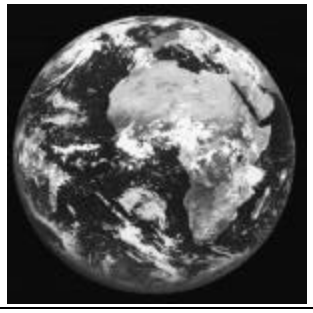
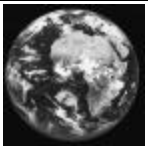
Chapter 7
Earth: Our Home in Space



After completing this chapter, you should be able to:

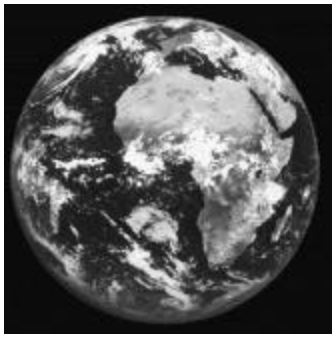
- describe the general physical properties of the Earth.
- describe Earth's composition in terms of refractory vs. volatile elements.
- describe the important characteristics of the Earth's atmosphere, hydrosphere, lithosphere, magnetosphere, and biosphere.
- list the major chemical components of the Earth's atmosphere
- explain why there are two high and two low tides each day
- describe the temperature, chemical, & pressure profiles of Earth's atmosphere
- discuss how Earth's internal structure has been probed.
- describe the Earth's internal structure.
- describe process of differentiation and its implications for understanding history of Earth's lithosphere.
- describe the model explaining plate tectonics.
- list the three major rock types and explain how each is formed.
- explain the current theory explaining the formation of Earth's magnetosphere.
- describe the chemical basis of Earth's biosphere.
- describe the interaction between the hydrosphere and atmosphere.
- describe the interactions between the Earth's various "spheres".
- describe how geologists date the ages of rocks.

Why Study the Earth?

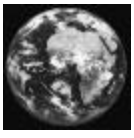


- **Easiest to study and best understood**
- **Serves as model for other planets**
  - **processes within, on, and around planet**
  - **properties of planets**
    - **Atmosphere: formation, composition, and evolution**
    - **Hydrosphere**
    - **Solid body**
      - **interior structure**
      - **surface features: formation and modification**
    - **Magnetic field**
    - **Life and its affect**

EARTH: Physical Properties

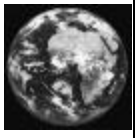


The Earth's Shape and Size



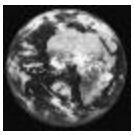
- **Round/spherical**
  - **ancient Greeks and Romans**
  - **Aristotle: lunar eclipse, stars at horizon**
  - **Fernando de Magellan: 1st to circumnavigate the globe, proof that the earth is round.**
  - **Modern measurements show Earth to be pear-shaped.**
- **Circumference**
  - **Eratosthenes (Greek, ~200 B.C.): measured the circumference of the Earth to be 250,000 stadia or ~40,000 km**
  - **measured by satellite to be 40,070 km**

The Earth's Mass



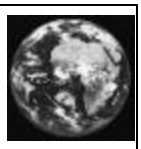
- **Applying Newton's modification to Kepler's third law for the Earth-Moon system**
  - $(M_{\odot} + M_m) P^2 = A^3$
  - **where $M_{\odot}$ is Earth's mass and M_m is the Moon's mass.**
- **Assuming that the mass of the Moon is far less than the mass of the Earth,**
  - $M_{\odot} = A^3/P^2$.
- **For Earth-Moon distance of 380,000 km (2.53×10^{-3} AU) and a period of 27.3 days (7.48×10^{-2} year),**
  - $M_{\odot} = (2.53 \times 10^{-3}\ \text{AU})^3/(7.48 \times 10^{-2}\ \text{year})^2$
  - $= 2.9 \times 10^{-6}$ solar masses
  - $= 5.8 \times 10^{24}$ kg (accepted value 5.98×10^{24} kg)

Earth's Average Density



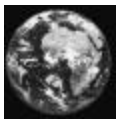
- Knowing the Earth's mass
  - $M_{\oplus} = 5.98 \times 10^{24}$ kg
- and the diameter of the Earth
  - $D_{\oplus} = 12{,}756$ km ($R_{\oplus} = D_{\oplus}/2 = 6{,}378$ km)
- the average density of the Earth can be calculated
  - average density = mass/volume
  - $= M_{\oplus} / (4/3\ \pi\ R_{\oplus}^3)$
  - $= 5.98 \times 10^{24}$ kg $/ (4/3\ \pi\ (6{,}378\ \text{km})^3)$
  - $= 5.5 \times 10^{12}$ kg/km^3
  - $= 5.5$ gm/cm^3

Earth's Surface Gravity



- Acceleration due to gravity at the Earth's surface is determined from
  - Newton's Second Law $F=ma$
  - Universal Law of Gravitation $F_g = GMm/r^2$
- Knowing the Earth's mass
  - $M_{\oplus} = 5.98 \times 10^{24}$ kg
- and the radius of the Earth
  - $R_{\oplus} = D_{\oplus}/2 = 6{,}378$ km
- the surface gravity of the Earth can be calculated
  - $g = G\ M_{\oplus} / R_{\oplus}^2$
  - $g = 9.8$ m/s^2

Properties of Earth



Satellites:	1
Semi-major axis:	1.00 AU
Period:	1.00 Earth years
Orbital inclination:	0° 0' 0"
Rotation period:	23 hr 56 m 4 s
Tilt of rotation axis:	23° 27' from orbit perpendicular
Mass:	5.98×10^{24} kg (1.000 $M_{\oplus}$)
Diameter (average):	12,756 km (1.000 $D_{\oplus}$)
Density (average):	5.5 gm/cm^3
Surface gravity:	9.8 m/s^2 (1.000 Earth gravity)
Escape velocity:	11.2 km/s
Surface Area:	5.1×10^8 km^2
Surface temperature:	200 to 300 K (-100 to 117° F)
Atmospheric pressure:	1.00 bar
Albedo:	0.37

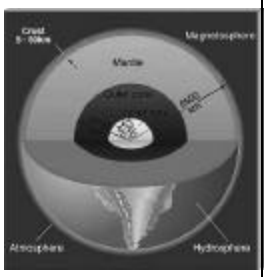
Five Planetary "Spheres" and Processes

Based on Earth:

1. Lithosphere
2. Hydrosphere
3. Atmosphere
4. Magnetosphere
5. Biosphere

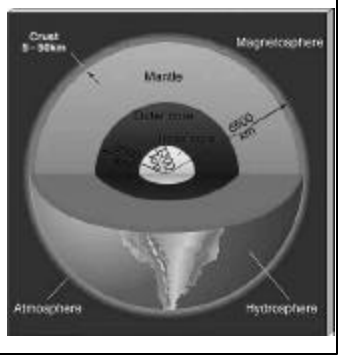
Earth in Cross-Section

- Solid Earth - Lithosphere
  - Inner core: 1300 km radius
  - Outer core: 1300-3500 km
  - Mantle: 3500-6400 km
  - Crust: tops mantle, 5-50 km
- Hydrosphere: water phases at surface
- Atmosphere: tops hydrosphere; majority within 50 km of surface
- Magnetosphere: outermost region, extends 1000's of km out into space



Solid Earth

- Solid Earth
  - Inner core
    - 1300 km radius
  - Outer core
    - 1300-3500 km
  - Mantle
    - 3500-6400 km
  - Crust:
    - tops mantle
    - 5-50 km



Studying the Earth's Interior

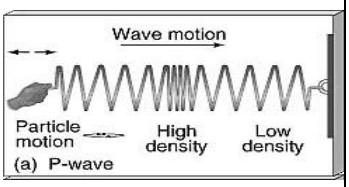
- **Only direct measurements are outermost skin of the Earth's crust (a few km).**
- **Composition and structure must be studied indirectly.**
- **Information about the interior from seismic waves:**
  - **natural earthquakes**
  - **artificial impacts or explosions.**

Earthquake Damage

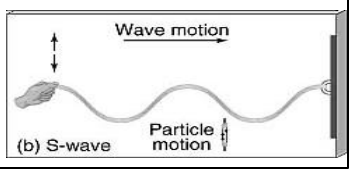


Seismic Waves: S and P Waves

- **P-wave**
- **primary waves,**
- **pressure waves,**
- **speed = 5-6 km/s,**
- **travel in solids, liquids and gases.**

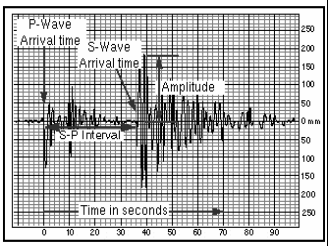


- **S-wave**
- **secondary waves**
- **shear waves,**
- **speed = 3-4 km/s,**
- ***cannot* travel in liquids**



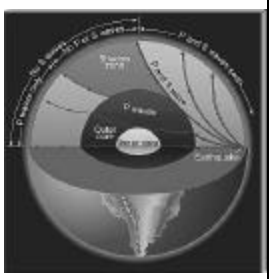
Seismograms

- **Records of waves from earthquakes.**
- **P-wave : first arrival.**
- **S-wave : second major arrival.**
- **S-P time interval: used to locate epicenter.**

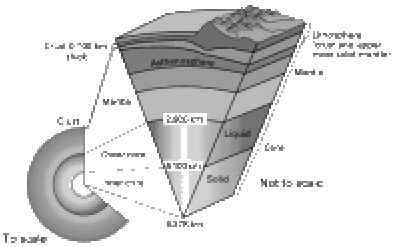


Seismic Waves

- **Earthquakes generate waves**
  - **pressure (P, primary) and**
  - **shear (S, secondary).**
- **S-waves are not detected by stations "shadowed" by the liquid core of Earth.**
- **P-waves do reach side of Earth opposite earthquake, but their interaction with Earth's core produces another shadow zone, where no P-waves are seen.**



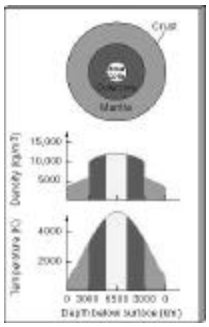
Earth's Interior Structure



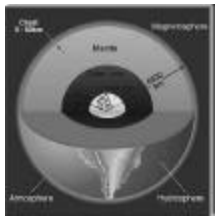
- **From theoretical studies of the planet's bulk density and shape, has been determined that Earth's interior must be layered.**
  - **heavier elements (Fe, Ni, Mg) sinking toward core**
  - **lighter elements (Si, O, Na, K) floating on top (crust).**

Earth: Density and Temperature Profile

- Earth is a layered structure:
  - low-density crust
  - intermediate-density mantle
  - high-density core.
- Differentiation: variation in density and composition with depth.
  - requires planet to be ~molten at some time in its history.
- The temperature rises from just under 300 K at the surface to well over 5000 K in the core.
- Source of heat:
  - Gravitational energy
  - Collisions
  - Differentiation
  - Radioactivity

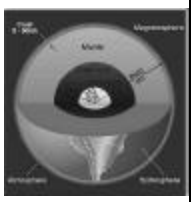


The Earth's Core



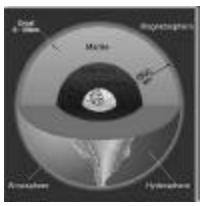
- Dense, metallic
  - Primarily iron, some nickel and sulfur
- 16% of Earth's volume
- Two sections
  - outer core
    - depth of 2900 km to 4400 km
    - liquid
  - inner core
    - total diameter ~2600 km (larger than Mercury)
    - solid, very dense

The Earth's Mantle



- Mantle stretches from outer core boundary, upwards 2900 km.
- Region of dense rock
  - lower region -
    - dense, strong, high pressure
    - densities to > 5 g/cm$^{3.}$
  - upper region, called the asthenosphere.
    - has reduced pressures and rock strength
    - density ~3.5 g/cm^3, increasing with depth.
    - more or less solid, but at pressures and temperatures found in this region, mantle rock can deform and flow slowly.

Earth's Crust



- Crust: makes up 0.3% Earth's mass
- Two types
  - Oceanic crust
    - covers 55% of the surface
    - ~ 6 km thick
    - composed of basalts - iron-magnesium -silicate
  - Continental crust
    - covers 45% of the surface
    - 20 to 70 km thick
    - predominately granites: more silicon and aluminum than basalts

Three Rock Types

- igneous rock
  - Formed from the cooling and solidification of molten material (e.g., volcanic rocks).
  - Formed in hot environment, completely molten.
- sedimentary rock
  - Formed when loose materials held in water, ice, or air settle onto a surface, stick and then build up (e.g., sandstone, carbonates).
  - Formed in cold environment.
- metamorphic rock
  - Material whose original form has been modified by high pressure, temperature, or both (e.g., slate).
  - Formed in hot environment, NOT completely molten.

ROCK CYCLE

- Any rock type can be transformed into any other rock type (rock cycle).
- The rock type found on a planet helps us to understand the environment in which the rock formed.

IGNEOUS ◄ ► SEDEMENTARY ◄ ► METAMORPHIC

Earth: Crustal & Surface Rocks

- 75% of Earth's surface is sedimentary rock.
- 95% of crustal material is igneous or metamorphic from igneous materials.



sedimentary



metamorphic



igneous

Earth's Surface: Chemical Composition

- Chemical elements most abundant in Earth's continental crust.

–Oxygen (O)	45%	Hydrogen (H)	0.1%
–Silicon (Si)	27%	Manganese (Mg)	0.1%
–Aluminum (Al)	8%	Phosphorous(P)	0.1%
–Iron (Fe)	6%	All others	0.8%
–Calcium (Ca)	5%		
–Magnesium (Mg)	3%		
–Sodium (Na)	2%		
–Potassium (K)	2%		
–Titanium (Ti)	0.9%		

Chemical Composition and Mineralogy

- Because silicon and oxygen are the most abundant elements in the crust, minerals made from them are most abundant on Earth.

- Silicates: minerals having silicon, oxygen, and one or more of the other abundant elements.
- Oxides: another common mineral group, includes quartz (SiO_2) and limonite (Fe_2O_3).
- Carbonates: composed of carbonate mineralogy (CO_3^{2}), includes limestone and dolomite.

Earth's Lithosphere: Surface Features

1. Ocean Basins
   lowlands
   71%
2. Continents
   highlands
   29%



- This bimodal distribution of surface features shows evidence of gradational (erosional), tectonics, volcanics, and cratering processes.
- These processes reflect both
  - slow and gradual changes (uniformitarianism) and
  - brief and dramatic changes (catastrophism).

Question

A new moon is discovered orbiting a planet.

The only rocks observed at the surface of the moon are igneous and metamorphic (from igneous).

What would you speculate about the environment in which the moon's surface rocks surface formed?

Tectonic Processes

Study of Large Scale Movements and Deformations of the Crust

Mountain Building
Trench Formation
Rift Zones
Fault Zones
Earthquakes

Plate Tectonics

- **The slow motion (a few inches per year) of large (7 major) crustal plates can explain most of the large geologic features found on Earth.**
- **The less dense crustal plates "float" on the denser rocks of the upper mantle - like rafts on a lake.**
- **Motion can explain the formation of most large-scale geologic features across the surface of planet Earth.**
- **Study of plate movement and its causes is known as plate tectonics.**

Crustal Plates



Puzzle Pieces





In 1858, geographer Antonio Snider-Pellegrini made these two maps showing his version of how the American and African continents may once have fit together, then later separated.

Left: The formerly joined continents before (avant) their separation.
Right: The continents after (aprés) the separation.
(Reproductions of original maps courtesy of Univ. of California, Berkeley.)

History of Plate Tectonic Theory

- **1596 Abraham Ortelius**
  - **Dutch map maker**
  - **Americas torn from Europe/Africa**
- **1912 Alfred Lothar Wegener**
  - **German meteorologist**
  - **"Continental Drift Theory"**
    - **Fit of continents**
    - **Geologic structure**
    - **Fossil record**
    - **Climatic changes**
- **What force large enough to push large masses of rock over great distances?**



Alfred Lothar Wegener

Driving Mechanisms

- **Driving mechanisms for plate tectonics are:**
  - **partial melting of the upper mantle and the lower crust by radioactive decay**
  - **lower density crustal plates "floating" on the denser, flexible upper mantle**
  - **slow convection cells of rock acting like conveyer belts, moving the plates.**

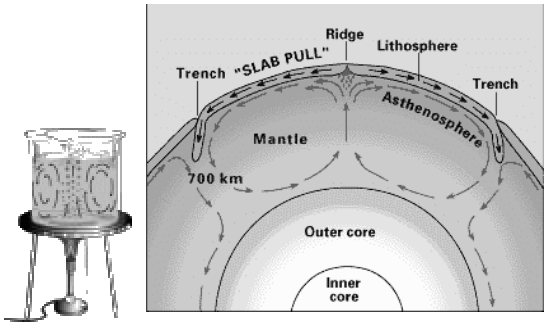
The Lithosphere and Density

- **The lithosphere is made up of low-density rock plates, floating on a more dense, rock aesthenosphere.**

  The lithosphere contains both
  the crust and
  a small part of upper mantle.
- **Aesthenosphere rocks deform like silly putty at high P and T, and flow over long periods of time.**



Plate Movement: Convection



Hot Air Balloons and Lithospheric Plates



- **Why do hot air balloons float?**
- **Do they need a burner?**



Convection



- **Convection is one method of transferring heat in fluids (liquids and gases).**
  - **As materials are heated, tend to be come less dense.**
  - **As they are cooled, tend to become more dense.**
- **A warm (less dense) material will rise in the surrounding cooler (more dense) material as the cooler material sinks.**
- **Warm material cools as it rises, becoming more dense; cool material warms as it sinks, becoming less dense.**
- **The resulting convection currents "stir" the material as it heats.**

Interactions of Lithospheric Plates

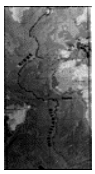
Four observed interactions between plates.

- **RIFT ZONES:**
  - **pull apart**
    - **Mid-Atlantic ridge, central African rift**
- **FAULT ZONES:**
  - **slide alongside each other**
    - **San Andreas Fault (Pacific & N. American plates)**
- **SUBDUCTION ZONES:**
  - **one can burrow under another**
    - **deep ocean trenches, Japan(Pacific plate under Eurasian plate)**
- **MOUTAIN BUILDING ZONES:**
  - **jam together**
    - **Himalayas (Indian & Eurasian plates)**

Rift Zones





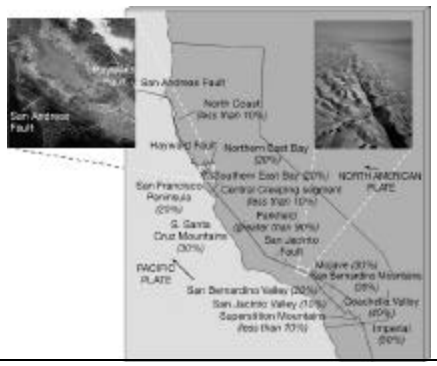




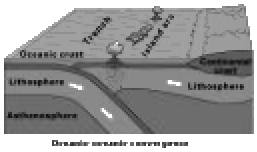


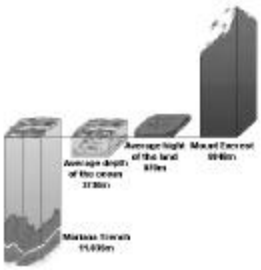


Fault Zones



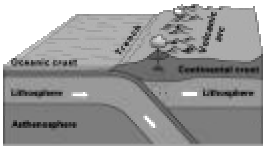
Subduction Zones

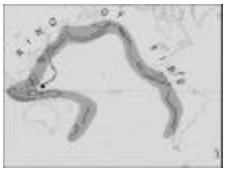




The Marianas Trench is caused by the Pacific plate shoving under the Phillipine plate, also producing the volcanic island Guam.

Subduction Zones







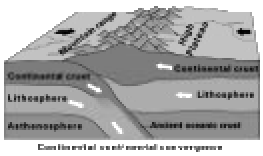




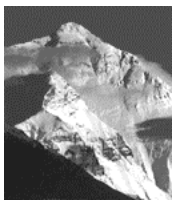
Mountain-building Zones

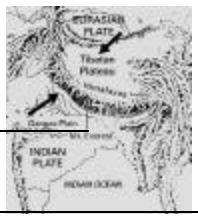


Nazca Plate – South America



Mt. Everest



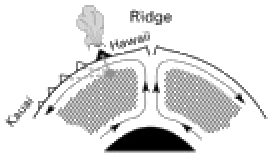


Hot Spots

Some volcanic and earthquake activity occurs in the center of tectonic plates and cannot be explained by the four plate boundary interactions.

- **e.g., the Hawaiian Island chain and Yellowstone.**

However, the Hawaiian Islands do support plate tectonic theory .



(a) Section



(b) Plan

Evidence for Plate Tectonics

- **Evidences for plate tectonics now comes from:**
  - **shapes of the continents.**
  - **fossil correlations.**
  - **mid-oceanic ridges.**
  - **sea-floor spreading.**
  - **mountain ranges.**
  - **locations of active volcanic and tectonic regions.**
  - **actual measurement of motions.**

Explanations from Plate Tectonics

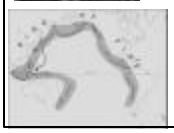




- **Plate tectonics can explain:**
  - **volcanically active regions.**
  - **tectonically active regions.**
  - **mid-ocean ridges.**
  - **ocean trenches.**
  - **mountain chains.**
  - **island chains.**



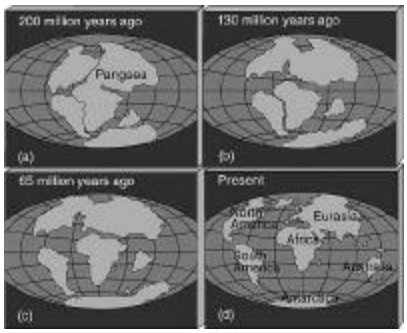








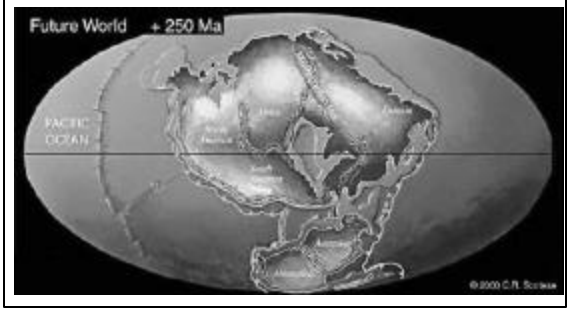
Continental Drift



What will surface of Earth look like in another 250 million years?

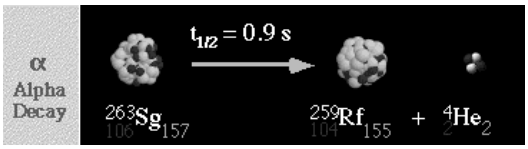
Future World?

What will surface of Earth look like in another 250 million years?



Rocks and the Age of the Earth

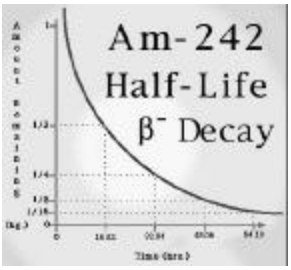
- **Radiometric dating of rocks is based on the natural radioactivity of some elements.**
- **They spontaneously emit nuclear particles (protons and alpha particles), as they change from heavy to lighter elements.**
- **Radioactive decay also generates heat, thus raising the temperature of planetary interiors.**



Half-Life

The rate of radioactive decay is known for each element.

The half-life is the time it takes 1/2 of the parent element to decay into the lighter daughter element.



Radiometric Dating and the Age of the Earth

- **It is possible to estimate the age of the rock by comparing the amounts of the parent and daughter elements.**
- **This method assumes:**
  - **a closed system with no outside contamination,**
  - **the rock's initial abundance of the daughter element can be estimated,**
  - **the half-lives are constant.**
- **Using this method, the oldest crystals in terrestrial rock have been found to be about 4.3 billion years old.**

Earth's Geologic History

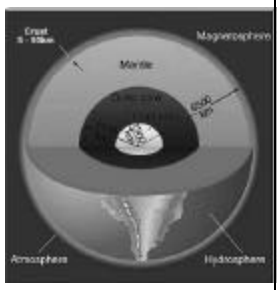
- **Gravitational condensation from the solar nebula of gases to solid particles about 4.5 billion years ago.**
- **Rapid accretion of particles to planetesimals about half the size of the current planet.**
- **Slower accretion from largest planetesimals. Complete melting of surface.**
- **Differentiation of interior.**
- **Cooling and solidifying of the mantle and crust.**
- **Partial re-melting of the upper mantle by heat from radioactive decay.**
- **Plate tectonics begins 3.7 billion years ago.**

Questions: Earth's Interior and Surface

- What information/evidence do geologists use to model the Earth's interior structure and composition?
  - Average density
  - Observed density of water and rock at/near surface
  - Volcanics
  - Earthquakes/seismic waves
- What process is responsible for the surface mountains, oceanic trenches, and other large scale features on Earth's surface?
  - Describe the interaction responsible for each.

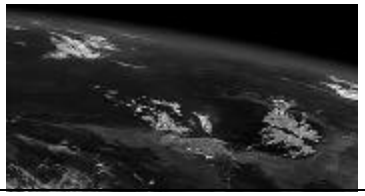
Earth in Cross-Section

- Solid Earth
  - Inner core: 1300 km radius
  - Outer core: 1300-3500 km
  - Mantle: 3500-6400 km
  - Crust: tops mantle, 5-50 km
- Hydrosphere : water phases at surface
- Atmosphere: tops hydrosphere; majority within 50 km of surface
- Magnetosphere: outermost region, extends1000's of km out into space



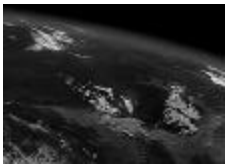
Components of the Hydrosphere

- Oceans - 98.9%
- Polar Caps - 1.05%
- Underground - 0.04%
- Lakes & Rivers - 0.01%
- Water Vapor - 0.001%



The Hydrosphere: Oceans

- Oceans cover 71% of the Earth's surface.
- Mean depth of the oceans is 4 km (2.4 miles).
- The extensive hydrosphere of liquid water makes Earth unique in the Solar System.
- It makes existence of life possible on our planet.





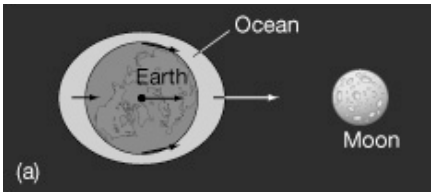
The Origin of Earth's Hydrosphere



- Internal origin:
  - Out-gassing from volcanoes
- External origin:
  - impacts from comets



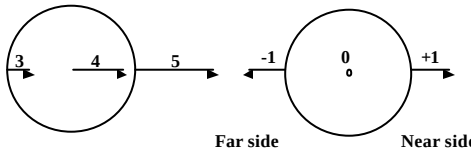
Hydrosphere: Tides



- Tides: direct result of the gravitational influence of Moon and Sun on Earth.
- Moon's gravitational attraction is greater on side of Earth that faces Moon than on the opposite side.

Differential Force

- **Tidal force = differential gravitational force**
- **Results from difference in pull of Moon on one side of Earth to the other,**
  relative to the pull at the center of the Earth.

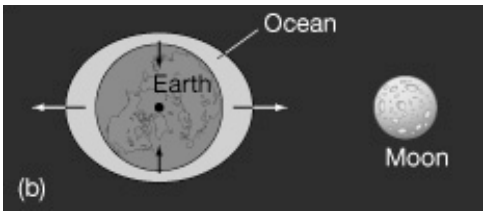


Far side
3 – 4 = -1

Center
4 – 4 = 0

Near side
5 – 4 = +1

Tides



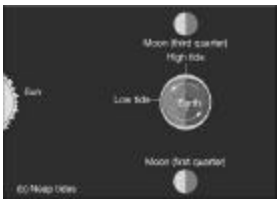
- **Differential force is small (only ~ 3%), but produces noticeable effect: tidal bulge**
- **High and low tides result twice per day as Earth rotates beneath bulges in oceans.**

Spring and Neap Tides

- **Sun's tidal influence is about 1/2 that of Moon.**
- **Two sets of tidal bulges:**
  - **one pointing toward Moon**
  - **the other toward Sun.**

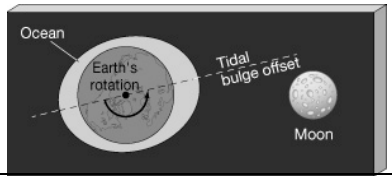


- **When Earth, Moon, and Sun are roughly lined up, gravitational effects reinforce one another, producing the highest tides: spring tides.**
- **When Earth-Moon line is perpendicular to Earth-Sun line (at the first, third quarters), daily tides are smallest: neap tides.**



Tides: Friction and Rotation Rates

- **Length of sidereal day is decreasing over time (15 ms/century) because of tidal effect of the Moon.**
- **Friction drags tidal bulges with rotation.**
- **Gravitational attraction between Moon and bulges reduces Earth's rotation rate.**
- **Moon moving further from Earth (4 cm/year). Process continues until Earth's rotation rate = Moon's orbital rate.**

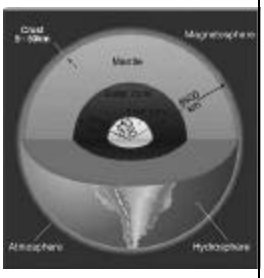


Questions: Tidal Forces

- **The Earth-Moon-Sun are in which orientation for neap tides to occur?**
- **If the Earth had no moon, would we know anything about tidal forces?**
- **If the Moon had oceans like Earth's, what would the tidal effect be like on the Moon?**
  - **How many high and low tides would there be each Moon "day"?**

Earth in Cross-Section

- **Solid Earth**
  - **Inner core: 1300 km radius**
  - **Outer core: 1300-3500 km**
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  - **Crust: tops mantle, 5-50 km**
- **Hydrosphere: water phases at surface**
- **Atmosphere : tops hydrosphere; majority within 50 km of surface**
- **Magnetosphere: outermost region, extends 1000's of km out into space**

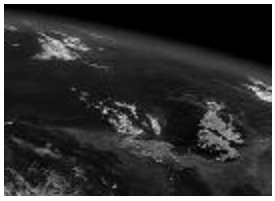


The Earth's Atmosphere

The atmosphere is an ocean of air.

50% lies within 5 km of surface; 99% within 30 km.

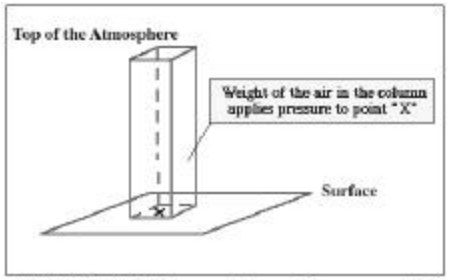
- **Composition**
  - **Nitrogen (N_2) 78%**
  - **Oxygen (O_2) 21%**
  - **Argon 0.9%**
  - **Carbon dioxide 0.003%**
  - **Water vapor 0.1 to 3%**
  - **Ozone (O_3) 0.00004%**
  - **Hydrogen 0**
  - **Helium 0**



Atmospheric Pressure

- **The atmosphere is a "sea of air" above the surface of the Earth.**
  - **Total mass = 5×10^{18} kg (one millionth total mass of the Earth)**
- **Measure amount of atmosphere in terms of its pressure on us.**
- **At sea level, a column of atmosphere having a cross-section of one square inch weighs 14.7 pounds.**
- **1 atmosphere = 14.7 pounds/inch^2**

Atmospheric Pressure



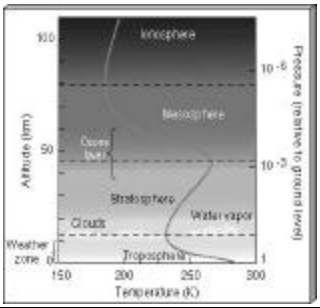
PRESSURE - is the force exerted per unit area on a surface by the weight of the air above it.

Atmospheric Sciences at the University of Illinois Urbana-Champaign

Earth's Atmosphere by Region

Layers defined by variation of temperature with height

- **Troposphere**
  T decreases with height
- **Stratosphere**
  T increases with height
- **Mesosphere**
  T decreases with height
- **Ionosphere**
  T increases with height



Earth's Atmosphere

LAYER	HEIGHT	TEMPERATURE	PRESSURE	COMPOSITION
Troposphere	0-10	70 to -70	1	N_2, O_2, Ar
Stratosphere	10-20	-70 to 30	10^{-2}	N_2, O_2, Ar, O_3
Mesosphere	20-600	30 to -100	10^{-9}	N_2, N, O_2, NO
Exosphere	Above 600	---	10^{-12}	H, He

The Troposphere



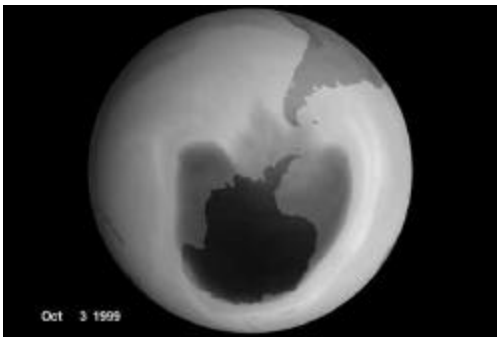
- **Region next to Earth's surface (0 - 12 km above surface);**
- **temperature decreases with altitude (Sun's light absorbed; re-radiated as heat from surface);**
- **weather occurs here;**
- **masses of air very well mixed together;**
- **most clouds form in this layer.**

The Stratosphere

- Temperature increases with altitude.
- 12 - 50 km above surface.
- Increasing temperature caused by presence of layer of ozone near altitude of 45 kilometers.
- Ozone molecules absorb Sun's high-energy UV rays which warm the atmosphere at that level.

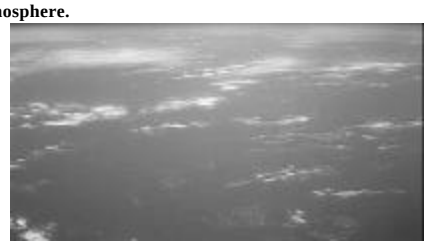


Ozone "Hole" over Antarctica



The Mesosphere

- 50 - 80 km above surface;
- Temperature decreases with altitude;
- Atmospheric temperatures reach lowest average value (-90°C);
- Air masses are relatively mixed together;
- Layer in which most meteors burn up while entering Earth's atmosphere.



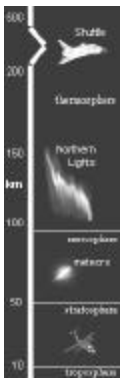
The Ionosphere

- Outermost region (above 80 km); increasing T with height.
- Absorption of Sun's UV radiation causes molecules to eject electrons (become ionized).
- Air is so thin that small increase in energy can cause a large increase in temperature.
- Radio signals reflected beyond horizon by ionosphere.



QUESTIONS: Layers of the Atmosphere

- Identify the atmospheric layer which best applies to the following:
  - commercial airliners cruising altitude.
  - Aurora Borealis is formed.
  - most meteors burn up.
  - the Space Shuttle orbits the Earth.
  - ozone layer tops this layer, absorbing high energy UV radiation from the Sun.



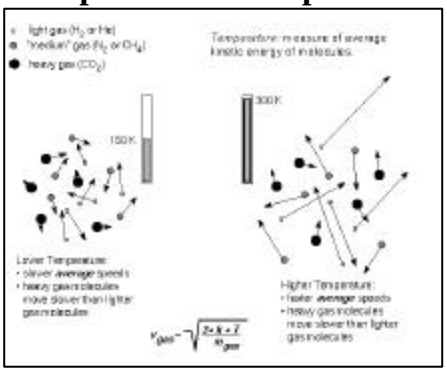
Origin of the Atmosphere

- Chemical make-up of atmosphere unexpected when compared to abundance in universe.
  - Expect hydrogen, helium, H-bearing compounds, neon.
- Original, primitive atmosphere probably lost and replaced by one observed today.
  - Light gases attain temperature high enough for their speed to exceed Earth's escape velocity (11.2 km/sec).
  - Gases with heavier elements trapped in interior of planet during formation.
  - Eventually escape interior to form new atmosphere by process called out-gassing.
  - O_2, N_2 levels increased last 2 - 2.5 billion years with life.

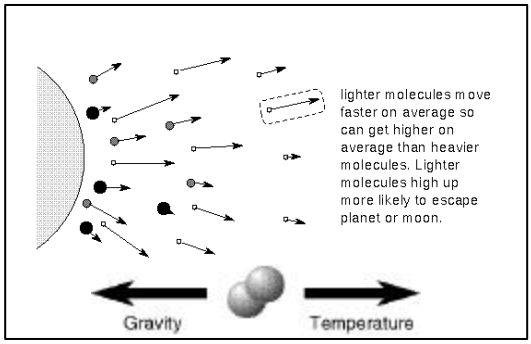
Evolution of Earth's Atmosphere

Stage	Composition	Internal Source Model	External Source Model
primary	H, He	solar nebula	solar nebula
secondary	CO, CO_2, NH_3, CH_4, H_2O	volcanic eruptions	volcanoes, comets
tertiary	N_2, O_2, CO_2, H_2O	volcanic eruptions, biology	impacts, volcanoes, biology

Atmosphere and Temperature

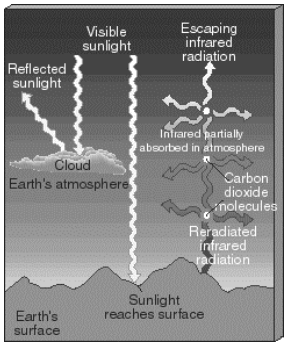


Atmospheres - Molecule Size

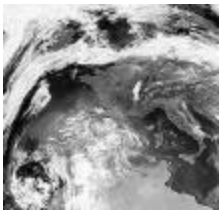


Greenhouse Effect

- **Sunlight not reflected by clouds reaches Earth's surface, warming it up.**
- **Infrared radiation re-radiated from surface, partially absorbed by H_2O and CO_2 in atmosphere.**
- **Causes overall surface temperature to rise.**
- **Greenhouse gases**
  - **Carbon dioxide (CO_2)**
  - **Water vapor (H_2O)**



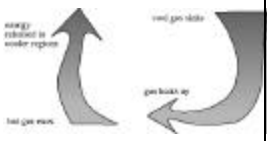
Atmospheric Circulation



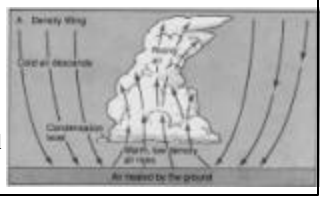
- **Atmosphere NOT static.**
  - **cloud systems**
  - **high/low pressure systems**
  - **storm systems**
- **Circulation driven by heat from Sun re-radiated into atmosphere by Earth's surface.**
- **Circulation patterns complicated by**
  - **non-uniform heating**
    - **angle of incidence for sunlight with latitude**
    - **75% of surface covered with water; continents warmer than water**
  - **Earth's rotation**

Atmospheric Convection

- **Convection occurs whenever cool fluid overlies warm fluid.**
- **The resulting circulation currents make up the winds in Earth's atmosphere.**

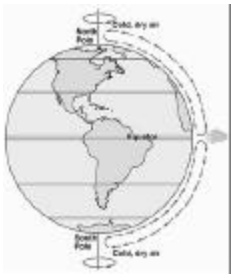


- **Hot air rises, cools, and falls repeatedly.**
- **Eventually, steady circulation patterns with rising and falling currents are established and maintained.**

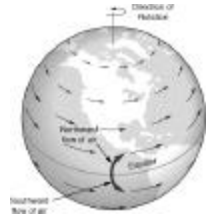


Convection and Circulation

- **Ignoring Earth's rotation:**
- **At equator, air heated, becomes less dense, rises.**
- **Atmospheric pressure at equator decreases.**
- **Air from N- and S-latitudes move toward low pressure region, creating surface winds.**
- **Warm air**
  - **moves toward poles,**
  - **cools,**
  - **sinks back to surface, and**
  - **circulates toward equator.**



Rotation and Circulation



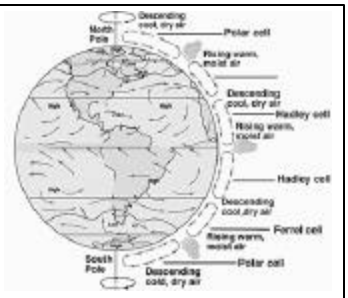
Corliolis effect

- **Earth's rotation causes northward moving surface winds to veer eastward: Coriolis effect.**
- **So, surface air moving southward from poles to equator produces westward moving winds.**

Coriolis Effect Example



Rotation, Circulation, Uneven Heating and Jet Streams



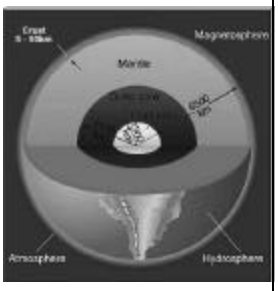
- **Uneven reservoir of heat on surface heats atmosphere unevenly, creating regions of low and high pressure.**
- **Atmosphere broken into cells.**
  - **–low pressure where cells rise**
  - **–high pressure where cells fall**
- **Upward and downward movements within cells from 30° to 60° latitude produce fast, westerly winds called the jet stream.**

Questions: Atmosphere

- **What is convection?**
  - **What effect does it have on the Earth's atmosphere? Earth's interior?**
- **What is the so-called "greenhouse effect" in Earth's atmosphere?**
  - **Why has it been important for life on Earth?**
- **What factors affect the atmospheric circulation patterns on Earth?**
- **How do average surface temperature and planetary mass factor into the presence or absence of a planetary atmosphere?**

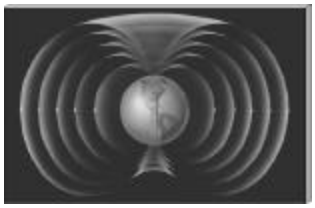
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- **Hydrosphere: liquid portions of Earth's surface**
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The Earth's Magnetic Field

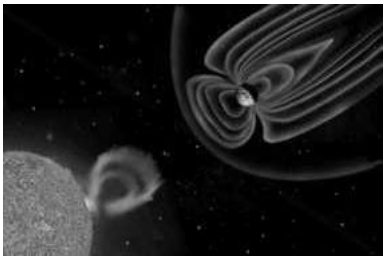
- Earth's magnetic field resembles that of an enormous bar magnet situated inside our planet.
- Arrows on field lines indicate direction in which a compass needle would point.
- The N and S magnetic poles (where magnetic field lines intersect Earth's surface vertically) are roughly aligned with Earth's rotation axis.
- Neither pole is fixed relative to planet surface:
  both drift at a rate of some 10 km per year.



Generation of Earth's Magnetic Field: Dynamo Theory

- Magnetic field produced by
  - moving electric charges.
- Field generation requires two factors
  - conducting liquid (metal outer core)
  - rapid rotation
- Connection between
  - internal structure,
  - rotation rate,
  - magnetic field.
- Dynamo effect explains many observations, but does NOT explain pole reversals.

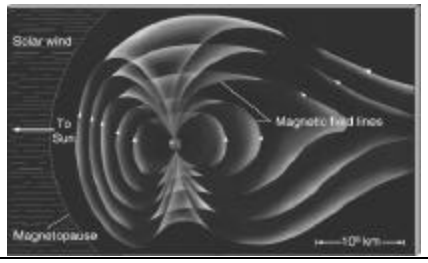
Solar Wind



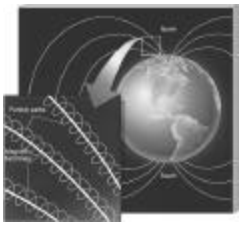
- Constant stream of particles produced by the Sun.
- Very low density, containing only about 5 particles/cm ^{3}.
- Responsible for such phenomena as creating a comet's tail and auroras.

The Earth's Magnetosphere

- Earth's surface protected from solar wind by the Earth's magnetic field called the magnetosphere .
- Particles from Sun interact with magnetic field lines, distorting the shape of the field.



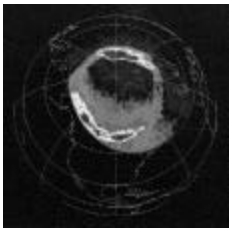
Charged Particles and Earth's Magnetic Field



Charged particles trapped in a magnetic field spiral around field lines toward the strongest part of the field (poles on Earth's field).

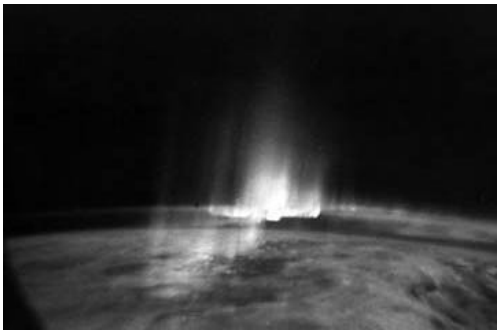
Aurora

- When large numbers of particles enter the upper atmosphere, gas atoms in the atmosphere begin to glow, forming an aurora.
- The aurora appears as a ring above both N- and S-magnetic poles.



False-color view of Earth's northern aurora taken by POLAR satellite.

Earth's Aurora from Space



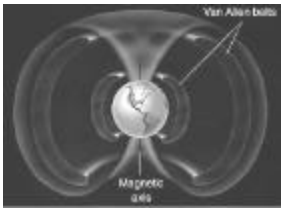
Aurora in Texas



Aurora photographed near El Paso,TX in August, 2000 during Persius meteor shower.

Van Allen Radiation Belts

- **Part of *magnetosphere.***
- **Electrons, protons, and heavier atomic ions trapped in two regions of Earth's magnetic field.**
- **Two doughnut-shaped belts**
  - **inner (1.5 Earth radii)**
  - **outer (3.5 Earth radii)**
- **These belts of trapped radiation near the Earth were discovered by first U.S. satellite launched in 1958 and are also known as Van Allen Belts after the scientist who discovered and analyzed them.**



Questions: Magnetosphere

- **What conditions are necessary to create a dynamo in Earth's interior?**
  - **What effect does this dynamo have?**
- **Briefly describe the Earth's magnetosphere.**
  - **How does it protect Earth from fast moving particles given off by the Sun?**
  - **What are the Van Allen radiation belts?**
  - **How were they discovered?**

Biosphere

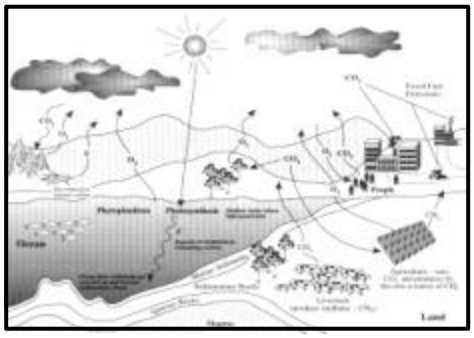


- **Earth is at just the right distance from the Sun to allow vast quantities of liquid water to be stable.**
- **This has apparently allowed life to form and thrive.**
- **All terrestrial life (plants and animals) is based on the chemistry of the carbon atom (organic chemistry).**
  - **Very complex atoms can be built from the carbon atom.**
- **A biosphere as we know it requires abundance of liquid water.**
- **The biosphere interacts with the atmosphere, hydrosphere, lithosphere, and magnetosphere.**

Life and the other "Spheres"

- **Earth is at a distance from the Sun that allows for water to be stable in liquid form at the surface.**
- **The out-gassed atmosphere that formed on Earth contained much CO and CO_2.**
- **Much of the CO_2 was dissolved in Earth's oceans and eventually incorporated into carbonate rocks by the carbon dioxide-water cycle, effectively removing it from the atmosphere.**
- **Life (both plant and animal)**
  - **interacts with the atmosphere, hydrosphere, and lithosphere and**
  - **is protected from the Sun's radiation by the magnetosphere.**

Carbon Cycle of Life



Question: Biosphere

- **What is the chemical basis for Earth's biosphere?**
- **How does the biosphere interact with the other "spheres"?**
  - **Atmosphere**
  - **Hydrosphere**
  - **Lithosphere**
  - **Magnetosphere**

Summary of Chapter 7

- **Earth's differentiated structure (inside to out)**
  - **inner core: solid, metallic, dense**
  - **outer core: liquid, metallic, very dense**
  - **mantle: solid, rocky, flows over long time periods, convection**
  - **crust: solid, rocky, oceanic and continental types**
    - **lithosphere = crust + rigid, upper part of mantle (tectonic plates)**
    - **asthenosphere = semi-fluid part of mantle**
  - **hydrosphere: liquid, oceans**
  - **atmosphere: gaseous**
    - **troposphere: weather, clouds, convection, T decrease with altitude**
    - **stratosphere: ozone layer, T increase with altitude**
    - **mesosphere: T lowest average value, T decreases with altitude, meteorites**
    - **ionosphere: charged particles, low density,increasing temperature**
  - **magnetosphere: magnetic field, dynamo theory ,Van Allen belts, trapped charged particles, aurora**

Summary of Chapter 7 (continued)

- **Evidence to Support Plate Tectonic Theory**
  - **Geologic surface activity traces out along well-defined lines, outline of "plates".**
    - **volcanoes, earthquakes**
  - **Motion of "plates" measured.**
    - **Measurements of distant quasar motion**
    - **Earth-based laser-ranging**
  - **Correlation of surface features to "plate" interactions.**
  - **Mid-ocean ridges and magnetic reversal pattern.**
  - **Fossil, climatic record.**

Summary of Chapter 7 (continued)

- **Tides**
  - **Moon**
  - **Sun**
  - **spring and neap tides**
    - **relative orientation of Sun and Moon**
  - **rotation rate of the Earth and distance to Moon**

Five Spheres

1. **LITHOSPHERE: The Solid Earth**
   - **Tectonic processes.**
   - **Volcanic processes.**
   - **Gradational processes.**
   - **Impact cratering.**
2. **HYDROSPHERE: The Water**
   - **State of water - gas, liquid, or solid.**
   - **Ocean distribution and currents.**
   - **Drainage patterns.**
   - **Glaciers.**
   - **Tidal forces.**

Five Spheres (continued)

3. **ATMOSPHERE: The Air**
   - **Convection.**
   - **Zonal flow.**
   - **Storms.**
   - **General circulation patterns.**
4. **MAGNETOSPHERE: Magnetic field and Charged Particles**
   - **Interaction with the solar wind.**
   - **Bow shock front.**
   - **Interaction with atmosphere.**
5. **BIOSPHERE: All Living Matter**
   - **Origin of life.**
   - **Effect of life on atmospheric evolution.**