Indian Institute of Technology, Kanpur

Department of Earth Sciences

ES0213A: Fundamentals of Earth Sciences

Lecture 05. Earth as a System

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Aims of this lecture

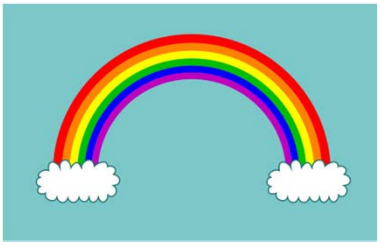
- Earth as a SYSTEM
- Definition and components of Earth (and Planetary) system

The Blue Planet

- Few basic and exclusive features
  - WATER – in liquid form on the surface
  - PLATE TECTONICS – active
  - ATMOSPHERE – O_2 rich and filters solar radiation
  - MAGNETIC FIELD – relatively strong
  - **LIFE** – primitive to intelligent

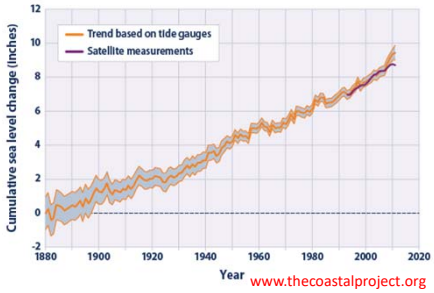
Do we know?

- **A Rainbow changes the sky brightness**
  1. True
  2. False

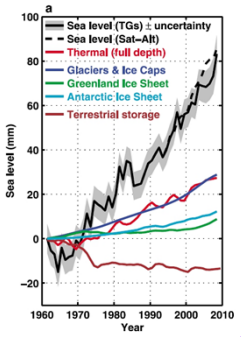


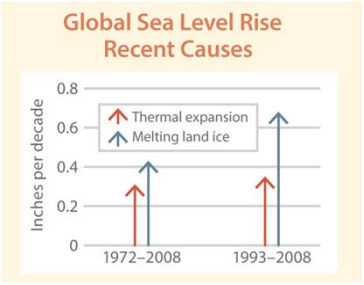
Do we know?

- **The main reason of present day sea-level rise**
  - 1. Melting of glaciers and ice-sheets
  - 2. More rain-fall
  - 3. Warming of ocean and sea water
  - 4. Ground water discharge to oceans



www.thecoastalproject.org

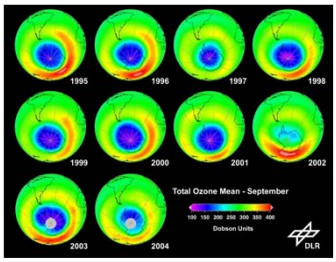




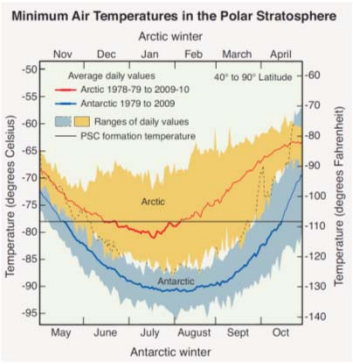
Church & White 2001;
Cazenave and Llovel, 2010

Do we know?

- **The hole / thinning in the ozone layer is related to GLOBAL WARMING.**
  - 1. Agree
  - 2. Disagree



- … and why we have the hole primarily over the Antarctic region?



Chlorofluorocarbons (CFCs) and other halogenated ozone depleting substances (ODS) are mainly responsible for man-made chemical ozone depletion.

The southern polar region is colder and more isolated than the north. Lower temperatures favor the formation of polar stratospheric clouds (PSCs) which serve as platforms for catalytic ozone breakdown. Unlike the Arctic, the circulation over the Antarctic is more persistent and vortex-like as a consequence of having less land. Air inside the vortex is prevented from mixing with warmer, ozone-rich air from lower latitudes. This vortex is not a feature of the Arctic. IOW, the chemistry of ozone loss works in both poles, but their meteorological conditions are different.

Do we know?

- **The maximum contribution of oxygen in the atmosphere comes from**
  - 1. Terrestrial biosphere
  - 2. Marine biosphere
  - 3. Volcanic eruption
  - 4. Washing powder !

The main source (~80%) of atmospheric oxygen, on Earth, is cyanobacteria (aka "blue-green algae") in the ocean.

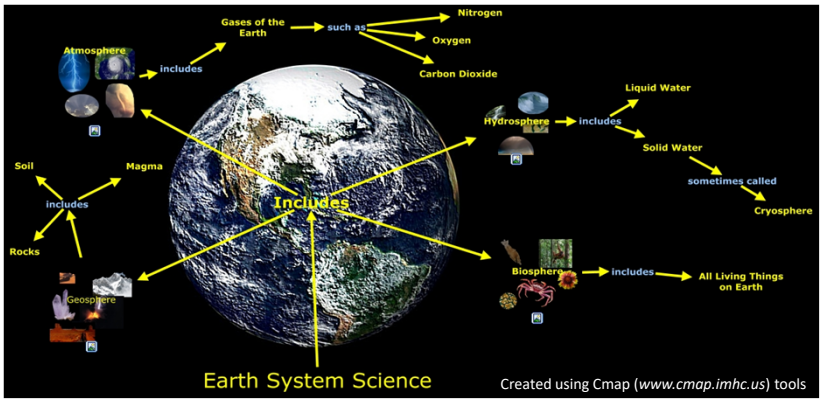
[Source: NASA]

System

- SYSTEM: A system is a group of related objects or parts or components that work together to form a whole.
- COMPLEX SYSTEM: Many of the individual components are themselves systems (subsystems).
- NONLINEAR SYSTEM: A particular issue cannot be judged by simply adding the effects of independent components, because there are hardly any independent components.

System – Earth System

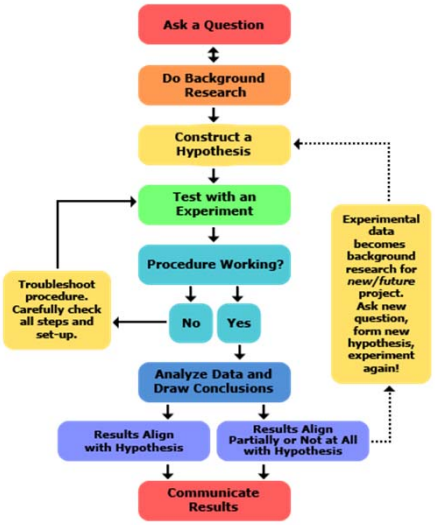
- EARTH: The densest planet in the Solar System and the only astronomical object known to have Oxygen rich atmosphere and accommodate life.
- EARTH SYSTEM: A system that considers and manages all of the matter, energy, and processes within Earth's boundary. The system is very much complex made of living and nonliving things, and matter and energy continuously cycle, interact and evolve through the smaller systems.



+ ANTHROPOSPHERE ?

Earth System Processes – a study of science?

- The Scientific Methods –What most of us follow

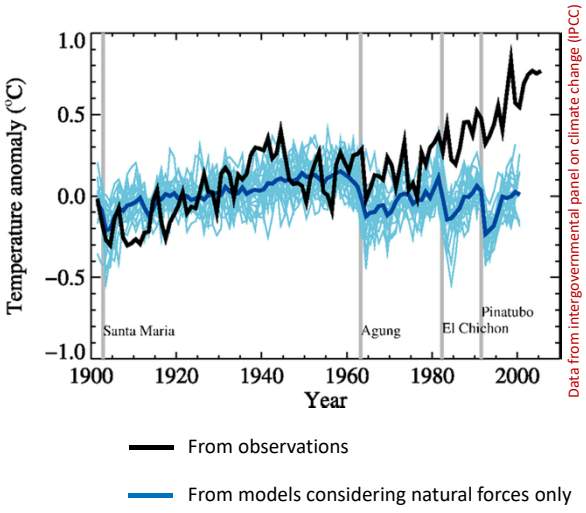


- HYPOTHESIS: an explanation based on guess, untested
- THEORY: an idea that has passed through many experiments and observations with few unexplained issues.
- LAW / PRINCIPLE: – a full proof theory; no exceptions.

Earth System Processes – a study of science?

- OBSERVATION: the average temperature of Earth is increasing over the last century.
- HYPOTHESIS: More volcanic activity, increasing solar radiation variability (i.e., natural changes – that happened even before) are responsible for the increasing temperature
- TEST: The hypothesis worked well until 1978-80. But an anomaly after that time! The hypothesis failed to explain.

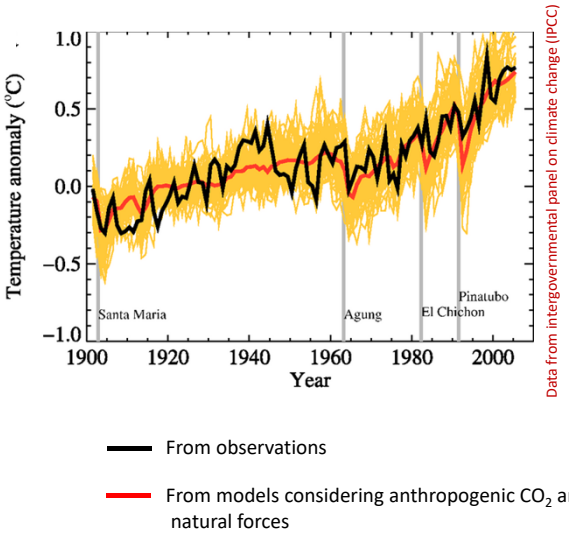
.. Reject the hypothesis and think for a new one.



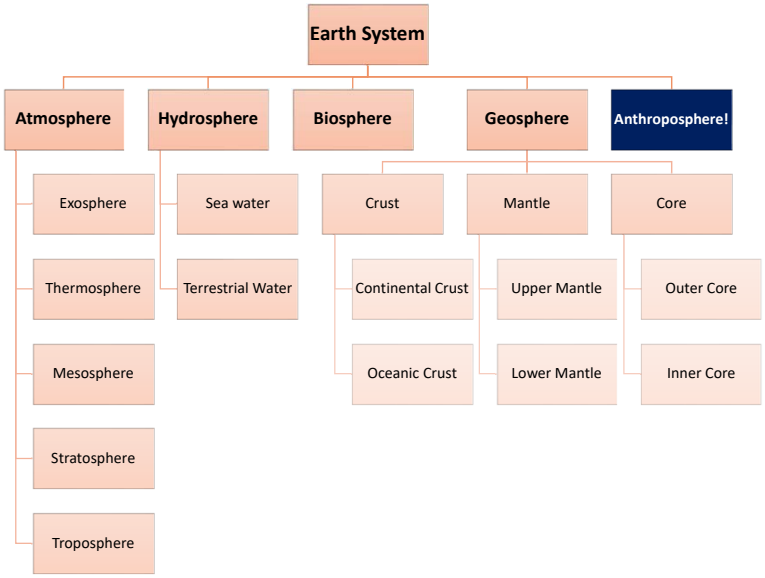
Earth System Processes – a study of science?

- OBSERVATION: the average temperature of Earth is increasing over the last century.
- HYPOTHESIS: Anthropogenic activities (more CO_2, methane and land-use) together with natural changes are the reason for global temperature increase.
- TEST: The hypothesis worked perfect and showed an excellent correlation.

.. However, after the successful test results, it remains still a hypothesis; not a theory or law as there are many local anomalies and level of uncertainty.



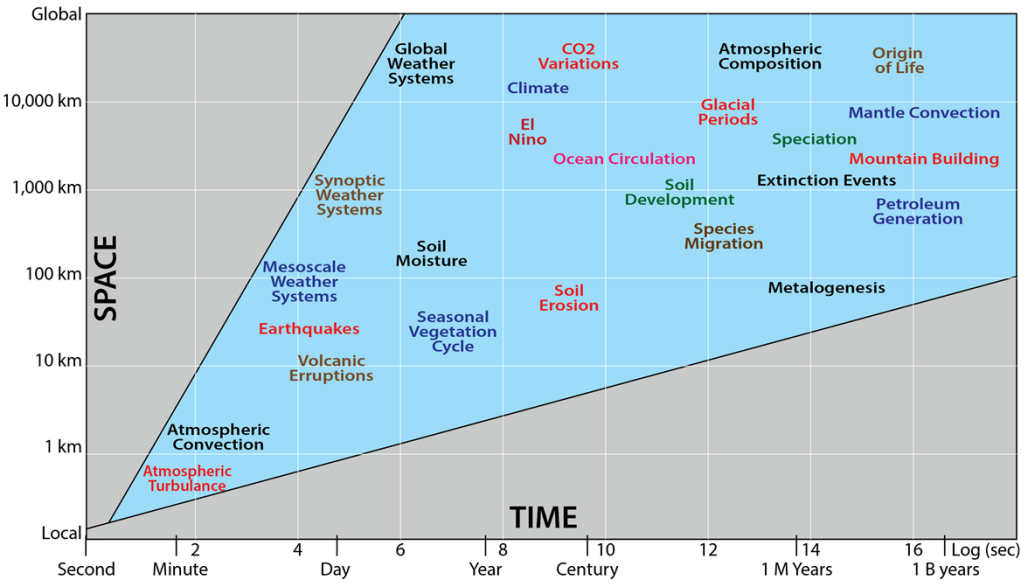
Hierarchy of Earth System – the components



The mutual interactions – Earth as a System

- OPEN systems defined as those that exchange energy (heat) and mass with other systems; CLOSED system only exchange energy. [more on this in the next lecture]
- The forces that drive heat and mass transfer include chemical potential, temperature and pressure gradients, Causing diffusion, reaction and advection (flow) – mostly irreversible with time.
- MODELS are developed considering time-dependency, degree of linearity, deterministic and / or probabilistic to simulate the earth as a system.
- Primary importance -
  - Different kinds of subsystems (e.g. the atmosphere, hydrosphere etc.)
  - Components of the subsystem (air, water, rocks, minerals etc.)
  - Physico-chemical state of the components (Pressure, temperature, composition etc.)
  - Interactions and mechanisms between sub-systems (fluxes of matter and energy)

Spatial-Temporal and Geological-Environmental events

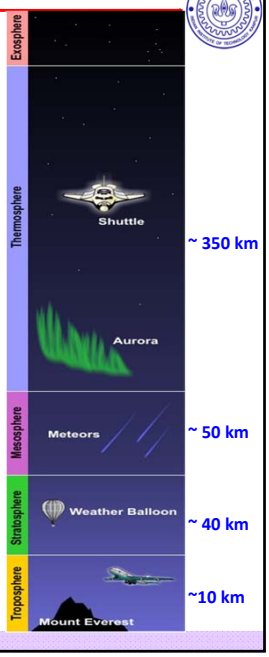


Source: NASA, 1986

The Atmosphere

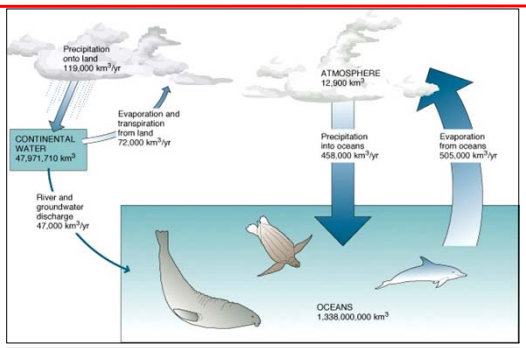
- The earth's atmosphere is a very thin layer wrapped around a very large planet
- Two gases make up the bulk of the earth's atmosphere: nitrogen (78% of the atmosphere), and oxygen (21%). Various trace gases make up the remainder.
- Based on temperature, the atmosphere is divided into four layers: the **troposphere**, **stratosphere**, **mesosphere**, and **thermosphere**. The outermost layer is exosphere.
- Energy is transferred between the earth's surface and the atmosphere via conduction, convection, and radiation.
- Ocean currents (and winds, too) play a significant role in transferring this heat poleward. Major currents, such as the northward flowing Gulf Stream, transport tremendous amounts of heat poleward and contribute to the development of many types of weather phenomena.

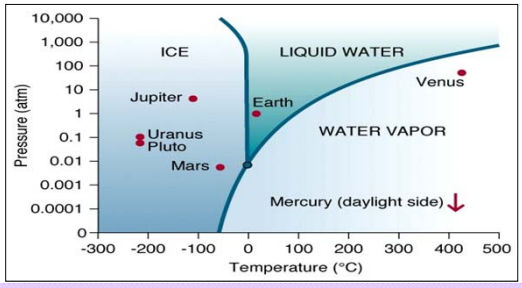
We shall spend a week in the atmosphere…



Hydrosphere

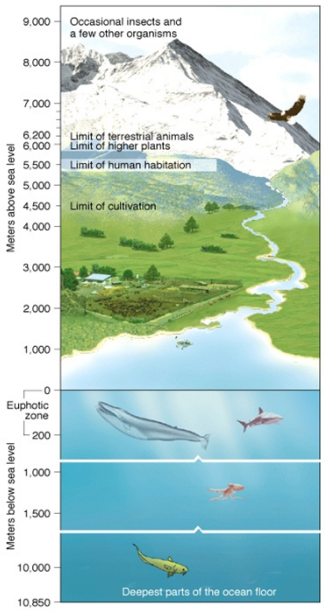
- Earth- the only watery planet! The BLUE planet.
- All forms of H_2O: water, ice, water-vapour.
- Responsible for many of the landform and surface features on continents.
- Without surface water, there would be no rivers, valleys, glaciers etc.





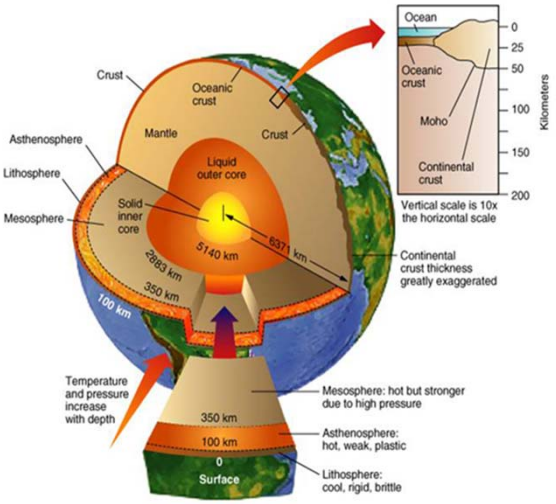
The Biosphere

- Considers the living world - microbes, plants, and animals. Age- 3.5 billion years.
- The biosphere extends to any place that life of any kind might exist. The biosphere extends to the upper areas of the atmosphere where birds and insects can be found. It also reaches to dark caves deep in the ground or to the bottom of the ocean at hydrothermal vents.
- Factors, that control the existence and diversity of the Biosphere
  - Big factors: distance from sun, tilt of earth, seasonal variation
  - Small factors: climate, daily weather, erosion, earthquake
  - Micro-factors: chemical erosion, oxidation, reduction.
  - What about US! Are we also a factor to biosphere?



The Geosphere

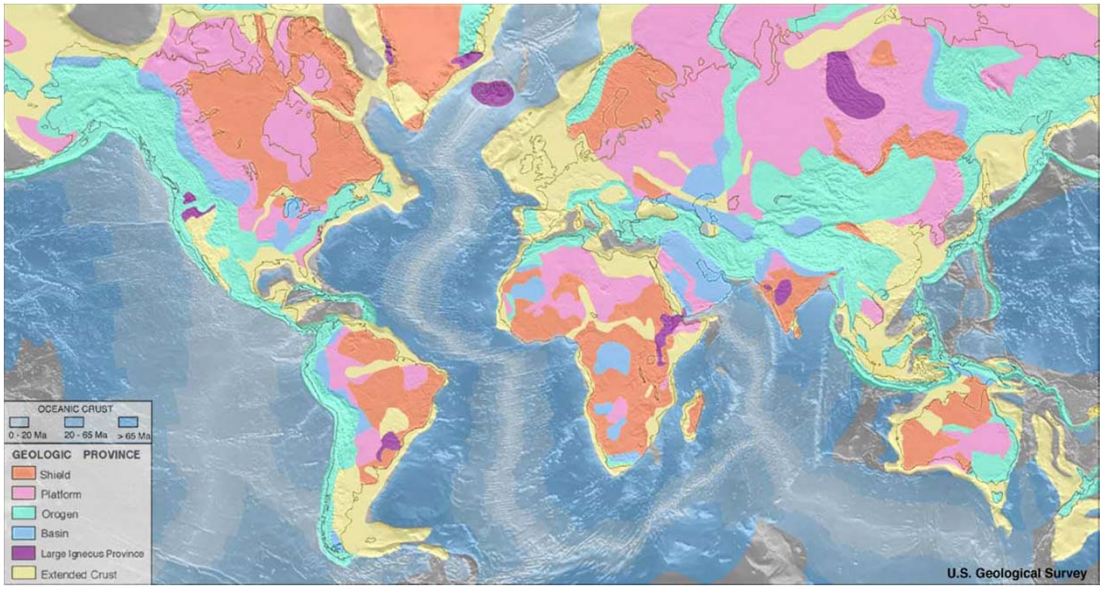
- While the whole Earth (crust, mantle and core) plays the role, the PEDOSPHERE and LITHOSPHERE have a greater participation is earth system.
- **Continental crust** – 35-65 km; Varied rock types, rich in Si and Al (lighter); Relatively Old (4.6 billion years).
- **Oceanic crust** - ~5 km; Volcanic rocks, rich in Mg and Fe (dense), Relative young (<150 my).
- **Lithosphere** – rigid (brittle), rocky outer layer of the Earth, consisting of the crust and the solid outermost layer of the upper mantle (~100 km). It is segmented as plates.
- **Asthenosphere** – layer beneath the lithosphere, covers the mantle from ~100-350 km and is much hotter and more fluid (ductile) than the lithosphere.
- **LAB** – Lithosphere-Asthenosphere Boundary.



The Geosphere – Continental Crust & Lithosphere

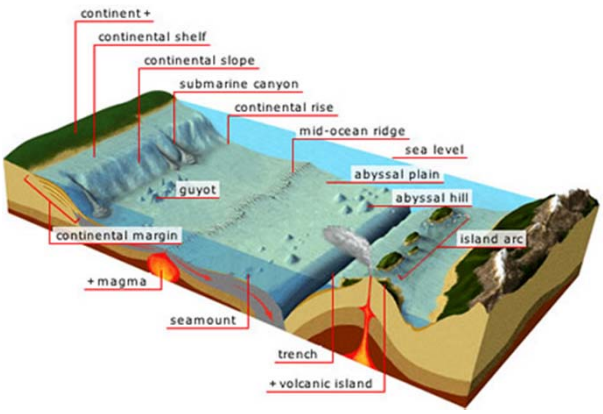
- Shields: deeply eroded expanses of low relief, which have been stable since Precambrian times.
- Platforms: similar to the above, but mantled by thick sedimentary cover, which may be entirely or in part Phanerozoic in age.
- Orogens: long, curved belts of folded rocks, usually forming mountain chains, mostly formed by continental collisions.
- Rifts: linear, fault-bounded depressions, traversing continents; these are the structures which originate crustal splitting and dispersion, and lead to midocean ridge formation, but they may, as in the case of the East African Rifts, be aborted, i.e., never developed into oceans.

The Geosphere – Continental Crust & Lithosphere

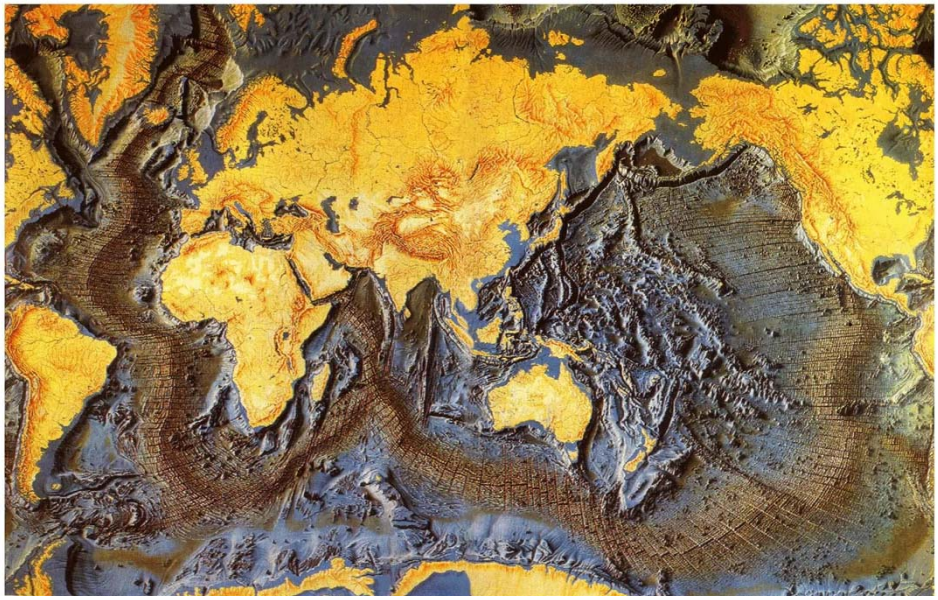


The Geosphere – Oceanic Crust & Lithosphere

- Volcanic islands: scatterings or chains of islands which mark mantle hotspots.
- Volcanic / Island arcs: above subduction zones (e.g., Aleutian Islands), these may be represented by their eroded underworks – chains of calc-alkaline batholiths (e.g., Peru).
- Trenches: the outer margin of subduction zones; the deepest parts of the oceans.
- Ocean basins/abyssal plains: the extensive flat, deep areas of oceans, beyond continental slopes.
- Marginal basins: small basins separating arcs, or landward from arcs (back-arc basins).
- Inland seas: seas within continents (e.g., Caspian).
- Mid Oceanic Ridge: underwater mountain range, typically having a valley known as a rift running along its axis, formed by plate tectonics. This type of oceanic ridge is characteristic of what is known as an oceanic spreading center

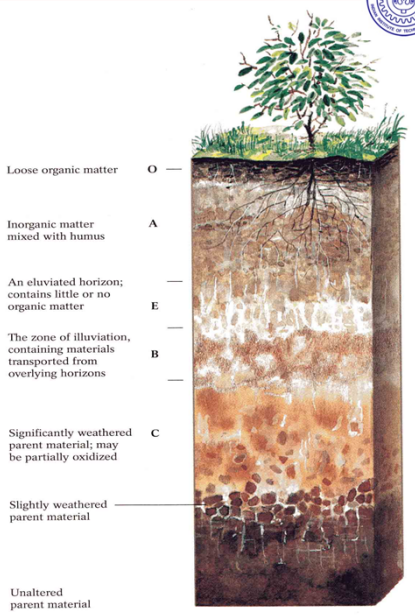


Continental and Oceanic Crusts: surface morphology



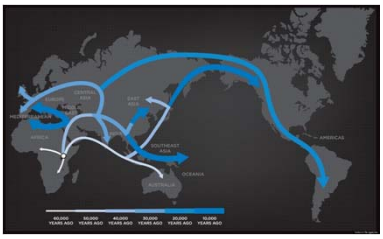
The Pedosphere

- Soils – disaggregated and weathered rock debris and organic matter.
- 100-200 m thick, supports all terrestrial agricultural activities and food production.
- Open system; rate of soil formation depends upon climate, rock type, organic matter, topography and time.
- Factors, that control soil formation
  - Parent material / rock
  - Topography
  - Animal and plant activity
  - Climate (rainfall, temperature)
  - Time



Anthroposphere

- 50-100 k years : Homo Sapiens appeared in Africa and migration started
- 25-12 k years : Ice age conditions; new land appeared, helped in migration
- 10 k years : Warmer global climate ; agriculture developed; domesticated animals; diversion of streams, irrigation canals, dams
- 7 k years : First cities arose; use of metals, fuels
- 1700 k years : Industrial revolution



Accelerated growth in the last few hundred years – exponential growth

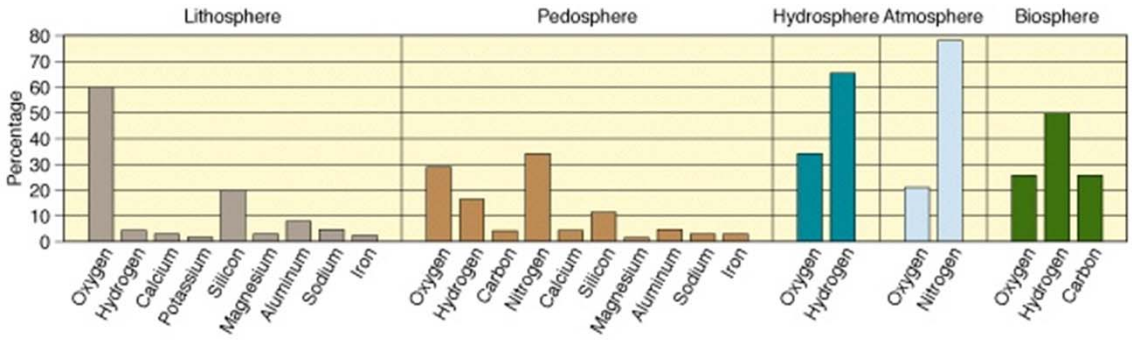
Post 1700 scenario

- Human population expanded
- Competition for food, air, water and space
- Negative impacts
  - Air/water pollution
  - Soil erosion
  - Concentration of waste
  - Diseases

Last few centuries

What else can you think?

Composition of Earth System



Suggested Additional Reading

- Summerfield, S.A. (1991) Global Geomorphology, Longman.
- Ernst, W.G. (2000) Earth Systems: Processes and Issues, Cambridge University Press.
- Merrits, D., Dewet, A. and Menking, K. (1998) Environmental Geology: An earth system science approach. W.H. Freeman.

Next Lecture

Principles of the Earth