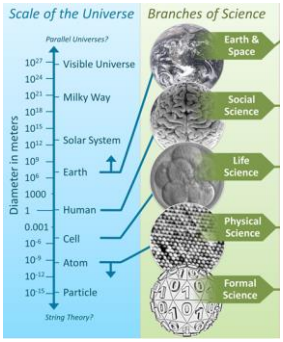
EARTH SYSTEMS (GEOL 1340)

What is Science?

- Science studies the natural world on scales ranging from the universe to subatomic particles
- A way of **thinking** in the pursuit of understanding nature
- A way of **investigating** claims about natural phenomenon
- A body of **knowledge** resulting from scientific inquiry



Scientific Inquiry Often Uses Both Inductive And Deductive Reasoning

- **Induction: Making generalizations from specific observations:**
  - **Example: It has been observed that the farther galaxies are from Earth, the faster they are moving away: The universe is expanding**
- **Deduction: Making predictions (deductions) from pre-existing generalizations:**
  - **Example: A meteorologist will look at certain weather patterns and, based on prior experience, predict that it will rain later today**

One Goal Of Science Is To Describe And Predict Events In Nature Using A Scientific Method

Inductive

- **Collection of data**
- **Analysis of data**

Scientific Data

- **Scientific data should be:**
  - **Representative and unbiased**
  - **Reproducible**
  - **Accurate and precise**
- **Scientific data may be:**
  - **Observational or experimental**
- **An observation that has been repeatedly confirmed is considered a "Scientific Fact" or "Law"**

One Goal Of Science Is To Describe And Predict Events In Nature Using A Scientific Method

Inductive

- **Collection of data**
- **Analysis of data**

Deductive

- **Development of a Hypothesis(es)**
- **Testing of Hypothesis**
- **Verification, modification, or rejection of hypothesis**
- **Development of a Theory**

A Hypothesis Is:

- A generalized statement designed to EXPLAIN a set of scientific observations:
  - Not the only explanation
  - Not necessarily the final explanation
  - …But an idea that we can test with additional data
- The best hypothesis is one that explains ALL of the existing observations

Testing a Hypothesis

- Hypothesis predicts a certain pattern or order to the data
- Collect additional data that would be predicted (deduced) on the basis of the hypothesis:
  - Perform more experiments and/or observations
  - Does the additional data verify the prediction?
- If the data are inconsistent with the prediction, then the hypothesis MUST be modified or abandoned

Example Of Induction And Deduction

- A hydrologist samples water from several wells in an area:
  - Analyzes the chemistry of the water
  - Water is contaminated in the sampled wells
- Induction (generalization):
  - Wells in this area are contaminated
- Deduction (hypothesis):
  - Contamination is from a nearby landfill
- How would we test our hypothesis?
  - Collect more water samples closer to landfill
  - Is contaminant consistent with pollutants from landfill?
  - Perhaps contaminant from nearby industrial plant

Hypothesis (Continued)

- If the data are consistent with the prediction, they support the hypothesis.
- Repeated verification of a hypothesis may result in the formation of a THEORY

A Theory Is:

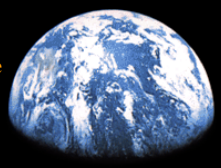
- "A well tested and widely accepted view that scientists agree best explain certain observational facts."
- Like the hypotheses from which it grew, it must also be testable and falsifiable!
- Therefore, all theories are considered provisional:
  - Nonetheless, theories are the end points of science!

There is no scientific statement stronger or more widely accepted than a theory!

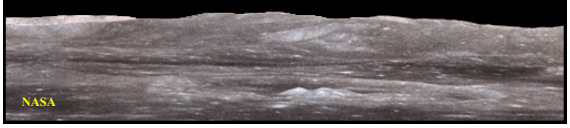
Earth Systems Science is a way of asking and answering questions about the physical universe

A View of Earth

Earth is a planet that is small and self-contained



- Hydrosphere
- Atmosphere
- Biosphere
- Solid Earth



NASA

Earth's Spheres And Cycles

Earth's spheres (reservoirs):

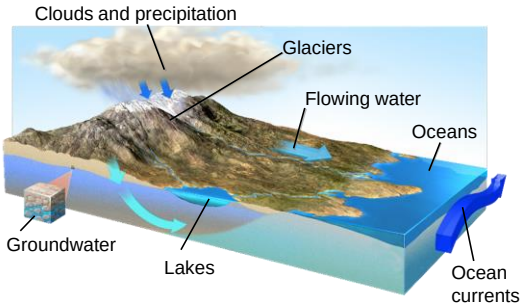
- Lithosphere (solid Earth)
- Cryosphere
- Hydrosphere
- Atmosphere
- Biosphere

Spheres interact through cycles

Earth Cycles

- A cycle is the continuous process by which matter and materials are circulated or recycled throughout the Earth
- Cycles are repetitious and recur, sometimes over specified periods of time
- Matter and materials are transferred from one reservoir to another and are sometimes changed in the process
- Examples of cycles:
  - The four seasons
  - Daily rise and fall of tides

The Hydrologic Cycle: How Water Is Stored And Moved Throughout Our Planet



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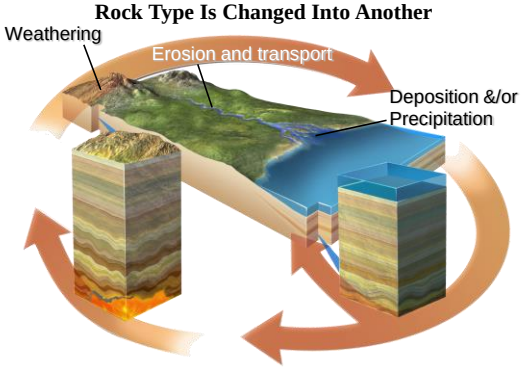
Rock Cycle: The Loop That Illustrates How One Rock Type Is Changed Into Another



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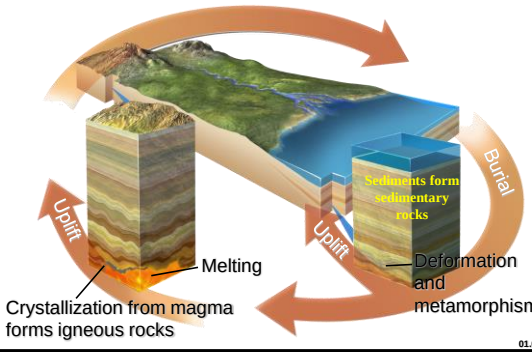

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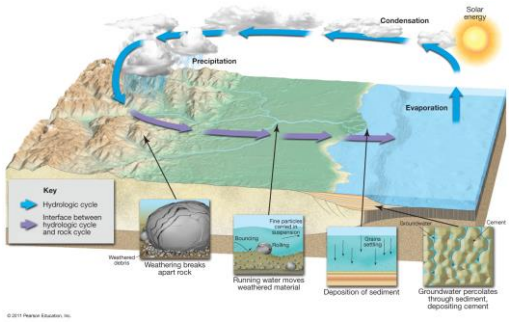
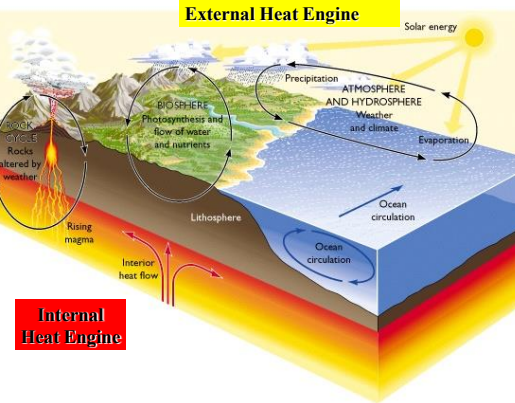
Interface Between The Hydrologic And Rock Cycle



Earth Systems Powered By Heat Engines

- A **Heat Engine** converts thermal energy into kinetic energy (motion) – e.g. your car
- Earth's **External Heat Engine** is powered by the Sun that drives the earth's fluid envelopes (the atmosphere and hydrosphere)
- Earth's **Internal Heat Engine** is powered by geothermal heat that drives cycles within the solid Earth:
  - Rock cycle
  - Tectonic cycle that moves lithospheric plates and recycles earth materials



Earth As a System

- Earth is a dynamic planet with interacting parts or spheres
- Earth System Science:
  - Aims to study Earth as a system composed of numerous interacting parts or subsystems
  - Employs an interdisciplinary approach to solve global environmental problems

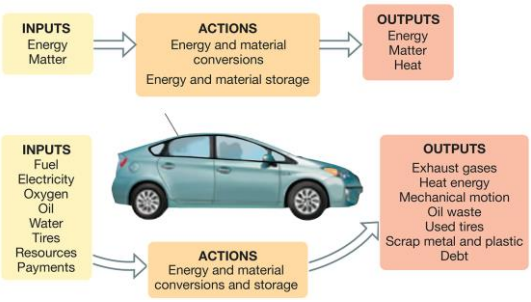
Earth As a System

- What is a system:
  - Any size group of interacting parts that form a complex whole
  - A system comprises any number of subsystems or cycles
  - Matter and energy are stored and retrieved
  - Energy can be transformed from one type to another (e.g. potential to kinetic energy)

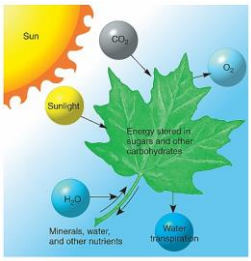
Earth As a System

- Open system:
  - Energy and matter flow into and out of system
- Closed system:
  - System shut off from surrounding environment
  - Self contained in that energy and/or matter does not enter or leave the system

Example Of An Open System

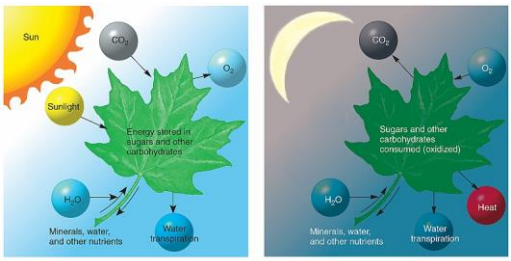


Leaf As A Natural Open System

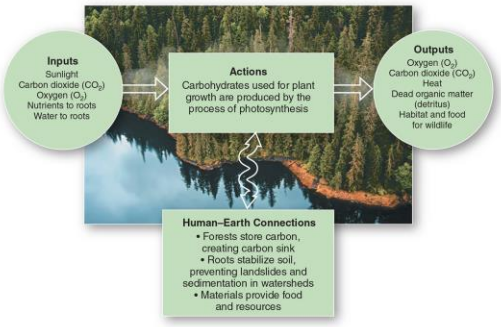


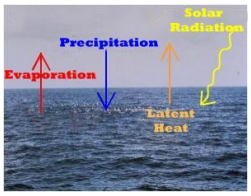
(a) Plant photosynthesis

Leaf As A Natural Open System

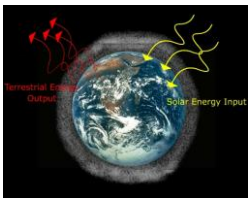


(a) Plant photosynthesis (b) Plant respiration

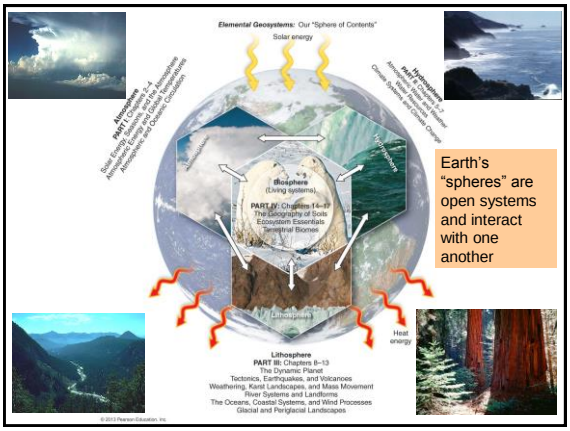




Ocean as an open system: Energy and matter flow into and out of the system



Earth is an open system for energy but a closed system to matter: Although energy enters and leaves earth freely, virtually no matter is exchanged between earth and the universe

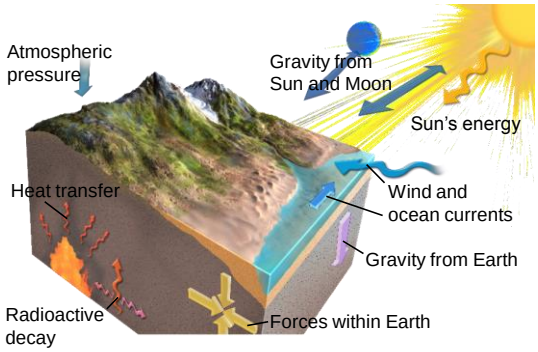


Earth's "spheres" are open systems and interact with one another

Time Scales Of Interaction

- ATMOSPHERE: Seconds to Days
- OCEANS: Hours to Centuries
- EARTH:
  - Earthquakes and Volcanoes: Seconds to Days
  - Movement of Continents and Opening of Ocean Basins: Millions of Years

Forces And Processes Affecting Earth's Materials



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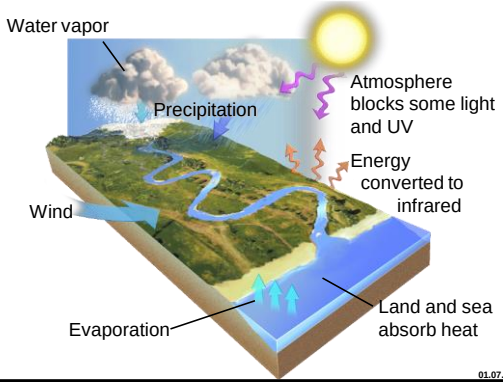
How The Atmosphere Affects Earth's Surface



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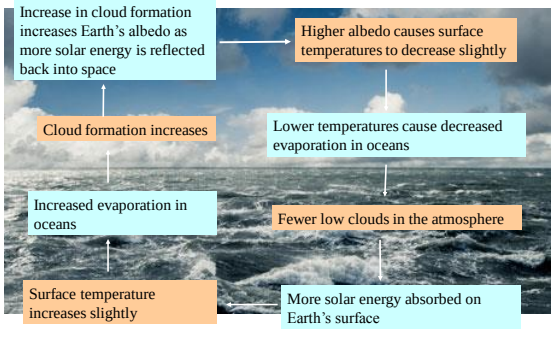
Feedback Mechanisms

- Negative feedback:
  - Maintains the status quo
  - A change in the system triggers one or more mechanisms that reverses that change

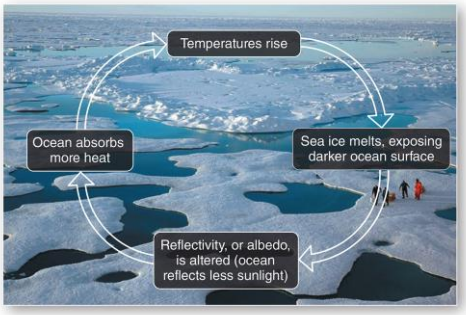
Negative Feedback



Feedback Mechanisms

- Positive Feedback:
  - Enhances or drives change
  - A change in the system triggers one or more mechanisms that further enhances or drives that change

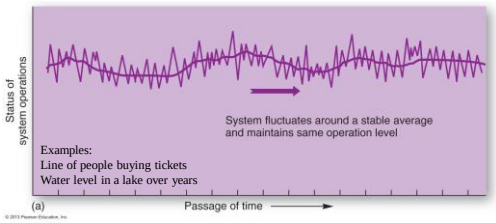
Positive Feedback



System Equilibrium

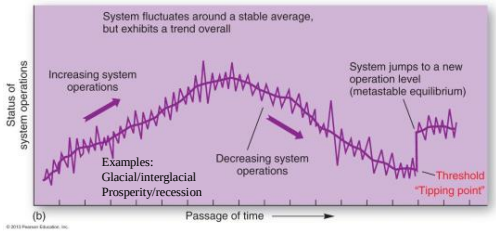
- **Most systems maintain structure and character over time**
- **Steady-state condition:**
  - **Energy and material in the system remains balanced over time**
  - **Conditions are constant or recur**

Steady State Equilibrium



- **Rates of inputs and outputs in the system are equal**
- **Amounts of energy and matter in storage are constant or fluctuate around a stable average**

Dynamic Equilibrium



- **Steady-state system demonstrates a changing trend over time**
- **System operations may gradually be increasing or decreasing over time**

System Equilibrium

- **Systems try to resist abrupt change**
- **However, a system may reach a threshold, beyond which it can no longer maintain its character**
- **Examples of exceeded thresholds:**
  - **Abrupt landslide**
  - **Sudden collapse of ice shelf**
  - **Extinction of a species**

Dynamic Equilibrium And Threshold

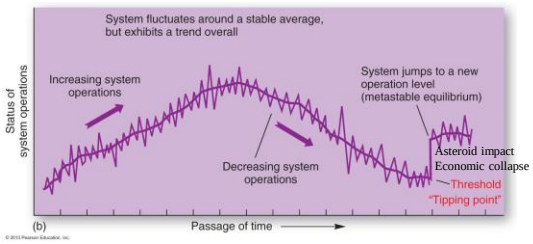
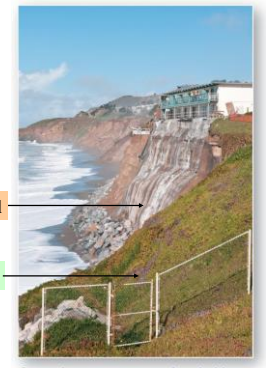


Fig. 1.5

Harlequin frog near extinction places community at threshold

Threshold Passed

Dynamic Equilibrium



Coastal systems pass a threshold.

Examples of Thresholds