Part I: The Dawn of Time

5. Radioactive Clocks and Geological Time: Absolute and Relative Time

Decay Times: Age of the Earth and Meteorites;
Principles of Stratigraphy: Sediment, Magnetic, Biological, Isotopic

Absolute, Relative Time: absolute ages based on radioactive decay as time elapsed since formative event (e.g. melting); relative ages (principles)

Radioactive Decay: disintegrating per unit time is proportional to total no. of radioactive atoms; half-life: time required for half original material to disintegrate; instability of specific nuclei determines decay rates (decay constant or l); parent/daughter relationships critical to age determination, e.g. $^{87}$Rb to $^{87}$Sr, multiple daughters for $^{235}$U, $^{238}$U; relative proportions of isotopes provide approaches to dating (e.g. $^{87}$Rb/$^{87}$Sr and $^{87}$Sr/$^{86}$Sr, $^{206}$Pb/$^{204}$Pb and $^{207}$Pb/$^{204}$Pb), isochrons used to calculate ages from multiple analyses (principles) (examples) (fig)

Age of rocks, lunar samples and meteorites: values based on $^{87}$Rb/$^{87}$Sr (examples)

Rock Records: sedimentary rocks record discontinuous depositional events, breaks are unconformities, individual discrete horizons are beds; principles of sedimentation: superposition: bed is younger than that below; initial horizontality: sediments are deposited horizontally; lateral continuity: sediments form continuous layers; cross-cutting: younger units cross-cut older units (principles) (fig)

Biostratigraphy: ages based on fossil assemblages, datums, first, last appearances of individual organisms; results from evolutionary changes (principles) (fig)

Magnetostratigraphy: sequence of magnetic reversals of known duration at defined times (principles) (fig)

Sequence Stratigraphy: sequences recognized to form as sea level changes; transgression (sea level rising or land sinking); regression (sea level falling or land rising) (principles) (fig)

Chemo or Isotopic Stratigraphy: established changes in chemical characteristics linked to global events or trends (e.g. oxygen isotopes of foraminifera reflect ice volumes) (principles) (fig)

Part II: Development of The Face of the Earth

6 & 7. Tectonics and Continental Configurations: Rifting and Drifting

Sea Floor Spreading; Convergence, Divergence; Formation of Ocean Basins
Paleogeography; Paleomagnetics; Supercontinents and Superoceans
Plate Tectonics; motion of oceans and continents driven by internal heat; surface mosaic of
pieces of lithosphere floating on asthenosphere, moved by convective processes in the mantle; plate interactions create earthquakes, volcanoes, which delineate their boundaries, divided into three categories. **(principles) (fig)**

Plate Boundaries: Divergent: sea floor spreading, extensional, mid-ocean ridges; basins expand on crustal conveyor; crust cools, becomes denser, thicker, sinks **(principles) (fig)**

Convergent: colliding, compressive, form trenches, mountain belts, ocean crust subducts, 3 types: ocean/ocean (e.g. Aleutians), ocean/continent (e.g. Andes), continent/continent (e.g. Himalayas **(principles) (fig)** Transform: sliding, slipping, transform faults created by lateral displacement, e.g. San Andreas **(principles) (fig) (examples)**

Volcanism: arcs (explosive), mid-ocean ridges (pillow basalts), hot spots **(examples) (fig)**
volcanic activity, explosive andesite volcanoes on continents (ocean/continent), islands (island arcs, ocean/ocean); continent collisions create mountains (continent/continent), folds, thrusts, thickens crust (India/Asia, Himalayas) **(examples) (principles) (fig)**

Supercontinents, Superoceans: long-term cycles of clustering (supercontinents, superoceans), break-up (e.g. Pangaea, Gondwanaland, Laurasia with Pantalassia, Tethys at 225Ma) process involved in tectonics and Wilson Cycle **(principles) (examples): accretion and growth of continents, rate of growth over geologic time (principles)**

Paleogeography: plate reconstructions, latitudinal position: climatic indicators (fossils, evidence of glaciation, corals, laterites, magnetic orientation (polar wandering) **(principles) (examples)**

8. EVOLUTION OF ATMOSPHERIC COMPOSITION: OXIDATION OF EARTH

Atmospheric structure: sequence of layers governed by temperature: troposphere (with clouds), stratosphere (ozone layer), mesosphere, thermosphere, bounded by tropopause, stratopause, mesopause. Major gases: \( \text{N}_2 \) (78.1%), \( \text{O}_2 \) (20.9%), \( \text{Ar} \) (0.9%), \( \text{CO}_2 \), inert gases, water vapor (variable, \( \sim \)1.4%), dust particles (trace)

Atmospheric circulation: Earth’s rotation creates Coriolis force and produces 6 cells as wind belts. Locations of rising air (0° and 60°) low pressure and high precipitation, and of sinking air (30°) high pressure and low rainfall. The locations and directions of surface winds: NE and SE trade winds, westerlies and polar easterlies. **(fig)**

Atmospheric cells: Hadley 0-30°, Ferrel 30-60°, polar 60-90°; boundaries: Intertropical convergence zone (ITCZ), doldrums at 0°, horse latitudes at 30°; monsoons; air pressures: winter low over ocean, high over land, reverse in summer **(fig)**

Early Earth Atmosphere: composition dissimilar from solar nebula; highly reducing with \( \text{H}_2 \), \( \text{NH}_3 \), \( \text{CH}_4 \) or weakly reducing with \( \text{H}_2 \text{O}, \text{CO}_2 \)? Product of formation and early outgassing. High \( \text{CO}_2 \) (2-3%) is likely. **(principles) (sequence)**

Modifiers of Atmospheric Composition: volcanic outgassing: loss of volatiles decreases over time? Sea floor spreading rates control \( \text{CO}_2 \): faster rates more \( \text{CO}_2 \). **(principles)**

Biological processes: uptake of \( \text{CO}_2 \), release of \( \text{O}_2 \), by photosynthesis (plants), reverse in respiration; \( \text{O}_2 \) enables build-up of ozone (\( \text{O}_3 \)) in stratosphere **(principles)**

Geochemical cycling: weathering, mineral reactions, acting as sinks for \( \text{CO}_2 \) and \( \text{O}_2 \)

Biogeochemical changes: coupled element cycles, and coupled controls on atmosphere. **(principles)**

Atmospheric Proxies: red beds, paleosols, deposits banded iron formations (BIFs), iron (II) or ferrous minerals indicative of no \( \text{O}_2 \). **(sequence) (fig)**

Coupling of carbonate and silica cycles: weathering and burial recorded in inventories of rocks
through time: \[ CO_2 + CaSiO_3 = CaCO_3 + SiO_2 \] describes \( CO_2 \) levels

Coupling of oxygen and sulfur cycles: \[ CO_2 + H_2O = CH_3O (org. matter) + O_2 \]
also \[ 2Fe_2O_3 + 16HCO_3^- + 16Ca^{2+} + 8SO_4^{2-} = 4FeS_2 + 16CaCO_3 + 8H_2O + 15O_2 \]
describes \( O_2 \) levels, changes through Phanerozoic by rock cycling, weathering (fig)

Changes over Geological Time: hydrogen: initially lost to space. Oxygen: gradual (or stepwise?) build-up, constrained by BIF’s, biology. Carbon Dioxide: initially high, fluctuates through greenhouse/icehouse cycles. (principles) (sequence) (fig)

\( CH_4 \) "burps" release from gas hydrates during warming (sea floor "pock" marks, Santa Barbara basin, Paleocene/Eocene boundary at \(-55Ma\)). Gas hydrates: \( CH_4 \) trapped in ice clathrates in temperature/pressure regimes of deep sea sediments. (principles) (examples)

Modern Records: gas concentrations (\( CO_2, CH_4 \)) in ice cores. Atmospheric perturbations from \( CH_4 \) "burps" recorded by carbon isotopes (\( \delta^{13}C \)) (fig)

Gaia hypothesis: concept that biology influences, sustains, or regulates Earth’s atmosphere and climate system. (principles)

9. **EVELOPMENT OF OCEAN CHARACTERISTICS: EARTH’S WATERY ENVELOPE**

*Ocean Dynamics: Temperature, Salinity and Density-Driven Circulation*

Temperature and Salinity of the Ocean: sea surface temperatures show strong latitudinal gradients; annual range controlled by ocean heat capacity; greatest annual change in oceans at mid and high latitudes; surface salinity controlled by evaporation, precipitation. (principles) (fig)

Salinity: salt content of oceans primarily composed of 7 dissolved ionic species: \( Cl^-, Na^+, SO_4^{2-}, Mg^{2+}, Ca^{2+}, K^+, HCO_3^- \); concentration of salt varies, composition is globally uniform.

Temperature/salinity variations control density: as salinity increases density increases, as temperature increases, salinity decreases. Water layers: each with specific salinity, temperature and density, reflects origins. (principles)

Ekman spiral, Ekman Transport: wind-driven currents deflected by Earth’s rotation: right in N. hemisphere, left in S. hemisphere, speed decreases with depth; net result: water movement at 90° to wind direction, dependent on wind persistence. (principles) (fig)

Geostrophic Flow: convergence of surface water thickens surface layer; water flows down mounds and is deflected by Coriolis effect. (principles)

Surface Currents and Deep Circulation: Coriolis effect acts on surface water deflecting it from the wind direction, creates circular motions: Gyres: circular current systems, eastward flowing water (weak) at higher latitudes, boundary currents parallel to continental margins. (principles) (fig)


Global Conveyer: movements of deep water; formed near Iceland, moves southward, mixes with AABW and moves eastward into Pacific; controlled by topography, (fig)