1

- **Geology**: is the science that pursues an understanding of planet earth.
- **Physical geology**: examines the materials composing earth and seeks to understand the processes that operate beneath and upon its surface.
- **Historical geology**: understand the origin of earth and its development through time.
- The study of physical geology logically comes first the study of earth history because we must first understand how earth works before we try to unravel its past.
- Earth is always changing either in fast rate or low, in large size or small.

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- A great deal of geology is based on observations and experiments conducted in the field.
- **Uniformitarianism**: the physical, chemical, and biological laws that operate today have also operated in the geologic past. "The present is the key to the past".
- Some important geologic processes are not currently observable, but evidence that they occur is well established.
- **Erosion**: processes that wear land away.
- using radioactivity for determining the age of the earth. The age of the earth is at about 4.5 billion years.

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- **Relative dating**: the events are placed in their proper sequence or order without knowing their age in years.
- **Law of superposition**: the youngest layer of rocks or lava flow layer is on top and the oldest in on the bottom, example like Grand Canyon.
- **Fossils**: the remains or trace of prehistoric life.
- **Principle of fossil succession**: fossil organisms succeed one another in a definite and determinable order, and therefore any time period can be recognized by its fossil content.

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- a geologic event that occurred 100 million years ago may characterized as recent, and a rock sample that has been dated at 10 million years may be called young.
- Scientific facts are gathered in many ways, including laboratory studies and field observation and measurements.
- **Hypothesis or model**: untested explanation.
- Science is the acceptance of what works and the rejection of what does not.
- **Theory**: is a well-tested and widely accepted view the scientific community agrees on.

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- **Scientific method**: researches gather facts through observations and formulate scientific hypotheses and theories.
- **Scientific investigations**:

1. Collection of scientific facts through observations and measurements.
2. Develop hypotheses/models to explain these facts.
3. Test the hypotheses.
4. Accept or reject the model.

- Earth four major spheres:

1. Hydrosphere "water".
2. Atmosphere "air".
3. Solid earth "rock".
4. Biosphere "all life on the plant".

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- **Hydrosphere**: is a dynamic mass of water that is continually on the move, evaporating from the oceans to the atmosphere, precipitating to the land, and running back to the ocean again (71% global ocean, it account for about 97% of earth's water). Radius of solid earth is about 6400 km.
- Earth system is powered by energy from two sources: 1. The sun: weather & climate, ocean circulation, and erosional processes "produce sedimentary rocks". 2. Earth's interior "create igneous & metamorphic rocks."
- **Rock cycle**: is the loop that involves the processes by which one rock changes to

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- **Magma**: is the molten material that forms in certain environments in earth's interior where temperature and pressure are such that rock.
- **Crystallization**: when magma cools and solidifies. May occur beneath the surface or at the surface. The resulting rocks are called igneous rocks.
- If igneous rocks are exposed at the surface, they will undergo weathering "full of fire".
- **Lithification**: sediment is usually into sedimentary rock when compacted by weight of overlying layers or when cemented as percolating water fills the pores with minerals matter.

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- If the resulting sedimentary rock is buried deep within earth and involved in the dynamics of mountain building, or intruded by a mass of magma, it will be subjected to great pressure and/or intense heat. The sedimentary rock will react to the changing environment and turn into metamorphic rock "form change".
- When metamorphic rock is subjected to additional pressure changes or to still higher temperatures, it will melt, creating magma, which will eventually crystallize into igneous rock.

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- **Divisions of earth's surface**:

1. Continents: elevation is about 840 m above sea level. 40% of earth's surface.
2. Ocean basins: average depth is 3800 meters. 60% of earth's surface.

- Examination of mountainous terrains reveals that most are places where thick sequences of rocks have been squeezed and highly deformed.
- The oceanic ridge system consists of layer upon layer of igneous rock that has been fractured and uplifted.
- Earth is one of nine planets that along with several dozens moons and numerous smaller bodies revolve around the sun.

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- the nebular hypothesis suggests that the bodies of our solar system evolved from an enormous rotating cloud called the solar nebula, composed mostly of hydrogen and helium, with a small percentage of the heavier elements.
- Earth three layers defined by their chemical compositions: crust, mantle, and core.
- Earth also can be divided into five layer based on physical properties. The physical properties used to define such zones include whether the layer is solid or liquid and how weak or strong it is.

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- **Crust**: usually thin, rocky outer skin, and is generally divided into oceanic and continental crust.

1. Oceanic: is roughly 7 kilometers thick and composed of dark igneous rocks called basalt. Rocks are younger (180 Ma or less and more dense about 3.0 g/cm^3)
2. Continental: curst average 35-40 kilometers thick but may exceed 70 kilometers. The upper crust consists of granitic rock called granodiorite, whereas the composition of the lowermost crust is more akin to basalt (rocks are old than an oceanic crust 4 billion years old and less dense about 2.7 g/cm^3).

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- **Mantle**: over 82 percent of earth's volume is contained in the mantle and extend to a depth of 2900 kilometers.
- The boundary between the crust and mantle represents a marked change in chemical composition.
- The dominant rock type in the upper mantle is peridotite that has a density of 3.3 g/cm^3.
- **Core**: the composition of the core is thought to be an iron-nickel alloy with minor amounts of oxygen, silicon, and sulfur. The iron-rich material has an average density of nearly 11 g/cm^3 and approaches 14 times the density of water at earth's centre.

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- Temperature at a depth of 100 kilometers is between 1200^0C and 1400^0C. Temperature at earth's centre may exceed 6700^0C.
- The increase in pressure with depth causes a corresponding increase in rock density.
- Earth can be divided into five main **layers based on physical properties** and mechanical strength:

1. Lithosphere "crust".
2. Asthenosphere "upper mantle".
3. Mesosphere "lower mantle".
4. Outer core.
5. Inner core.

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- The deepest mine in the world is 4 km in South Africa, and the deepest drilled hole in the world is 12 km in Russia.
- **Lithosphere** averages about 100 km but may be more than 250 km thick below the older portions of the continents. In the ocean, lithosphere is only a few km thick along the oceanic ridges but increases to perhaps 100 km in regions of older and cooler oceanic crust.
- **Asthenosphere** is up to 660km, soft comparatively weak layer. The top layer has a temperature/pressure regime that results in a small amount of melting.

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- At the depth of the uppermost asthenosphere, rocks are close enough to their melting temperature that they are very easily deformed.
- **Mesosphere** is the depth when rocks gradually strengthen with depth. Depth between 660 and 2900 km. rocks are very hot and capable of very gradual flow.
- **Outer core** is a liquid layer 2270 km thick. It is the convective flow of metallic iron that generate earth's magnetic field.
- **Inner core** is a sphere having a radius of 3486 km. materials are stronger than the outer core and behaves like a solid.

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- **Continental drift**: continents moved about the face of the planet.
- **Theory of plate tectonics**: earth's lithosphere is broken into numerous slabs called plates that are in motion and are continually changing shape and size.
- **Seven major lithosphere plates**: North America, South America, Pacific, African, Australian, and Antarctic. Intermediate-size plates include the Caribbean, Nazca, Philippine, Arabian, Cocos, and Scotia plates.
- Lithospheric plates move relative to each other at a very slow but continuous rate that averages about 5 cm a year.

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- The movement of the plates is driven by the unequal distribution of heat within earth. This movement generates earthquakes, volcanoes, and mountains.
- **Plate boundaries**: 1. Divergent: where plates move apart, resulting in upwelling of material from the mantle to create new sea floor. 2. Convergent: where plates move together, resulting in the subduction of oceanic lithosphere into the mantle. Convergence can also result in the collision of two continental margins to create a major mountain system. 3. Transform: where plates grind past each other without the production or destruction of lithosphere.

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- **Divergent**: occur at the mid-ocean ridge. Hot material slowly cools to hard rock, production new slivers of seafloor. This happens over millions of years, adding thousands of square kilometers of new seafloor [Mid-Atlantic Ridge] that extend for over 70,000 km through all major ocean basins.
- This mechanism has created the floor of the Atlantic Ocean during the past 160 Ma and is appropriately called **seafloor spreading**.
- Low spreading rate is 2.5 cm/yr as in North Atlantic. Fast spreading rate is 20 cm/yr as in East Pacific Rise.

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- The thickness of oceanic lithosphere is age dependent. The older (cooler) it is, the greater its thickness.
- Although new lithosphere is constantly being added at the oceanic ridges, the planet is not growing in size; its total surface area remains constant.
- **Convergent**: as two plates slowly converge, the leading edge of one slab is bent downward, allowing it to slide beneath the other [Nazca plate].
- **Subduction zone**: plate margins where oceanic crust is being consumed.
- As the subducted plate moves downward, it enters a high-temperature, high-pressure environment.

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- **Volcanic island arc**: chain of volcanic structure that emerged from the sea [Aleutian, Mariana, and Tonga Island].
- **Transform**: located where plates past each other without either generating new lithosphere or consuming old lithosphere. These faults form in the direction of plate movement [San Andreas Fault and the Alpine fault of New Zealand].

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- All of the processes studied by geologists are in some way dependent on the properties of the basic earth materials' rocks and minerals.
- **Minerals**: any naturally occurring inorganic solids that possess any orderly internal structure and a definite chemical composition.
- For any earth material to be considered a mineral, it must exhibit the following characteristics: 1. It must occur naturally. 2. It must be inorganic. 3. It must be a solid. 4. Its atoms must be arranged in a definite pattern. 5. It must have a definite chemical composition that may vary within specified limits.

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- **Rock**: is any solid mass of mineral or mineral-like matter that occurs naturally as part of our planet. A few rocks are composed almost entirely of one mineral like limestone [calcite].
- **Aggregate**: minerals are joined in such a way that properties of each mineral are retained.
- Around 4,000 minerals are defined by its chemical compositions and internal structure.
- Most minerals are chemical compounds with unique properties that are very different from the elements that comprise them.

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- A rock is a mixture of minerals, with each mineral retaining its own identity.
- **Physical properties of minerals**:

1. Crystal form. 2. Luster: is the appearance or quality of light reflected from the surface of a mineral. 3. Color. 4. Hardness. 5. Cleavage: the tendency of a mineral to break along planes of weak bonding. 6. Fracture: most minerals fracture irregularly. 7. Specific gravity: the ratio of the weight of a mineral to the weight of an equal volume of water.

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- **Igneous rocks**: form as molten rock cools and solidifies; they make up the bulk of earth's crust.
- **Magma** is formed by a process called partial melting that occurs within earth's crust and upper mantle to depths of 250 km. Magma exists beneath earth's surface
- **Lava** formed from magma that reaches earth's surface and has lost materials as gas or water vapor.
- **Extrusive/Volcanic** when igneous rocks solidify at the surface.
- **Intrusive/Plutonic** when igneous rocks form at depth before reaching the surface.

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- The solid components in magma are silicate minerals that have already crystallized from the melt. As the magma body cools, the size and number of crystals increase.
- Water vapor (H_2O), carbon dioxide (CO_2), and sulfur dioxide (SO_2) are the most common gases found in magma.
- **Volatiles**: are those materials that will readily vaporize at surface pressure.
- **Crystallization**: when magma cools, the ion in the melt begin to lose their mobility and arrange themselves into orderly crystalline structure.
- In the process of crystallization, cooling reverses the event of melting.

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- Magma may generate rocks with widely differing compositions.
- Igneous rocks are classified by their texture and mineral composition.
- **Texture**: is used to describe the overall appearance of the rock based on: size, shape, and arrangement of its interlocking crystal.
- Three factors contribute to the textures of igneous rocks: 1. The rate at which magma cools. 2. The amount of silica present. 3. The amount of dissolved gases in the magma.
- The rate of cooling is the dominant factor.

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- Slow cooling promotes the growth of fewer but larger crystal.
- **Aphanitic**: igneous rocks that from at the surface or as small masses within the upper crust where cooling is relatively rapid possess a very fine-grained texture.
- Fine-grained rocks are defined as light, intermediate, dark in color.
- **Phaneritic**: when magma slowly solidify far below the surface. Rocks consist of a mass of intergrown crystal, which roughly equal in size and large enough so that the individual minerals can be identified without the aid of microscope.

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- **Viscosity**: measure the fluid's resistance to flow.
- The products of mechanical and chemical weathering constitute the raw materials fro **sedimentary rocks**.
- Sedimentary rocks account for only about 5% of earth's outer 16 km.
- About 75% of all rock outcrops on the continents are sedimentary, and they are deposited at the earth's surface.
- Sedimentary rocks contain within them indications of past environments in which their particles were deposited and clues to the mechanisms involved in their transport.

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- Sedimentary rocks contain fossils which are vital tools in the study of the geologic pas.
- Coal is an important for energy. Petroleum and gas are associated with sedimentary rocks.
- Change can occur to sediment from the time it is deposited until it becomes a sedimentary rock and is subsequently subjected to the temperature and pressure that convert it to metamorphic rock.
- The deeper sediment is buried, the more it is compacted and the firmer it become.

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- **Pore pressure**: is the open space between particles.
- An orange or dark red color in a sedimentary rock means that iron oxide is present.
- **Types of sedimentary rocks**:

1. **Detrital sedimentary rocks**: derived from both mechanical and chemical weathering, like clay minerals, quartz, feldspars and mica. The presence in sedimentary rocks indicates that erosion and deposition were fast enough to preserve some of the primary minerals from the source rock before they could be decomposed.

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- Particle size is the primary basis fro distinguishing among various detrital sedimentary rocks, plus the size of component grains.
- Currents of water or air sort the particles by size; the stronger the current, the larger the particle size carried. Very little energy needed to transport clay
- Common detrital sedimentary rocks, in order of increasing particle size, are shale, sandstone, and conglomerate or breccia.

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2. **Chemical sedimentary rocks**: produced largely by chemical weathering.
- **Inorganic**: processes such as evaporation and chemical activity can produce chemical sediments.
- **Limestone** represents about 10% of the total volume of all sedimentary rocks, which is the abundant chemical sedimentary rock. It is composed of the mineral calcite ($CaCO_3$).

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- Sedimentary rocks are important in the interpretation of earth history. By understanding the conditions under which sedimentary rocks form, including information about the origin of its component particles, the method and length of sediment transport, and the nature of the place where the grains eventually came to rest; that is, the environment of deposition.
- Each site characterized by a particular combination of geologic processes and environmental conditions. That is, their component minerals originated and were deposited in the same place.

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- **Sedimentary environments** are placed into one of three categories: 1. Continental environments: are dominated by the erosion and deposition associated with streams. The nature of the sediments deposited is influenced by climate 2. Marine environments: shallow marine and deep marine. 3. Transitional (shoreline): the zone between marine and continental environments.
- Changes in past can be seen when a signal nit of sedimentary rock is traced laterally.

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- Sedimentary rocks form as layer upon layer of sediments accumulates in various depositional environments. These layer, called **strata** "deposit as horizontal layer**"**, or **beds**, are the single characteristics feature of sedimentary rocks.
- The variations in texture, composition, and thickness reflect the different conditions under which each layer was deposited.
- **Bedding planes** are flat surfaces along which rocks tend to separate or breaks. Change in the grain size or in the composition of the sediments can create bedding planes.

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- Each bedding plane marks the end of one episode of sedimentation and the beginning of another.
- **Ripple marks** are small waves of sand that develop on the surface of a sediment layer by the action of moving water or air.
- **Metamorphism** occurs deep within earth, beyond our direct observation.
- The study of metamorphic rocks provides important insights into the geologic processes that operate within earth's crust and upper mantle.
- **Metamorphic rocks** are produced from preexisting igneous, sedimentary, or even other metamorphic rocks.

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- Every metamorphic rock has a **parent rock**, the rock from which it was formed.
- Metamorphism takes place where preexisting rock is subjected to temperature and pressure unlike those in which it formed.
- They begin to occur a few kilometers below earth's surface and extending into the upper mantle.
- During metamorphism the rock must remain essentially solid.
- **Regional metamorphism**, which produces the greatest volume of metamorphic rock, occurs at convergent boundaries where lithospheric plates collide.

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- **The agent of metamorphism**: heat, pressure "stress", and chemically active fluids.
- In the upper crust the increase of temperature with depth, (**geothermal gradient**), average between 20-30^{o}C per kilometer.
- The deeper one goes, the hotter it gets.
- Pressure increase with depth as the thickness of the overlying rock increases.
- **Confining pressure** which is analogous to water pressure, where the forces are applied equally in all directions.
- **Differential stress**: when rocks are subject to direct pressure where tectonic plates collide to generate mountains.

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- A **geologic time scale** was developed to show the sequence of events based on relative dating principles.
- **Eons** represent the greatest expanses of time. The eon that began about 540 million years ago is the **Phanerozoic,** "visible life". The Phanerozoic eon is divided into **eras**. The three eras within the Phanerozoic are the **Paleozoic** "ancient life", the **Mesozoic** "middle life", and the **Cenozoic** "recent life". Each era is subdivided into time units known as **periods**. The Paleozoic has seven, the Mesozoic three, and the Cenozoic two. Each period is divided into smaller units called **epochs**.

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- The **Cambrian** is divided into three eons, the **Hadean** "world of departed spirit", the **Archean** "ancient", and the **Proterozoic** "before life". They are also referring as the **Precambrian**.
- The farther back we go, the less that is known.
- The results of tectonic activity are strikingly apparent in earth's major mountain belts.
- **Deformation** refers to all changes in the original form and/or size of a rock body. It also produces changes in the location and orientation of rock.
- Most crustal deformation occurs along plate margins.

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- Plate motions and the interactions along plate boundaries generate tectonic forces that cause rock units to deform.
- **Types of stress**:

1. **Differential stress**: when stress is applied unequally in different directions. Differential stress that shortens a rock body is known as compressional stress which is associated with plate collisions tend to shorten and thicken earth's crust by folding, flowing, and faulting.
2. **Tensional stress**: when stress tends to elongate or pull apart a rock unit. Where plates are being rifted apart, tensional stresses tend to lengthen those rock bodies located in the upper crust.

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3. **Strain**: where differential stress causes rocks to move relative to each other in such a way that their original size and shape are preserved. Strained bodies do not retain their original configuration during deformation.

- **Seismic energy** travels out from its source in all directions as waves. **Ray** is the path taken by these waves.
- The velocity of seismic waves depends on the density and elasticity of the intervening material. Crystalline rock transmits seismic waves more rapidly than does a layer of unconsolidated mud.

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- **The speed of seismic waves** generally increases with depth because pressure increases and squeezes the rock into a more compact elastic material.
- **P-waves** "compressional wave" vibrate back and forth in the same plane as their direction travel, are able to propagate through liquids as well as solids because, when compressed, these materials behave elastically; that is, they resist a change in volume and, like a rubber band, return to their original shape as a wave passes. P-wave travel faster than S-wave

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- **S-wave** "shear wave" vibrate at right angles to their direction of travel, cannot propagate through liquids because, unlike solids, liquids have no shear strength. That is, when liquids are subjects to forces that act to change their shapes, they simply flow.
- **Discontinuity** is the boundary between the two dissimilar materials.
- Compositional layering in earth's interior resulted from density sorting that took place during an early period of partial melting. During this period heavier elements, like iron and nickel, sank as the lighter rocky components floated upward.

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- The **crust**: earth's comparatively thin outer skin that ranges in thickness from 3km at the oceanic ridges to over 70km in some mountain belts, such as the Andes and Himalayas.
- The **mantle**: a solid rocky 9silica-rich) shell that extends to a depth of about 2900km.
- The **core**: an iron-rich sphere having a radius of 3486 km.
- The increase in pressure with depth causes a corresponding increase in rock density.
- Pressure also increases with depth and tends to increase rock strength.

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- **The five main layers of earth based on their physical properties**:

1. **Lithosphere**: average about 100 km in thickness but may be 250 km thick or more below older portions of the continent. Within the ocean basins, lithosphere is only few kilometers thick along the oceanic ridges but increases to 100 km in regions of older and cooler oceanic crust.
2. **Asthenosphere**: is soft and weak layer. The rocks get progressively hotter and weaker with increasing depth "more easily deformed". The uppermost is weak because it is near its melting point.

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3. **Mesosphere**: between the depth of 660 km and 2900 a more rigid layer. The rocks are still very hot and capable of very gradual flow.
4. **Outer core**: is a liquid layer 2270 km thick. It is the convective flow of metallic iron within this zone that generates earth's magnetic field.
5. **Inner core**: is a sphere having a radius of 3486 km. the material is stronger than the outer core and behaves like a solid.

- **Moho**: the boundary that separates crustal materials from rocks of different composition in the underlying mantle.

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- P-wave velocities decrease by 40% as they enter the core, because melting reduced the elasticity of rocks.
- **Wave shadow zone**: P-wave diminishes and eventually dies out completely about 105^{o} from an earthquake. Then, about 140^{o} away, the P waves reappear, but two minutes later than would be expected based on the distance traveled.

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Continental crust:

- Earth's crust averages less than 20 km thick, making it the thinnest of earth's divisions.
- Crustal rocks of the stable continental interiors average about 35-40 km thick. However, the crust may exceed 70 km.
- The oceanic crust is much thinner, ranging from 3-15 km thick and averaging about 7 km thick. Further, crustal rocks if the deep-ocean basins are compositionally different from those of the continents.
- Continental rocks have an average density of about 2.7 g/cm^3 and some exceeds 4 billion years old.

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- The average composition of upper continental rock is estimated to be comparable to the Felsic igneous rock **granodiorite**.
- The continental crust is enriched in the elements potassium, sodium, and silicon.
- Large quantities of basaltic and andesitic rocks are also found on the continents.
- The lowermost crust is thought to have a composition similar to basalt.

Oceanic crust:

- The rocks are younger 180 million years or less and more dense about 3.0 g/cm^3.
- Most composition of ocean floor is basalt.

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- Over 82% of earth's volume is contained within the **mantle**, a nearly 2900 km thick shell of silicate rock extending from the base of the crust (Moho) to the liquid outer core.
- The mantle is described as a solid rocky layer, the upper portion of which has the composition of the ultramafic rock peridotite.
- The mantle is divided into mesosphere "lower mantle" and asthenosphere "upper mantle". At a depth of about 410 km a relatively abrupt increase in seismic velocity occurs.

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- The **core** is larger than the planet Mars, the core is earth's dense central sphere, with a radius of 3486km. The core consists of a liquid outer layer about 2270km thick and a solid inner sphere with a radius of 1216km.
- The average density of the core is nearly 11 $g/cm^{3,}$ and the earth's center it approaches 14 times the density of water.
- **Meteorites** provided an important clue to earth's internal composition, because they are assumed to be representative samples of the material from which earth originally accreted.

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- **Convection** is the transfer of heat by the mass movements or circulation in a substance. Convection flow in the mantle is the most important process operating earth's interior.
- This thermally driven flow is the force that propels the rigid lithospheric plates across the globe, and it ultimately generates earth's mountain belts and worldwide earthquake and volcanic activity. Recall that plumes of superheated rock are thought to form near the core-boundary and slowly rise towards the surface.

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Structure of the oceanic crust:

- Ocean floor consists of three distinct layers. The upper layer is composed mainly of basaltic **pillow lavas**. The middle layer is made up of numerous interconnected dikes called **sheeted dikes**. Finally, the lower layer is made up of gabbro; the coarse-grained equivalent of rocks is called an **ophiolite complex**. The magma that migrates upward to create new ocean floor originates from partially melted peridotite in the asthenosphere.

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- **Continental drift**: a single supercontinent called **Pangaea** "all earth" once existed. At about 200 million years ago this supercontinent began breaking into smaller continents, which then drifted to the present positions. The fit of the geographic distribution of fossils, rock type and structural similarities, and ancient climates all seemed to support the idea that these now separate landmasses were once joined. One of the main objections to **Alfred Wegener's hypothesis** stemmed from his inability to provide a mechanism capable of moving the continents across the globe.

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- Examples of active continental rifts include the **East African rift valleys** and the Baikal Rift. Extensional forces must be acting on the lithospheric plate is the main cause for continental splitting. These forces are thought to arise from the "pull" of cold lithospheric plates as they subduct along the margins of a continent. These extensional forces are not great enough to tear the lithosphere apart. The rupture of the lithosphere is initiated only in those settings where plumes of hot rock rise from the mantle. The rift valleys in these areas will lengthen and deepen.

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- Plate tectonics is the first theory to provide a unified explanation of earth's major surface features.
- Within the framework of plate tectonics, geologists have found explanations for the geologic distribution of earthquakes, volcanoes, and mountain belts.
- The theory of plate tectonics, although a powerful tool, is nonetheless an evolving model of earth's dynamic processes.