GEOLOGY EXAM 1: COMPREHENSIVE GUIDE

1 INTRODUCTION TO GEOLOGY

1.1 Basics of Geology

- **Geology**: The science of Earth's processes, composition, structure, and history. Interdisciplinary (Chem, Phys, Bio).
- **Physical Geology**: Study of Earth materials and internal/surface processes.
- **Historical Geology**: Study of Earth's origin and development through time.
- **Why Study?**: Resource dependence (minerals, energy, water), Hazards, Environmental health.

1.2 Scientific Principles

- **Uniformitarianism**: "The present is the key to the past." Processes operating today (erosion, volcanism, gravity) operated in the past.
- **Scientific Method**:
  1. **Observation**: Data collection.
  2. **Hypothesis**: Tentative, testable explanation.
  3. **Theory**: Well-tested, widely accepted view (e.g., Plate Tectonics).
- **System**: Group of interacting parts (e.g., Earth System).
  - **Open System**: Energy/matter flow in/out.
  - **Feedback Mechanisms**: +/- loops.

1.3 Geology & Society (Facts)

- **Resource Usage**: Each American uses 3.5 million lbs of minerals/metals/fuels in a lifetime.
- **Population Bomb**: Exponential growth ($N = N_0 e^{kt}$ - you don't need to memorize the formula but know it's exponential).
- **Carrying Capacity**: Max population Earth can support without degradation.
- **Env. Disasters**:
  - **BP Deepwater Horizon (2010)**: Largest marine oil spill. 152 days.
  - **Tohoku Earthquake (2011)**: Mag 9.1. Waves up to 133 ft, 435 mph. Moved Japan 8 ft. Shifted Earth axis 10 inches. Increased rotation speed (1.8 microseconds/day).

2 ORIGINS & TIME

2.1 Origin of the Universe & Solar System

- **Big Bang**: 13.7 Billion years ago (estimated 10-15 Ga). All matter/energy expanded from a point.
- **Nebular Theory**: Solar system evolved from a rotating cloud of gas/dust (Solar Nebula).
  - Collapse → Spinning Disk → Proto-Sun → Planetesimals.
- **Age of Earth/Solar System**: 4.6 Billion Years (4.6 Ga).

2.2 Early Earth Evolution

- **Formation**: Accretion of high-velocity debris.
- **Molten Earth**: Heat from impacts and radioactive decay caused melting.
- **Differentiation**: Separation by density.
  - **Iron/Nickel** sank to center (Core).
  - **Lighter rock** floated (Crust/Mantle).
  - **Gases** escaped to form primitive atmosphere (Outgassing).

2.3 Geologic Time

- **Scale**: Eons → Eras → Periods → Epochs.
- **Precambrian**: Hadean, Archean, Proterozoic (88% of Earth history).
- **Phanerozoic**: "Visible Life" (Paleozoic, Mesozoic, Cenozoic).
- **Analogy**: If Earth history = 1 year, Humans appear at 11:49 PM on Dec 31st.

3 EARTH'S STRUCTURE

3.1 Compositional Layers (Chemistry)

- **Crust**: Thin, rocky outer skin.
  - **Oceanic**: Thin (7 km), Denser (3.0 g/cm^3), Basaltic (Mafic). Young (¡180 Ma).
  - **Continental**: Thick (35-70 km), Less Dense (2.7 g/cm^3), Granitic (Felsic). Old.
- **Mantle**: Solid, rocky shell. 82% of Earth's volume. **Peridotite** (Ultramafic).
- **Core**: Iron-Nickel alloy. Very dense.

3.2 Physical Layers (Properties)

- **Lithosphere**: Crust + Uppermost Mantle. Cool, rigid, brittle. Forms Tectonic Plates.
- **Asthenosphere**: Weak, ductile (plastic) layer in upper mantle. Allows plates to move.
- **Mesosphere**: Lower mantle. Solid, strong.
- **Outer Core**: **Liquid** Fe-Ni. Generates Earth's **Magnetic Field**.
- **Inner Core**: **Solid** Fe-Ni. Immense pressure prevents melting despite high temps.

3.3 Seismic Evidence

- **P-Waves**: Primary, Push-pull (compressional). Travel through solids, liquids, gases. Fastest.
- **S-Waves**: Secondary, Shear. Travel ONLY through solids. Stopped by Outer Core (proving it's liquid).

4 PLATE TECTONICS

4.1 Development of the Theory

- **Continental Drift (1915)**: Alfred Wegener. Pangaea. Rejected due to lack of mechanism.
- **Plate Tectonics (1960s)**: Unified theory. Lithosphere broken into plates moving on asthenosphere.
- **Driving Forces**:
  - **Slab Pull**: Main driver. Cold, dense slab sinks.
  - **Ridge Push**: Gravity slides plate off high ridge.
  - **Mantle Convection**: Heat transfer.
- **Plate Rate**: Average 3 cm/year (fingerprint growth). North American plate is relatively slow.

4.2 Plate Boundaries

- **Divergent** (←→): Plates move apart. New crust created.
  - **Features**: Mid-Ocean Ridges (seafloor spreading), Rift Valleys.
  - **Melting**: Decompression Melting.
  - **Examples**: Mid-Atlantic Ridge, East African Rift, Iceland.
- **Convergent** (→←): Plates move together. Crust recycled/destroyed.
  - **Ocean-Continent**: Subduction. Trench + Continental Volcanic Arc (e.g., Andes, Cascades).
  - **Ocean-Ocean**: Subduction. Trench + Volcanic Island Arc (e.g., Japan, Aleutians).
  - **Continent-Continent**: Collision. No subduction. Huge Mountains (e.g., Himalayas).
  - **Melting**: Flux Melting (Water from slab lowers melting point).

- **Transform** (↑↓): Plates slide past. No production/destruction.
  - **Features**: Faults, Earthquakes. No volcanoes.
  - **Example**: San Andreas Fault.

4.3 Evidence for Plate Tectonics

- **Paleomagnetism**: Iron minerals (Magnetite) align with magnetic field at **Curie Point** (585°C / 1800°F).
- **Magnetic Reversals**: Symmetric "bar code" stripes of normal/reversed polarity on seafloor. Proves seafloor spreading.
- **Seafloor Age**: Youngest at ridges, oldest at trenches. Atlantic ocean doesn't exist ¿200 Ma.
- **Hot Spots**: Stationary mantle plumes (intraplate). Plate moves over them.
  - Example: Hawaii. Chain shows direction of plate motion.
- **GPS**: Direct measurement of motion.

5 MINERALS

5.1 Definition

- **Criteria**: 1) Naturally occurring, 2) Inorganic, 3) Solid, 4) Ordered crystalline structure, 5) Definite chemical composition.
- **Rock**: Solid aggregate of minerals.
- **Atom Basics**: Protons (+), Neutrons (0), Electrons (-). Bonding occurs to satisfy shells.

5.2 Chemical Bonding

- **Ionic**: Transfer of electrons. Electrostatic attraction (e.g., Halite NaCl). Soluble.
- **Covalent**: Sharing of electrons. Strongest bond (e.g., Diamond).
- **Metallic**: Electrons drift freely ("sea of electrons"). Conductive, malleable (e.g., Gold, Copper).
- **Van der Waals**: Weak residual forces between sheets (e.g., Graphite).

5.3 Physical Properties

- **Lustre**: Appearance in light (Metallic vs Nonmetallic).
- **Color**: Diagnostic for some, unreliable for others (e.g., Quartz varies due to impurities).
- **Streak**: Color of powdered mineral (Streak plate).
- **Hardness**: Resistance to scratching (Mohs Scale).
  - 1 (Softest): Talc. 2.5: Fingerprint. 10 (Hardest): Diamond.
- **Cleavage vs Fracture**: Breaking along planes of weakness (Cleavage) vs random (Fracture/Conchoidal).
- **Specific Gravity**: Density ratio.
- **Special Properties**:
  - **Calcite**: Reacts with HCl (fizzes).
  - **Magnetite**: Magnetic.
  - **Halite**: Salty taste.
- **Polymorphs**: Same composition, different structure/properties. (Diamond [High P] vs Graphite [Low P] - both Carbon).

5.4 Mineral Groups

- **Silicates**: Most common group (¿90% of crust). Based on Silicon-Oxygen Tetrahedron (SiO_4^{4-}).
  - **Mafic (Dark)**: Rich in Fe, Mg. High density, high melt temp. (Olivine, Pyroxene, Amphibole, Biotite).
  - **Felsic (Light)**: Rich in Si, Al, K, Na. Low density, low melt temp. (Quartz, Feldspar, Muscovite).
- **Non-Silicates**:
  - **Carbonates**: Calcite, Dolomite (Limestone, Marble).
  - **Halides**: Halite (Salt), Fluorite.
  - **Oxides**: Hematite, Magnetite (Ores).
  - **Sulfides**: Galena, Pyrite (Ores).
  - **Native Elements**: Gold, Copper, Sulfur.
- **Rock-Forming** (Abundant) vs **Economic** (Valuable).

6 MAGMA & IGNEOUS ROCKS

6.1 Magma Components

- **Melt**: Liquid portion.
- **Solids**: Crystallized minerals.
- **Volatiles**: Gases (H_2O, CO_2, SO_2) dissolved in melt. Escape at surface.

6.2 Generation of Magma (Melting)

- **Geothermal Gradient**: Temp increases w/ depth (25°C/km). Rock in mantle is solid (hot but high P).
- **Decompression Melting**: Pressure drops as rock rises, lowering melting point. (Divergent boundaries, Hot Spots).
- **Flux (Volatile) Melting**: Water released from subducting slab lowers melting point of mantle wedge. (Subduction zones).
- **Heat Transfer**: Rising magma melts surrounding crustal rock.

6.3 Evolution of Magma

- **Differentiation**: Separation of components.
- **Crystal Settling**: Early formed crystals (heavy) sink.
- **Assimilation**: Melting surrounding host rock.
- **Magma Mixing**: Two bodies join.
- **Bowen's Reaction Series**: Predictable order of crystallization.
  - **Discontinuous**: Olivine (High T) → Pyroxene → Amphibole → Biotite.
  - **Continuous**: Ca-rich Plagioclase → Na-rich Plagioclase.
  - **Last to Crystallize (Low T)**: K-Feldspar, Muscovite, Quartz.

6.4 Igneous Classifications

- **Intrusive (Plutonic)**: Cools slowly underground. Large crystals.
- **Extrusive (Volcanic)**: Cools quickly on surface. Small crystals.

6.5 Intrusive Structures (Plutons)

- **Dikes:** cut across layers (Vertically)
- **Sills:** cut through layers (Horizontally)
- **Batholith:** Deep-seated magma chambers that cool slowly underground. (Huge)
- **Laccolith:** Smaller version that looks like a dome.

6.6 Textures (Crystal Size)

- **Phaneritic**: Coarse-grained (Visible). Slow cooling (Intrusive).
- **Aphanitic**: Fine-grained (Microscopic). Fast cooling (Extrusive).
- **Porphyritic**: Large crystals (Phenocrysts) in fine matrix (Groundmass). Two-stage cooling, and the result of slow cooling followed by a sudden increase in the cooling rate..
- **Glassy**: No crystals (Obsidian). Instant cooling.

- **Vesicular**: Holes from gas bubbles (Pumice, Scoria).
- **Pyroclastic**: Fragmented rock/ash (Tuff).

6.7 Compositions

- **Felsic** (Granitic): High Silica (¿65%). Light color. High Viscosity.
  - Intrusive: **Granite**. Extrusive: **Rhyolite**.
- **Intermediate** (Andesitic): Moderate Silica. Gray color.
  - Intrusive: **Diorite**. Extrusive: **Andesite**.
- **Mafic** (Basaltic): Low Silica. High Fe/Mg. Dark color. Low Viscosity.
  - Intrusive: **Gabbro**. Extrusive: **Basalt**.
- **Ultramafic**: Very low Silica. Green (Olivine). Mantle rock.
  - Intrusive: **Peridotite**.

7 VOLCANOES & HAZARDS

7.1 Viscosity & Eruptions

- **Viscosity**: Resistance to flow. Controls explosivity.
  - **High Viscosity**: High Silica (Felsic), Low Temp. Gas trapped → **Explosive**.
  - **Low Viscosity**: Low Silica (Mafic), High Temp. Gas escapes → **Effusive**.
  - **Simplified Rule:** Subduction/Explosive → Stratovolcanoes. Hotspots → Shield/Effusive.

7.2 Volcano Types

- **Shield Volcano**: Broad, slight dome. Fluid Basaltic lava. Liquid flows. (e.g., Mauna Loa, Hawaii).
- **Cinder Cone**: Small, steep. Built from ejected lava fragments (scoria). Short-lived. (e.g., Paricutin).
- **Composite Cone (Stratovolcano)**: Large, classic cone. Interbedded lava/pyroclastics. Violent. Ring of Fire. (e.g., Mt. Rainier, St. Helens, Fuji).
- **Caldera**: Large collapse depression (¿1 km). (e.g., Crater Lake, Yellowstone).
- **Flood Basalts**: Massive volume of fluid lava from fissures. (e.g., Columbia River Basalts).

7.3 Volcanic Hazards

- **Pyroclastic Flow**: Superheated gas/ash avalanche. ¿100 km/h. Most deadly.
- **Lahars**: Volcanic mudflows (Ash + Water). Concrete-like. Can occur without eruption (rain/melt). Major threat to valleys.
- **Ejecta / Tephra**: Ash (fine), Lapilli (gravel), Blocks (hard), Bombs (molten-streamlined).
- **Lava Flows**: Property damage, usually slow. Pahoehoe (ropy, hotter, less viscous), A'a (jagged, otherwise same compistion).
- **Gas**: H_2O, CO_2, SO_2. CO_2 is denser than air, collects in lows (Lake Nyos).

7.4 Monitoring & Status

- **Active**: Erupting or recent. **Dormant**: Sleeping, capable. **Extinct**: No magma source.
- **Signals**: Earthquakes (magma movement), Ground deformation (inflation), Gas emission changes.

8 OCEAN FLOOR

- **Bathymetry**: Mapping ocean depth (Sonar).
- **Continental Margin**: Transition from land to deep sea.
  - **Shelf**: Flooded continent, gentle slope.
  - **Slope**: Steep drop-off.
  - **Rise**: Sediment accumulation.
- **Deep Ocean Basin**:
  - **Abyssal Plain**: Flat, sediment covered.
  - **Trenches**: Deepest points (subduction).
  - **Seamounts**: Submerged volcanoes.
- **Mid-Ocean Ridge**: Longest topo feature. Rift valley in center.