

## Plate Tectonics

S=slide

S1

First theory to provide a comprehensive view of Earth's processes

S2

Tectonics – the deformation of Earth's crust -> results can be the formation of mountains

S3 Key Concepts

1. Continental drift – evidence for and reasons against the hypothesis
2. Plate tectonic theory – evidence and types of boundaries
3. Paleomagnetism – definition and how it is used in plate tectonics
4. How rates of seafloor spreading are calculated
5. Driving mechanisms for plate tectonics

S4 Continental Drift

Wegener - the beginning of a revolution

Pangaea – proposed supercontinent

about 200 million years ago it began to break apart

Evidence

Continental puzzle

Fossil match across oceans

Rock types and structure match

Ancient climate match

S5

Continental jigsaw puzzle – Coasts of Africa and South America fit together

Argument against – coasts are modified by erosion and even if they did belong together in the past they would not fit today

Argument for – Wegener's map was crude but we now know the outer boundary is the edge of the continental shelf – see fit

S6

Fit of the coasts of Africa and South America along the continental slope at a depth of 900 meters

S7

Fossil match across the ocean – identical fossil organisms were known from rocks on both continents – there must have been some kind of land connection

S8 Animal and plant connections across the oceans

A variety of organisms were found on land masses that could not have crossed the ocean

### S9 Rock types and structures match

If the continents were once joined then the rocks found on one continent should match in age and type those on the other continent

Appalachian mountains trend NE and disappear off the coast of Newfoundland  
Mountains of similar age and composition are present in the British Isles and Scandinavia

### S10 Rock types and structures match

Wegener noted that 2.2 billion year old igneous rocks in Brazil closely matched similar aged igneous rocks in Africa (left side)

Pangaea ~200 million years ago

Precambrian arrangement of continents

### S11 Ancient Climates

Wegener found evidence of Paleozoic glacial deposits throughout the Southern Hemisphere and India

Deposits of the same age were found in South America, southern Africa, India, and Australia

Could not have been a major glacial episode with continents as they are today because of swamp deposits in North America, Europe, and Siberia of similar age to glacial deposits

### S12

Continents today -

Blue arrows show direction of movement inferred from glacial grooves

Continents restored to former position -

Blue arrows show direction of movement away from the South pole

Wegener thought this evidence was the most compelling

### S13 Continental Drift Debate

Not much criticism until translated into English in 1924 – afterwards it faced hostile criticism in the North Hemisphere – most evidence in Southern Hemisphere

No mechanism capable of moving the continents across the globe

A few geologists thought the ideas were possible and continued to look for more evidence

### S14 Plate Tectonics – New Paradigm

Post WWII oceanic ridge system discovered, Earthquake activity at trench systems noted, no oceanic crust older than 180 million years

By 1968 plate tectonics had been developed

Major plates

Plate Boundaries

### S15

Earth's major plates – on the uppermost mantle and crust in a layer known as the lithosphere. Plates are thinnest in the oceans (few km to 100 km in deep ocean)

basins) and thickest in continental lithosphere (100-150 km). The lithosphere overlies a weak mantle region called the asthenosphere (rocks are near their melting points)

#### S16 Earth's layered structure review

- lithosphere includes the crust

- upper mantle includes part of the lithosphere and the asthenosphere  
weak asthenosphere allows the plates (outer shell) to move

#### S17

Seven major plates are recognized - North American, South American, Pacific, African, Eurasian, Australian-Indian, and Antarctic

Most of the large plates include a continent plus ocean floor - different than Wegener's drift hypothesis

#### S18

Intermediate size plates include the Caribbean, Nazca, Philippine, Arabian, Cocos, Scotia, and Juan de Fuca plates.

There are several small plates

Plates move as coherent units relative to all other plates, in general points on a plate remain the same distance apart while points between plates change

Convection from below causes the movement

#### S19 Plate Boundaries

Divergent boundaries - (constructive margins) plates move apart → upwelling of material to create new seafloor

Convergent boundaries - (destructive margins) plates move together and one plate subducts under the other or they collide

Transform fault boundaries - (conservative margins) no crust made or destroyed

Each plate is bounded by a combination of these boundaries

#### S20 Divergent Boundaries

Oceanic ridges are elevated seafloor that is very long and about 1000 - 4000 km wide

center of ridge may have a downfaulted rift valley

Process is called seafloor spreading

Ridges are composed of hot material causing them to be elevated - cooled material is denser and is why ocean basins are deep away from the ridges

The older (cooler) it is the greater the thickness

#### S21

Most divergent boundaries are located along mid-ocean ridges and can be thought of as constructive boundaries - new crust is made

Plates are moving away from each other and magma wells up from below - new oceanic crust when the magma cools

Divergent boundaries can form in continents

S22

Divergent boundaries can develop within continents – continent is split into two or more segments

Thought to begin with elongated depression called continental rift (East African Rift)

Tensional forces stretch and thin the crust – volcanoes can erupt

If tensional forces continue the rift lengthens and deepens – narrow sea forms (Red Sea, 20 mya)

If the process continues an elevated ridge may form

Not all rift valleys form spreading centers

S23 Convergent Boundaries

In general, oceanic crust is denser than the asthenosphere – continental crust is less dense

Slabs of oceanic crust descend at a variety of angles due to temperature (age) and density – hot, young crust at shallow angles and cool, old crust at angles close to 90 degrees

S24

Convergent boundaries – Earth is not getting larger from spreading → convergent boundaries where crust is destroyed

Convergent boundaries are where two plates are moving toward each other and the leading edge of one is subducted under the other to form a trench or they rise in mountains. Convergent margins are also called subduction zones

S25

Oceanic- Continental Margins – The buoyant continental crust ‘floats’ and the oceanic slab sinks into the mantle. At around 100 km (60 miles) depth partial melting begins in the asthenosphere above the slab due to water driven off the sediments and minerals in the subducting slab

Melt starts as basalt and interacts with SiO<sub>2</sub> in rock above to become SiO<sub>2</sub> richer  
Continental volcanic arcs

S26

Oceanic-Oceanic Margins – similar to oceanic-continental but with both plates composed of oceanic crust. One side sinks producing magma that rises to form volcanic island arcs

S27

Continental-Continental Margins – both sides are composed of the buoyant continental crust and neither side will subduct to any depth – result is collision between the two – mountains form

S28

Before the two continents collide there is usually ocean floor between them which slides beneath the other plate and a volcanic arc forms on one of the plates based on the location of the subduction zone

S29

Eventually the seafloor is consumed and the landmasses collide. The sediments from the seafloor and the margins of the landmasses are folded and deformed into a mountain range composed of the sediments, volcanic arc material, and some ocean floor material. This has happened several times in the geologic past – i.e., Urals, Appalachians, and Alps.

S30 Transform Fault Boundaries

Plates slide horizontally past each other

No material added or removed → conservation margin

Most join two segments of an oceanic ridge known as fracture zones

Provide the means to move the crust formed to where it can be destroyed

Indicate direction of past plate movement

S31 Testing the Model

Some evidence has been presented already

New evidence or new interpretations follow

Ocean drilling

Hot spot evidence

Paleomagnetism

S32

Ocean drilling through the sediment to the basalt basement rock to find the oldest sediments for age dating. Plot of age versus distance from ridge crest supported seafloor spreading hypothesis. No sediment found older than 180 myr. Sediments are almost absent on the ridge crests and thicken with distance from ridge crests

S33

Hot spots – mapping of seamount chains revealed linear chains of volcanic structures. Radiometric dating of structures indicated they were getting older away from the hot spot. Ascending mantle plume (magma rising from the mantle) melts the lithosphere which erupts on the ocean floor and eventually the ocean surface. Hot spots are areas of volcanism, high heat flow, and crustal uplifting that are a few hundred kilometers across

Some mantle plumes start at the core-mantle boundary and others much shallower

S34 Paleomagnetism

Earth's magnetic field is similar to a bar magnet. Invisible lines of force pass through the planet and extend from one pole to the other pole

S35

Compass needles point to the magnetic north which is not the same as the geographic poles of the Earth. Iron-rich minerals act as fossil compasses – they are aligned to the magnetic north at the time they cooled below the Curie point. If the rock is moved the original magnetic mineral will point in the direction of north at the time it was formed.

S36

Paleomagnetism (fossil magnetism) is the ancient rock record of the orientation to the poles at the time the rock formed

Apparent polar wandering – idea that the pole had migrated through time

Even though the magnet north does not match the geographic north at any one time an average of the magnetic poles do align with the geographic poles

If poles don't move the continents must move - Wegener

S37

1950's – found that the magnetic alignment of magnetic minerals pointed to many different poles in the past

The magnetic poles for North America different than the magnetic poles from Europe - shape the same

S38

No evidence found for two magnetic poles that later merged into one in the geologic record

Put the two continents together and the poles overlap for the period from about 400 to 160 Mya (million years ago)

S39

Magnetic Reversals – Earth's magnetic field periodically reverses polarity – north pole becomes the south pole and vice versa

Rocks showing the north pole as it is today have 'Normal polarity' and those that show the opposite have 'Reversed polarity'

Found in all rocks of same age around the world

Magnetic time scale for past few million years determined

S40

Oceanographers towing magnetometers across the ocean found changes in the Earth's magnetic field on the ocean floor. This was unexpected

In 1963 Fred Vine and D.H. Mathews demonstrated that the changes in the strength of the magnetic field was due to magnetic reversals - the basalt forming at mid-ocean ridges solidified with the polarity of the time

-those areas with the same polarity as present were stronger than the opposite polarity → stripes

S41

Basalt forming along the ridge has the polarity at the time of formation

New basalt is added and the older basalt moves away from the ridge on both sides (pattern of stripes is symmetrical)

Width of stripes can be used to calculate spreading rates

– know the width of the ocean floor and how long the polarity lasted

S42

Wegener used various pieces of evidence to put the continents together into Pangaea. Geologists have used modern methods to determine the breakup of Pangaea

S43

New ocean basin formed between North America and Africa

S44

Atlantic ocean basin widens and includes the breakup between South America and Africa. Africa and Antarctica break apart. India heads northward.

S45

Australia has separated from Antarctica

S46

India has collided with Eurasia and the Himalayas have started to form. Greenland has separated from Eurasia

S47

Arabia has rifted from Africa to form the Red Sea and Baja California has separated from Mexico. The Panama arc has joined North and South America.

S48 Measuring Plate Motion

Hot spot tracks (Hawaiian Islands) trace movement of the plate relative to the mantle below – measure length of chain and age of rocks to determine rate (3000km/65Mya= $\sim$ 9cm/yr)

Plate motion away from ridges using paleomagnetism

Very Long Baseline Interferometry (VLBI) – radio telescopes record signals from quasars –used to measure changes in distance between two points far apart

Global Positioning System (GPS) uses satellites to calculate relative positions with accuracy – can be used across faults

S49

Rates determined by Very Long Baseline Interferometry

S50 What Drives Plate Motion

Plate tectonics describes plate motion and the role the motion plays in generating and/or modifying features of the crust

Convective flow in the mantle

Mantle convection & plate tectonics part of same system  
Driven by unequal distribution of heat in the interior

#### S51 Force that Drive Plate Motion

Slab pull – as the cold plates sink they pull the plate down into the asthenosphere

Ridge push – gravity driven mechanism due to higher heat and elevation at the ridges causing the slabs to slide away

Slab suction – drag of subducting slab induces circulation in the adjacent mantle

#### S52

Models of Plate-Mantle Convection

Must be consistent with observed physical and chemical properties of the mantle

#### S53

Layering at 660 kilometers – layer cake model – 2 zones of convection, one above 660 km and one below – explains composition of basaltic lavas at ridges that is different than hot spots, ridge basalt from upper layer and hot spots from lower layer

Seismic studies show cold slabs going below the 660 km boundary – should cause mixing

#### S54

Whole-mantle convection – slabs of cold lithosphere descend to great depths and stir the entire mantle, hot mantle plume come from near the core-mantle boundary bringing heat and material toward the surface

#### S55 Plate Tectonics in the Future

50 million years

#### S56 Plate Tectonics in the Future

250 million years