EARTH SCIENCE
STUDY GUIDE

Costa Rica, Photo: Kane

Mustapha KANE, Ph.D.
# EARTH SCIENCE STUDY GUIDE

(In the online version you can open hyperlinks to the internet for more information about a specific subject)

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1 - COURSE DESCRIPTION:

You may ask: why do I need an Earth Science class? It does not matter if you are a nurse, a pharmacist or an accountant, your actions and your life, as a living organism, will impact or will be impacted by changes in the Earth systems. As the human population increases rapidly, we are now on a collision course with the dwindling and the degradation of our natural support system (water, soil, mineral resources, oil and gas, etc) upon which our civilization depends. It is our responsibility to learn as much as possible, about our living planet and our impact on its future and ours as well. The use and misuse of Earth natural resources and the environmental degradation that resulted from it have prompted people to be more Earth conscious and to find ways to better understand the planet we all call home. If that is not enough, Katrina’s devastation of New Orleans, as well as the terrible tsunami of December 26, 2004 in Indonesia are a grim reminder of Earth awesome power that has the potential to wipe out our modern civilization. Will Durant said it best when he wrote “Civilization exist by geological consent, subject to change without notice”.

This is a science class. You will learn about the scientific method which is the way science works. Science, in general, is a way to decipher nature’s way, model it, predict it, and harness its forces for the sake of mankind. The Earth is getting more and more violent with an increasing frequency of deadly earthquakes, floods, tsunami, hurricanes, landslides, etc… Why and what can we do to protect ourselves against a seemingly violent and unpredictable Earth? There must be a reason or reasons behind all this as Albert Einstein said “God does not play dice”. Nature always operates in a consistent and predictable manner. That’s where science in general and Earth science in particular comes in. Earth Science can be defined as the branch of Physical Science that studies human interactions with the physical environment. The Earth is a dynamic planet and an ever-changing environment. To understand Earth processes that shape the environment is to understand the laws that govern the planet we live in. An Earth Science class is probably the most comprehensive way to bring you closer to the whole spectrum of Earth’s physical processes, by teaching you about Earth systems and their impact on human civilization.

Every student, science majors as well as non-science majors at any college or university should have a basic knowledge in Earth and Environmental sciences, and an objective understanding of the interactions between people and our planet we call home.

Anything around you is made in part from minerals and rocks mined from Earth. As Whitman put it, "Your house came from a mine":

"The foundation is probably concrete (limestone, clay, shale, gypsum and aggregate mining).

The Insulation in the walls may be of glass, wool (silica, feldspar) and from mining, or expanded vermiculite (vermiculite mining).

The water pipe is of iron or copper or aluminum (iron ore mining or copper mining).

The sanitary facilities are made of porcelain (clay, feldspar mining).

Etc."

Earth scientists have a dual role to play:

1. Help understand Earth natural processes in order to find economic resources (mineral, oil, and gas, water, building material) for our civilization

2. Preserve, and monitor the environment for future generations to enjoy.

2 - COURSE OBJECTIVES:

The objective of this course is to teach you the basic and some in-depth knowledge of the Earth and its systems, and give you an objective understanding of the interactions between people and the physical environment. Understanding the Earth Systems (geosphere, hydrosphere, atmosphere, and biosphere) is not only crucial but also critical to solving environmental problems. The main components of this course are physical geology, hydrogeology, oceanography, meteorology, and astronomy.
Upon completion of this course you should be able to:

- Understand how Earth interactive systems and their processes operate.
- Know the two Earth’s engines and Earth’s internal structure that keep it “alive.”
- Understand and be able to recognize and apply the scientific methodology.
- Know the causes behind geological, atmospheric, oceanographic, and astronomic phenomena’s, such as earthquakes, volcanism, flood, landslides, hurricane, climate changes, coastal processes, and how they shape the Earth, and affect human lives.
- Know the role of Earth scientists and Earth resources, and their impact in building our modern civilization.
- And much more...

LECTURE VIDEOS:

This course is supported by a series of videos called “Earth Revealed.” Chapters of every section of the textbook are linked to videos you can watch. It gives you more visual information and a better understanding of the Earth. To watch video open the Earth Revealed link and register, it’s free. To play “The Habitable Planet” series videos click on the link. Once you open it, scroll down to “Individual Program Descriptions”, then choose a video title and the VOD icon across from the title and click on it to register when asked. Make sure to ask the system to remember you so you will not need to register again.

PART – I: INTRODUCTION TO EARTH SCIENCE

The Earth as a System:

There is much more to Earth than just rock and soil, especially when viewed from space. Earth is a dynamic system. What is a system? It’s a body made of interacting parts that work together to accomplish a task or a goal. A car is a system, a computer is a system, and your body is a system. Self-contained systems are called “closed systems” because they do not exchange matter with the outside. “Open systems” in the other hand allow the flow of energy and matter in and out. Most natural systems are open systems.

Feedback Mechanisms: Natural systems experience external forces that tend to enhance them or even destabilize them. When this happens, the system will react to either allow or oppose the changes. I am sure you have in your life experienced external forces, either through peer pressure or parental pressure, that try to move you in directions that may or may not be good for you. Reactions to these forces are what we call Feedback mechanisms. There are:

a. **Negative Feedback Mechanisms:** They resist changes to the system
b. **Positive Feedback Mechanisms:** They enhance the changes and go with the flow

Earth system is made of distinct but interacting spheres (atmosphere, hydrosphere, geosphere, and biosphere). Earth Science is a collective science that includes geology, oceanography, meteorology, and astronomy that study Earth spheres that are:

- **Geosphere** =Rocky body that represents the solid earth itself. Geology studies the geosphere
- **Hydrosphere** =Dynamic mass of water on the earth surface. Oceans represent 70% of the Earth’s surface and 97% of Earth’s waters. Oceanography, hydrogeology, and hydrology specialize in the study of the hydrosphere.
- **Atmosphere** =Envelope of gases around the earth. Atmospheric gases are made of 21% oxygen, 78% nitrogen and 1% argon, carbon dioxide, and other minor gases. Atmospheric sciences specialize in the study of the atmosphere.
- **Biosphere** =All the life forms on the earth surface, in oceans, and continents. Biological sciences and environmental sciences specialize in the study of the biosphere. The Earth is a system because its spheres interact to produce changes to one another. Volcanic eruptions from the geosphere can change Earth’s temperatures and climate in the atmosphere. The use of fossil fuels by human in the biosphere can lead to global warming of the atmosphere that will in turn affect the oceans in the hydrosphere.

Geology is an important part of Earth Science. Although geology means in Greek, Earth Science (Geo=Earth, Logos=Science), it only studies the rocky part of the Earth. Geology is the study of Earth (not the Solar system!). Since the antiquity the study of Earth materials (mineral and rocks) was the main focus of geology. With the development of space
exploration, scientists acquired a broad understanding of Earth and its different but interacting part (or spheres) such as the atmosphere, the hydrosphere, the geosphere, and the biosphere. The Earth is now viewed as a system, and geology studies only part of it. There is more to geology however, than just the study of rocks. As W. Durant put it “Civilization exists by geological consent subject to change without notice”.

Throughout history, wars have been fought, and civilizations have risen and fallen over the acquisition and control of Earth’s mineral resources (gold, copper, iron deposits), energy resources (oil, and gas), agricultural resources (fertile soil), and water resources. Mass exodus and migrations of people have been also dictated, throughout history, by huge environmental catastrophes such as global warming, ice ages, desertification, floods, volcanic eruptions, and earthquakes, as a result of Earth continuing geological evolution. The destiny of mankind is forever linked to Earth geological processes. To understand Earth is to understand our destiny. Geology, as a science existed since the Antiquity, around 2300 yrs ago, early Greeks period. It is divided into two broad areas:

**Physical Geology**: It studies the structure, composition, and evolution of the Earth materials (minerals and rocks) and the processes (magmatism, earthquakes, sedimentation, metamorphism etc...) involved in its formation. It can be summarized in one question: How did Earth features and material form?

**Historical Geology**: It studies the origin of the Earth material and its life forms, and its evolution through time. It can be summarized in one question: When did Earth features and material form?

### Origin of the Earth

The Universe originated 15 billion years ago from the explosion (Big Bang theory) of primitive matter that then started to expand away from the center. Cosmic Background Radiations are used to confirm the Big Bang Theory. Open the link and listen to the noise of the Big Bang explosion.

**The Nebular Hypothesis**: The Solar system formed about 5 billion years ago from the contraction of an enormous nebular cloud of mostly hydrogen and helium gases. Nebular rotation and contraction inward under own gravity, flattening into a disk; formation of the protosun (original sun) in center, and protoplanets at the periphery. Plates with denser core and thinner atmosphere formed close to the sun (Inner plates), and those with lighter core and thicker atmosphere made of ice formed farther away from the sun (Outer planets)

### Earth Internal Structure

The Earth is 5.6 to 4.5 billion years old. Using the Bible in 1650, Archbishop Ussher calculated and concluded that the Earth was created in 4004BC. The Earth internal structures are:

**Crust**: Rocky, cool, and brittle outermost layer of 5-70km thick. The earth crust is divided into

a. **Continental crust** - Granitic composition (K, Na, Al, Ca...), density 2.7 g/cm3, 30-70 km thick

b. **Oceanic crust** - Basaltic composition (Fe, Mg), density 3 g/cm3, 5-15km thick

Lithosphere: (sphere of rocks), Crust + uppermost mantle, rocky, cool, rigid and brittle, 50 -100km thick

**Mantle**: Rocky solid like layer beneath the crust, capable of flowing, 2900km thick, 82% of earth volume, dense, and hot.

**Core**: Fe-Ni rich innermost part of the earth, high temperature and high pressure, high-density molten rock, density 11 g/cm3

The boundary between the crust and the mantle is called the Mohorovicic discontinuity or Moho

**Dynamic Earth**: The Earth is a dynamic planet, constantly renewing itself under dynamic geological processes divided into:

- Constructive processes: Igneous activity and tectonic activity (crustal deformation, mountain building)
- Destructive processes: Weathering, erosion, mass wasting

Earth lithosphere is divided into plates that ride on top of the mantle. Places where plates interact are called **plates margins**. There are three kinds of plate margins:

a. **Divergent or constructive margins** where plates move away from each other. Example is the mid-ocean ridge. It is a site with a constant magmatic activity (volcanism). Mid ocean ridges and Rift Valleys are examples of divergent boundaries.

b. **Convergent or destructive margins** where plates collide. In the case where an oceanic plate collides with a continental plate, the oceanic plate slides under the continents and melt. Magma rises up to produce volcanic activity on the margin of the continent. Such is the case with the Andes volcanoes in South America and the Cascade Range volcanoes in the Pacific Northwest of the United States.

c. **Transform fault** where plates slide pass each other. Such margins do not produce magma. Instead, they produce lots of stress which leads to earthquakes. An example of such margin is the San Andreas Fault in California. The first two margins produce earthquakes as well.
The Earth has two heat engines:

a. **The Sun** which is responsible of providing heat energy that fuels external processes like weather related patterns (Hurricanes, tornadoes, floods, and weathering and erosion of rocks)

b. **The Earth Interior** which provides magma related heat energy responsible of internal processes like earthquakes, volcanic eruptions, mountain building, etc…

**Environmental Challenges:**

**Earth Rapid Population growth**: We are currently 6.5 billion people on Earth and it keeps on going and going and going…It has grown rapidly exponentially since the 1830s Industrial Revolution.

**Earth Resources** are either **renewable** like the food we grow, or **non renewable** like the fossil fuel and mineral resources we use for our industries. We worry about oil but water is actually the resource we should worry about the most. **Ninety percent (90%)** of the water we use in Florida and around the world comes from the ground. Yet groundwater is less than 1% of all waters available on earth. We are either consuming or polluting the groundwater faster than it is replenished. That is why although groundwater is a renewable resource we chose to consider it as a non renewable resource. Earth scientists have a dual obligation which is to find resources for our civilization’s needs, and to lead us in the protection of the environment. The environmental problems facing our society are of two kinds:

**Human-induced:**
- Urban Air pollution
- Acid Rain
- Ozone Depletion and the CFCs
- Global Warming

**Natural Hazards:**
- Earthquakes
- Volcanoes
- Landslides
- Hurricanes
- Etc…

**Scientific Method.** Science is based on the assumption that the natural world behaves in a consistent and predictable manner. The goals of science are to discover underlying logical patterns in the natural world, construct models to predict what could or should happen given these circumstances. The tools are the observation of the natural phenomena through rigorous steps called the scientific method or scientific Inquiry.

- **Observation** is key in science, and is certainly the first step to understanding nature.
- **Hypothesis** is a logical explanation of the observed phenomena.
- **Experiments** are reconstructing models to test the hypothesis.
- **Theory** is an accepted confirmed hypothesis after considerable experimental support and scrutiny.
- **Paradigms** (such as the plate tectonics theory) are theories held in high confidence.

Be aware of **pseudoscience** (astrology, alchemy, UFO, ESP, etc...). Some of these branches of knowledge such as astrology use scientific terms like energy and frequency to gain acceptance from the scientific community, and credibility from the public.

**How does the scientific community work?**

Research: **applied research** (mostly funded by private companies with the objective to provide immediate technological application; example: research to cure Aid or Cancer), and **basic research** (mostly government funded research in academia, etc...; such research do not necessarily have immediate technological application; Their objective is a basic understanding of nature).

**Scientific organizations**: National and international associations that hold meetings, conferences, and collaborative research, and publish findings in local and international scientific journals.
UNIT ONE: EARTH MATERIALS

- **LEARNING OBJECTIVES:** Upon completion of this part, the student should be able to:

  1. Distinguish between physical geology and historical geology
  2. Contrast the concept of catastrophism and uniformitarianism
  3. Understand the rock cycle and how the formation of various types of rocks can be interrelated
  4. Distinguish between rocks and minerals
  5. Distinguish and be able to define the physical properties used to identify minerals
  6. Briefly describe the silicon-oxygen tetrahedron
  7. Describe the chemical classification of minerals

CHAPTER – 1: MINERALS: BUILDING BLOCKS OF ROCKS

- **MINERALS:**

Minerals, building blocks of rocks, are aggregates of one or more chemical elements held together by chemical bonding: example: NaCl (halite or table salt), SiO₂ (silica or Quartz), CaCO₃ (Calcite), C (diamond or graphite), etc...

**Definition:** A mineral is defined as a “naturally occurring, inorganic, solid substance with definite chemical composition and crystalline structure.

**Chemical Classification of Minerals:** Minerals are classified into two major groups:

  - **Silicates Minerals:** They represent up to 90% of the earth crust, among them the rock-forming minerals (major igneous rocks constituents). Their chemistry is based on the silicon-oxygen tetrahedron (one silicon atom bonded to four oxygen atoms: SiO₄) which is the building-block of silicate minerals. Depending on the tetrahedron arrangement, silicates minerals can form: single tetrahedron (olivine), single chain (pyroxene), double chain (amphibole), sheets (micas), tridimensional network (feldspars, quartz). This increase in the structure translates into an increase in the amount of silica content (% SiO₂) in the mineral, and a decrease in the temperature at which the mineral crystallizes.

  - **Nonsilicates Minerals:** Less abundant than the silicates minerals (10%). Some examples are:

    - **Native elements:** Chemical elements that precipitate in their native form, such as native gold (Au), native silver (Ag), native copper (Cu), etc.
    - **Sulfide Minerals:** When sulfur ion (S²⁻) bonds with other elements: FeS₂ (pyrite), PbS (galena), etc.
    - **Carbonate Minerals:** when (CO₃⁻²) ion bonds with other ions: CaCO₃ (calcite), plus sulfates, oxides, hydroxides, halides, phosphates, etc...

**Physical Properties of Minerals:** The simplest and fastest way used by geologists to identify minerals on the field is by checking their physical properties. The most reliable set of physical properties is:

  - **Luster:** It is the way a mineral surface appears under reflective light. It can be either metallic (like polished metal) or nonmetallic (dull, glossy, silky, etc.). Most metallic ore minerals (galena, hematite, pyrite, ...) exhibit a metallic luster
  
  - **Cleavage:** Because in the crystal structure of a mineral, some chemical bonds are weaker than others, minerals will break preferentially along these weaker bonds. A cleavage is the tendency of a mineral to break along weak bond by leaving smooth, flat planes. Example: micas have one direction of cleavage; calcite has three directions of cleavages not at 90 degrees. Some minerals, such as quartz, do not have cleavage, they have fracture. They break along smooth curved surface (conchoidal fracture).

  - **Streak:** It is the color of a mineral powder obtained by rubbing it across an unglazed porcelain plate (streak plate). Metallic mineral have brown to black streak.

  - **Hardness:** It is the mineral resistance to scratching or abrasion: It is determined by rubbing a mineral of unknown hardness against one of known hardness. The Mohs scale of hardness (1 to 10) gives a relative scale of hardness. The softest mineral is talc (1), the hardest is diamond (10).

  - **Specific Gravity:** It is the ratio of the weight of a mineral to the weight of an equal volume of water. It can be roughly estimated by hefting the mineral in your hand. Galena has a high specific gravity (SG = 7.5).
- **Color and Crystal Form** can be used but are not very good diagnostic physical properties.
- **Other properties** include reaction to hydrochloric acid for carbonates minerals like calcite; radioactivity for uranium and radioactive elements rich minerals; magnetism for magnetite mineral; double refraction for calcite minerals, etc...

Asbestos a different kind of minerals: Asbestos are fibrous minerals that form the serpentinisation (kind of weathering) of magnesium rich silicate minerals like olivine found in mafic and ultramafic rocks.

**CHAPTER - 3 & 9: ROCKS, VOLCANOES & OTHER IGNEOUS ACTIVITY**

- **LEARNING OBJECTIVES:** Upon completion of this paragraph, the student should be able to:
  1. Contrast magma and lava
  2. Explain the effect of temperature, pressure, and volatile content in magma genesis
  3. Explain the effect of silica, temperature, and volatile content on the viscosity and the crystallization of magma
  4. Describe the three types of plate boundary and give examples of their location
  5. Describe how the rate of cooling influences the textures of igneous rocks
  6. List the different igneous rock textures (aphanitic, phaneritic, porphyritic, pegmatitic, vesicular, glassy, and pyroclastic) and explain their origin
  7. Explain the Bowen’s reaction series and magma crystallization
  8. Classify igneous rocks based on their silica (SiO2 %) content
  9. Contrast ultramafic/mafic, intermediate, and felsic magmas and igneous rocks.
  10. Know the three major types of volcanoes and their lava type.

**1 - IGNEOUS ROCKS & IGNEOUS ACTIVITY:**

- **ORIGIN OF MAGMA**

  Magma = Molten rock with a mixture of suspended crystals and dissolved gases, principally water vapor
  Lava = magma that reaches Earth's surface and essentially depleted of its gases.

  Magma originates when solid rock in the mantle or the crust melt due to **three main factors:**
  - **Heat increase:** from geothermal gradient and radioactivity source
  - **Reduction of the confining pressure** (along plate boundaries): It causes a decompression melting
  - **Increase in volatiles:** It causes the rock to melt at lower temperatures

  Most igneous activity is generated along **plate margins:** There are **three types of plate margins**:
  - **Divergent boundary:** place where plates move apart, resulting in upwelling of magma, creating a new sea floor; ex : the mid-ocean ridges (a lot of undersea volcanism)
  - **Convergent boundary** (subduction zones): place where plates move together, resulting into subduction (consumption) of oceanic material into the mantle; ex: the Andes trench (siege of both volcanic and seismic activity)
  - **Transform fault boundary:** Plates move along each other without production or consumption of lithosphere (no magma is produced); ex: San Andreas Fault, siege of a lot of seismic activity (earthquakes)

  Chemical Composition of Magma:
  - **Felsic (granitic) magma:** Rich in silica (SiO2 > 65%, high viscosity), and poor in ferromagnesians (Fe, Mg), it forms and crystallizes at 800 C to form **felsic rocks** (SiO2 >65%)
  - **Ultramafic/Mafic (basaltic) magma:** Poor in silica (SiO2<55%, low viscosity), rich in ferromagnesians (Fe, Mg), it forms and crystallizes at high temperature, 1200 C to form **ultramafic/mafic rocks** (SiO2<50%)
  - **Intermediate (andesitic) magma:** It is a mixture of both mafic and felsic magmas, it forms **intermediate rocks** (65%>SiO2>50%)

- **BOWEN'S REACTION SERIES**

  According to N. L. Bowen, minerals in a cooling magma crystallize in a **systematic order:** The first to crystallize at high temperature are the Fe, Mg rich mafic minerals (olivine, then pyroxene, then amphibole, and biotite) along with the Ca-rich plagioclase feldspars. The last to crystallize are the felsic minerals (K-feldspars, muscovite, followed by quartz at
lower temperature). Crystallization creates depletion of the melt successively in mafic and felsic minerals leaving it SiO2 richer. The early formed minerals react (reaction series) with the (SiO2) melt to form the next, ex: olivine + SiO2 = pyroxene; Pyroxene + SiO2 = amphibole, this is called discontinued series
SiO2 rich magma (granitic) will not form rocks with stable olivine, and pyroxene, but with biotite, muscovite, quartz, and conversely: No coexistence of olivine and free quartz in a rock; Ca - rich minerals early formed (plagioclase) react with the Na ions of the melt to form Na rich minerals (alkali feldspars), this is called continued series; the richer the melt in Na the more granitic the rock formed.

- **IGNEOUS ROCKS TEXTURES:**
  Three factors influence igneous rock textures:
  - Cooling rate of the magma (slow, fast, or slow then fast)
  - Amount of silica (viscosity)
  - Amount of volatile (gases: water vapor, carbon dioxide, sulfur, nitrogen, etc…)

A rock texture is the crystal arrangement in the rock. Igneous rocks are classified according to the rate of cooling of the magma, which is determined by the level (inside or outside the Earth’s crust) at which the magma solidifies: Intrusive (plutonic) igneous rocks: They form when magma solidifies inside the Earth’s crust at a slow rate of cooling. It forms crystals visible to the naked eye (phaneritic texture). The slower the cooling rate of the magma, the larger the crystals formed, with very coarse grains (pegmatitic texture). Such rocks are granite, pegmatite, gabbro, etc...

Intrusive igneous rocks form small to very large bodies (plutons) that can range from batholith (very large plutons), stocks (small plutons), dike (discordant sheetlike plutons), sill (concordant sheetlike plutons), to laccolith (a sill with a hump). Extrusive (volcanic) igneous rocks: They form when lava solidifies quickly on the Earth’s surface. It forms crystals invisible to the naked eye (aphanitic texture) typical of volcanic rocks such as basalt. Some magma may start cooling slowly and then erupt to cool quickly, resulting in a mix texture of few large crystals in a fine-grained matrix (porphyritic texture). A lava rich in silica, with no crystals solidifies to form a vitreous, glassy rock (glassy texture) called obsidian. Volcanic ash solidifies to form a fragmental rock (pyroclastic texture) called volcanic tuff. A lava filled with gas solidifies to form a vesicles filled rock (vesicular texture) called pumice (when light felsic) or scoria (when dark mafic).

- **IGNEOUS INTRUSIVE BODIES:**
  Igneous intrusive bodies (plutons) are classified according to their size and shape. They can be massive (irregular) or tabular (sheetlike), concordant (same orientation as the host rock) or discordant (cutting through):.
  - Dike: It is a tabular discordant igneous body.
  - Sill: It is tabular concordant igneous body.
  - Laccolith: It is a tabular concordant igneous body with a hump.
  - Batholith: It is a massive, large (x kms) igneous body often at core of mountain ranges (I.e. Sierra Nevada batholiths)
  - Stock: It is a small batholith (x ms).

- **VOLCANISM AND VOLCANOES:**
  Three factors determine volcanic eruption and the type of volcanoes produced:
  1. Viscosity (amount of silica SiO2) of the lava: felsic lava forms small thick flows, mafic lava forms large fluid flows. Most explosive volcanoes erupt felsic pyroclastic flows (ash and fragments), full of gases.
  2. Temperature of lava: High temperature decreases viscosity and increases magma’s ability to flow; Temperature of lavas = 800 C (felsic high viscosity like rhyolite lava forms short thick flows); 1200 C (mafic low viscosity like basaltic lava forms large fluid flows)
  3. Dissolved gases: Increase in gases decreases viscosity and increases magma’s ability to flow, pressure decrease increases the gases; gases content in magma is: 70% water vapor, 15% carbon dioxide, 5% sulfur, 5% nitrogen, chlorine, and hydrogen.
1 **IGNEOUS ACTIVITY AND PLATE BOUNDARY:**

Most igneous activity and volcanic eruptions occur along

1. **Convergent plate boundary:** where the dominant type of magma/lava is andesitic
2. **Divergent plate boundary:** where the dominant type of magma/lava is basaltic
3. **Hot spot.** Hot spots are not a plate boundary, the dominant type of magma/lava is basaltic

Most igneous activity is located along plate tectonic boundaries (divergent and *convergent boundaries*) and at hot spots

1. Volcanism of felsic and intermediate lava is mostly associated with ocean-continent convergent plates boundaries (ex: Andes), and continental rift divergent boundaries (ex: East African rift valley), or above hot spots (ex: Yellowstone); however, some basaltic lava can also be found in these places
2. Volcanism of basaltic lava is mostly associated with ocean basins at divergent plates boundaries (ex: Mid-Ocean ridge), and ocean-ocean convergent plate boundaries (ex: Island arcs), or within plate above hot spots (Ex: Hawaiian volcanoes)

2 **TYPES OF VOLCANOES:**

There are three main types of volcanoes:

1. **Shield volcano:** Broad slightly domed structure that resembles a shield, It is made primarily of basaltic flow (*pahoehoe, and aa*) and little pyroclastic material. It is mostly associated with the ocean floor *divergent boundary* and *hot spot*, like in Hawaii. Its eruptions are *peaceful*.
2. **Cinder cone volcano:** Very steep slope (30-40 degrees), they are small volcanoes built from lava fragments (*cinder*), can form as a parasitic cone of larger volcanoes. They are mostly associated with *convergent plate boundary*. They are explosive. Example Sun Crater, Arizona.
3. **Composite cone or Stratovolcano:** It erupts both viscous (*felsic to intermediate*) lava and felsic pyroclastic flows, forming alternating layers of lava and pyroclastic material, it has steep slope (>40 degrees) due to accumulation of viscous felsic lava. They are found in *convergent boundaries* and are the most picturesque and *deadliest volcanoes*. They produce the *most violent eruptions*. ex: Mt. St Helens, Vesuvius, etc...

The danger of volcanoes comes not only from volcanic eruptions but also from the effect it generates;

*Lahar:* Mudflows resulting from ash flow mixed with water (torrential rain or flood). In 1985 it killed 25,000 people in a village in Colombia.

*Debris flows:* Resulting from melting of ice sheet on top of volcanoes.

*Climate changes:* Ash flow blocking sunlight for months (it brings snowfall in summer). In 1885 an eruption in Indonesia affected world climate the same way.

**Summary on volcanoes**

II - SEDIMENTARY ROCKS:

- **LEARNING OBJECTIVES:** Upon completion of this paragraph, the student should be able to:
  1. Contrast detrital weathering and chemical weathering
  2. Define the process of lithification
  3. Name the two major types of sedimentary rocks know how they form.

- **ORIGIN OF SEDIMENTARY ROCKS:**

Sedimentary rocks are produced by the *deposition* and consolidation of sediments by a process called *lithification* (cementation and compaction of loose sediments into solid rock).

Sediments are produced by subsurface destructive processes called *weathering* and *erosion.*

*Weathering* is a process in which a rock is either mechanically (*mechanical weathering*) or chemically (*chemical weathering*) disintegrated or decomposed into sediments.
**TYPES OF SEDIMENTARY ROCKS:**

Detrital sedimentary rocks:
They form from clastic material produced by both mechanical and chemical weathering.

*Shale*: silt and clay size particle in thin layers (*laminae*); *Sandstone*: sand-sized grain rock w/ predominantly quartz (*quartz sandstone*), can be well sorted or poorly sorted;
*Conglomerate*: large gravels, well sorted (rounded)
*Breccia*: large gravels, poorly sorted (angular)

**Chemical sedimentary rocks:**
They form from soluble material produced largely by chemical weathering (oxidation, hydrolysis, or dissolution).

1. **Inorganic**: They form from direct precipitation or evaporation from solution.
   *Evaporites*: From evaporation in lakes, small seas, lagoons, etc...
   - *halite*, *gypsum*,
   *Dolostone* (some magnesium replacing calcium in calcite to form Ca-Mg carbonate)
   *Chert* (microcrystalline silica rich rock, can also be of organic origin).

2. **Organic**: They form from accumulation from organic skeletons.
   *Limestone*: mainly calcite + sediment; organic/inorganic; coral reefs. Limestone is easily weathered by slightly acidic running or groundwater resulting in karstic terrain with the formation of sinkholes, caves and caverns.
   *Coquina*: coarse organic debris, *Chalk*: soft, porous, *Coal*: Compacted, altered debris of organic matter (plants, wood, etc...) in oxygen deficient environment
   *Peat*: First layer of coal w/ little decomposition, *Lignite*, *Bituminous*: more decomposed and C rich coal. *Oil and gas* form as a result of further decomposition of the organic matter under higher conditions of pressure and temperature.

**III - METAMORPHIC ROCKS:**

**LEARNING OBJECTIVES**: Upon completion of this paragraph, the student should be able to:

1. Know the three main agents of metamorphism
2. Name the two types of metamorphism and their location
3. The causes of metamorphism

**AGENTS OF METAMORPHISM:**

Metamorphism = change of form (also mineral composition, and texture), affects igneous, sedimentary or metamorphic rocks by (combined) actions of metamorphic agents:

- **Pressure**: Directed stress; lithostatic pressure (confining pressure), or hydrostatic; high stress produces melting and recrystallization, ex: *migmatite granite* (rock with both igneous and metamorphic features).
- **Temperature**: Comes from: magma intrusion (produces baking), or geothermal gradient (heat increase with depth), or mechanical heat due to high stress.
- **Fluids**: hydrothermal and or meteoric fluids, mineral dehydration; chemical action of circulating fluids mostly water causes metamorphism.

**TYPES OF METAMORPHISM:**

1. Contact Metamorphism: Contact between intrusion and host rocks forms an aureole or halo, it’s a *high-temperature low pressure* (baking) conditions, it involves fluids circulation and/or *mineral recrystallization*, ex: *marble*
2. Regional Metamorphism: Represents large scale regional deformation (ex: in subduction zones, cratons or shields) due to plate motions and mountain building, *high pressure (stress)* conditions (compression, tension, shear), *low (blueshist facies)* to *high (granulite facies)* temperature, affect large areas of metamorphic rocks; involves *folding, foliation, changes in mineral composition*, ex: *schists, gneiss.*
• **EFFECTS OF METAMORPHISM:**

1. **Textural changes:**
   - **Rock compaction:** shale or clay changes to *slate* under low-grade metamorphic conditions.
   - **Foliation:** Under high stress (compression) minerals flatten; ex: granite changes to *gneiss*, clay to *slate* then to *schist* (*schistosity=*mineral orientation).
   - **Recrystallization:** Under high-temperature metamorphic conditions limestone changes to *marble*, sandstone to *quartzite*.

2. **Mineralogical changes:**
   Most chemical changes occur during metal rich *hydrothermal fluids* (mostly hot water) circulation, i.e.: pyroxene + water changes to amphibole, CaCO3 + SiO2 form CaSiO3 pyroxene (wallastonite). Some low temperature minerals can form during compaction and recrystallization: i.e *mica*, and *chlorite* form from clay minerals.

*Take a rock quiz here:*

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### UNIT THREE: FORCES WITHIN

**CHAPTERS 7, 8, 10:** **EARTHQUAKES, PLATE TECTONICS, and MOUNTAIN BUILDING**

- **LEARNING OBJECTIVES:** Upon completion of this chapter, the student should be able to:
  1. Distinguish between Continental Drift and Plate Tectonics theory
  2. Explain the idea of Seafloor Spreading and its relation to Continental Drift
  3. Know the three major plate boundaries and their role in Earth’s dynamics
  4. Explain the importance of Plate Tectonics and how it provides a unified explanation to all geological processes.
  5. Define earthquake, intensity, and magnitude
  6. Know the major earthquakes location and origin

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### CHAPTER 8: PLATE TECTONICS (CONTINENTAL DRIFT & SEAFLOOR SPREADING)

**I - CONTINENTAL DRIFT:**

Alfred Wegener first formulated the idea in 1912/1915: It's the break up 200 million years ago, of a single supercontinent called *Pangea*, into pieces of small continents that drifted apart. It started with the opening of the North Atlantic Ocean which led to the formation of Laurasia (Europe and N-America), and Gondwanaland or Gondwanaland (Africa, S-America, Australia, India, and Antarctica).

**Evidences for Continental Drift**

- **Continents fit like a jigsaw puzzle pieces:** ex: Africa and S-America
- **Fossil evidence:** Identical fossil remains (ex: Mesosaurus) in different continents that can only be explained by the existence of landmasses between them
- **Rock type:** Some mountain belts are found in different sides of the continents, ex: Appalachians in the US and Canada, Mauritanides in West Africa, and similar belts in England and Scandinavia form a continuous chain; Same cratons in Brazil and West Africa
Paleoclimatic Evidence: The same glacial deposits of 200 million yrs are found in S-America, S-Africa, Australia, and India; Coal deposits (ancient swamps) of same age are found in N-America and Europe.

Polar wandering: Migration of the magnetic poles through time; Paleomagnetism: Earth old magnetic field
Geomagnetic Reversals: Vine and Matthews found alternating stripes of high and low intensity magnetic field in ocean floor rocks due to geomagnetic reversals.

Normal Polarity: Rocks magnetic field parallel to the present Earth magnetic field
Reverse Polarity: Rocks magnetic field opposite the present Earth magnetic field

II - SEAFLOOR SPREADING (“essay in geopoetry”)

Formulated in 1962 by Harry Hess while studying the depth of seafloor: It states that Plates move apart from each other as new oceanic lithosphere is created by magma rising from the ocean ridges, and the old seafloor is consumed as it descends into the mantle at subduction zones. The seafloor is created in a conveyor-belt fashion. Lacking evidences to sustain his idea, Hess called it “essay in geopoetry”.

Evidences to confirm Hess seafloor spreading idea came from Vine and Mathews dating the ocean floor on either part of the mid-ocean ridge: They found that as you move away from the ridge the ocean floor rocks become older: New oceanic floor is created at mid ocean ridges, the old floor is consumed away at subduction zones.

III - PLATE TECTONICS THEORY:

Continental drift and sea floor spreading formed the plate tectonics theory in 1968: It states that “Earth lithosphere is divided into moving plates”. Its importance in earth sciences is so great that it has been called a revolution in earth sciences and is compared to the Theory of Evolution in life sciences: In a single unifying theory, geoscientists can explain as never before, all Earth geological processes such as volcanism, earthquakes, mountain building, ore formation, etc...

- PLATE BOUNDARIES:

Most igneous activity is generated along plate margins: There are three types of plate margins:
Divergent boundary Where plates move apart, resulting in upwelling of magma, creating a new sea floor; ex: the mid-ocean ridges (a lot of undersea volcanism)
Convergent boundary
Transform fault boundary:

1. Divergent Boundaries: (constructive margins)
Where plates move apart, resulting in upwelling of magma, creating a new sea floor; i.e.: the mid-ocean ridges (a lot of undersea volcanism), rift valleys
2. Convergent Boundaries: (subduction zones): Where plates move together, resulting into subduction (consumption) of oceanic material into the mantle; ex: the Andes trench (siege of both volcanic and seismic activity):
   - Ocean-Continental Convergence: When an oceanic slab descends under a continental plate; ex: the Andes
   - Ocean-Ocean Convergence: When an oceanic slab descends under another oceanic slab creating islands arcs; ex: the Aleutian island arcs
   - Continent-Continental Convergence: When two continental plates collide; ex: the Himalayas, Alps, and Urals mountains
3. Transform Faults: (strike slip fault) Plates move along each other without production or consumption of lithosphere (no magma is produced); ex: San Andreas fault, origin of a lot of seismic activity (earthquakes)
Hot Spots: Not a plate boundary. It is created by a plume rising from deep in the mantle and emerging in the middle of a plate as stationary center of volcanic eruptions; ex: Hawaiian hot spot. Overtime, it creates a volcanic chain.
CHAPTER 7: EARTHQUAKES AND THE EARTH’S INTERIOR
(When the Earth quakes)

• LEARNING OBJECTIVES: Upon completion of this chapter, the student should be able to:
  
  1. Know the two major types of seismic waves and their characteristics
  2. Define seismograph, focus, and epicenter
  3. Know the difference between intensity and magnitude of an earthquake
  4. Know what causes earthquakes, and earthquakes distribution around the world

I - SEISMIC WAVES

In Physics you have learned that energy can travel in two forms that are the particle and the wave, and that “waves are a mode of transfer of energy without transfer of mass”. We are all familiar with certain types of waves such as electromagnetic waves (light, radio waves), sound waves (sound of a voice), water waves (ocean waves), etc. But rarely anyone has experienced the terrible effect of seismic waves (earthquakes). What are seismic waves?

- Definition: Seismic waves are produced by a rapid release of elastic energy due to stress. They are characterized by the “shaking of the ground” (earthquake). Simply put, seismic waves are “shock waves”. They can also be produced by other mean such as an explosion, the passing of a train, etc.

The branch of physical geology that studies seismic activity and earthquakes is called seismology or geophysics.

NATURE OF SEISMIC WAVES:

1. Seismic energy travels out from its source (called focus) in all directions as waves.
2. The velocity of seismic waves depends on the density and elasticity of the intervening material.
   Seismic waves travel most rapidly in rigid material that elastically spring back to their original shapes when the stress caused by the seismic wave is removed. For instance, crystalline rock like granite, transmits seismic wave more rapidly than does unconsolidated sediment like mud, or sand. However, unconsolidated sediments amplify seismic waves more than crystalline rocks do.
3. The speed of seismic waves generally increases with depth because with depth, pressure increases and squeezes the rock into a more compact elastic material.

TYPES OF SEISMIC WAVES: There are two types of seismic waves:

1. P waves (Primary waves) or “push-pull” waves. They vibrate back and forth and parallel to their direction of travel. They produce compression and expansion of the rocks. They change the volume of material. That’s why they can travel through solids, liquids, and gases. P waves are faster (x 1.7) than the S waves. P waves are longitudinal waves. The time interval between the arrival of P waves and S waves at the recording station is called travel time. The greater the travel time, the farther away the epicenter of the earthquake.

2. S waves (Secondary waves, or shear waves). They vibrate perpendicular to their direction of travel. They change the shape of material. That’s why they cannot travel through liquids and gases. Because liquids and gases have no shear strength. That is, when liquids and gases are subjected to forces that act to change their shapes, they simply flow. S waves are transverse waves.
   P waves and S waves form what is called Body waves: They travel through the Earth interior.

Surface waves in the other hand, travel on the surface of the Earth in an “up and down”, and side to side motion.

II - EARTHQUAKES

An earthquake is the vibration of the Earth produced by the rapid release of energy.
The energy released in a form of seismic waves radiates in all directions from its deep (within the Earth interior) source called focus. The epicenter of an earthquake is the projection of the focus on the Earth surface.
A foreshock is a minor earthquake that precedes the major one.
An aftershock is a minor earthquake after the major one.
• **WHAT CAUSES EARTHQUAKES?**

The Earth is a dynamic system with an engine (Earth's internal heat with its convective cells) that drives the lithosphere, made of numerous plates that slide over the mantle (plate tectonics theory). When plates collide at **subduction zones**, or slide past each other at **transform faults**, stress builds up and creates earthquakes. Earthquakes occur along these major plate boundaries, mostly in the circum-Pacific belt, also called ring of fire.

**Earthquake Depth:**
- **0-70km:** Shallow depth earthquakes. They represent 90% of earthquakes.
- **70-300km:** Intermediate depth earthquakes.
- **300km:** Deep earthquakes.
- The Ocean ridge system has shallow depth earthquakes,
- Deep earthquakes are found mostly along subduction zone, along the Wadati-Benioff zone.

• **MAGNITUDE AND INTENSITY OF EARTHQUAKE:**

1. **Mercalli Scale** measures the **intensity** of earthquake. It assesses the physical damages caused by earthquakes. It goes from I to XII.

2. **Richter Scale** measures the **magnitude** or the total **amount of energy** released by an earthquake. It is a logarithmic scale and goes from 0 to infinity. It represents the highest amplitude of a seismic wave recorded within 100 km of the epicenter. So far, the largest magnitude earthquake ever recorded is 9.6, in Southern Chile, in 1960. The lowest magnitude earthquake that can be felt by humans is 2.0. It resembles the rumbling of a passing train. Each unit of Richter magnitude equates to roughly a 32-fold energy increase. For example, an earthquake of magnitude 6.5 releases 32 times more energy than one with a magnitude 5.5.

• **EARTHQUAKES EFFECTS:**

1. **Soft sediments:** They amplify vibrations more than **solid bedrock**; soft sediments can be **liquefied** by an earthquake and produce more damages.

2. **Seiches:** They are waves generated in lakes and pools.

3. **Tsunami:** They are huge sea waves or tidal waves with speed up to 500-950km/hour resulting from uplift on part of the ocean floor.

4. **Landslide, ground subsidence:** Normal faults create landslide and ground subsidence.

**CHAPTER-10: CRUSTAL DEFORMATION AND MOUNTAIN BUILDING:**

• **LEARNING OBJECTIVES:** Upon completion of this chapter the student should be able to:

1. Know the three different types of stress (compressional, tensional, and shear stress)
2. Contrast fault and fold
3. Identify the two major types of fault (dip-slip and strike-slip faults) and their examples.
4. Know the different types of fold (anticline, syncline, basin, and dome)
5. Know the two major types of deformation (elastic and plastic)
6. Define orogenesis, and isostasy.
I - TYPES OF STRESS:

The earth is a dynamic planet. Plate motion is the main cause of crustal deformation and mountain building process also called orogenesis. It generates tremendous amount of force that subjects rocks to enormous stress, mainly along plate boundary. There are three major stress corresponding to the three major plate margins:

1. **Compressional stress**: It occurs along *convergent plate boundary* (subduction zone) where plates collide. It shortens and thickens Earth’s crust by folding, flowing, and faulting. It is the major component in crustal deformation and mountain building.

2. **Tensional stress**: It occurs along *divergent plate boundary* (i.e. mid-ocean ridges). It produces a pull apart effect on rocks. It also creates a thinning and elongation of the Earth’s crust.

3. **Shear stress**: It occurs along *transform fault boundary* (i.e. San Andreas fault). It creates a slippage, and major offset on rock layers.

II - TYPES OF DEFORMATION:

1. **Elastic Deformation**: It’s a type of deformation that does not produce permanent changes in a rock. The rock will return to its original shape and size when the stress is removed. This type of deformation is also called *ductile deformation* (without fracturing). It occurs deep within the earth crust where temperatures are higher. The rocks behave elastically.

2. **Plastic Deformation**: It’s a type of deformation that produces *permanent changes* in a rock. Once the elasticity limit is reached, the rock will not return to its original shape and size. *Brittle deformation* (with fracturing) is this type of deformation.

III - GEOLOGICAL STRUCTURES:

- **FOLDS**: Folds are wavelike undulations produced when flat-lying sedimentary or volcanic rocks are deformed during mountain building. There are two main types of folds:
  1. **Anticline**: Elongated arch like structure in which the *limbs dip away from the axis with the oldest rocks at the bottom of the structure*. A *dome* is like an anticline but often circular.
  2. **Syncline**: Elongated depression like structure in which the *limbs dip toward the axis, with the oldest rock at the bottom*. A *basin* is like a syncline but often circular.

1 DIP AND STRIKE:

1. **Dip**: It is the angle of inclination of the surface of a rock layer or fault plane measured from a horizontal plane.
2. **Strike**: It is the direction angle between the magnetic North and a line defined as an intersection between the horizontal and a rock layer or fault plane.

- **FAULTS**: Faults are fractures in the crust that produce *displacement*, offset. They are the result of brittle deformation. They are classified into two major types depending on their orientation:
  1. **DIP-SLIP FAULTS**: They are faults that produce an *up or down displacement* of the rock block, along the *dip* of the rock layer. They are created by either *tensional or compressional stress*.
    - **Normal Fault**: It’s a type of dip slip fault in which the hanging wall (block on the upper side of the inclined fault) moves downwards. Normal faults are a result of tensional stress.
    - **Reverse Fault**: It’s a type of dip-slip fault in which the hanging wall moves upwards. It is created by compressional stress.
    - **Thrust faults** are a type of reverse fault in which the fault plane is very inclined with an angle less than 45 degrees (30-25).
  2. **STRIKE-SLIP FAULTS**: They are faults that produce a *horizontal displacement* of the rock block along the *strike* of the rock layer. They are associated with *shear stress*. Transform faults are a type of strike-slip fault:
    - **Right Lateral Fault**: When the block in the opposite side of the...
fault moves to the right.

*Left Lateral Fault*: When the block in the opposite side of the fault moves to the left.

- **JOINTS**: Unlike faults, joints are fractures with *no displacement*.

- **TYPES OF MOUNTAINS**:

  1. *Volcanic mountains*: They are created mostly by igneous activity along subduction zones that produces volcanoes and huge batholiths. An example is the Andes Mountains.
  2. *Fault-block mountains*: They are created by normal faults. An example of such mountains is found in the basin and range province in California and Nevada.
  3. *Fold mountains*: They are created by folded rock layers that form series of anticlines and synclines. An example is the Alps, the Himalayas, the Appalachians, etc.

- **ISOSTASY**: 

  When weight is added to the Earth’s crust, the crust will subside. When the weight is removed from the crust by erosion, the crust will rebound. This process is called *isostatic adjustment*. In the same way, when a material is added to a mountain, it will subside or sink to increase its root to balance the weight added. In the other hand, when a mountain is eroded, the effect will be compensated by uplift, so the mountain will seem to grow more. It is just like weight added to or removed from a series of wooden blocks of different heights floating in water.

**UNIT TWO**  
**SCULPTURING EARTH’S SURFACE**  
*(SURFACE PROCESSES)*

**CHAPTERS 4, 5 & 6**:  
**WEATHERING, SOIL, MASS WASTING/RUNNING WATER & GROUNDWATER/ GLACIERS, DESERTS, and WINDS**

- **LEARNING OBJECTIVES**: Upon completion of this chapter the student should be able to:

  1. Contrast erosion and weathering
  2. Contrast mechanical and chemical weathering
  3. Know the primary agents of chemical weathering
  4. Define soil and soil types
  5. Know the optimum climate for soil production
  6. Know the problems associated with chemical weathering
  7. Know the types and causes of mass wasting
  8. Define an aquifer, types of aquifers, and the water table
  9. Define an artesian well
  10. Know the seafloor topography

The Earth’s surface *destructive processes* can be put in three categories:

- Weathering
- Erosion
- Mass wasting

**CHAPTER – 4: WEATHERING & SOIL**:

It is a process in which a rock is either *mechanically* (physically) or *chemically* disintegrated or decomposed. It is the main geological processes that lead to the formation of sediments and sedimentary rocks.
I - MECHANICAL WEATHERING:

It’s when a rock is broken into small pieces by physical forces, without changes in its mineral composition. Some types of mechanical weathering are:

- **Frost Wedging and Permafrost:** It’s a repeated cycle of freezing and thawing of water inside a rock joints and pores that causes its expansion, cracking, and breakdown.
- **Unloading:** When an overlying rock is eroded, it exposes and releases the pressure over an underlying pluton that begins to expand and peels off, forming onionlike layers (sheeting). It causes slabs of the rock to separate from the rock body, creating exfoliation dome such type of weathering is found in Stone Mt, GA.
- **Thermal Expansion:** Daily extreme variations of temperatures (i.e. in a Desert) cause expansion and contraction of a rock resulting in its breakdown.
- **Biological Activity:** Plants, animals and humans expose rocks to the elements and contribute to its rapid weathering.

II - CHEMICAL WEATHERING:

It consists of chemically decomposing a rock into new material by action of chemical agents such as water. The optimum environment for chemical weathering is a combination of warm temperatures and abundant moisture (i.e. Tropical climate). Water is the most important agent in chemical weathering. The more acidic the water, the quicker the weathering process. The major processes in chemical weathering consist of:

- **Dissolution:** Acidic water dissolves minerals. Acidic water (rich in H+) is created by carbon dioxide and sulfur (CO₂, S) in the atmosphere and rain drops to produce carbonic acid or sulfuric acid. Also, the dissolution in water of carbonate minerals like calcite (CaCO₃) found in limestone and marble, and sulfide minerals like pyrite (FeS₂) found in mined ore deposits, increases water acidity that in turn increases the chemical weathering. Karst topography (caves, caverns, sinkholes, etc...) is the result of the dissolution (chemical weathering) of calcite (CaCO₃) rich terranes.
- **Oxidation:** It’s a reaction of a chemical element with oxygen with loss of electron to the oxygen. In rocks, oxidation attacks mostly Fe and Mg rich minerals such as olivine, pyroxene, amphibole, and biotite, to produce iron oxide minerals (red, brown, or orange in color) such as hematite, limonite, etc... It can be compared to metal rusting. Acid Mine occurs when sulfide minerals exposed by mining activity react with oxygen in the air (oxidation) to produce sulfuric acid and acidic waters that pollute the environment (underground water, and aquatic organisms) with metals. Rocks with Fe and Mg rich minerals (mafic/ultramafic rocks) weather first, and weather into iron oxide rich soil. Rocks with K and Al and silica rich minerals weather last, and weather into clay rich soil.

III - SOIL:

The product of weathered rocks (without humus) is called regolith. Soil is defined as a combination of weathered rocks and organic matter (humus), it also contains water and air. Some factors in soil formation are:

- **Parent material:** It’s the source of the weathered rocks. It can be a bedrock (granite) or unconsolidated sediments
- **Climate:** Hot and wet climate causes heavy chemical weathering and thick soil, cold, and dry climate causes mechanically weathering and little, and little.
- **Plants and Animals:** Heavy vegetation help form soil: Prairie soil, tundra soil, forest soil are types of soil developed under heavy vegetation. Organic matters create organic acid that fastens chemical weathering; it also converts nitrogen of air into organic nitrogen as fertilizer.
- **Slope:** It controls the amount of water in soil, and the amount of soil erosion: Steep slopes create poorly developed and highly eroded soil; flat to undulating upland surface create the best soil development. Soil erodes through wind, ice, and water agents. Plants help reduce soil erosion. Rate of soil erosion depends on climate, slope, and type of vegetation. Soil erosion can transport and deposit sediments and pesticides in draining water reservoir, limiting its capacity and polluting it.
A vertical cross-section of a soil is called soil profile. An ideal soil profile is divided into three main layers:

- **Topsoil**: zone of humus mixed with mineral matter
- **Zone of leaching**: no humus, zone of mineral leaching
- **Zone of accumulation**: Accumulation of clay transported from above.

Depending on the climate, there are three major soil types:

- **Pedocal**: Calcium carbonate rich soil with little or no clay, developed in drier climate with little chemical weathering (i.e. in arid semi arid Western US)
- **Pedalfer**: Soil with accumulation of iron oxide and clay minerals due to intense leaching. It forms brown to red-brown soil due to unleached Fe oxides and clay minerals (i.e. Eastern US)
- **Laterite**: Deep red soil composed essentially of Fe oxide and Al oxides due to very heavy leaching, developed in wet and hot climate (i.e. Tropical regions w/ heavy rainfall)
- **Bauxite formation** (or Aluminum laterite) is an Al rich soil mined to produce Al. It represents the ultimate leaching of Al rich rocks to produce high Al concentration in soil.

**CHAPTER - 6: EROSION (RUNNING WATER, GLACIERS, DESERTS & WIND):**

It is a physical destruction of rocks and sediments by wind, glaciers, streams, waves, and gravity (down slope movement).

**I - STREAM:**

Runoff is surface water that does not infiltrate into the ground, and contributes to stream development. 

*Gradient* of a stream is its slope (vertical drop over a horizontal distance)

Stream Transportation: Part of running water, stream transports sediments as a stream load. It consists of:

- **Dissolved load**: sediments transported as solutions.
- **Suspended load**: Fine sediments carried as suspensions in the upper part of the stream.
- **Bed load**: Heavy sediments transported along the bottom of the stream.

*Competence* of a stream is the maximum size particles it is capable of transporting. *Capacity* of a stream is the maximum load it can carry.

Stream Deposition:

- **Sorting** is a process by which a stream deposits sediments in accordance with their various particle sizes.
- **Alluvium** is a well-sorted material deposited by a stream.

Stream Erosion: Stream erodes by abrasion and dissolution of soluble material. The result of stream erosion is:

- **Narrow V-shaped valley**: It indicates that the erosion is mainly at the stream’s base level, the lower level rock that limits a stream’s erosive power. The ultimate base level of rivers is sea level.
- **Wide Valley**: It indicates that the stream’s erosion is side-to-side resulting in floodplain.
- **Floodplain** designates the widened and flattened valley floor due to side-to-side cutting of a stream.

A stream can twist and turn, following a least resistance path forming a loop called meander. When a stream cuts itself, (cutoff) it isolates water filled meander or oxbow lake.
Flood and Flood Control: Floods can be the result of natural (rain, ice cap melting,) or human induced (dams) factors. There are regional floods, flash floods, ice-jam floods, and dam-failure floods. Floods can be controlled by artificial levees, flood-Control Dams, channelization, and by nonstructural and preventive approaches (zoning regulations, and appropriate land use).

Drainage Basin: It is the part of the land area that provides water to the stream. Drainage basins are separated by a divide. Drainage patterns depends on the slope, they can be either dendritic, rectangular, trellis, or radial.

II - GLACIERS:

They are thick ice masses that form on land over hundred or thousands of years from the accumulation, compaction, and recrystallization of snow.

- **TYPES OF GLACIERS:**
  - Valley glaciers (or Alpine glaciers) are glaciers that form on valley floor. Because glaciers are big and they flow they carry a tremendous corrosive power.
  - Ice Sheets or Continental ice sheets like the Greenland, are large masses of ice sheets.
  - Ice Caps are like ice sheets but much smaller.
  - Piedmont Glaciers occupy broad lowland at the base of steep mountains.

- **TYPES OF GLACIAL MOVEMENT:** Glaciers flow.
  - Plastic Flow: It's a movement of fragments of ice within the glaciers until it reaches a certain weight equivalent of a pressure of 50m, then the whole glacier starts to move.
  - Slipping along the ground. It’s when the lowest portion of the ice sheet under pressure moves along the ground, and the upper part still brittle (called Zone of Fracture) is carried along by "piggyback". Crevasses are cracks resulting from tension in the zone of fracture. Zone of Accumulation refers to the part of the glaciers gains snow due to snowfalls. Zone of Wastage is the part of the glacier that looses snow due to melting.

- **GLACIAL EROSION** works in two ways, by:
  - Plucking: melted water penetrates the rock beneath the glacier, freezes and expands breaking down the rock.
  - Abrasion: By sliding over the rock, the glacier acts like sandpaper, smoothing and polishing the rock surface. Abrasion creates Rock Flour (pulverized rock), it also creates linear scratch on the bedrock called Glacial Striaions.

- **GLACIAL DEPOSITS:** As they move, glaciers transport and deposit eroded material. Such material is called:
  - Glacial Drift: It is composed of:
    - Till: Types of glacial drift deposited directly by glaciers,
    - Stratified drift: Types of glacial drift formed when glaciers melt and deposit their load of sediment.
  - Moraines are landforms made of glacial deposits or till.
  - Lateral moraines: Glaciers deposits on the valley walls.
  - Median moraines: glacial deposits in the center of the valley.
  - End Moraines: Ridge or till that forms at the end of the glacier
  - Ground Moraine: Layer of till deposited when the glacier melts away
  - Outwash Plains: Broad accumulation of stratified drift.
  - Kettle: Occurs when blocks of stagnant ice buried under till melt leaving a depression forming ponds or lakes.
  - Drumlins: Asymmetric hill formed with till.
• **LANDFORMS CREATED BY GLACIAL EROSION:**
  - Glacial Trough is a U-shaped glacial valley
  - Hanging Valleys are valleys of tributary glaciers after the glaciers have receded
  - Cirque is a bowl shaped depression at the head of the glacier
  - Arêtes are sinuous sharp-edged ridges produced by glacial erosion
  - Horn is a sharp pyramid-like peak
  - Fiords are deep steep sided inlets

• **CAUSES OF GLACIATION**
  Ice Age (a glaciation cycle) began 2-3 million years ago (Pleistocene epoch), it occurs every 100,000 years (evidence from marine sediments), and it covers 30% of Earth surface. Sea level fluctuates over 100 meters. Two theories:
  - Plate Tectonics: Glaciation occurs on landmasses that moved to higher latitudes. It does not explain period between glacial and interglacial climates.
  - Shift of Earth Orbit: Changes in the eccentricity, obliquity, and precession.

II - WIND:
• **WIND EROSION:** Wind is relatively a weak erosional agent compared to running water and glaciers. For wind erosion to be very effective dryness and scanty vegetation are needed, it is more effective in arid land than in humid areas. Wind erosion can also be devastating to farming. Remember the dust bowl in the 1930s in the Great Plains. Wind erodes mainly by
  - Deflation: lifting and removal of loose material) creating blowouts (shallow depression due to removal of sediments), and
  - Desert pavement (blowouts covered with coarse-grained sediments). Wind also erodes by
  - Abrasion, which is the smoothing, and polishing of rock surface.

• **WIND DEPOSITS:** Desert landforms such as sand dunes, and crossbeds are one example of the erosive and depositional power of the wind.
  - Loess is a silty type of wind deposit that blankets the desert surface.
  - Sand Dunes are load of sediments (sand) deposited when the wind looses its velocity. Wind direction is oriented toward the steep slope of the sand dune. Wind moves by saltation. Wind forms crossbeds, which are inclined layers of sand.
  - Types of Sand dunes: Sand dunes are consistent patterns of sand deposition that reflect the direction of the wind and abundance of sand.
    - Barcan Dunes: Crescent-like isolated sand dunes that form where supplies of sand are limited.
    - Transverse Dunes: Series of long continuous ridges at right angle to the wind direction. They occur where sand is plenty and wind prevalent.
    - Longitudinal Dunes: Long discontinuous ridges more or less parallel to wind direction. They occur where sand supplies are moderate.
    - Parabolic Dunes: They resemble the barcan dunes except their tips point to the wind direction, and they occur where vegetation partially covers the sand.
    - Star Dunes: They are isolated, star-shaped complex forms of sand dunes. They form where sand supplies are abundant and wind prevalent with variable directions.
    - Barchanoid Dunes: Intermediate type between barchan and transverse dunes.

**CHAPTER – 4: MASS WASTING:**

It is the downslope movement of rocks under the influence of gravity.

I - **CONTROLS AND TRIGGERS OF MASS WASTING**

The causes are:
  - Water is an important catalyst in mass wasting. Most often mass wasting is triggered after heavy rainfall or snowmelts saturate the surface materials, acting as a lubricant.
- Earthquakes are another trigger of mass wasting.
- Oversteepened slopes by waves, and streams trigger mass wasting.
- Removal of vegetation from slope where water is plentiful and the slope steep create soil instability and mass wasting.

II - MASS WASTING PROCESSES:
- Fall: refers to freefall of detached individual pieces of rock of any size
- Slide: When coherent material moves along a well-defined surface (joint, fault, bedding plane)
- Flow: when material move downslope as viscous fluid.

III - TYPES OF MASS WASTING:
- Landslide refers to large blocks of consolidated bedrock (rockslide) or unconsolidated debris (debris slide)
- Slump refers to the sliding of a mass of rock or unconsolidated material along a curved surface.
- Debris flow (mudflows) refers to a rapid type of mass wasting with a flow of soil and regolith with huge amount of water.
- Lahars are a type of mudflows that occur along volcanoes slope. Sheets of pyroclastic flows melt during heavy rainfall or when the volcano’s ice cap melts, generating mudflows or lahars.
- Creep is a slow, gradual (year after year) type of mass wasting usually due to freezing and thawing, or wetting and drying of the rocks that over time, generate instability.

CHAPTER – 5: GROUNDWATER:

I – GROUNDWATER CHARACTERISTICS:

It’s the water that soaks into the ground where it occupies open spaces within sediments and rocks.
- Aquifer: Permeable rocks or sediments that store and transmit groundwater, (i.e. sand, gravel)
- Aquitard: Impermeable rocks or sediments that retain and shield water from movement, (i.e. clay)

- Porosity: Voids and openings (faults, joints, cavities, vesicles,...) in sediments and rocks. The degree of sorting, packing, amount of cement material in sediments affect porosity. The quantity of groundwater that can be stored in a rock depends on the porosity of that rock. Porosity is a storage capacity of a rock.
- Permeability: Ability to transmit fluid. A permeability of a rock is the ability of that rock to allow groundwater to flow. Pores of a rock need to be connected to allow permeability. It is the most decisive factor in term of how much groundwater is available.
- Zone of saturation: Zone of open spaces filled with groundwater. The water table is the upper limit of the zone of saturation, or groundwater
- Zone of aeration: Unsaturated zone located above the zone of saturation or groundwater.
- Capillary fringe: Zone between the saturation and the aeration zones where water is mainly held by surface tension of the rock’s particles
- Specific yield: Amount of groundwater free to moves under gravity. This is the usable groundwater
- Specific retention: Amount of groundwater bound to the rock particles and does not circulate. It’s the unusable groundwater
  i.e.: clay has high porosity but low permeability because of its high specific retention, low specific yield.
- Zone of recharge: Area where the groundwater is replaced (top of the aquifer)
- Zone of discharge: Area where the groundwater is running off (i.e. stream, rivers,)
II - GROUNDWATER MOVEMENT: Darcy's law

Groundwater moves mainly under the influence of gravity (water table slope or hydraulic gradient) expressed by Darcy’s law:

\[ Q = K \times A \times (h_1 - h_2) / d \]

\( Q \) = discharge or volume of water flowing at a section of an aquifer per unit of time;

\( K \) = hydraulic conductivity

\( A \) = a given cross section of an aquifer where the discharge is measured

\( h_1 - h_2 \) = the head (difference between recharge and discharge elevation points)

\( d \) = length of flow (distance between the two discharge and recharge elevation points)

Hydraulic gradient: It’s the water table slope = \( h_1 - h_2 / d \)

- **Springs:**
  - **Hot Spring:** 6-9 degrees C warmer than local waters, Source of heat indicative activity
  - **Geysers:** Intermittent columns of hot waters ejected with pressure; geysers are located in volcanic areas
    where circulating underground water comes in contact with heat from a magma chamber, ex: Yellowstone National Park;
    Geyser or hot-spring waters can dissolve and precipitate silica rich rock (siliceous sinter), or calcium rich rock (travertine or calcareous tufa).

- **Wells:** It’s a hole bored from the surface to the zone of saturation;
  - **Drawdown:** Lowering of the watertable due to withdrawing water from the well, it creates a cone shaped depression of the water table (cone of depression)
  - **Artesian well:** A type of well in which groundwater under pressure rises up freely above the level of the aquifer due to hydraulic pressure. To produce an artesian well, an aquifer must be:
    - Inclined (so the pressure can exist between the two ends)
    - Limited by two aquitards (impermeable layers)
    - Also the pressure surface must be above ground level to produce a flowing well.

  - **Artesian spring:** Artesian system where water flows through a spring, not a well.

III - GROUNDWATER AND ENVIRONMENTAL ISSUES:

Groundwater must be treated as a nonrenewable resource, which it is in many desertic regions, where exists fossil aquifer due to absence of recharge. When the discharge largely exceeds the recharge, problems can arise such as:

- **Land Subsidence:** When the pressure on the land is not supported by the aquifer anymore due to heavy groundwater withdrawal;

- **Karst Topography:** Topography resulting from groundwater activity in soluble sediments or rock formation rich in calcium carbonate such as limestone, the results are:
  - **Caverns, and Sinkholes:** Underground depression due to erosion from underground water
  - **Stalactites:** Dripstone features pointing downward due to gradual dissolution of the rock
  - **Stalagmites** Dripstone pointing upward due to gradual dissolution of the rock

- **Salt water Contamination:** Where groundwater meets seawater, especially in coastal regions or areas with paleo-oceanic sediments, saltwater contamination may occur if extensive groundwater withdrawal exceeds recharge.

- **Pollution Contamination:** Contamination by sewage from septic tanks and other sewage systems; Industrial chemical pollutants from the oil, mining, pharmaceutical, nuclear, manufacturing, and agricultural industries, as well as landfills, pose serious problems to the drinking water.
UNIT FOUR  
DECIPHERING EARTH’S HISTORY

CHAPTERS - 11 & 12  
GEOLOGICAL TIME/EARTH’S HISTORY

- LEARNING OBJECTIVES: Upon completion of this chapter, the student should be able to:
  1. Contrast relative dating and absolute dating
  2. Know the principles in relative dating
  3. Define half-life
  4. Know the age of the Earth
  5. Significance and age of the K-T boundary

CHAPTER – 11:  
GEOLOGICAL TIME

Geological time is a method of ordering and measuring past geological events. There are two methods:

I - RELATIVE DATING:

Events are placed in their proper sequence, order of formation, without knowing their absolute occurring date. Among other tools, relative dating uses fossils that remnants of prehistoric life preserved in a rock. Fossils can be used to correlate rock formations. Here are some principles used in relative dating.

- **Principle of Superposition**: In an undeformed sequence of sedimentary rocks layers or lava flows, each layer is older than the one above it and younger than the one below it.

- **Principle of faunal succession**: Fossils organisms succeed one another in a definite and determinable order, and therefore, any time period can be recognized by its fossil content.

- **Principle of cross-cutting relationship**: Any rock such as igneous intrusion is younger than the rock it cuts.

- **Inclusions**: Any rock fragment such as pebbles is older than the rock that contains it.

- **Deformation**: Any rock affected by a deformation event like folding or tilting must be older than the deformation episode itself.

- **Unconformities**: Rocks layers that have been deposited without interruption are called conformable. Unconformities represent sites that exhibit span in geological time. There are:
  - **Angular Unconformity**: Tilted or folded sedimentary rocks overlain by younger horizontal layers.
  - **Disconformity**: It represents a missing sequence or rocks due to erosion or non-deposition.
  - **Nonconformity**: Characterized by a break that separates old underlying metamorphic or igneous intrusive rocks with younger overlying sedimentary layers.

I Correlation of rock layers: It is matching rocks of similar age in different regions. It often relies upon fossils.

Types of fossils:

1. **Petrified**: Cavities and pores are filled with precipitated mineral matter
2. **Formed by replacement**: Cell material is removed and replaced with mineral matter
3. **Mold**: Shell or other structure is buried and then dissolved by underground water
4. **Cast**: Hollow space of a mold is filled with mineral matter
5. **Carbonization**: Organic matter becomes a thin residue of carbon
6. **Impression**: Replica of the fossil’s surface preserved in fine-grained sediment
7. **Preservation in amber**: Hardened resin of ancient trees surrounds an organism
8. **Indirect evidence**: When only hints of the fossil existence can be found. They include:
   - Tracks
   - **Burrows**
   - **Coprolites**: Fossil dung and stomach contents
   - **Gastroliths** – stomach stones used to grind food by some extinct reptiles

Conditions favoring fossil preservation

- **Rapid burial**: The fossil has to be buried as soon it dies.
- **Possession of hard parts**: Hard parts give the best preservation.
Index fossils are time indicators fossils, and useful for paleo-environmental reconstruction.

1. They are widespread geographically
2. They existed for a short range of geologic time. i.e. clam shell in limestone indicates shallow water environment; Coral indicates warm shallow tropical sea, like Florida and Bahamas.

II - ABSOLUTE DATING:

It’s a precise dating method that is able to generate an age in years using the decay with time of radioactive elements. It is the most used dating method for ages between 100 and 4500 My.

1. Radioactivity:
   2. **Radioactive decay:** It is the spontaneous breaking apart (decay) of atomic nuclei
   3. **Parent:** It’s an unstable isotope that decays.
   4. **Daughter products:** They are isotopes formed from the decay of a parent

2. Types of radioactive decay:
   - **Alpha emission:** emission of 2 neutrons and 2 protons (mass reduced by 4 and charge by 2)
   - **Beta emission:** emission of an electron from nucleus (mass unchanged)
   - **Electron capture:** electron + proton form 1 neutron (mass is unchanged)

**Half-life.** Refers to the time needed for a parent material to decay half of its mass. It is the rate of radioactive disintegration. The older a rock, the greater the ratio daughter/parent radionucleides.

**Carbon-14 dating:** It is used to date very recent events. Its has a Half-life of only 5730 years. Carbon-14 is produced as a result bombardment of nitrogen-14 gas by cosmic radiation. It is converted into Carbon dioxide in atmosphere.

Some conditions must be satisfied for radiometric dating to be possible.
1. The rock should be a close system (no addition or loss of parent or daughter radionucleide since the formation of the rock), i.e. K-Ar method error, weathering...
2. The age of the rock should not differ too much from the half-life of the parent radionucleide.
3. No daughter element present in the rock when it formed.

**Major radionucleides used for Radiometric dating:**
- C-14, N-14 for living organisms
- For rocks and minerals
  - Potassium -40, Argon- 40
  - Uranium -235, Lead-207
  - Uranium-238, Lead-206
  - Thorium-232, Lead-208
  - Rubidium-87, Strotium-86

CHAPTER – 12: EARTH’S HISTORY

It was originally developed using relative dating, then refined after, with the radiometric absolute dating. The Earth is 4.6 billion years old and its history is divided into Eon, Era, Period, and Epoch.

1. **Precambrian era**
   - It spans from 4.6 billion to 540 million years
   - It represents 88% of Earth's history
   - Most Precambrian rocks are devoid of fossils, due to intense volcanic and tectonic activity. As a result, only a sketchy knowledge is available about life in that era
     1. **Precambrian rocks**
     - Most Precambrian are buried from view by overlying younger rock formations
     - They form a "core area" of Precambrian rocks called a **shield or craton**
     - They contain extensive iron ore deposits that are mined, however no fossil fuels deposits are found in them
     2. **Earth's Precambrian atmosphere**
     - Precambrian era is characterized by a **Primitive atmosphere** formed from volcanic gases from a process called outgassing that produced water vapor, carbon dioxide, nitrogen, and several trace gases There was very little free oxygen available.
- Water vapor condenses and forms primitive oceans as Earth cools from igneous activity
- Bacteria evolves
- Plants evolve and photosynthesis produces oxygen
- Oxygen content in the atmosphere increases as a result of photosynthesis and a slowing of iron oxide deposits formation
- Then, by about 4 billion years after Earth formed, abundant ocean-dwelling organisms that require oxygen appear, at the turn the Precambrian era

3. **Precambrian fossils**
- The most common fossils characteristic of the Precambrian era are *stromatolites*. They represent material deposited by algae. They abounded around 2 billion years ago
- *Microfossils of bacteria* and algae have been found in chert in several locations
  a. Southern Africa (3.1 billion years of age)
  b. Lake Superior area (1.7 billion years of age)
- *Plant fossils* are also found associated with the middle Precambrian, and *animal fossils*, with the late Precambrian
- By the close of the Precambrian (beginning of Paleozoic era), diverse and *multicelled organisms* appear

II. **Paleozoic era**
- It spans from 540 million years to about 248 million years
- It is characterized by the abundance of fossils and the appearance of the *first life forms with hard parts*

4. **Early Paleozoic history**
- Southern continent of Gondwanaland exists
- North America emerges from sea, however, it was a barren lowland and seas move inland and recede several times and shallow marine basins evaporate leaving rock salt and gypsum deposits
- A mountain building episode known as the Taconic orogeny, affected eastern North America

5. **Early Paleozoic life (invertebrates dominant)**
   The dominant life form was *invertebrates*.
   - They were sea dwelling organisms (restricted to seas)
   - Vertebrates had not yet evolved
   - They consisted in several *invertebrate groups* that are:
     a. *Trilobites*
     b. *Brachiopods*
     c. *Cephalopods*
   - They were the *first organisms with hard parts*, such as shells (perhaps for protection)

6. **Late Paleozoic history**
   - Formation of the Supercontinent Pangaea (All landmasses were connected into one continent).
   - Several mountain belts formed during the movements of the continents
   - The world’s climate becomes very seasonal, causing the dramatic *extinction of many species*

7. **Late Paleozoic life: (Fishes and amphibians were dominant).**
   - Organisms became diversified dramatically
   - *Land plants* appear
   - *Fishes* evolve into two groups of bony fish
     a. *Lung fish*
     b. *Lobe-finned fish that become the amphibians*
   - *Insects* invade the land
   - *Amphibians* diversify rapidly
   - Extensive *coal swamps* develop that will lead to *coal, oil, and gas deposits*.

III. **Mesozoic era**
- It spans from 248 million years to about 65 million years
- It is often called the *“age of dinosaurs”*, because dinosaurs were the dominant species of that era.

8. **Mesozoic history**
- It begins with *much of the world’s land above sea level*
- Seas invade western North America
- Breakup of Pangaea begins with the opening of the Atlantic Ocean
- North American plate began to override the Pacific plate
Mountains of western North America began forming. *Mesozoic life*: Dinosaurs, reptiles, and birds were the dominant life forms.
- Most were survivors of the great Paleozoic extinction
  - Gymnosperms become the dominant trees
  - Reptiles (first true terrestrial animals) readily adapt to the dry Mesozoic climate
  - Reptiles have shell-covered eggs that can be laid on the land
  - Dinosaurs became the dominant specie
  - One group of reptiles evolved into birds
  - Dinosaurs, and many reptile groups, along with many other animal groups, become **extinct at the close of the Mesozoic**, 65 million years ago. Two hypotheses:
    a. A large asteroid or comet struck Earth at the Yucatan peninsula
    b. Another possibility is **extensive volcanism that clouded the atmosphere with ash and changed the Earth's climate.**

IV. **Cenozoic era**
- It spans from 65 million years ago to the present
- It is often called the "age of mammals"
- Represents a smaller fraction of geologic time than either the Paleozoic or the Mesozoic
- **In North America**
  1. Most of the continent was above sea level throughout the Cenozoic era
  2. There were many tectonic events of mountain building with volcanism, and earthquakes, in the West
  3. In Eastern North America
     a. Stable with abundant marine sedimentation
     b. Eroded Appalachians were raised by isostatic adjustments
  4. Western North America
     a. End of the Rocky Mountains formation episode
     b. As a result, a whole region is uplifted
        1. The Basin and Range Province (west coast) formed
        2. It re-elevates the Rockies
        3. Rivers erode and form gorges (e.g., Grand Canyon and Black Canyon)
     c. Volcanic activity is common
        1. Fissure eruptions form the Columbia Plateau
        2. Volcanoes form from northern California to the Canadian border
     d. Coast Ranges form
     e. The Sierra Nevada formed as fault-block mountains

10 **Cenozoic life**
- **Mammals** replace reptiles as the dominant land animals
- Angiosperms (flowering plants with covered seeds) dominate the plant world
  - It strongly influenced the evolution of both birds and mammals, as it became the main food source for both birds and mammals
  - Two groups of mammals evolve after the reptilian extinctions at the close of the Mesozoic
    a. Marsupials
    b. Placentals
  - Mammals diversify quite rapidly and some groups become very large, many large animals became extinct
  - Humans evolve.

Some important dates in Earth’s history are:
4600 My (Hadean Eon) Age of the Earth and the Solar system
3600 My (Precambrian Era)- The earliest life form
540 My (Cambrian Period)- First organisms with shells
200 My (Mesozoic Era)- Break up of the Super Continent Pangaea
65 My (K-T: Cretaceous - Tertiary boundary) Disappearance of Dinosaurs
1.6 My (Quaternary period) - Earliest Humans
PART – II: OCEANOGRAPHY

UNIT FIVE THE GLOBAL OCEAN

CHAPTER -13: THE OCEAN FLOOR

1. Describe the extent of the world ocean.
2. Describe the features associated with both passive and active continental margins.
3. List and describe the major topographic units of the ocean basin floor.
4. Discuss the general structure of mid-ocean ridges.
5. Describe how each of the three broad categories of seafloor sediments originates and the association between seafloor sediments and climate change.
6. List several resources obtained from the seafloor.

I – THE WORLD OF OCEANS:
Oceans represent 70% of Earth surface and 97% of Earth waters. 90% of the world population relies on groundwater for drinking, yet groundwater represents less than 1% of earth’s waters. Water, water everywhere, not a drop to drink. There are four major oceans:
- **Pacific Ocean**: The largest with the most tectonically ocean floor and continental margins. Also the deepest (13,000 feet on average)
- **Atlantic Ocean**: Half the size of the Pacific with passive continental margins.
- **Indian Ocean**: Smaller than the Atlantic with the same average depth.
- **Arctic Ocean**: Less than 10% the size of the Pacific and 25% its depth.

II - OCEAN FLOOR TOPOGRAPHY:
Ocean exploration did gain much attention compared to space exploration. But it’s a vast realm than can be as intriguing and exciting to study as the solar system.
- **Bathymetry**: Measurement of ocean depth. It was made possible with the development of new techniques based on sonar (Sound Navigation and Ranging), like
- **Echo Sounders**: Sound waves sent from a ship or a satellite bounces off the ocean floor and help determine the ocean depth and ocean floor topography.

Three major units form the sea floor topography: Continental margin, Deep-ocean basin, and Mid-ocean ridge.

- **CONTINENTAL MARGINS**: They are divided into:

  **Passive Margin**: It is not associated with plate boundaries, it is not tectonically active; it has weathered material from continents: i.e. around the Atlantic Ocean; It is divided into:
  - **Continental Shelf**: Submerged part of the continent
  - **Continental Slope**: Deep slope marking the boundary between continental crust and oceanic crust
  - **Continental Rise**: Where the continent gently declines toward the sea

  **Active margins**: They are associated with plate tectonic boundaries and are tectonically active (earthquakes and volcanism); they have highly deformed sediments; ex: around the Pacific Ocean;
  - **Accretionary Wedge**: Triangle-shaped border along the subduction zone, between continent and ocean, where sediments accumulate.

- **DEEP-OCEAN BASINS**: They lie between the continental margin and the Ocean ridge; It comprises:

  - **Deep-Ocean Trenches**: Deep linear structures formed by plate subduction; Mostly located in the Pacific Rim; the deepest trench is the Mariana trench 11km deep
  - **Abyssal plains**: Flat sediments covered areas with little or no topography, mostly in the Atlantic Ocean.
Sea-Floor Sediments:
- Terrigenous Sediments (weathered from the continents, i.e. sand);
- Biogenous Sediments (from marine organisms, i.e. limestone);
- Hydrogenous Sediments (direct precipitation from seawater, i.e. manganese nodules).

- Seamounts: They represent volcanic peaks mostly located within ocean ridges.

Guyots: Are flat-topped seamounts, remains of eroded volcanic islands.
Atolls: Coral Island associated with the sinking of oceanic crust.

• MID-OCEAN RIDGE: It’s the longest topographic structure on Earth, 70,000km long, 3,000km large, and 3km high. The ridge is offset by transform faults. It contains deep faulted segments called rift valleys.

Hydrothermal vents represent chimneys-like structures that produce thick and minerals rich dark clouds of hot poisonous gases known as black smokers. These black smokers are responsible of some economic concentrations of metal rich sulfide minerals known as volcanic massive sulphides (VMS) associated with submarine volcanism.

CHAPTER - 14 - OCEAN WATER & OCEAN LIFE:

I – COMPOSITION OF SEAWATER:
Seawater consists of about 3.5% (by weight) dissolved minerals (3.5 per mill = 3.5g/kg)
A. Salinity is the ratio of mass of dissolved material to the mass of the water sample.
   The average salinity is 35‰. (the Dead Sea has 330 per mill). Major constituent is sodium chloride
B. Sources of sea salts
   1. Chemical weathering of rocks
   2. Outgassing – gases from volcanic eruptions
C. Processes affecting seawater salinity
   Variations in salinity are a consequence of changes in the water content of the solution
   1. Processes that decrease seawater salinity (add water)
      a. Precipitation
      b. Runoff from land
      c. Icebergs melting
      d. Sea ice melting
   2. Processes that increase salinity (remove water)
      a. Evaporation
      b. Formation of sea ice (salt will not become part of the ice)
4. Surface salinity in the open ocean ranges from 33‰ to 38‰

II. OCEAN TEMPERATURE
A. Surface water temperature varies with the amount of solar radiation received
   1. Lower surface temperatures are found in high-latitude regions (Poles)
   2. Higher temperatures found in low-latitude regions (Tropics)
B. Temperature variation with depth
   1. Low-latitudes regions (Tropics) have:
      a. High temperature at the surface
      b. Rapid decrease in temperature with depth (called Thermocline)
   2. High-latitudes (Poles) have:
      a. Cooler surface temperatures
      b. No rapid change in temperature with depth
C. Ocean temperature over time
   The unique thermal properties of seawater make it resistant to temperature changes but Global warming could eventually influence ocean temperatures
III. OCEAN DENSITY
A. Density is mass per unit volume - how heavy something is for its size
B. Determines the water’s vertical position in the ocean.
C. Factors affecting seawater density
   1. Salinity
   2. Temperature - the greatest influence (because it influences salinity)
D. Variations with depth
   1. Low-latitudes (Tropics)
      a. Low density at the surface
      b. Density increases rapidly with depth (called pycnocline) because of colder water at depth
   2. High-latitudes (Poles)
      a. High-density (cold) water at the surface
      b. Little change in density with depth
E. Ocean layering
   1. Layered according to density
      - Low-density water near the ocean surface
      - High-density water below
   2. Three-layered structure only in low latitudes (Tropics) not in high-latitudes (Poles)
      a. Surface mixed zone
         1. Sun-warmed zone
         2. Zone of mixing
         2. Shallow (300 meters)
      b. Transition zone
         1. Between surface layer and deep zone
         2. Thermocline and pycnocline
      c. Deep zone
         1. Sunlight never reaches this zone
         2. Temperatures are just a few degrees above freezing
         3. Constant high-density water
   3. Three-layer structure does not exist in high latitudes

IV. OCEAN LIFE
A. Marine environment is inhabited by a wide variety of organisms
B. Most organisms live within the sunlight surface waters (zone of photosynthesis)
C. Classification of marine organisms depends on where they live and how they move
   1. Plankton (that drift w/ ocean currents, they represent most Earth biomass)
      a. Algae (Plants are phytoplankton)
      b. Animals (Animals are zooplankton; diatoms)
      c. Bacteria
   2. Nekton (swimmers)
      a. All animals capable of moving independently of the ocean currents (fish, marine mammals and reptiles.)
      b. They are unable to move throughout the breath of the ocean, higher water depth limit their movement
   3. Benthos (bottom dwellers)
      a. They are organisms that live on or in the ocean bottom
      b. A great number of species exist on the shallow coastal floor
      c. Most live in perpetual darkness in deep water
D. Marine life zones
   1. Several factors are used to divide the ocean into distinct marine life zones
      a. Availability of light
         1. Photic (light) zone
            Upper part of ocean exposed to sunlight. Euphotic zone is the portion of the photic zone near the surface where the light is strong
            - Phytoplankton use sunlight to produce food
            - Different wavelengths of light are absorbed at different depths
2. **Aphotic** (without light) zone
   a. Deep ocean
   b. No sunlight

b. **Distance from shore**
1. Intertidal zone: area where land and ocean meet and overlap
2. Neritic zone: seaward from the low tide line, the continental shelf out to the shelf break
3. Oceanic zone: beyond the continental shelf

c. **Water depth**
   1. Pelagic zone – Open Ocean of any depth
   2. Benthic zone – includes any sea-bottom surface
   3. Abyssal zone – a subdivision of the benthic zone
      a. Deep
      b. Extremely high water pressure
      c. Low temperatures
      d. No sunlight
      e. Sparse life
      f. Food sources
         - Decaying particles from above
         - Large fragments falling
         - Hydrothermal vents

**V. OCEAN PRODUCTIVITY**

A. **Related to primary productivity**
   1. The amount of carbon fixed by organisms through the synthesis of organic matter
   2. Sources of energy
      a. Photosynthesis (solar radiation)
      b. Chemosynthesis (chemical reactions)
   3. Influenced by
      a. Availability of nutrients
      b. Amount of solar radiation
   4. Most abundant marine life exists where there is ample
      a. Nutrients, and
      b. Good sunlight

B. **Productivity in polar oceans**
   1. Because of nutrients rising from deeper water, high-latitude surface waters have higher nutrient concentrations
   2. Low solar energy limits photosynthetic productivity

C. **Productivity in tropical oceans**
   1. Low in the open ocean
   2. Thermocline eliminates the supply of nutrients from deeper waters below

D. **Productivity in temperate oceans**
   1. Winter
      a. Low productivity
      b. Days are short and sun angle is low
   2. Spring
      a. Spring bloom of phytoplankton is quickly depleted
      b. Productivity is limited
   3. Summer
      a. Strong Thermocline develops so surface nutrients are not replaced from below
      b. Phytoplankton population remains relatively low
   4. Fall
      a. Thermocline breaks down and nutrients return to the surface
b. Short-lived fall bloom of phytoplankton
E. Highest overall productivity occurs in temperate regions

VI. OCEAN FEEDING RELATIONSHIP
A. Main oceanic producers
   1. Marine algae
   2. Plants
   3. Bacteria
   4. Bacteria-like archaea
B. Only a small percentage of the energy taken in at any level is passed on to the next
C. Trophic levels
   1. Chemical energy stored in the mass of the ocean’s algae is transferred to the animal community mostly through feeding
   2. Each feeding stage is called a trophic level
D. Transfer of energy between trophic levels is very inefficient (about 2%)
E. Food chains and food webs
   1. Food chain - a sequence of organisms through which energy is transferred
   2. Food web
      a. Involves feeding on a number of different animals
      b. Animals that feed through a food web rather than a food chain are more likely to survive

CHAPTER – 15: THE DYNAMIC OCEAN:

1. List the factors that influence surface ocean currents.
2. Discuss the importance of surface ocean currents.
3. Describe deep-ocean circulation.
4. Describe wave characteristics and types.
5. Describe wave erosion and the features produced by wave erosion.
6. Discuss shoreline erosional problems and solutions.
7. Explain the differences between an emergent and submergent coast.
8. Discuss the factors that influence tides.
9. Describe the monthly tidal cycle, tidal patterns, and tidal currents.

The ocean circulation patterns are the result of the atmospheric circulation patterns (winds), the Coriolis effect, and the effect of the moon and the sun tides. Ocean motion can be divided into three types that are currents, waves, and tides.

I. Ocean water movements
   A. Surface circulation

   1. Ocean currents are masses of water that flow from one place to another
   2. Surface currents are created from friction between the ocean water and the wind that blows across the surface of the ocean
   3. Huge, slowly circular moving currents or gyres develop as a result

   There are five main gyres related to atmospheric circulation (wind).

   a. North Pacific Gyre
   b. South Pacific Gyre
   c. North Atlantic Gyre
   d. South Atlantic Gyre
   e. Indian Ocean Gyre
As they circulate, the Coriolis effect, as a consequence of the Earth rotation, deflects the gyres:

- Gyres in the Northern Hemisphere are deflected to the right
- Gyres in the Southern Hemisphere are deflected to the left

There are four main ocean currents within each gyre (see map).

The main result of surface currents is to affect climate:

- Currents that flow from low latitudes (equator) into higher latitudes (poles), warm currents, transfer heat from warmer to cooler areas
- The influence of cold currents is most pronounced in the tropics or during the summer months in the middle latitudes

B. Upwelling

- It is the rising of cold water from depth as a result of temperature difference in the ocean layers
- It is most prevalent and characteristic along west coasts of continents
- It brings greater concentrations of dissolved nutrients to the ocean surface

C. Deep-ocean circulation (Thermohaline circulation)

1 It develops in response to density difference between cold salty, and dense waters in the poles, and warm, less salty, and less dense waters in the Equatorial regions
2 Factors creating a dense, and salty mass of water
   - Temperature: cold water is denser than warm water
   - Salinity: density increases with increasing salinity
3 It moves cold waters from the poles to the equator, and warm waters from the equator to the poles in every 500 to 2000 years.
4 It is believed to be responsible of global climate changes.
5 A simplified model of ocean circulation is similar to a conveyor belt that travels from the Atlantic Ocean, through the Indian and Pacific Oceans and back again

D. Waves

1 Waves represent energy traveling along the interface between ocean and atmosphere
2 Waves are created by winds that move from high pressure regions (polar) to the low pressure regions (equatorial)
3 Wave characteristics
   a. Crest (highest part)
   b. Trough (lowest part)
   c. Wave height – the distance between a trough and a crest
   d. Wavelength – the horizontal distance between successive crests (or troughs)
   e. Wave period – the time interval for one full wave to pass a fixed position
1 Wave height, length, and period depend on
   a. Wind speed
   b. Length of time the wind blows
   c. Fetch – the distance that the wind travels
2 As the wave travels, the water passes energy along by moving in a circle
   a. Waveform moves forward
   b. At a depth of about one-half the wavelength, the movement of water particles becomes negligible (the wave base)
II. **Beaches and shoreline processes**

**A. Beaches are composed** of whatever material is available, mineral material from erosion, biological material (shell fragments, etc.), some beaches from volcanic islands show a dark sand from their dominant basaltic rock
- Some beaches have a significant biological component, mainly shell fragments
- Beach material does not stay in one place

**B. Wave erosion**

3. It is minimal during calm weather, but maximal during storm weather
4. It is caused by
   a. Wave impact and pressure on the beach
   b. Wave erodes mainly by *abrasion*, by grinding the beach rocks into rock fragments
1. Abrasion breaks down rock material and supplies sand to beaches

**C. Wave refraction**

a. It is the bending of waves as they reach the shore
b. Wave arrives parallel to shore
   - Wave energy is concentrated against the sides and ends of headland
   - Wave erosion straightens an irregular shoreline

**E. Longshore transport**

Sand is transported in two ways along the beach:
   a. *Beach drift*: It moves sediment in a zigzag pattern along the beach
   b. *Longshore current*
      - It is the current in the surf zone
      - Flows parallel to the shore and moves sediment parallel to the shoreline
      - Moves substantially more sediment than beach drift

III. **Shoreline features**

They are the result of erosion and deposition

**A. Erosional features**

2. Wave-cut cliff
3. Wave-cut platform
4. Marine terraces
5. Associated with headlands
   a. Sea arch
   b. Sea stack

**B. Depositional features**

1. Spit: a ridge of sand extending from the land into the mouth of an adjacent bay with an end that often hooks landward
2. *Baymouth bar*: a sand bar that completely crosses a bay
3. Tombolo: a ridge of sand that connects an island to the mainland
4. Barrier islands
   a. They are found mainly along the Atlantic and Gulf Coastal Plains (flat and gently sloping coastline)
   b. They are parallel to the coast
   c. Originate in several ways

IV. **Stabilizing the shore**

Shoreline erosion is a natural hazard that is less destructive, and more predictable than earthquakes or volcanoes.

**A. Shoreline** erosion is influenced by local factors such as

1. Proximity to sediment-laden rivers
2. Degree of tectonic activity
3. Topography and composition of the land
4 Prevailing wind and weather patterns
5 Configuration of the coastline

B. Responses to erosion problems
1 Hard stabilization: Structures built to protect the shoreline from erosion. They are:
   a. Groin: It is a barrier built at right angle to the coast to trap sand moving parallel to the shore
   b. Breakwaters
      - They are barriers built offshore and parallel to the coast
      - They protect boats from the force of large breaking waves
   c. Seawalls
      - They are also built parallel to the shoreline
      - They armor the coast against the force of breaking waves
      - They stop waves from reaching the beach areas behind the wall
   Often these structures are not effective. Some alternatives to hard stabilization are used.
      a. Beach nourishment: Adding sand to the beach system
      b. Relocating buildings away from beach

C. Erosion problems along U.S. Coasts
Shoreline erosion problems are different along the Atlantic and Pacific Coasts due mainly to the fact that the East Coast is a passive margin (not uplifted) and the Pacific Coast is an active margin (uplifted and less prone to waves erosion).
2 Along the Atlantic Coast (submergent coast)
   a. Real estate development occurs mainly on barrier islands causing more erosion problems
   b. Because it is flat and has large, wide open to the sea, it faces the full force of storms, and tides which create more erosion
   c. Development has taken place more rapidly than our understanding of barrier island dynamics
3 Pacific Coast (emergent coast)
   a. It is characterized by relatively narrow beaches backed by steep cliffs and mountain ranges (uplifted)
   b. The major problem is the narrowing of the beaches which put the cliffs at the wave’s reach
      - Dams and reservoirs interrupt incoming sediment that would nourish the beaches
      - Rapid erosion occurs along the beaches

V. Coastal classification
The classification based on changes with respect to sea level
A. Emergent coast
4 The coast rises well above sea level due to
   a. Uplift of the land, or
   b. A drop in sea level
5 Features of an emergent coast are
   a. Wave-cut cliffs
   b. Marine terraces

B. Submergent coast
6 They are irregular and low-lying coastline due to
   a. Land adjacent to sea subsides, or
   b. Sea level rises and floods the coast
7 Features of a submergent coast
   a. Highly irregular shoreline
   b. Estuaries (drowned river mouths) are common

VI. Tides
A. They represent changes in elevation of the ocean surface
B. They are caused by the gravitational forces exerted upon the Earth by the
   a. Moon, and to a lesser extent by the
   b. Sun
A. Monthly tidal cycle
8 Spring tide
a. It occurs during new and full moons  
b. Sun and Moon gravitational forces are added together  
c. It has especially high and low tides  
d. It has large daily tidal range  

9 **Neap tide**  
a. It occurs at first and third quarters of the Moon  
b. When Sun and Moon gravitational forces are offset  
c. The resulting daily tidal range is least  

D. **Tidal patterns**  
10 Many factors influence the tides  
a. Shape of the coastline  
b. Configuration of the ocean basin  
c. Water depth  
11 Main tidal patterns are  
a. Diurnal tidal pattern  
  - Produces a single *high and low* tide each tidal day  
  - Occurs along the northern shore of the Gulf of Mexico  
b. Semidiurnal tidal pattern  
  - Produces two *high and two low* tides each tidal day  
  - There is little difference in the high and low water heights  
  - Common along the Atlantic Coast of the U.S.  
c. Mixed tidal pattern  
  - Produces *two high and two low* tides each tidal day  
  - There is a large inequality in high water heights, low water heights, or both  
  - It is prevalent along the Pacific Coast of the U.S.  
12 **Tidal currents**  
a. It is the horizontal flow accompanying the rise and fall of tides  
b. Types of tidal currents  
  - Flood current: When seawaters advance into the coastal zone  
  - Ebb current: When seawaters move back to the ocean  
c. Tidal deltas are deposits created by tidal current. They can be either  
  - Flood deltas as a result of flood current, or  
  - Ebb deltas, as a result of ebb current
PART-III: METEOROLOGY

UNIT SIX: EARTH DYNAMIC ATMOSPHERE

CHAPTER – 16: COMPOSITION AND STRUCTURE

I. WEATHER AND CLIMATE
   A. Weather
      Weather is defined as an atmospheric condition over a short period of time. Example today’s weather in Lake City. It is constantly changing as daily atmospheric conditions vary
   B. Climate
      Climate is defined as an average atmospheric condition over a long period of time. Example, Florida’s climate.
      Climate is a generalized, composite of weather (average weather of a location).
   C. Elements of weather and climate
      These are physical properties that are measured regularly and help define the atmospheric conditions at that time.
      The most important elements that are measured are:
      a. Air temperature
      b. Humidity
      c. Cloudiness
      d. Precipitation
      e. Air pressure
      f. Wind speed and direction

II. COMPOSITION OF THE ATMOSPHERE
   A clean, dry air is a mixture of discrete gases that are:
   1. Nitrogen (N): 78%
   2. Oxygen (O₂): 21%
   3. Argon and other gases
   4. Carbon dioxide (CO₂): 0.036%. Although in small amount, it plays an important role,
      It absorbs heat energy from Earth
   There are also variable components of air
   1. Water vapor
      Up to about 4% of the air’s volume. It play important roles in the atmosphere:
      - Forms clouds and precipitation
      - Absorbs heat energy from Earth
   2. Aerosols
      a. They are tiny solid and liquid particles suspended into the air
      b. They help water vapor condense
      c. Aerosols also reflect sunlight and help color sunrise and sunset
   3. Ozone
      a. It is a gas formed from three oxygen atoms (O₃)
      b. The distribution of the ozone is not uniform in the atmosphere
      c. It is concentrated between 10 to 50 kilometers above the Earth surface
      d. It plays an important role by absorbing harmful UV (ultraviolet) radiation that can cause cancer
      e. Human activity is depleting ozone by adding chlorofluorocarbons (CFCs) to the air

III. STRUCTURE OF THE ATMOSPHERE
   A. Pressure changes
      1. Pressure is simply the weight of the column of air above
      2. The average pressure at sea level is
         - Slightly more than 1000 millibars
         - About 14.7 pounds per square inch (1kg/cm²)
The atmospheric pressure decreases with altitude (the closer to the earth, the higher the pressure)

1. One-half (50%) of the atmosphere is below 3.5 miles (5.6 km)
2. Ninety percent (90%) of the atmosphere is below 10 miles (16 km)

A. Atmospheric layering based on temperature

Based on temperature difference, the atmosphere can be divided into four layers that are:

1. **Troposphere** (between 0km and 12km)
   - It is the bottom layer where we live, where all important weather phenomena occur
   - In the troposphere, temperature decreases with altitude at a rate of
     - 6.5 degrees C per kilometer, or 3.5 degrees F per 1000 feet (on average)
     - It is called the *environmental lapse rate*
   - The upper limit of the troposphere is called the *tropopause*

2. **Stratosphere** (between 12km and 50 km)
   - It is in the stratosphere that the *ozone layer* is concentrated at about 20km
   - Temperature is constant until 20km, then it increases at the top of the stratosphere due to the heating of the ozone layer by the UV radiation
   - The upper limit of the stratosphere is called the *stratopause*

3. **Mesosphere** (between 50km and 80 km)
   - Temperature decreases with altitude in the mesosphere up to –90C
   - Outer boundary of the mesosphere is named the *mesopause*

4. **Thermosphere** (above 80km)
   - It has no well-defined upper limit
   - Temperature increase up to 1000C because the gases move at high speed
   - It represents a tiny fraction of the atmosphere’s mass

IV. EARTH-SUN RELATIONS

The sun is the second Earth’s heat engine. The sun’s energy drives all the earth external geological and atmospheric processes, including weather and climate

A. Earth motions

   The Earth has two types of motions:
   1. Rotation: Earth rotates on its (imaginary) axis in 24hrs, which causes *day and night*
   2. Revolution: Earth revolves on its orbit around the Sun in one year (365 days)

B. Seasons

   1. They are the result of the earth’s axis inclination (23½) relative to the sun. It controls the amount of sun energy (*solar radiation*) that reaches earth’s surface. *The higher the sun angle, the more intense the solar radiation.* Two things characterize seasons:
      1. Changing Sun angle (Earth’s axis inclination)
      - Earth inclined toward the sun produces more solar radiation
      2. Changing length of daylight: Daylight changes as a result of changes in season
   2. Special days (Northern Hemisphere)
      a. Summer solstice
      1. June 21-22
      2. Sun’s vertical rays are located at the Tropic of Cancer (23½°N latitude)
      b. Winter solstice
      1. December 21-22
      2. Sun’s vertical rays are located at the Tropic of Capricorn (23½°S latitude)
      c. Autumnal equinox
      1. September 22-23
      2. Sun’s vertical rays are located at the Equator (0° latitude)
      d. Spring equinox
      1. March 21-22
      2. Sun’s vertical rays are located at the Equator (0° latitude)

V. ATMOSPHERIC HEATING

It is the result of solar radiation. The lower latitudes (Equatorial regions) receive more solar radiation than the higher latitude (Polar regions). This differential heating of the earth’s regions is responsible of all the weather dynamic in the atmosphere. As a result:
**Heat in the atmosphere, is always transferred by convection from warmer to cooler regions.**

**B. General mechanisms of heat transfer**

1. **Conduction**: Heat propagates through matter by way of molecular collisions. Air is a very poor conductor of heat.

2. **Convection**:
   a. Heat propagates by mass movement or circulation
   b. Convection is an up and down motion (convective cells)
   c. Heat in the atmosphere is carried by convection

3. **Radiation** (electromagnetic radiation)
   Energy travels through the vacuum of space as electromagnetic radiation, no need of a medium. *Sun energy is transferred to the atmosphere through electromagnetic radiation*
   a. Particles travel at velocity: 300,000 kilometers (186,000 miles) per second in a vacuum
   b. Electromagnetic radiation consists of different wavelengths that are from short waves (high energy) to long waves (low energy) radiation:
      - Gamma rays (very short waves)
      - X-rays
      - Ultraviolet light (UV)
      - Visible light (violet to red light)
      - Infrared (IR)
      - Microwaves
      - Radio (longest waves)
   c. Some basic laws of radiation are:
      3. All objects, at whatever temperature, emit radiation
      4. Hotter objects radiate more total energy per unit area than do cooler objects
      5. The hotter the radiating body, the shorter the wavelength (more energy) of maximum radiation
      6. Objects that are good absorbers of radiation are good emitters as well

**C. Incoming solar radiation**

1. The atmosphere is largely transparent to incoming solar radiation, which is converted into heat as it reaches the earth surface and reradiated to the atmosphere. However, not all the solar radiation reaches the Earth.
   a. Most of the visible radiation (sunlight) reaches the Earth’s surface
   b. About only 50% of it is absorbed at Earth’s surface

2. The atmosphere produces different effects on the sun’s incoming solar radiation:
   a. **Reflection**: About 30% of the solar radiation bounces back to space. An *albedo* of a surface is the percentage of solar radiation that is reflected by that surface. Earth’s albedo is about 30%. (it reflects 30%). It depends on cloud cover and sun angle.
      - The whiter a surface, the higher its albedo
      - The lower the sun angle on a surface, the higher the albedo.
   b. **Scattering**: It occurs when light hits small solid particles (aerosols) of the atmosphere. The result is a diffusion of light in every direction.
   c. **Absorption**: Water vapor and carbon dioxide are the principal absorbers of sun energy (long wave radiation).

**D. Radiation from Earth's surface**

1. Earth re-radiates heat (terrestrial radiation) at the longer wavelengths (IR)
2. Longer wavelength (terrestrial radiation) is absorbed by:
   a. Carbon dioxide and
   b. Water vapor in the atmosphere
3. The atmosphere is heated from ground up where the solar tradition reaching earth is converted into heat (infrared radiation) then absorbed by water vapor and carbon dioxide in the atmosphere.

**C. Heating of the atmosphere is termed the greenhouse effect**

About 50% of the solar radiation that reaches the Earth is absorbed. About 20% is then re-radiated skyward in a form of long wavelength (heat), which absorbed by water vapor, carbon dioxide, and trace gases (methane, nitrous oxide, and chlorofluorocarbons) in the atmosphere. Part of that absorbed energy is then re-emitted back to Earth surface, adding to the heat already produced by the incoming solar radiation. As a result, the Earth surface is being heated more and more creating a *greenhouse effect*, as the amount of carbon dioxide and the trace gases in the atmosphere increases.
Industrialization is the main source of these gases also called greenhouse gases.

VI. TEMPERATURE MEASUREMENT
Temperature is one of essential characteristic to determine weather and climate conditions at a given time. Temperature is measured on a regular basis, as:

A. Daily maximum and minimum measurements or
B. Other measurements
   1. Daily mean temperature: adding daily maximum and minimum and dividing by two
   2. Daily range: Difference between the daily maximum and the minimum temperature
   3. Monthly mean: Daily means of each day divided by the number of days of the month
   4. Annual mean: Monthly means divided by the number of months
   5. Annual temperature range: Difference between the highest and the lowest monthly means

C. Human perception of temperature
   1. Anything that influences the rate of heat loss from the body also influences the sensation of temperature.
   2. Important factors that influence our perception the air around us:
      a. Air temperature
      b. Relative humidity (increase in air moisture makes it feel like hotter)
      c. Wind speed (cold and windier make it feel like colder: wind chill factor)
      d. Sunshine (increase in sunshine heats up the air)

VII. CONTROLS OF TEMPERATURE
   - They cause temperature to vary from time to time, and place to place.
   - The amount of solar radiation received is the most important control of temperature.
   - Other important controls of temperature
     1. **Differential heating of land and water**
        Land and water absorb solar energy differently, which causes difference in temperature of the air above it.
        a. Land heats more rapidly than water
        b. Land gets hotter than water
        c. Land cools faster than water
        d. Land gets cooler than water
        The reasons in such differential heating between land and water are:
        - **Specific heat capacity:** It’s the amount of energy needed to raise 1g of any substance to 1 degree.
          Water has higher Specific heat capacity than land.
        - Water is more opaque than land, it allows solar radiation to go deep, and so it takes longer to heat it.
        - Because of water currents, surface water that is heated mixes with colder water below to decrease its temperature.
        - Water evaporates quicker than land; therefore, it looses its heat quicker.
     3. **Altitude:** Places located at high altitude are cooler than those at low altitude.
     4. **Geographic position:** Coastal locations with wind blowing from coast to land (windward coast) experience difference in temperature from coastal location where wind blows from land to ocean (leeward coast).
     5. **Cloud cover:** Due to their high albedo, clouds reflect more sunlight back to space and keep the ground cooler.
     6. **Albedo:** Earth surfaces with high albedo reflect more (absorb less) solar radiation, and keep the ground relatively cooler than low albedo surfaces.

VIII. WORLD DISTRIBUTION OF TEMPERATURES
A. Temperature maps are made using isotherms.
   1. Isotherms: they are lines connecting places of equal temperature
   2. Temperatures readings are adjusted to sea level
   3. January and July are used for analysis because they represent the temperature extremes

B. Global temperature patterns
   1. Earth’s temperature decreases from the tropics to the poles
   2. Isotherms exhibit a latitudinal shift with the seasons
   3. The warmest and coldest temperatures on Earth always occur over land
   4. In the Southern Hemisphere
a. Isotherms are straighter
b. Isotherms are more stable
5. Isotherms show ocean currents (Temperature maps overlap ocean currents maps)
6. Annual temperature range varies as follows:
   a. It is small near the equator (where the temperature is relatively constant)
   b. It increases with latitude, due to higher seasonal temperature difference.
   c. It is greatest over continental locations, because land gets colder and warmer than the ocean.

CHAPTER - 17: MOISTURE, CLOUDS, AND PRECIPITATION

I. Changes of state of water
   A. Heat energy
      1. Heat is a form of energy, it is measured in calories: One calorie is the heat necessary to raise the temperature of one gram of water to one degree Celsius. Heat reflects the total kinetic energy (energy of motion) of all the atoms and molecules of a substance. Whereas, temperature is the measure of the average kinetic energy of the atoms and molecules in a substance. Heat always travels from warmer regions to colder regions, to bring about a heat balance between the two.
      2. Latent heat:
         It is the stored or hidden heat in a substance. It is not derived from temperature change, but comes from changes in state of a substance. When water vapor in the atmosphere changes into snow, it releases latent heat, which contributes to warming of the atmosphere. It plays an important role in atmospheric processes.
   B. Three states of matter
      1. Solid, i.e. ice
      2. Liquid, i.e. water
      3. Gas, i.e. water vapor
   C. Changes in state of a substance are accompanied by either heat
      1. Absorption, or
      2. Release
   D. Processes of changes in state are:
      1. Evaporation
         a. Liquid is changed to gas
         b. 600 calories per gram of water are added – called latent heat of vaporization
      2. Condensation
         a. Water vapor (gas) is changed to a liquid
         b. Heat energy is released – called latent heat of condensation
      3. Melting
         a. Solid is changed to a liquid
         b. 80 calories per gram of water are added – called latent heat of melting
      4. Freezing
         a. Liquid is changed to a solid
         b. Heat is released – called latent heat of fusion
      5. Sublimation
         a. Solid is changed directly to a gas (e.g., ice cubes shrinking in a freezer)
         b. 680 calories per gram of water are added
      6. Deposition
         a. Water vapor (gas) changed to a solid (e.g., frost in a freezer compartment)
         b. Heat is released

II. Humidity
   A. It’s the amount of water vapor in the air
      1. When air is filled with water vapor to capacity, it is said to be saturated
      2. Water vapor capacity is temperature dependent – warm air has a much greater capacity for moisture
      3. Water vapor increases air pressure. Pressure associated with water vapor increase is called vapor pressure

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B. **Measuring humidity:** What is measured?

1. **Mixing ratio:** It measures the amount of water vapor in a unit of air (ratio of moist air over dry air, in g/kg)
2. **Relative humidity**
   a. It is the ratio of the air’s actual water vapor content compared with the amount of water vapor required for saturation at that temperature (and pressure). It indicates how close to saturation the air is, rather than just how much moisture is in the air (humidity).
   b. It is expressed as a percentage. 80% relative humidity means the air is at 80% close to saturation
   c. Saturated air
      - Air is saturated when it has reached **100% of its relative humidity.** It means that air water vapor content is equal its capacity
   d. Relative humidity can be changed in two ways
      - By adding or subtracting moisture to the air. **Adding moisture raises the relative humidity,** **removing moisture lowers the relative humidity**
      - By changing the air temperature. **Lowering the temperature raises the relative humidity,** **increase the chance for condensation.** Raising the temperature lowers the relative humidity

3. **Dew point temperature**
   1. It is the temperature to which a parcel of air would need to be cooled to reach saturation
   2. Cooling the air below the dew point causes condensation
      a. i.e., dew, fog, or cloud formation
      b. Water vapor requires a surface to condense on

C. **How to measure humidity:** Two types of **hygrometers** are used to measure humidity

1. Psychrometer
   Consists of two thermometers mounted side by side. Humidity is computed by comparing temperatures of Wet-bulb thermometer, and Dry-bulb thermometer. If the air is saturated (100% relative humidity) both thermometers read the same temperature. The greater the difference between the thermometer readings, the lower the relative humidity.
2. Hair hygrometer. It reads the humidity directly.

III. **Adiabatic heating/cooling**

One of the most important roles water vapor plays in weather is cloud formation. Cloud formation is associated with change in air temperature and pressure with altitude and the rise of water vapor in the atmosphere, due to adiabatic temperature changes or air lifting processes.

A. **Adiabatic temperature** changes occur when
   - **When air is compressed it warms.** Air is compressed at low altitude due to an increase in atmospheric pressure near the Earth’s surface. Therefore, descending air is compressed due to increasing air pressure.
   - **When air expands it cools.** Air expands with an increase in altitude. Rising air will expand due to decreasing air pressure with altitude.

B. **Adiabatic rates**
   1. **Dry adiabatic rate**
      For an unsaturated air, rising air expands and cools at 1°C per 100 meters (5.5°F per 1000 feet)
      While unsaturated descending air is compressed and warms at 1°C per 100 meters

   2. **Wet adiabatic rate**
      Once wet air has reached the dew point it condenses, then the latent heat is liberated by the condensing water reduces the rate of cooling. Wet adiabatic rate varies from 0.5°C to 0.9°C per 100 meters.

IV. **Processes that lift air**

   For an air to expand and cool with altitude, it needs to be lifted up. There are four ways an air mass can be lifted to trigger condensation and cloud formation:

A. **Orographic lifting**

   It occurs mainly along elevated terrains such as mountain ranges that act as barriers that lift air along the windward (ocean side) mountain slope. Lifted air condenses and cools at the top of the mountain producing rain. Then, the dry air descend on the leeward (continent side) of the mountain slope, it is warmed and compressed making precipitation less likely. The result is a desert (rain shadow desert) on the leeward side of the mountain. i.e. deserts in western USA.
B. **Frontal wedging**
When two contrasting air masses (cold and warm) collide, a front develops along which warm air is lifted above the cold air mass. Cool air acts as a barrier to warm air. Frontal wedging is responsible for the weather system in central United States. Fronts are part of the storm systems called middle-latitude cyclones.

C. **Convergence**
When air is flowing together at the lower atmosphere, it rises. It is called convergence. This phenomenon is responsible for the major weather process in the Florida peninsula. As air masses are brought over the warm region from the ocean, uplift occurs generating midafternoon thunderstorms.

D. **Localized convective lifting**
When unequal surface heating occurs, it causes localized pockets of air to rise because of their buoyancy. These rising localized parcels of air (thermals) create a localized weather pattern known in the inner cities as urban heat island, compared to the suburbs.

V. **Stability of air**
Air stability is the reason why clouds and precipitation vary so much. It determines to a large degree the type of clouds that develop and the intensity of the precipitation.

A. **Types of stability**
1. **Stable air**
   When air is cooler and denser than surrounding air, and it resists vertical displacement. As a result, it tends to sink. No adiabatic cooling develops. Absolute stability occurs when the environmental lapse rate is less than the wet adiabatic rate. It often results in widespread clouds with little vertical thickness. Precipitation, if any, is light to moderate.

2. **Absolute instability**
   When air is warmer and less dense than surrounding air, it rises like a hot air balloon. It continues to rise until it reaches an altitude with the same temperature. An adiabatic cooling develops, with an environmental lapse rate greater than the dry adiabatic rate. It often generates towering clouds and occasionally thunderstorms and tornadoes.

3. **Conditional instability** occurs when the atmosphere is stable for an unsaturated parcel of air but unstable for a saturated parcel.

VI. **Condensation and cloud formation**

A. **Condensation**
   - It occurs when water vapor in the air changes to liquid and forms dew, fog, or clouds.
   - Water vapor requires a surface to condense on. Possible condensation surfaces on the ground can be the grass, a car window, etc. Possible condensation surfaces in the atmosphere are tiny bits of particulate matter called condensation nuclei, dust, smoke, etc. Ocean salt crystals, also serve as hygroscopic (“water seeking”) nuclei.

B. **Clouds**
   They are made of millions and millions of minute water droplets, or tiny crystals of ice. Clouds classification is based on

1. **Form:** there are three basic forms
   - Cirrus: They form high, white, thin clouds
   - Cumulus: They form globular cloud masses often associated with fair weather
   - Stratus: they form sheets or layers and stretch to cover much or all of the sky

2. **Height:** The altitude at which clouds are found.
   - High clouds are above 6000 meters altitude. There are three types
     a. Cirrus
     b. Cirrostratus
     c. Cirrocumulus
   - Middle clouds are between 2000 and 6000 meters altitude. There are two types
     a. Altocumulus
     b. Altostratus
   - Low clouds are below 2000 meters altitude. There are three types
     b. Stratocumulus
     c. Nimbostratus (nimbus means "rainy")
   - Clouds of vertical development
     They are associated with unstable air and form from low to high altitudes. They are towering
clouds called *cumulonimbus*. They often produce rain showers, and thunderstorms.

VII. Fog
Fogs are considered an atmospheric hazard because it reduces visibility. Fog is a cloud that forms at or very near the ground. Most fogs form because of radiation cooling (on cool, clear calm nights when the earth looses its heat from radiation), or from a movement of air over a cold surface (when warm moist air moves over a cool surface).

A. Types of fog
1. **Fogs caused by cooling**
   a. *Advection fog*: When warm, moist air moves over a cool surface
   b. *Radiation fog*: When earth's surface cools rapidly, during cool, clear, calm nights
   c. *Upslope fog*: When humid air moves up a slope an adiabatic cooling occurs which leads to fog formation

2. **Evaporation fogs**
   a. *Steam fog*: When cool air moves over warm water and moisture is added to the air fog forms. Water has a steaming appearance.
   b. *Frontal fog or precipitation fog*: It forms during frontal wedging when warm air is lifted over colder air. It rains and rain evaporates to form fog.

VIII. Precipitation
Clouds contain water, then why don’t all clouds produce rain? The answer lies in the size of cloud droplets: They can be small, less than 20 micrometers (0.02 millimeter) in diameter (human hair = 75 micrometers)
Due to their small size they fall incredibly slow. Larger size droplets (2000 micrometers) are needed for precipitation. There are two mechanisms that generate the massive droplets for precipitation:

A. Precipitation from cold clouds:
1. **Bergeron process**
   It is *dominant in the middle latitudes*, and occurs when the *temperature in the cloud is below freezing*. Water in the cloud is supercooled. Water vapor collects on ice crystals; large snowflakes form and fall to the ground as snow, or melt on their descent and form rain.

2. **Collision-coalescence process**
   It is *common in the tropics*, and occurs within *warm clouds*. From large hygroscopic condensation nuclei, large droplets form. As they fall, they collide with other smaller, slower droplets and coalesce to form rain.

C. Forms of precipitation
1. Rain and drizzle
   3 Rain – droplets have at least a 0.5 mm diameter
   4 Drizzle – droplets have less than a 0.5 mm diameter

2. Snow – ice crystals, or aggregates of ice crystals

3. Sleet and glaze
   1 Sleet
   It’s a wintertime phenomenon. It forms small particles of ice and occurs when warmer air overlies colder air rain freezes as it falls.

   2 Glaze, or freezing rain – impact with a solid causes freezing

   3 Hail
   They are hard rounded pellets with concentric shells and diameters ranging from 1 to 5 cm. They occur in large cumulonimbus clouds with violent up- and down drafts. Layers of freezing rain are caught in up- and down drafts in the cloud. Pellets fall to the ground when they become too heavy.

   4 Rime
   It forms on cold surfaces when freezing of supercooled fog, or cloud droplets occurs.

D. Measuring precipitation
1. Rain
   It is the easiest form of precipitation to measure

   2 Measuring instruments
      - Standard rain gauge
         It uses a funnel to collect and conduct rain. A cylindrical measuring tube measures rainfall in centimeters or inches
      - Recording gauge
2. **Snow**

   Snow has two measurements
   - Depth
   - Water equivalent: The general ratio is 10 snow units to 1 water unit, and it varies widely

3. Radar is also used to measure the rate of rainfall

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**CHAPTER – 18: AIR PRESSURE AND WIND**

1. Describe air pressure, how it is measured, and how it changes with altitude.
2. Explain how pressure gradient force, Coriolis effect, and friction influence wind.
3. Describe the movements of air associated with the two types of pressure centers.
4. Describe the idealized global patterns of pressure and wind.
5. Discuss the general atmospheric circulation in the mid-latitudes.
6. List the names and causes of the major local winds.

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**I. Atmospheric pressure**

Air pressure is defined as the force exerted by the weight of the air above. The average atmospheric pressure at sea level is 1 kilogram per square centimeter (14.7 pounds per square inch). The atmospheric pressure decreases with increasing altitude and it is measured in Millibar (mb) or in inches of mercury. The standard sea level pressure is 1013.2 mb or 29.92 inches of mercury.

Instruments for measuring atmospheric pressure:

1. **Barometer** There are two types of barometers:
   a. **The Mercury barometer**
      It was invented by Torricelli in 1643. It uses a glass tube filled with mercury. The height of the mercury column is directly proportional to the atmospheric pressure. Mercury barometers can represent an environmental hazard due to the mercury.
   b. **Aneroid barometer**
      It uses no mercury; it is "without liquid". It uses an expanding chamber. When an aneroid barometer is connected to a recording mechanism it is called a Barograph. It continuously records the air pressure as a function of time.

**II. Wind**

Wind is the horizontal movement of air. Wind flows from areas of high pressure into areas of low pressure.

**Factors affecting wind**

1. **Pressure-gradient force**
   Wind is the result in difference of pressure between areas. The greater that difference, the greater the wind speed. The pressure-gradient is the force that moves air. The pressure changes over distance. Isobars are lines of equal air pressure represented on a weather map.

2. **Coriolis effect**
   The apparent deflection in the wind direction due to Earth’s rotation is called the Coriolis effect. The deflection is to the right in the Northern Hemisphere, and to left, in the Southern Hemisphere. The faster the wind speed, the greater the deflection.

3. **Friction**
   It acts to slow the air's movement. It is only important near the Earth’s surface. Friction changes wind direction.

   **Upper air winds** that do not experience friction and blow generally parallel to isobars are called **geostrophic winds**. They result from the balance between the Coriolis effect and the pressure-gradient force.

   **Jet stream**
   It is a fast moving upper level, high altitude, airflow or "River" of air with speed 120-240km/hour. One such jet stream front is situated over the polar front between the cold polar and the warm subtropical air.
III. Cyclones and anticyclones
As a rule, rising air is associated with cloud formation and precipitation, whereas subsiding air is associated with clear skies, and no rain.

A. Cyclone
It is a center of low-pressure. In a cyclone the pressure decreases toward the center. The air is spiraling inward (it is called convergence) in a counterclockwise fashion in the Northern Hemisphere, and clockwise in the Southern Hemisphere. Cyclones are associated with rising air, and often bring clouds and precipitation.

B. Anticyclone
An anticyclone is a center of high-pressure. Pressure increases toward the center. The air is spiraling outward (called divergence) in the clockwise fashion in the Northern Hemisphere, and counterclockwise in the Southern Hemisphere. Anticyclones are associated with subsiding air, and often bring fair weather and no precipitation.

IV. General atmospheric circulation
The underlying cause of wind is the unequal heating of the Earth surface due to more solar radiation (more heat) in the tropics, and less solar radiation (less heat) in the poles. On the rotating Earth there are three pairs of atmospheric cells that redistribute the heat.

A. Idealized global circulation
The global circulation is dominated by four pressure zones that are:
1. Equatorial low-pressure zone
   It is a region near the equator associated with rising air, and marked by abundant precipitation. The air rises up near the equator and sinks back to earth near the subtropical zone, creating hot, and arid, conditions (desert).
2. Subtropical high-pressure zone
   It is located at near 30 degrees latitude, and is characterized by subsiding, stable, dry air traveling equatorward from the subtropical high produces the trade winds. That subsiding dry air creates hot, arid conditions that are the major deserts in this latitude (i.e. Sahara). The air traveling poleward from the subtropical high produces the westerly winds.
3. Subpolar low-pressure zone
   When the warm westerlies move poleward, they encounter the cool easterlies in the Subpolar low their interaction produces an area of storms known as the polar front.
4. Polar high-pressure zone
   It a zone of cold, subsiding air spreading equatorward and producing polar westerly winds.

B. Influence of continents
Seasonal temperature differences, and the presence of landmasses, disrupt the global pressure patterns, and the global wind patterns. Its influence is most obvious in the Northern Hemisphere:

- Monsoon
  It is a seasonal change in wind direction that occurs over continents such as India. During warm months warm, moist air from the ocean flows onto land and produces rainy summer monsoon.
  During winter months dry, continental air flows off the land. This seasonal pattern over lands complicates and changes the global circulation.

V. Circulation in the mid-latitudes
The circulation in middle latitudes (between 30 and 60 degrees latitude) is dominated by the complex zone of the westerlies. The West to East airflow is interrupted by cyclones. Cells moving west to east in the Northern Hemisphere create anticyclonic and cyclonic flow, which is associated with the upper-level airflow.

VI. Local winds
Beside Earth’s large scale winds there are small-scale winds called local winds produced from temperature differences within a local area. The types of local winds are
1. Land and sea breezes
2. Mountain and valley breezes
3. Chinook and Santa Ana winds (warm and dry winds in the Rockies)
VII. **Wind measurement**

There are two basic measurements:

*Wind direction and wind speed*

1. **Direction**
   - Winds are labeled from where they originate (e.g., a North wind blows from the north toward the south)
   - The instrument for measuring wind direction is the wind vane
   - The direction is indicated by either compass points (N, NE, etc.) or by a scale of 0˚ to 360˚
   - Prevailing wind comes more often from one direction. Changes in wind direction are associated with locations of Cyclones and anticyclones, and often bring changes in temperature and moisture conditions.

2. **Speed** – often measured with a cup anemometer

VIII. **El Niño and La Niña**

A. **El Nino**
   - It is a warm countercurrent that flows southward along the coasts of Ecuador and Peru
   - It usually appears during the Christmas season. It is related to a large-scale atmospheric circulation due to pressure changes between the eastern and western sides of the Pacific Ocean, called the *Southern Oscillation*. The result is changes in trade winds that creates a major change in the equatorial current system, with *warm water flowing eastward* bringing heavy rains in Ecuador and Peru, and ferocious storms in California.
   - Changes in upwelling of colder, nutrient-filled water, occur. The strongest El Niño events on record occurred between 1982-83 and 1997-98. The effects of El Nino are highly variable depending in part on the temperatures and the size of the warm water pools.

B. **La Niña**
   - It is the opposite of El Niño and is triggered by colder than average surface temperatures in the eastern Pacific.
   - In a Typical La Niña winter, colder than normal air blows over the Pacific Northwest and northern Great Plains while warming much of the rest of the United States. Greater precipitation is expected in the Northwest.
   - Events associated with El Niño and La Niña are now understood to have a significant influence on the state of weather and climate almost everywhere.

IX. **Global distribution of precipitation**

   - It is relatively complex pattern which is related to global wind and pressure patterns

1. High pressure regions are characterized by:
   - Subsiding air that creates divergent winds and dry conditions. i.e. Sahara and Kalahari deserts.

2. Low pressure regions are characterized by:
   - Ascending air that creates converging winds and ample precipitation. i.e Amazon and Congo basins.

   Global distribution of precipitation is also related to distribution of land and water:
   - 1. Large landmasses in the middle latitudes often have less precipitation toward their centers
   - 2. Mountain barriers also alter precipitation patterns. As a result
      - Windward (seaside) slopes receive abundant rainfall from *orographic lifting*
      - Leeward (continent side) slopes are usually deficient in moisture and form deserts (rain shadow deserts).
I. Air masses
   A. Characteristics:
      An air mass is a large body of air 1600 km (1000 mi.) or more across, perhaps several kilometers thick with
      similar temperature and moisture at any give altitude. It moves and affects a large portion of a continent.
      A source region is the area where an air mass acquires its properties
      1. Classification of an air mass
         a. Latitude of the source region
            - A Polar air mass (P) comes from high latitudes (poles) and is cold.
            - A Tropical air mass (T) comes from low latitudes (Tropics) and is warm.
         b. Nature of the surface in the source region
            - Continental air mass (c) forms over land and is likely to be dry
            - Maritime air mass (m) originates over water and is humid.
      2. Types of air masses
         a. Continental polar (cP)
         b. Continental tropical (cT)
         c. Maritime polar (mP)
         d. Maritime tropical (mT)
   B. Air masses and weather
      The cP and mT air masses are the most important air masses in North America, especially east of the Rockies
      The Weather in North America (east of the Rocky Mountains) is defined by
      1. Continental polar (cP)
         - It originates from northern Canada and the interior of Alaska
         - In winter it brings cold, dry air
         - In summer it brings cool relief
         It is responsible for lake-effect snows
         - When a cP air mass crosses the Great Lakes air picks up moisture from the lakes and snow falls on
           the leeward (continental) shores of the lakes
      2. Maritime tropical (mT)
         - It originates from the Gulf of Mexico and the Atlantic Ocean,
         - It brings warm, moist, unstable air
         - It also brings precipitation to the eastern United States
         - Continental polar and Maritime tropical have the most influence on the weather in North America
      3. Continental tropical (cT)
         - It originates from the Southwest and Mexico. It has the least influence on the weather in North
           America.
         - It brings Hot, and dry air
         - It is seldom important outside the source region
      4. Maritime polar (mP)
         - It often originates as a continental polar from Siberia, and cross the Pacific to become a mP
         - It brings precipitation to the western mountains
         - Occasionally it influences the northeastern United States and causes the "Northeaster" in New
           England with its cold temperatures and snow
         - cT and mP have the least influence on the weather in North America
   II. Fronts
      It is the boundary that separates air masses of different densities. When two air masses collide it creates a front with
      the following:
      - Air masses retain their identities
      - The warmer, less dense air is forced aloft (up) no matter what air mass is advancing
      - The cooler, denser air acts as wedge
A. **Types of fronts**

1. **Warm front**
   It occurs when warm air advances and replaces cooler air. It is shown on a map by a line with semicircles. It forms small slope (1:200). Clouds become lower as the front nears. It advances at slow rate. A warm front is associated with *light-to-moderate precipitation*, and gradual temperature increase (warming up) with the passage of the front.

2. **Cold front**
   It's when cold air advances and replaces warm air. It is shown on a map by a line with triangles. It forms slopes twice as steep (1:100) as warm fronts. It advances faster than a warm front. It is associated with a more violent weather than a warm front, and the intensity of precipitation is greater, and the duration of precipitation is shorter.

   The weather behind a cold front is dominated by:
   - *Cold air mass*
   - *Subsiding air*
   - *Clearing conditions (clear sky)*

3. **Stationary front**
   It occurs when a flow of air on both sides of the front is almost parallel to the line of the front. The surface position of the front does not move.

4. **Occluded front**
   It's when an active *cold front overtakes a warm front*. The cold air wedges the warm air upward. The resulting weather is often complex, and precipitation is associated with warm air being forced aloft.

III. **Middle-latitude cyclone**

   It is the primary weather producer in the middle-latitudes and is associated with a front with a continental polar (cP) air often north of the front and a maritime tropical (mT) air often south of the front.

   **A. Idealized weather**
   Changes in weather are associated with the passage of a middle-latitude cyclone. Middle-latitude cyclones move eastward across the United States. Changes depend on the path of the storm. The first signs of their approach are in the western sky. It requires two to four days to pass over a region. It is the largest weather contrasts in the spring.

   1. Weather associated with Middle-latitudes fronts occurs with:
      a. **Warm front**
         - Clouds become lower and thicker
         - Light precipitation
         - After the passage of a warm front, winds become more southerly. After passing, warmer temperature is experienced (mT air mass)
      b. **Cold front**
         - It is a wall of dark clouds bringing heavy precipitation, hail, and occasional tornadoes
         - After the passage of a cold front, wind becomes north to northwest, with a drop in temperature as a cP air mass moves in bringing clear skies.

   **B. Role of airflow aloft**
   Cyclones and anticyclones are generated and maintained by upper-level airflow. They are typically found adjacent to one another.

   1. **Cyclone**
      A cyclone is a *low-pressure system* characterized by a surface convergence (air affluence from below), and a divergence aloft (Outflow above surface) that sustains the low pressure.

   2. **Anticyclone**
      An anticyclone is a high-pressure system associated with cyclones. It is characterized by convergence aloft (air affluence from above) and a divergence below.

IV. **Severe weather types**

   **A. Thunderstorms**
   It is the result of vertical movement of warm unstable air. It is a storm accompanied by lightning and thunder. Because so much heat is needed for their development, *thunderstorms are most common in the afternoon and early evening*. Thunderstorms are characterized by
   - Towering cumulonimbus clouds
- Heavy rainfall
- Lightning
- Occasional hail
- Most frequent in Florida and the Eastern Gulf Coast region
- All thunderstorms require warm and moist air
- Instability (air lifting) is the main mechanism to generate thunderstorms. A thunderstorm needs high surface temperatures, and it is most common in the afternoon and early evening.
- It requires continuous supply of warm air and moisture; each surge causes air to rise higher.
- Eventually heavy precipitation forms with gusty winds, lightning, and hail.
- Cooling effect of precipitation marks the end of thunderstorm activity

**B. Tornadoes**

They are local storm of short duration characterized by a low pressure inside that causes the air to rush in causing
- Violent windstorm
- Rotating column of air that extends down from a cumulonimbus cloud
- Winds approach 480 km (300 miles) per hour
- Smaller suction vortices can form inside stronger tornadoes
- They are most frequent from April through June
- They are associated with severe thunderstorms

The exact cause of tornadoes formation is not known. Conditions for the formation of tornadoes occur most often along cold front during the spring months, and are associated with huge thunderstorms called *supercells*. Most tornadoes move toward the northeast with maximum winds range beyond 500 kilometers (310 miles) per hour. Tornadoes’ intensity measured by the *Fujita intensity scale*. Tornadoes are difficult to forecast because of their small size.

**C. Hurricanes**

They are the most violent storms on Earth. A hurricane is defined by
- Wind speed in excess of 119 kilometers (74 miles) per hour
- A rotary cyclonic circulation
- It forms in all tropical waters (seas) between the latitudes of 5 degrees and 20 degrees (zone of maximum Coriolis effect and heat) except in South Atlantic and Eastern South Pacific.
- Energy needed comes from condensing water vapor from the oceans.
- The best season is most often in late summer when warm water temperatures provide energy and moisture

Hurricane are know as
- *Typhoons* in the western Pacific (Asia)
- *Cyclones* in the Indian Ocean

North Pacific has the greatest number per year

1. **Eyewall** of an hurricane is near the center and is characterized by
   - Rising air
   - Intense convective activity
   - Wall of cumulonimbus clouds
   - Greatest wind speeds
   - Heaviest rainfall

2. **Eye** of a hurricane is at the very center and is characterized by
   - About 20 km (12.5 miles) diameter
   - Precipitation ceases
   - Winds subsides
   - Air gradually descends and heats by compression
   - Warmest part of the storm
   - Wind speeds reach 300 km/hr
   - Generate 50-foot waves at sea
   - *Tropical depression* has winds 61 kilometers (38 miles) per hour
   - *Tropical storm* has winds between 61 to 119 km (38 and 74 miles) per hour
Hurricane intensity diminishes whenever the hurricane
- Moves over cooler ocean water
- Moves onto land
- Large-scale flow aloft is unfavorable
The factors that affect amount of hurricane damage are
- Strength of storm (the most important factor)
- Size and population density of the area affected
- Shape of the ocean bottom near the shore
- Saffir-Simpson scale ranks the relative intensities of hurricanes

CHAPTER – 20: CLIMATE

I. The climate system
A climate is an aggregate of weather. It is the average weather in any location over a period of time. It involves the exchanges of energy and moisture that occur among the Earth’s spheres: Atmosphere, Hydrosphere, Solid Earth, Biosphere, and Cryosphere (ice and snow)

II. World climates
Every location has a distinctive climate. The most important elements in a climatic description are
1. Temperature, and
2. Precipitation

III. Climate classification
It tries to bring order to large quantities of information. Many climatic-classification systems have been devised, only one seems to prevail: The Köppen classification of climates. It is the Best known and most used system. It uses mean monthly and annual values of temperature and precipitation, and divides the world into climatic regions in a realistic way. The boundaries Köppen chose were largely based on the limits of certain plant association.
There are five principal climate groups
a. Humid tropical (A)
b. Dry (B)
c. Humid middle-latitude with mild winters (C)
d. Humid middle-latitude with severe winters (D)
e. Polar (E)
A, C, D, and E climates are defined on the basis of temperature characteristics, precipitation is the primary criterion for the B group.

IV. Köppen climates
A. Humid tropical (A) climates
It is a winterless climate, with all months having a mean temperature above 18°C. This type of climate is not found in the US. There are two main types
1. Wet tropics
   - High temperatures and year-round rainfall
   - Luxuriant vegetation (tropical rainforest)
   - Discontinuous belt astride the equator
   - Strongly influenced by the equatorial low pressures
2. Tropical wet and dry
   - Between the poles and the wet tropics, and between the equator and the tropical deserts
   - Tropical grassland (savanna)
   - Seasonal rainfall
B. Dry (B) climates
The evaporation exceeds the precipitation and there is a constant water deficiency. It is determined by average annual precipitation, average annual temperature, and seasonal distribution of precipitation. Dry climates are found in the southwestern United States. There are two climatic types
1. Arid or desert (BW)
2. Semiarid or steppe (BS)
   - It is more humid than arid climate
   - It surrounds desert
Deserts and steppes in the low latitudes, e.g., North Africa to southwestern India, northern Mexico, southwestern U.S.
are caused by the dry, stable, subsiding air of the sub-tropical high-pressure. In the middle-latitude, deserts and steppes are due to their position in the deep interiors of large landmasses and/or the presence of high mountains. Most deserts are located in the Northern Hemisphere.

C. Humid middle-latitude climates with mild winters (C climates)
The average temperature of the coldest month is below 18°C but above -3°C. This climate type is found in the southeast and the west coast of the United States. There are three types.
1. Humid subtropics
   - Associated with eastern sides of continents around 25 to 40 degree latitude range
   - Hot, sultry summers and mild winters like in Florida
   - Winter precipitation is generated along fronts
2. Marine west coast
   - Along the western (windward) side of continents between 40 to 65 degrees north and south latitude
   - Onshore flow of ocean air
   - Mild winters and cool summers like in California and the Pacific Northwest
3. Dry-summer subtropics
   - Along west sides of continents between latitudes 30° and 45’
   - Strong winter rainfall maximum
   - Often called a Mediterranean climate

D. Humid middle-latitude climates with severe winters (D climates)
The average temperature of the coldest month is below -3°C and the warmest monthly mean exceeds 10°C. It is found in the United States, in the Midwest, the Great lakes, Alaska, and the Northeast. It is a land-controlled climate, and is absent in the Southern Hemisphere. There are two types.
1. Humid continental
   - Confined to the central and eastern portions of North America and Eurasia between 40 and 50 degrees north latitude.
   - Severe winter and summer temperatures
   - High annual temperature ranges
   - Precipitation is generally greater in the summer than in the winter
   - Snow remains on the ground for extended periods
2. Subarctic
   - North of the humid continental climate
   - Often referred to as the taiga climate
   - Largest stretch of continuous forests on Earth
   - Source regions of cP air masses
   - Frigid winters, remarkably warm but short summers

E. Polar (E) climates
This type of climate is not found in the United States. The mean temperature of the warmest month is below 10°C. Enduring cold, and meager precipitation characterize this climate. There are two types of polar climate
1. Tundra climate (ET)
   - Treeless climate
   - Almost exclusively in the Northern Hemisphere
   - Severe winters, cool summers
   - High annual temperature range
2. Ice cap climate (EF)
   - No monthly mean above 0°C
- Average temperature is always below freezing at all time.
- Landscape is a permanent ice cap
PART - IV

UNIT SEVEN: EARTH'S PLACE IN THE UNIVERSE

CHAPTER - 21: ORIGIN OF MODERN ASTRONOMY

I. Early history of astronomy
   A. Ancient Greeks
      1. Used philosophical arguments to explain natural phenomena
      2. Also used some observational data
      3. Most ancient Greeks held a geocentric (Earth-centered) view of the universe
         a. "Earth-centered" view
            1. Earth was a motionless sphere at the center of the universe
            2. Stars were on the celestial sphere
               a. Transparent, hollow sphere
               b. Celestial sphere turns daily around Earth
         b. Seven heavenly bodies (planetai)
            1. Changed position in sky
            2. The seven wanderers included the
               a. Sun
               b. Moon
               c. Mercury through Saturn (excluding Earth)
      4. Aristarchus (312-230 B.C.) was the first Greek to profess a Sun-centered, or heliocentric, universe
      5. Planets exhibit an apparent westward drift
         a. Called retrograde motion
         b. Occurs as Earth, with its faster orbital speed, overtakes another planet
   B. Birth of modern astronomy
      1. 1500s and 1600s
      2. Five noted scientists
         a. Nicolaus Copernicus (1473-1543)
            1. Concluded Earth was a planet
            2. Constructed a model of the solar system that put the Sun at the center, but he used circular orbits for the planets
            3. Ushered out old astronomy
         b. Tycho Brahe (1546-1601)
            1. Precise observer
            2. Tried to find stellar parallax – the apparent shift in a star's position due to the revolution of Earth
            3. Did not believe in the Copernican system because he was unable to observe stellar parallax
         c. Johannes Kepler (1571-1630)
            1. Ushered in new astronomy
            2. Planets revolve around the Sun
            3. Three laws of planetary motion
               a. Orbits of the planets are elliptical
               b. Planets revolve around the Sun at varying speed
               c. There is a proportional relation between a planet's orbital period and its distance to the Sun (measured in astronomical units (AU's) – one AU averages about 150 million kilometers, or 93 million miles)
         d. Galileo Galilei (1564-1642)
            1. Supported Copernican theory
            2. Used experimental data
3. Constructed an astronomical telescope in 1609
4. Galileo's discoveries using the telescope
   a. Four large moons of Jupiter
   b. Planets appeared as disks
   c. Phases of Venus
   d. Features on the Moon
   e. Sunspots
5. Tried and convicted by the Inquisition
   e. Sir Isaac Newton (1643-1727)
      1. Law of universal gravitation
2. Proved that the force of gravity, combined with the tendency of a planet to remain in straight-line motion, results in the elliptical orbits discovered by Kepler
II. Constellations
   A. Configuration of stars named in honor of mythological characters or great heroes
   B. Today 88 constellations are recognized
   C. Constellations divide the sky into units, like state boundaries in the United States
   D. The brightest stars in a constellation are identified in order of their brightness by the letters of the Greek alphabet – alpha, beta, and so on
III. Positions in the sky
   A. Stars appear to be fixed on a spherical shell (the celestial sphere) that surrounds Earth
   B. Equatorial system of location
      1. A coordinate system that divides the celestial sphere
      2. Similar to the latitude-longitude system that is used on Earth's surface
      3. Two locational components
         a. Declination – the angular distance north or south of the celestial equator
         b. Right ascension – the angular distance measured eastward along the celestial equator from the position of the vernal equinox
IV. Earth motions
   A. Two primary motions
      1. Rotation
         a. Turning, or spinning, of a body on its axis
         b. Two measurements for rotation
            1. Mean solar day – the time interval from one noon to the next, about 24 hours
      2. Sidereal day – the time it takes for Earth to make one complete rotation (360°) with respect to a star other than the Sun – 23 hours, 56 minutes, 4 seconds
   B. Other Earth motions
      1. Precession
         a. Very slow Earth movement
         b. Direction in which Earth's axis points continually changes
      2. Movement with the solar system in the direction of the star Vega
      3. Revolution with the Sun around the galaxy
      4. Movement with the galaxy within the universe
V. Motions of the Earth-Moon system
   A. Phases of the Moon
      1. When viewed from above the North Pole, the Moon orbits Earth in a counterclockwise (eastward) direction
      2. The relative positions of the Sun, Earth, and Moon constantly change
3. Lunar phases are a consequence of the motion of the Moon and the sunlight that is reflected from its surface.

B. Lunar motions
   1. Earth-Moon
      a. *Synodic month*
         1. Cycle of the phases
         2. Takes 29½ days
      b. *Sidereal month*
         1. True period of the Moon's revolution around Earth
         2. Takes 27 days
      c. The difference of two days between the synodic and sidereal cycles is due to the Earth-Moon system also moving in an orbit around the Sun.
   2. Moon's period of rotation about its axis and its revolution around Earth are the same, 27 days.
      a. Causes the same lunar hemisphere to always face Earth.
      b. Causes high surface temperature on the day side of the Moon.

C. Eclipses
   1. Simply shadow effects that were first understood by the early Greeks.
   2. Two types of eclipses
      a. Solar eclipse
         1. Moon moves in a line directly between Earth and the Sun.
         2. Can only occur during the new-Moon phase.
      b. Lunar eclipse
         1. Moon moves within the shadow of Earth.
         2. Only occurs during the full-Moon phase.
         3. For any eclipse to take place, the Moon must be in the plane of the ecliptic at the time of new- or full-Moon.
         4. Because the Moon's orbit is inclined about 5 degrees to the plane of the ecliptic, during most of the times of new- and full-Moon the Moon is above or below the plane, and no eclipse can occur.
         5. The usual number of eclipses is four per year.

CHAPTER - 22: TOURING OUR SOLAR SYSTEM

I. Overview of the solar system
   A. Solar system includes
      1. Sun
      2. Nine planets and their satellites
      3. Asteroids
      4. Comets
      5. Meteoroids
   B. A planet's orbit lies in an orbital plane
      1. Similar to a flat sheet of paper.
      2. The orbital planes of the planets are inclined.
         a. Planes of seven planets lie within 3 degrees of the Sun's equator.
         b. Mercury's is inclined 7 degrees.
         c. Pluto's is inclined 17 degrees.
   C. Two groups of planets occur in the solar system
      1. *Terrestrial (Earth-like) planets*
         a. Mercury through Mars
         b. Small, dense, rocky
         c. Low escape velocities.
      2. *Jovian (Jupiter-like) planets*
         a. Jupiter through Neptune
         b. Large, low density, gaseous.
c. Massive

4. Ammonia

e. High escape velocities

3. Pluto not included in either group

D. Planets are composed of

1. Gases
   a. Hydrogen
   b. Helium

2. Rocks
   a. Silicate minerals
   b. Metallic iron

3. Ices
   a. Ammonia (NH₃)
   b. Methane (CH₄)
   c. Carbon dioxide (CO₂)
   d. Water (H₂O)

II. Evolution of the planets (see textbook Introduction)

A. Nebular hypothesis
   1. Planets formed about 5 billion years ago
   2. Solar system condensed from a gaseous nebula

B. As the planets formed, the materials that compose them separated
   1. Dense metallic elements (iron and nickel) sank toward their centers
   2. Lighter elements (silicate minerals, oxygen, hydrogen) migrated toward their surfaces
   3. Process called chemical differentiation

C. Due to their surface gravities, Venus and Earth retained atmospheric gases

D. Due to frigid temperatures, the Jovian planets contain a high percentage of ices

III. Earth's Moon

A. General characteristics
   1. Diameter of 3475 kilometers (2150 miles) is unusually large compared to its parent planet
   2. Density
      a. 3.3 times that of water
      b. Comparable to Earth's crustal rocks
      c. Perhaps the Moon has a small iron core
   3. Gravitational attraction is one-sixth of Earth's
   4. No atmosphere
   5. Tectonics no longer active
   6. Surface is bombarded by micrometeorites from space which gradually makes the landscape smooth

B. Lunar surface
   1. Two types of terrain
      a. Maria (singular, mare), Latin for "sea"
         1. Dark regions
         2. Fairly smooth lowlands
         3. Originated from asteroid impacts and lava flooding the surface
      b. Highlands
         1. Bright, densely cratered regions
         2. Make up most of the Moon
         3. Make up all of the "back" side of the Moon
         4. Older than maria
   2. Craters
      a. Most obvious features of the lunar surface
      b. Most are produced by an impact from a meteoroid which produces
1. Ejecta
2. Occasional rays (associated with younger craters)
3. Lunar regolith
   a. Covers all lunar terrains
   b. Gray, unconsolidated debris
   c. Composed of
      1. Igneous rocks
      2. Breccia
      3. Glass beads
      4. Fine lunar dust
   d. "Soil-like" layer
   e. Produced by meteoric bombardment

C. Lunar History
1. Hypothesis suggests that a giant asteroid collided with Earth to produce the Moon
2. One method used to work out lunar history is to observe crater density
   a. Older areas have a higher density
   b. Younger areas are still smooth
3. Moon evolved in three phases
   a. Original crust (highlands)
      1. As Moon formed, its outer shell melted, cooled, solidified, and became the highlands
      2. About 4.5 billion years old
   b. Formation of maria basins
      1. Younger than highlands
      2. Between 3.2 and 3.8 billion years old
   c. Formation of rayed craters
      1. Material ejected from craters is still visible
      2. e.g., Copernicus (a rayed crater)

IV. Planets: a brief tour
A. Mercury
1. Innermost planet
2. Second smallest planet
3. No atmosphere
4. Cratered highlands
5. Vast, smooth terrains
6. Very dense
7. Revolves quickly
8. Rotates slowly
   a. Cold nights (-280˚F)
   b. Hot days (800˚F)
B. Venus
1. Second to the Moon in brilliance
2. Similar to Earth in
   a. Size
   b. Density
   c. Location in the solar system
3. Shrouded in thick clouds
   a. Impenetrable by visible light
   b. Atmosphere is 97% carbon dioxide
   c. Surface atmospheric pressure is 90 times that of Earth's
4. Surface
   a. Mapped by radar
   b. Features
      1. 80% of surface is subdued plains that are mantled by volcanic flows
      2. Low density of impact craters
      3. Tectonic deformation must have been active during the recent geologic past
      4. Thousands of volcanic structures
C. Mars
1. Called the "Red Planet"
2. Atmosphere
   a. 1% as dense as Earth's
   b. Primarily carbon dioxide
   c. Cold polar temperatures (-193°F)
   d. Polar caps of water ice, covered by a thin layer of frozen carbon dioxide
   e. Extensive dust storms with winds up to 270 kilometers (170 miles) per hour
3. Surface
   a. Numerous large volcanoes – largest is Mons Olympus
   b. Less-abundant impact craters
   c. Tectonically dead
   d. Several canyons
      1. Some larger than Earth’s Grand Canyon
      2. Valles Marineras – the largest canyon
         a. Almost 5000 km long
         b. Formed from huge faults
   e. "Stream drainage” patterns
      1. Found in some valleys
      2. No bodies of surface water on the planet
      3. Possible origins
         a. Past rainfall
         b. Surface material collapses as the subsurface ice melts
4. Moons
   a. Two moons
      1. Phobos
      2. Deimos
   b. Captured asteroids
D. Jupiter
1. Largest planet
2. Very massive
   a. 2.5 more massive than combined mass of the planets, satellites, and asteroids
   b. If it had been ten times larger, it would have been a small star
3. Rapid rotation
   a. Slightly less than 10 hours
   b. Slightly bulged equatorial region
4. Banded appearance
   a. Multicolored
   b. Bands are aligned parallel to Jupiter's equator
   c. Generated by wind systems
5. Great Red Spot
   a. In planet's southern hemisphere
   b. Counterclockwise rotating cyclonic storm
6. Structure
   a. Surface thought to be a gigantic ocean of liquid hydrogen
   b. Halfway into the interior, pressure causes liquid hydrogen to turn into liquid metallic hydrogen
   c. Rocky and metallic material probably exists in a central core
7. Moons
   a. At least 28 moons
   b. Four largest moons
      1. Discovered by Galileo
      2. Called Galilean satellites
      3. Each has its own character
         a. Callisto
            1. Outermost Galilean moon
            2. Densely cratered
b. Europa
   1. Smallest Galilean moon
   2. Icy surface
   3. Many linear surface features

c. Ganymede
   1. Largest Jovian satellite
   2. Diverse terrains
   3. Surface has numerous parallel grooves

d. Io
   1. Innermost Galilean moon
   2. Volcanically active (heat source could be from tidal energy)
   3. Sulfurous

8. Ring system

E. Saturn
   1. Similar to Jupiter in its
      a. Atmosphere
      b. Composition
      c. Internal structure
   2. Rings
      a. Most prominent feature
      b. Discovered by Galileo in 1610
      c. Complex
      d. Composed of small particles (moonlets) that orbit the planet
         1. Most rings fall into one of two categories based on particle density
            a. Main rings contain particles from a few centimeters to several meters in diameter
            b. Faintest rings are composed of very fine (smoke-size) particles
         2. Thought to be debris ejected from moons
      e. Origin is still being debated
   3. Other features
      a. Dynamic atmosphere
      b. Large cyclonic storms similar to Jupiter's Great Red Spot
      c. Thirty named moons
      d. Titan – the largest Saturnian moon
         1. Second largest moon (after Jupiter's Ganymede) in the solar system
         2. Has a substantial atmosphere

F. Uranus
   1. Uranus and Neptune are nearly twins
   2. Rotates "on its side"
   3. Rings
   4. Large moons have varied terrains

G. Neptune
   1. Dynamic atmosphere
      a. One of the windiest places in the solar system
      b. Great Dark Spot
      c. White cirrus-like clouds above the main cloud deck
   2. Eight satellites
   3. Triton – largest Neptune moon
      a. Orbit is opposite the direction that all the planet's travel
      b. Lowest surface temperature in the solar system (-391°F)
      c. Atmosphere of mostly nitrogen with a little methane
      d. Volcanic-like activity
      e. Composed largely of water ice, covered with layers of solid nitrogen and methane

H. Pluto
   1. Not visible with the unaided eye
   2. Discovered in 1930
   3. Highly elongated orbit causes it to occasionally travel inside the orbit of Neptune, where it resided from 1979 through February 1999
4. Moon (Charon) discovered in 1978
5. Average temperature is -210°C

V. Minor members of the solar system

A. Asteroids
1. Most lie between Mars and Jupiter
2. Small bodies – largest (Ceres) is about 620 miles in diameter
3. Some have very eccentric orbits
4. Many of the recent impacts on the Moon and Earth were collisions with asteroids
5. Irregular shapes
6. Origin is uncertain

B. Comets
1. Often compared to large, "dirty snowballs"
2. Composition
   a. Frozen gases
   b. Rocky and metallic materials
3. Frozen gases vaporize when near the Sun
   a. Produces a glowing head called the coma
   b. Some may develop a tail that points away from Sun due to
      1. Radiation pressure and the
      2. Solar wind
4. Origin
   a. Not well known
   b. Form at great distance from the Sun
5. Most famous short-period comet is Halley’s comet
   a. 76 year orbital period
   b. Potato-shaped nucleus (16 km by 8 km)

C. Meteoroids
1. Called meteors when they enter Earth’s atmosphere
2. A meteor shower occurs when Earth encounters a swarm of meteoroids associated with a comet’s path
3. Meteoroids are referred to as meteorites when they are found on Earth
   a. Types of meteorites classified by their composition
      1. Irons
         a. Mostly iron
         b. 5-20% nickel
      2. Stony
         a. Silicate minerals with
         b. Inclusions of other minerals
      3. Stony-irons – mixtures
      4. Carbonaceous chondrites
         a. Rare
         b. Composition
            1. Simple amino acids
            2. Other organic material
         c. May give an idea as to the composition of Earth’s core
         d. Give an idea as to the age of the solar system
CHAPTER 23: LIGHT, ASTRONOMICAL OBSERVATION, AND THE SUN

I. The study of light
   A. Electromagnetic radiation
      1. Visible light is only one small part of an array of energy
      2. Electromagnetic radiation includes
         a. Gamma rays
         b. X-rays
         c. Ultraviolet light
         d. Visible light
         e. Infrared light
         f. Radio waves
      3. All forms of radiation travel at 300,000 kilometers (186,000 miles) per second
   B. Light (electromagnetic radiation) can be described in two ways
      1. Wave model
         a. Wavelengths of radiation vary
            1. Radio waves measure up to several kilometers long
            2. Gamma ray waves are less than a billionth of a centimeter long
         b. White light consists of several wavelengths corresponding to the colors of the rainbow
      2. Particle model
         a. Particles called photons
         b. Exert a pressure, called radiation pressure, on matter
         c. Shorter wavelengths correspond to more energetic photons
   C. Spectroscopy
      1. The study of the properties of light that depend on wavelength
      2. The light pattern produced by passing light through a prism, which spreads out the various wavelengths, is called a spectrum (plural: spectra)
      3. Types of spectra
         a. Continuous spectrum
            1. Produced by an incandescent solid, liquid, or high pressure gas
            2. Uninterrupted band of color
         b. Dark-line (absorption) spectrum
            1. Produced when white light is passed through a comparatively cool, low pressure gas
            2. Appears as a continuous spectrum but with dark lines running through it
         c. Bright-line (emission) spectrum
            1. Produced by a hot (incandescent) gas under low pressure
      2. Appears as a series of bright lines of particular wavelengths depending on the gas that produced them
      4. Most stars have a dark-line spectrum
      5. Instrument used to spread out the light is called a spectroscope
   D. Doppler effect
      1. The apparent change in wavelength of radiation caused by the relative motions of the source and observer
      2. Used to determine
         a. Direction of motion
            1. Increasing distance – wavelength is longer ("stretches")
            2. Decreasing distance – makes wavelength shorter ("compresses")
         b. Velocity – larger Doppler shifts indicate higher velocities

II. Astronomical tools
   A. Optical (visible light) telescopes
      1. Two basic types
         a. Refracting telescope
            1. Uses a lens (called the objective) to bend (refract) the light to produce an image
            2. Light converges at an area called the focus
            3. Distance between the lens and the focus is called the focal length
            4. The eyepiece is a second lens used to examine the image directly
            5. Have an optical defect called chromatic aberration (color distortion)
         b. Reflecting telescope
1. Uses a concave mirror to gather the light
2. No color distortion
3. Nearly all large telescopes are of this type

2. Properties of optical telescopes
   a. Light-gathering power
      1. Larger lens (or mirror) intercepts more light
      2. Determines the brightness
   b. Resolving power
      1. The ability to separate close objects
      2. Allows for a sharper image and finer detail
   c. Magnifying power
      1. The ability to make an image larger
      2. Calculated by dividing the focal length of the objective by the focal length of the eyepiece
      3. Can be changed by changing the eyepiece
      4. Limited by atmospheric conditions and the resolving power of the telescope
      5. Even with the largest telescopes, stars (other than the Sun) appear only as points of light

B. Detecting invisible radiation
1. Photographic films are used to detect ultraviolet and infrared wavelengths
2. Most invisible wavelengths do not penetrate Earth's atmosphere, so balloons, rockets, and satellites are used
3. Radio radiation
   a. Reaches Earth's surface
   b. Gathered by "big dishes" called radio telescopes
      1. Large because radio waves are about 100,000 longer than visible radiation
      2. Often made of a wire mesh
      3. Have rather poor resolution
      4. Can be wired together into a network called a radio interferometer
   5. Advantages over optical telescopes
      a. Less affected by weather
      b. Less expensive
      c. Can be used 24 hours a day
      d. Detects material that does not emit visible radiation
      e. Can "see" through interstellar dust clouds
      6. A disadvantage is that they are hindered by man-made radio interference

III. Sun
   A. One of 200 billion stars that make up the Milky Way galaxy
   B. Only star close enough to allow the surface features to be studied
   C. An average star
   D. Structure can be divided into four parts
      1. Solar interior
      2. Photosphere
         a. "Sphere of light"
         b. Sun's "surface" – actually a layer of incandescent gas less than 500 kilometers thick
         c. Grainy texture made up of many small, bright markings, called granules, produced by convection
         d. Most of the elements found on Earth also occur on the Sun
         e. Temperature averages approximately 6000 K (10,000˚F)
      3. Chromosphere
         a. Just above photosphere
         b. Lowermost atmosphere
         c. Relatively thin, hot layer of incandescent gases a few thousand kilometers thick
         d. Top contains numerous spicules – narrow jets of rising material
      4. Corona
         a. Outermost portion of the solar atmosphere
         b. Very tenuous
         c. Ionized gases escape from the outer fringe and produce the solar wind
         d. Temperature at the top exceeds 1 million K
   E. Solar features
1. **Sunspots**
   a. On the solar surface
   b. Dark center, the umbra, surrounded by a lighter region, the penumbra
   c. Dark color is due to a cooler temperature (1500 K less than the solar surface)
   d. Large spots are strongly magnetized
   e. Pairs have opposite magnetic poles

2. **Plages**
   a. Bright centers of solar activity
   b. Occur above sunspot clusters

3. **Prominences**
   a. Huge arching cloudlike structures that extend into the corona
   b. Condensations of material in the corona

4. **Flares**
   a. Explosive events that normally last an hour or so
   b. Sudden brightening above a sunspot cluster
   c. Release enormous quantities of energy
   d. Eject particles that reach Earth in about one day and interact with the atmosphere to cause the auroras (the Northern and Southern Lights)

IV. Solar interior
   A. Cannot be observed directly
   B. Nuclear fusion occurs here

**CHAPTER - 24: BEYOND OUR SOLAR SYSTEM**

1. Source of the Sun's energy
2. Occurs in the deep interior
3. Nuclear reaction that produces the Sun's energy is called the **proton-proton reaction**
   a. Four hydrogen nuclei are converted into a helium nuclei
   b. Matter is converted to energy
   c. 600 million tons of hydrogen is consumed each second
4. Sun has enough fuel to last another five billion years

I. Properties of stars
   A. Distance
   1. Measuring a star's distance can be very difficult
   2. Stellar parallax
      a. Used for measuring distance to a star
      b. Apparent shift in a star's position due to the orbital motion of Earth
      c. Measured as an angle
      d. Near stars have the largest parallax
      e. Largest parallax is less than one second of arc
   3. Distances to the stars are very large
   4. Units of measurement
      a. Kilometers or astronomical units are too cumbersome to use
      b. Light-year is used most often
         1. Distance that light travels in 1 year
         2. One light-year is 9.5 trillion km (5.8 trillion miles)
   5. Other methods for measuring distance are also used
   B. Stellar brightness
   1. Controlled by three factors
      a. Size
      b. Temperature
      c. Distance
2. Magnitude
   a. Measure of a star’s brightness
   b. Two types of measurement
      1. **Apparent magnitude**
         a. Brightness when a star is viewed from Earth
         b. Decreases with distance
         c. Numbers are used to designate magnitudes
            1. Dim stars have large numbers
               a. First magnitude appear brighter
               b. Sixth magnitude are the faintest stars visible to the eye
            2. Negative numbers are also used
      2. **Absolute magnitude**
         a. “True” or intrinsic brightness of a star
         b. Brightness at a standard distance of 32.6 light-year
         c. Most stars’ absolute magnitudes are between -5 and +15

C. Color and temperature
   1. Hot star
      a. Temperature above 30,000 K
      b. Emits short-wavelength light
      c. Appears blue
   2. Cool star
      a. Temperature less than 3000 K
      b. Emits longer-wavelength light
      c. Appears red
   3. Between 5000 and 6000 K
      a. Stars appear yellow
      b. e.g., Sun

D. Binary stars and stellar mass
   1. Binary stars
      a. Two stars orbiting one another
         1. Stars are held together by mutual gravitation
         2. Both orbit around a common center of mass
      b. Visual binaries are resolved telescopically
      c. More than 50% of the stars in the universe are binary stars
      d. Used to determine stellar mass
   2. Stellar mass
      a. Determined using binary stars – the center of mass is closest to the most massive star
      b. Mass of most stars is between one-tenth and fifty times the mass of the Sun

II. Hertzsprung-Russell diagram
   A. Shows the relation between stellar
      1. Brightness (absolute magnitude) and
      2. Temperature
   B. Diagram is made by plotting (graphing) each star’s
      1. Luminosity (brightness) and
      2. Temperature
   C. Parts of an H-R diagram
      1. Main-sequence stars
         a. 90% of all stars
         b. Band through the center of the H-R diagram
         c. Sun is in the main-sequence
      2. Giants (or red giants)
         a. Very luminous
         b. Large
         c. Upper-right on the H-R diagram
         d. Very large giants are called supergiants
3. White dwarfs
   a. Fainter than main-sequence stars
   b. Small (approximate the size of Earth)
   c. Lower-central area on the H-R diagram
   d. Not all are white in color
   e. Perhaps 10% of all stars

D. Used to study stellar evolution

III. Variable stars
   A. Stars that fluctuate in brightness
   B. Types of variable stars
      1. Pulsating variables
         a. Fluctuate regularly in brightness
         b. Expand and contract in size
      2. Eruptive variables
         a. Explosive event
         b. Sudden brightening
         c. Called a nova

IV. Interstellar matter
   A. Between the stars is "the vacuum of space"
   B. Nebula
      1. Cloud of dust and gases
      2. Two major types of nebulae
         a. Bright nebula
            1. Glows if it close to a very hot star
            2. Two types of bright nebulae
               a. Emission nebula
                  1. Largely hydrogen
                  2. Absorb ultraviolet radiation
                  3. Emit visible light
               b. Reflection nebula
                  1. Reflect the light of nearby stars
                  2. Composed of interstellar dust
         b. Dark nebula
            1. Not close to any bright star
            2. Appear dark
            3. Contains the material that forms stars and planets

V. Stellar evolution
   A. Stars exist because of gravity
   B. Two opposing forces in a star are
      1. Gravity – contracts
      2. Thermal nuclear energy – expands
   C. Stages
      1. Birth
         a. In dark, cool, interstellar clouds
         b. Gravity contracts the cloud
         c. Temperature rises
         d. Radiates long-wavelength (red) light
         e. Becomes a protostar
      2. Protostar
         a. Gravitational contraction of gaseous cloud continues
         b. Core reaches 10 million K
         c. Hydrogen nuclei fuse
1. Become helium nuclei
2. Process is called hydrogen burning
d. Energy is released
e. Outward pressure increases
f. Outward pressure balanced by gravity pulling in
g. Star becomes a stable main-sequence star
3. Main-sequence stage
a. Stars age at different rates
   1. Massive stars use fuel faster and exist for only a few million years
   2. Small stars use fuel slowly and exist for perhaps hundreds of billions of years
b. 90% of a star's life is in the main-sequence
4. Red giant stage
a. Hydrogen burning migrates outward
b. Star's outer envelope expands
   1. Surface cools
   2. Surface becomes red
c. Core is collapsing as helium is converted to carbon
d. Eventually all nuclear fuel is used
e. Gravity squeezes the star
5. Burnout and death
a. Final stage depends on mass
b. Possibilities
   1. Low-mass star
      a. 0.5 solar mass
      b. Red giant collapses
c. Becomes a white dwarf
   2. Medium-mass star
      a. Between 0.5 and 3 solar masses
      b. Red giant collapses
c. Planetary nebula forms
      1. Cloud of gas
      2. Outer layer of the star
d. Becomes a white dwarf
   3. Massive star
      a. Over 3 solar masses
      b. Short life span
c. Terminates in a brilliant explosion called a supernova
d. Interior condenses
e. May produce a hot, dense object that is either a
   1. Neutron star (from a massive star) or a
   2. Black hole (from a very massive star)
D. H-R diagrams are used to study stellar evolution

VI. Stellar remnants
   A. White dwarf
      1. Small (some no larger than Earth)
      2. Dense
         a. Can be more massive than the Sun
         b. Spoonful weighs several tons
c. Atoms take up less space
         1. Electrons displaced inward
         2. Called degenerate matter
      3. Hot surface
      4. Cools to become a black dwarf
   B. Neutron star
      1. Forms from a more massive star
a. Star has more gravity  
b. Squeezes itself smaller  

2. Remnant of a supernova  

3. Gravitational force collapses atoms  
   a. Electrons combine with protons to produce neutrons  
   b. Small size  

4. Pea size sample  
   a. Weighs 100 million tons  
   b. Same density as an atomic nucleus  

5. Strong magnetic field  

6. First one discovered in early 1970s  
   a. Pulsar (pulsating radio source)  
   b. Found in the Crab Nebula (remnant of an A.D. 1054 supernova)  

C. Black hole  
   1. More dense than a neutron star  
   2. Intense surface gravity lets no light escape  
   3. As matter is pulled into it  
      a. Becomes very hot  
      b. Emits x-rays  
   4. Likely candidate is Cygnus X-1, a strong x-ray source  

VII. Galaxies  

A. Milky Way galaxy  
   1. Structure  
      a. Determined by using radio telescopes  
      b. Large spiral galaxy  
         1. About 100,000 light-years wide  
         2. Thickness at the galactic nucleus is about 10,000 light-years  
      c. Three spiral arms of stars  
      d. Sun is 30,000 light-years from the center  
   2. Rotation  
      a. Around the galactic nucleus  
      b. Outermost stars move the slowest  
      c. Sun rotates around the galactic nucleus once about every 200 million years  
   3. Halo surrounds the galactic disk  
      a. Spherical  
      b. Very tenuous gas  
      c. Numerous globular clusters  

B. Other galaxies  
   1. Existence was first proposed in mid-1700s by Immanuel Kant  
   2. Four basic types of galaxies  
      a. Spiral galaxy  
         1. Arms extending from nucleus  
         2. About 30% of all galaxies  
         3. Large diameter of 20,000 to 125,000 light years  
         4. Contains both young and old stars  
         5. e.g., Milky Way  
      b. Barred spiral galaxy  
         1. Stars arranged in the shape of a bar  
         2. Generally quite large  
         3. About 10% of all galaxies  
      c. Elliptical galaxy  
         1. Ellipsoidal shape  
         2. About 60% of all galaxies  
         3. Most are smaller than spiral galaxies; however, they are also the largest known galaxies  
      d. Irregular galaxy
1. Lacks symmetry
2. About 10% of all galaxies
3. Contains mostly young stars
4. e.g., Magellanic Clouds

C. Galactic cluster
1. Group of galaxies
2. Some contain thousands of galaxies
3. Local Group
   a. Our own group of galaxies
   b. Contains at least 28 galaxies
4. Supercluster
   a. Huge swarm of galaxies
   b. May be the largest entity in the universe
VIII. Red shifts
A. Doppler effect
1. Change in the wavelength of light emitted by an object due to its motion
   a. Movement away stretches the wavelength
      1. Longer wavelength
      2. Light appears redder
   b. Movement toward “squeezes” the wavelength
      1. Shorter wavelength
      2. Light shifted toward the blue
2. Amount of the Doppler shift indicates the rate of movement
   a. Large Doppler shift indicates a high velocity
   b. Small Doppler shift indicates a lower velocity
B. Expanding universe
   1. Most galaxies exhibit a red Doppler shift
      a. Moving away
      b. Far galaxies
         1. Exhibit the greatest shift
         2. Greater velocity
   2. Discovered in 1929 by Edwin Hubble
   3. Hubble's Law – the recessional speed of galaxies is proportional to their distance
   4. Accounts for red shifts
IX. Big Bang theory
A. Accounts for galaxies moving away from us
B. Universe was once confined to a "ball" that was
   1. Supermassive
   2. Dense
   3. Hot
C. Big Bang marks the inception of the universe
   1. Occurred about 15 billion years ago
   2. All matter and space was created
D. Matter is moving outward
E. Fate of the universe
   1. Two possibilities
      a. Universe will last forever
      b. Outward expansion still stop and gravitational; contraction will follow
   2. Final fate depends on the average density of the universe
      a. If the density is more than the critical density, then the universe would contract
      b. Current estimates point to less then the critical density and predict an ever-expanding, or
         open, universe