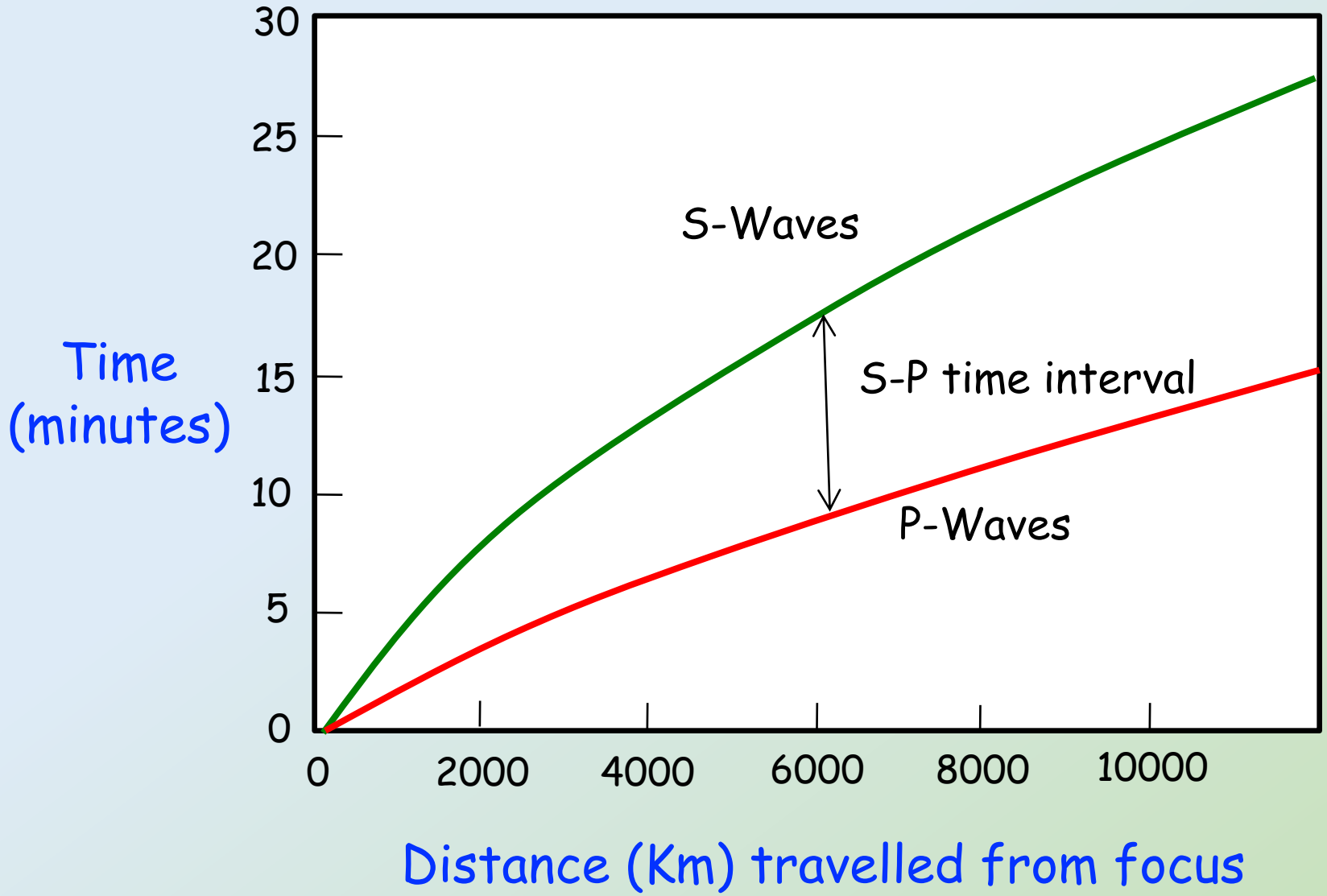
The Richter Scale

- Largest earthquake ever recorded measured 9.5 on the Richter Scale
- earthquakes of magnitude 5 can cause significant damage if they occur at a shallow depth, if deep (e.g. 300m+) → little damage
- the 1989 Newcastle earthquake was only magnitude 5.5, shallow (11.5km)
- earthquakes of magnitude 6 and up are considered major and can cause serious damage
- great earthquakes of magnitude 8 or more occur every 5-10years
- a magnitude 8 earthquake is about 1000-10,000 times bigger than a large nuclear explosion

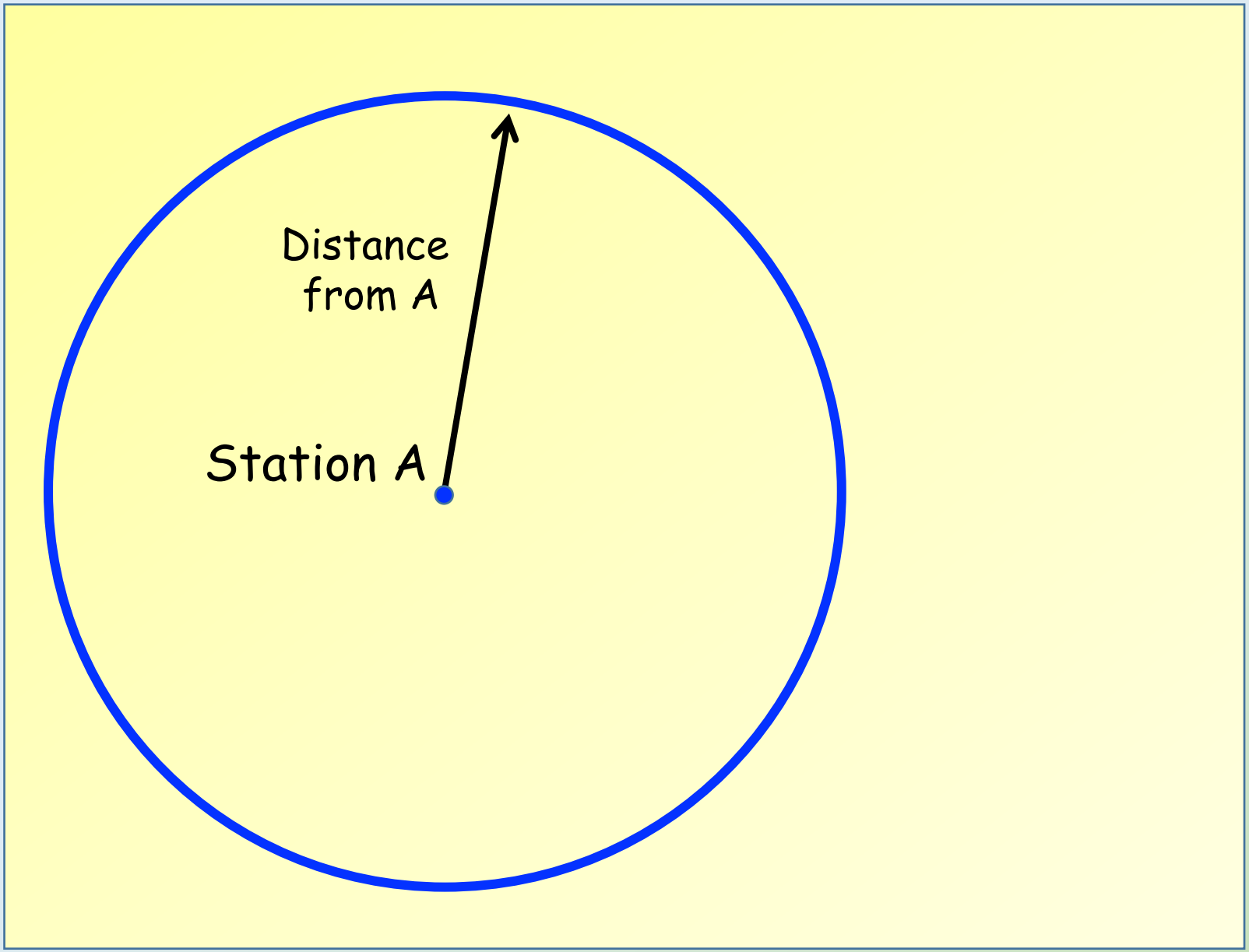
Earthquake location

- P-waves and S-waves travel at different speeds
- P-waves arrive first and sometime later the S-waves arrive at a seismic centre → only gives arrival time on seismogram
- the difference in arrival time between the P and S-waves is proportional to the distance from the earthquake focus
- using the calculated distance from three different seismograph stations, the precise location of the epicentre can be located
- there is an international network of seismographs and international exchange of information

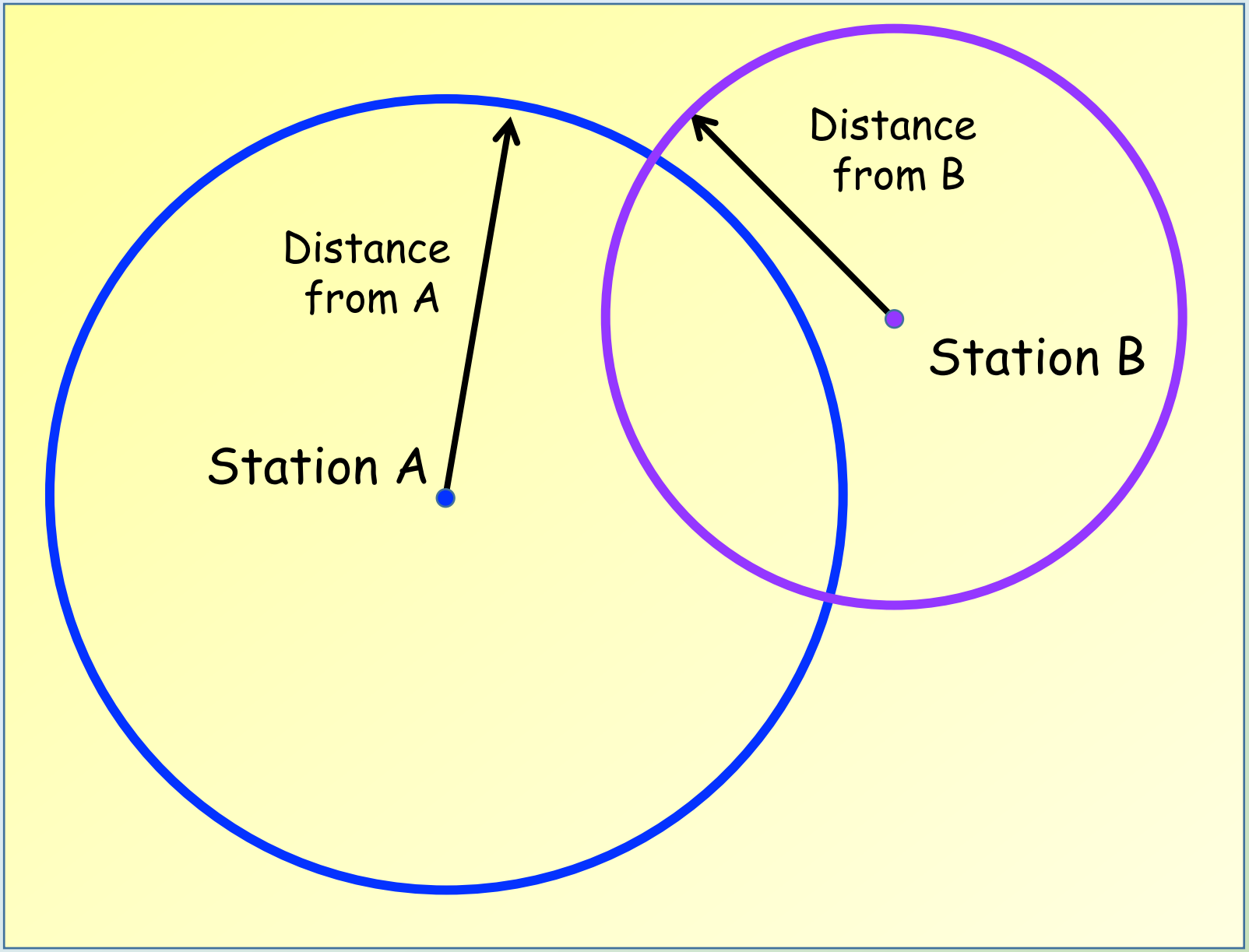
Time-distance graph for seismic body waves



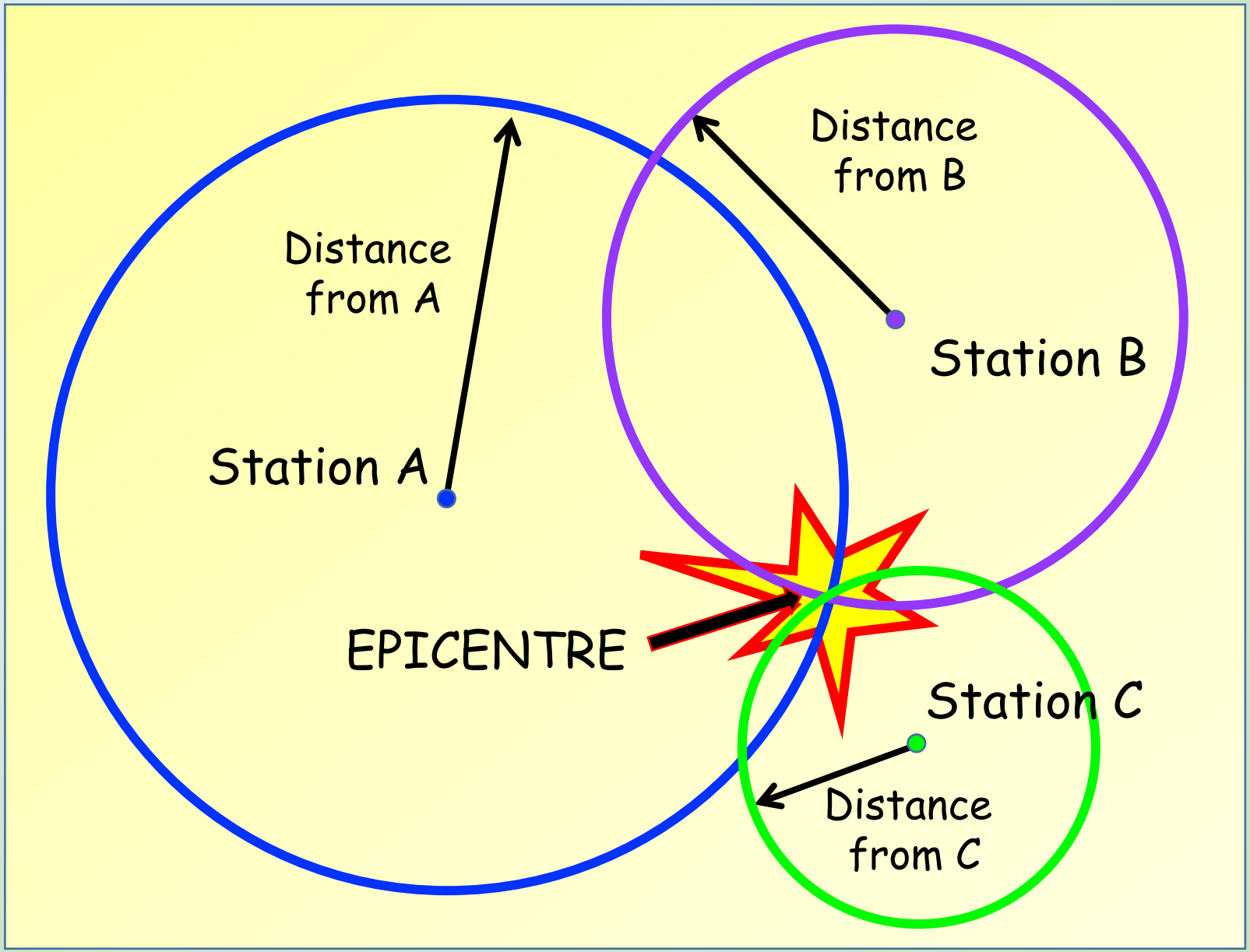
Locating an earthquake



Locating an earthquake



Locating an earthquake



Earthquake depth

- Earthquakes usually occur at some depth below the Earth's surface
- the depth of the focus can be calculated from seismograph records
- earthquake foci are described as :

  shallow → less than 70km depth

  intermediate → 70-300km depth

  deep → 300-700km depth

- 90% of earthquake foci are <100km deep
- large earthquakes are mostly <60km depth
- no earthquakes occur deeper than 700km (rocks too hot and ductile)