Topic 12: Earth's Dynamic Crust and Interior

Topic 12 Section 1

Overview: earthquakes and volcanoes are evidence that Earth's crust changes. Observing layers of rock gives further evidence of change. The crust is the upper portion of the lithosphere. The lithosphere is the outer shell of Earth's interior. Properties of Earth's interior help explain observations of the lithosphere.

Small scale crustal changes

Most evidence of movement in the crust is based on the concept of *original horizontality*

Original horizontality assumes that surface lava and sedimentation occurs in layers parallel to the surface of the Earth

Layers of sedimentary rock and extrusive lava are called *strata* or *beds*

Strata that are not horizontal are thought to be deformed by crustal movement

Types of deformed layers:

- folded – bent or curved layers
- tilted – layers are slanted or tipped
- faulted – a crack forms and layers move, usually up or down, relative to each other

folding

tilting

faulting

Some layers can be *displaced* but still remain horizontal:

- sea fossils are sometimes found high above sea level – *uplift* has occurred
- some shallow sea fossils have been found deep in the ocean – sinking has occurred

Scientists believe uplift and sinking occurred because fossils are found thousands of meters above or below current sea level, but believe the ocean level has only changed by a few hundred meters

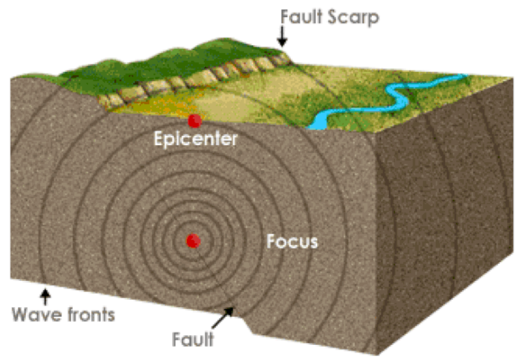
Topic 12: Earth's Dynamic Crust and Interior

Topic 12 Section 2

Earthquakes and Igneous Activity, Including Volcanoes

Earthquake – a natural rapid shaking of the lithosphere caused by the release of energy stored in rocks

- most earthquakes are caused by faults or faulting
- earthquakes are also caused by movement of magma associated with volcanoes



During earthquakes, potential energy stored in rocks is given off as *seismic waves*

- focus – point, usually beneath the surface, from which seismic waves are emitted
- epicenter – the point on the surface of the Earth, land or water, directly above the focus

Properties of earthquake waves

- for any given material, P-waves are fastest, S-waves are the second fastest
- the velocity of seismic waves depends on the properties of the material they pass through
  - higher density and rigidity, the faster waves can travel
  - when waves travel from one medium to another, they will bend or *refract*
- in a given material, increased pressure will increase the velocity of seismic waves
- P-waves are compression or longitudinal, S-waves are shear or transverse
  - P-waves can travel through solids, liquids, or gases
  - S-waves can only travel through solids
- some P-waves and S-waves are reflected by dense rock layers in the Earth
  - this property can be used to locate valuable resources

Location of an epicenter

Epicenters are located using the difference in velocity between P-waves and S-waves

use the Earthquake P-Wave and S-Wave Travel Time chart, page 11, PS/ESRT

Locating an epicenter requires triangulation – you must have data from three reference points

- obtain or calculate the time difference between P-wave and S-wave arrival
- use the PS/ESRT to determine the distance from the reference point to the epicenter
- use a map legend scale to draw a circle with a radius equal to the distance
- repeat this process for all three reference points
- the circles should intersect at one point, the epicenter

There is a sample on the next page

Topic 12: Earth's Dynamic Crust and Interior

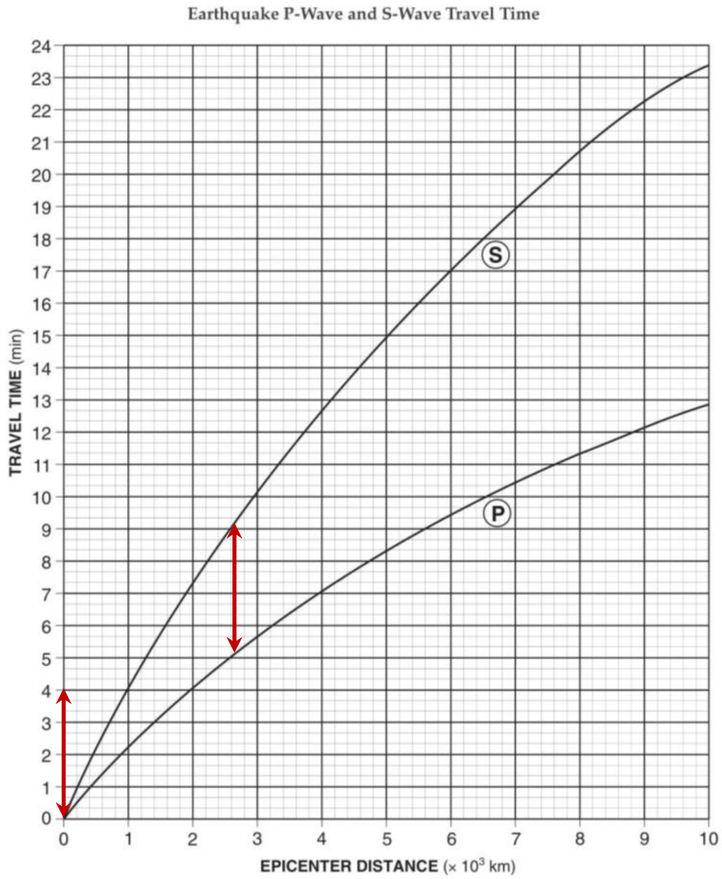
The interval between the P-wave and the S-wave is 4 minutes

Make a 4 minute line on paper and slide it up to 4 minutes between the P-wave and S-wave (red arrows at right) 2650 km

Draw a circle with a radius of 2650 km on a map

The map below shows a similar process repeated for three places

The epicenter is at the point where all three circles intersect in Mexico



Finding the origin time of earthquakes

- use the same procedure used above to find the distance to the epicenter
- instead of reading down the graph to find the epicenter distance, read across to the left from the P-wave to find the travel time
- the origin time of the quake is the P-wave arrival time – the travel time

Example: find the time an earthquake occurred if the P-wave arrived at 1:44 p.m. and the S-wave arrived at 1:48 p.m.

- the difference between P-wave and S-wave arrival is 4:00 minutes
- read to the left and find the travel time was 5 minutes 10 seconds (5:10)
- P-wave arrival – travel time = 1:44:00 – 5:10 = 1:38:50

Magnitude of earthquakes

Measuring the strength of an earthquake based on the type of damage an earthquake does is called an *intensity scale*

Scientists usually use a *magnitude scale* which measures the energy of the quake

Magnitudes range from 1 to 9.5

Earthquakes as a natural hazard

Earthquake damage is the result of a series of events

- the quake causes a break in a train rail
- a train derails causing a wreck
- hazardous chemicals escape from tanker cars
- fires or explosions result from the chemical spill

Most fatalities in earthquakes result from parts of buildings falling on people

Earthquake prediction

Scientists have been unsuccessful in predicting earthquakes

- except for long-term general predictions in specific zones where earthquakes are common
- the history of frequent occurrence makes general predictions possible

Emergency planning for earthquakes

Even though quakes are unpredictable, proper planning can reduce damage, injury, and deaths

- for individuals, remember "drop, cover, and hold"
  - do not go far
  - get under some reinforced area: table, desk, doorframe, in a bathtub
  - turn away from windows, cover eyes with one hand
  - do not exit buildings until the shaking is over
  - practice earthquake drills
  - keep emergency supplies at home, work, and in the car
- on a community level
  - proper planning and construction of roads and buildings
  - retrofitting older buildings: bolting buildings to foundations and cross bracing walls

Tsunami – "wave in the harbor"

A special condition for earthquakes on the ocean floor causes seismic sea waves or *tsunamis*

Types of sea floor disruptions that can result in a tsunami:

- faulting associated with an earthquake
- volcanic eruptions
- meteoric impacts
- rapid landslide or mass movement

A tsunami can, in rare cases, reach 30 meters

In the event of a tsunami, move inland, to higher ground, or to a high floor of a strong building

Igneous activity and volcanoes

Remember that igneous rock can be intrusive (plutonic) or extrusive (lava)

Extrusive lava flows can form:

- large flat areas called *lava plateaus* like the Columbia Lava Plateau which covers Oregon, Washington, and Idaho
- significant mounds with a slope of at least a few degrees called *volcanoes*

Volcanoes can be:

- cinder cones caused by volcanic eruptions – 1980 Mt. St. Helens eruption
- shield cones caused by quiet volcanic flows – Hawaiian islands
- composite cones caused by alternating eruptive and quiet flows – Mt. St. Helens

Volcanic eruption – out gassing, lava, lava rock, or ash into the air or Earth's surface

Topic 12: Earth's Dynamic Crust and Interior

Volcanoes as a natural hazard

Volcanoes result in many events that can damage, injure, or kill:

- flowing lava
- falling rock
- 1000°C gases
- land resources and buildings buried by lava or ash

Secondary events can be even more destructive:

- ash mixes with glacier meltwater resulting in mudslides
- CO_2, chlorine, sulfur, and compounds of Cl and S are toxic
- aerosols from eruptions block sunlight and cool the planet

Prediction of volcanic eruptions

Most volcanoes go unpredicted, dangerous volcanoes in populated areas are monitored

- satellites measure heat from rising magma
- tilt meters report increasing slope as magma swells a volcano
- benchmarks are used to detect increasing elevation or latitude/longitude deviations
- rising magma causes earthquakes, epicenters can be triangulated

These methods allow early warnings for emergency and rescue plans

Zones of crustal activity

- young continental mountains
- ocean trenches
- island arcs
- mid-ocean ridges

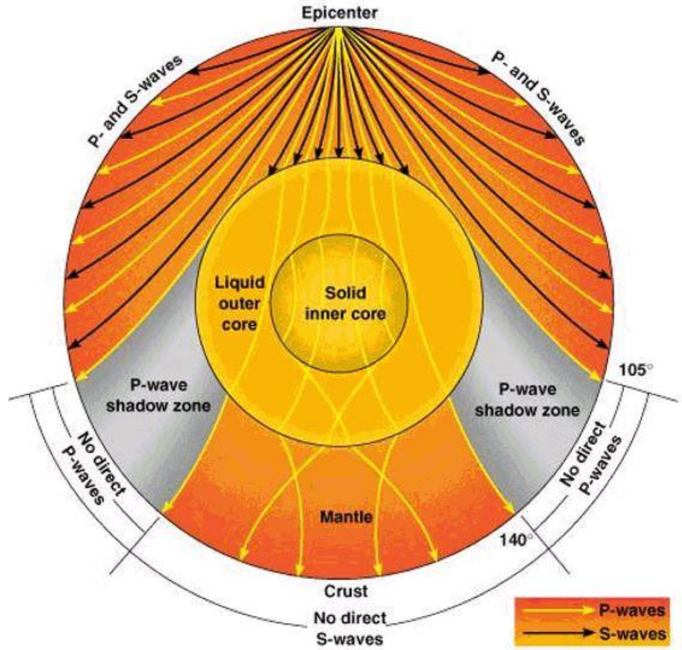
The "Ring of Fire" around the Pacific Basin explains these zones

Topic 12 Section 3

A model of Earth's interior – because direct observation of Earth's interior is difficult, such properties have been inferred from the study of earthquake waves

Methods of studying Earth's interior

- the deepest mines are only 3.5 km (a hole in Russia is 12 km deep)
- earthquake waves allow us to study Earth's interior (like x-rays in humans)
- oil industry and nuclear explosions allow scientists to study earthquake wave:
  - refraction
  - reflection
  - velocities
  - voids around the planet



Zones of Earth

Lithosphere – the crust and the rigid mantle – the lithosphere is divided into sections called *plates*

Earth's crust – the outermost part of the Earth is below the atmosphere and the hydrosphere

- mostly solid rock
- also includes soil and weathered rock deposits

Moho – very thin interface between the crust and mantle

Mantle – the thickest zone containing 80% of Earth's volume

Rigid mantle – the very uppermost part of the mantle

Asthenosphere – another portion of the upper mantle

- causes decrease in speed of seismic waves
- 100 to 700 km below Earth's surface
- called the *plastic mantle* and is believed to be partly molten
- much of the magma and lava in the crust is thought to originate here
- allows movement of the plates in the lithosphere

Stiffer mantle – the majority of the mantle, below the asthenosphere

Core – has two parts, both composed of iron and nickel

Outer core – liquid as indicated by absence of S-waves

Inner core – believed to be solid due to intense pressure

Composition of Earth's interior

Scientists think the outer and inner core are composed largely of iron and nickel based on the composition of many meteorites (iron and nickel), Earth's magnetic field, and the behavior of seismic waves

Mantle – high density core and low density crust indicate some intermediate composition of the mantle

The crust is low density rocks and minerals with granitic continental and basaltic oceanic crusts

Topic 12: Earth's Dynamic Crust and Interior

Topic 12 Section 4

Plate tectonics

Plate tectonics is a unifying theory that explains most, if not all, Earth's features and events

The plate tectonic theory

The basic theory is that the lithosphere is broken up into sections called plates

The movement and interactions of these plates produce the features, events, and changes on Earth's surface

- plates move around Earth's surface at a rate of a few centimeters per year
- plates can also *uplift* and *sink* at rates of a few millimeters per year because they are riding on the plastic asthenosphere
- plates do not always follow continental or ocean boundaries – ESRT pg 5
- most plates have oceanic or continental crust on top
- a small number of plates are oceanic – they have only oceanic crust

At least three times in the past, most of the large land masses have come together at one place on the Earth forming supercontinents – Rhodinia (800 mya), Pannotia (600 mya), Gondwana (350 mya), and Pangaea (250 mya)

Types of plate boundaries

Divergent plate boundaries – two plates are separating

Magma will rise to fill the gap between the plates

Divergence results in many shallow earthquakes, continental rift valley of mountains, and much volcanic activity

Divergence in oceans results in mid-ocean ridges – a basaltic mountain range often with a central depression called a *rift valley*

Convergent plate boundaries – two plates collide

Both plates have oceanic crust

The denser crust will *subduct* or move under the less dense plate

Subduction in the ocean will result in ocean trenches and volcanic island arcs

The subducting plate bends down under the other plate causing a long, steep, narrow depression called an ocean trench

Melting of the subducting plate creates magma that breaks through the solid crust forming an arc of volcanic islands – an island arc

The subducting process results in deep earthquake activity

The heat and pressure associated with subduction causes large areas of *regional metamorphism*

Both plates have continental crust

Usually no subduction occurs, instead both plates bunch up causing a thickening of the crust and lithosphere and the highest type of young mountains occurs (Himalayas)

Plate convergence that results in young mountain growth is called *orogeny*

Four orogenies have formed mountains in NYS: Grenville, Taconian, Acadian, and Alleghenian

One plate has oceanic crust and the other plate has continental crust

The denser oceanic crust will subduct

Ocean trenches off the continent coast often result

Magma from melting crust does not form an island arc because there is a continent above the region of magma formation

- If there is a continent at the point of convergence, the crust of the continent may bend down forming a *down-warped ocean basin* which will become the site of deposition of large amounts of sediment – many rocks of eastern NYS formed in a down-warped basin
- Young mountains form instead of an island arc – these mountains are mostly volcanic but can be a combination of volcanic, faulted, and folded

Transform plate boundaries form when two plates form by sliding past each other

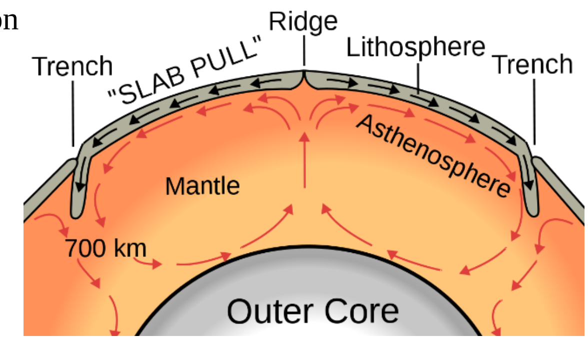
- Friction and drag of the rocks along the boundary builds up a lot of potential energy – this energy is eventually released as kinetic energy in the form of earthquakes
  - Example: San Andreas, California is between the Pacific and North American Plates

Driving forces of plate tectonics

Most scientists accept the plate tectonic theory, but there is still debate over what causes the plates to move

Current best theory is the Mantle Convection Current theory

- energy source is heat from Earth's core
- hot magma rises and diverges under divergent plates
- cooling magma sinks under convergent plates

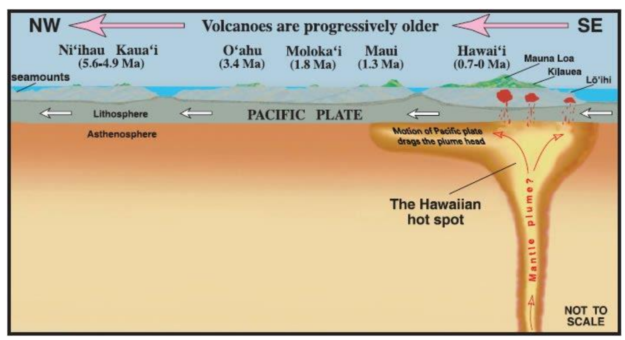


Hot spots

Difficult to explain why areas in the interior of a plate shows high volcanic activity

Scientists think hot spots result from areas where rising hot magma remains stationary for millions of years and melts its way close to the surface

- Examples of hot spots: Yellowstone in Montana and Wyoming, Hawaii, and possibly the Adirondack Mountains in NYS



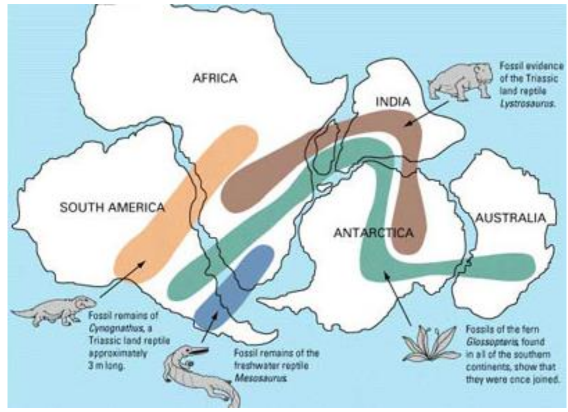
The rising magma can form mountains

Because the plate moves over the hot spot, magma that melts to the surface will form a chain of volcanoes

- Such chains can be used to infer past movements of plates

Hot spots can also occur at plate boundaries

Topic 12: Earth’s Dynamic Crust and Interior



Effects of plate tectonics

Appearance of continents

Outlines of present day continents fit together like a jig-saw puzzle

See PS/ESRT 2011 ed., page 9 for a history of continental movement

Features of landmasses

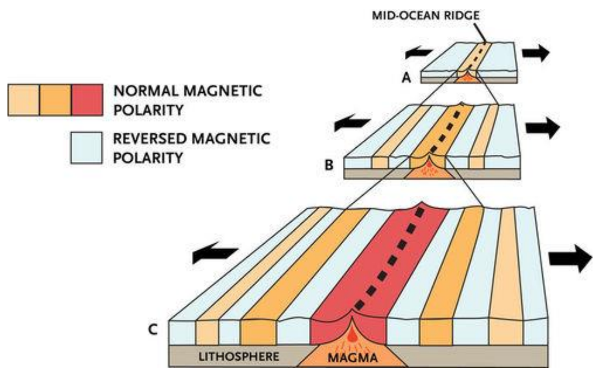
Similarities in minerals, rocks, age of rocks, features of mountain ranges, and fossil records indicate that landmass regions were once joined – see diagram at right

Age and heat patterns of oceanic rocks

Magma rises at the divergent plates in mid oceanic ridges and forms new ocean basalt rocks

The age of mid ocean basalt increases with distance on both sides of the ridge

Heat measurements also indicate that the rock is cooler the farther it is from the mid ocean ridge



Magnetic patterns of oceanic basaltic rocks

Earth’s magnetic poles reverse polarity over time – this shows in stripes on the ocean floor because as magma cools and crystalizes the rocks will align with Earth’s magnetic field

The stripes on the diagram to the right do not show visually, but are revealed by studying the direction of their magnetic polarity

Other effects of plate tectonics

- volcanic eruptions, earthquakes, and tsunamis
- changes in Earth’s climate as continents change latitude and mountains and ocean positions change wind patterns
- changes in local weather due to distribution land and oceans and how mountains affect wind patterns
- the rock cycle
- major landscape features change – continents, ocean basins, mountains, plains, and plateaus
- exposing rocks to weathering and erosion and form sediment deposits