Earth Systems and Cycles

Spheres of the Earth

- **Atmosphere**
- **Hydrosphere**
- **Biosphere**
- **Lithosphere**

The Atmosphere

The Earth is surrounded by an **atmosphere** of **gases**.

The predominant gases are:

Nitrogen, Oxygen, Carbon Dioxide, and Water Vapor.

No other planet in the solar system has such an atmosphere.

The Hydrosphere

The **Hydrosphere** consists of the oceans. Lakes, and streams; underground water; and snow and ice, including glaciers.

The **Hydrosphere** is another unique characteristic of the Earth.

3. The Biosphere

The **Biosphere** (life sphere) is the totality of the Earth's living matter.

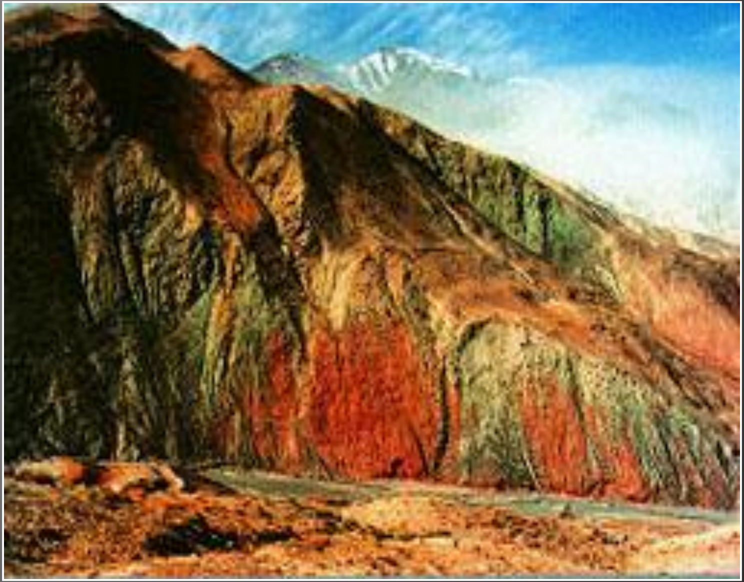
The **Biosphere** embraces innumerable living things, large and small, which are grouped into millions of different species.

4. The Lithosphere

It is the outermost rocky layer of the Earth.

Because the Earth's **lithosphere** is a thin, cold, brittle shell, it has broken up into a series of enormous rocky plates.It is mobile

These plates move around as a result of movements in the hot, mobile material underneath.



The System Concept

A **system** is any portion of the universe that can be isolated from the rest of the universe for the purpose of observing changes.

The first step in viewing the Earth as a system is to identify the smaller systems that are its component parts.

There are **four principle systems** within the larger Earth system:

- **Atmosphere**
- **Hydrosphere**
- **Biosphere**
- **Lithosphere**

Each of these can be further divided into smaller systems.

Systems must have **boundaries** that set it apart from its surroundings.

The nature of these boundaries define the characteristics of the system, leading to three kinds of systems:

- **Open System**
- **Closed System**
- **Isolated System**

Isolated System

- It is the simplest to understand.

- The boundaries **prevent** the system from exchanging either **matter** or **energy** with its surroundings.

- Such a system is **imaginary** because although it is possible to have boundaries that prevent the passage of matter, in the real world it is impossible for any boundary to be perfectly insulating.

Closed System

- It is the nearest thing to an isolated system in the real world.

- Such a system has boundaries that permit the exchange of energy, but not matter, with its surroundings.

- Such as an oven, which allows the material inside to be heated but does not allow any of that material to escape.

Open System

- It can exchange both matter and energy across its boundaries.

- Rain falling on an island is a simple example of an open system: some of the water runs off via streams and groundwater while some evaporates back to the atmosphere.

Box Models

The way that we are portraying systems and the different relation between them

Systems are commonly depicted in the form of box models.

This is for simplicity and convenience.

A box model can be used to show:

-The rates at which material and/or energy enter and leave the system.

-The amount of matter or energy in the system.

Essential features of the box models are **input**, **output**, and **size** of the reservoir:

-If input increases or output decreases, the size of the reservoir increases.

-If input decreases or output increases, the size of the reservoir decreases.

Living in a Closed System

The Earth is a **natural closed system**.

Or at least a very close approach to such a system.

The fact that the Earth is a closed system has two important implications for environmental geology:

1. The amount of matter is fixed and finite.

This means that the mineral resources on this planet are all we have and all we will ever have.

This means that we must treat them with respect and use them wisely and cautiously.

This means that material wastes must remain within the confines of the Earth system.

2. When changes are made in one part of a closed system, the results of those changes will eventually affect other parts of the system.

Even though the Earth system is closed, its innumerable smaller parts are open systems.

These systems are in a dynamic state of balance. When something disturbs one of the smaller system, the rest also change as they seek equilibrium.

Dynamic Interactions Among Systems

Sulfur Dioxide

generated by a coal-fired power plant in

Ohio

Combines with moisture in the atmosphere

Acid Rain

falls in

Northern Ontario

Pesticides

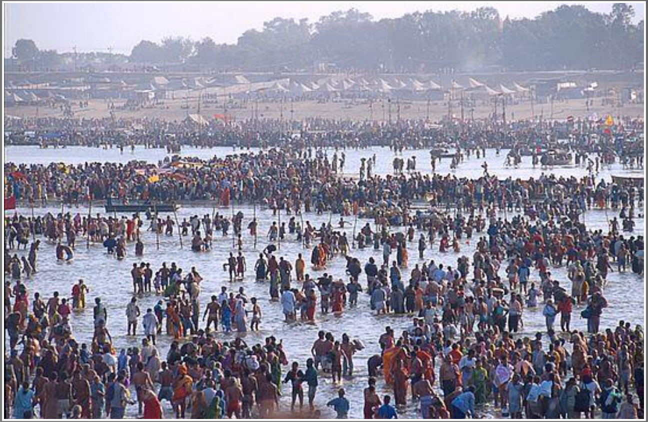
used in the cotton fields of

India

Pesticides

in the waters of the

Ganges River



Pesticides

in the waters of the

Sea

Pesticides

in the blubber of the

Whales

Pesticides

ingested by the

Fish

Pesticides

caught and eaten by the

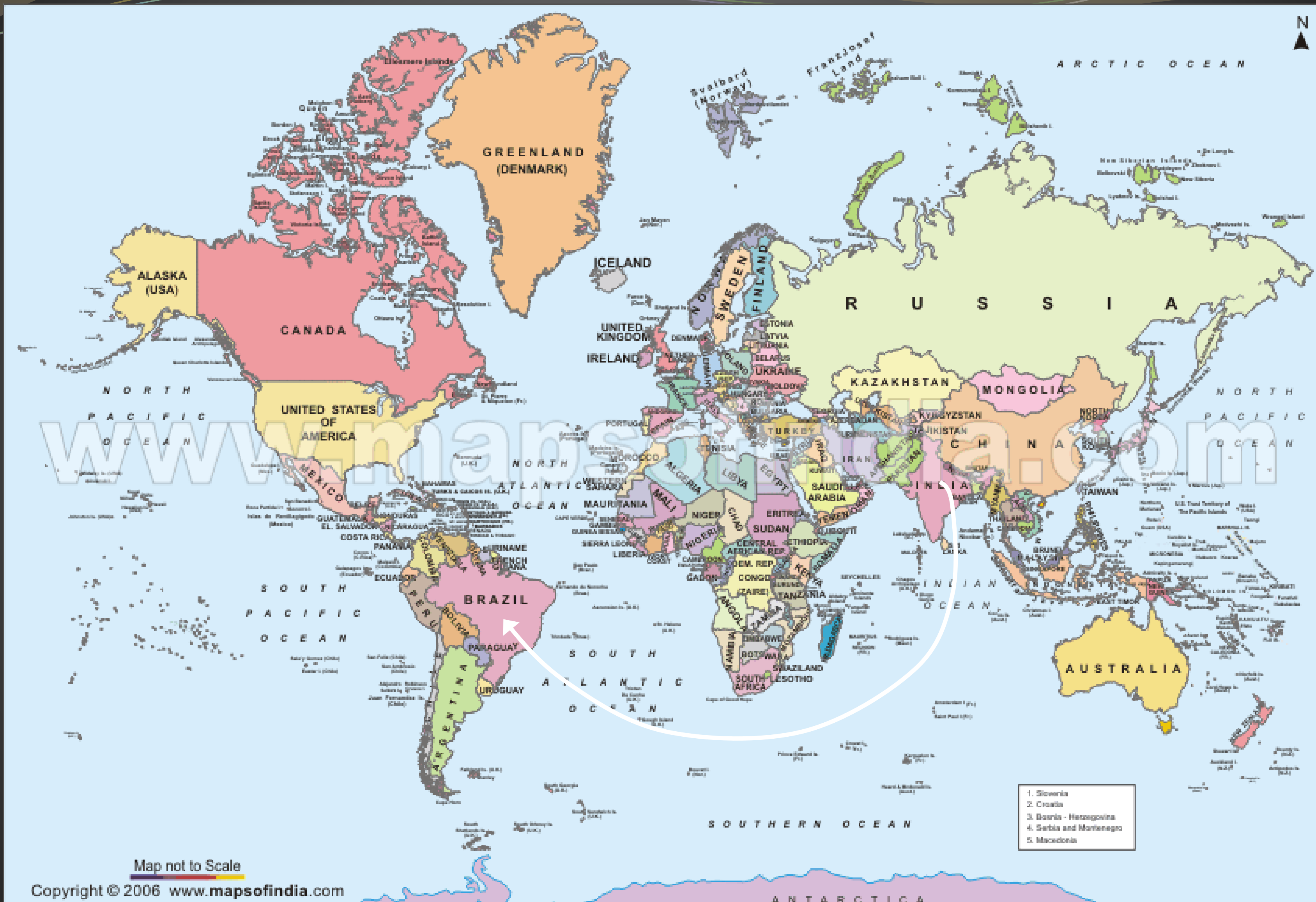
Humans

Pesticides

halfway around the world from the place where they were applied (e.g. Brazil)

in the breast milk of the

Mothers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GREENLAND (DENMARK)
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UNITED KINGDOM
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SWEDEN
FINLAND
ESTONIA
LATVIA
UKRAINE
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MONGOLIA
KYRGYZSTAN
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TAIWAN
TURKEY
IRAN
IRAQ
SAUDI ARABIA
YEMEN
I N D I A
SRI LANKA
THAILAND
PHILIPPINES
MALAYSIA
BRUNEI
EAST TIMOR
NORTH PACIFIC OCEAN
PORTUGAL
MOROCCO
TUNISIA
ALGERIA
LIBYA
EGYPT
WESTERN SAHARA
MAURITANIA
MALI
NIGER
CHAD
SUDAN
ERITREA
DJIBOUTI
ETHIOPIA
NIGERIA
SIERRA LEONE
LIBERIA
GABON
CENTRAL AFRICAN REP.
DEM. REP. CONGO (ZAIRE)
KENYA
TANZANIA
ANGOLA
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ZIMBABWE
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LESOTHO
SOUTH AFRICA
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PARAGUAY
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ARGENTINA
SOUTH PACIFIC OCEAN
SOUTH ATLANTIC OCEAN
AUSTRALIA
SOUTHERN OCEAN
ANTARCTICA
1. Slovenia
2. Croatia
3. Bosnia - Herzegovina
4. Serbia and Montenegro
5. Macedonia
Map not to Scale
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Cycles in the Earth System

It is useful to envisage interactions within the Earth system as a **series of interrelated cycles**.

Both **material** and **energy** can be stored in **reservoirs**, and the storage times (**residence times**) can differ greatly.

For example, *carbon stored in plants may have a* ***residence time of a few months or years****, whereas carbon buried in the rock reservoir may have a* ***residence time of millions of years***.

This means that a single cycle may include processes that operate on several different time scales.

Since **material** is constantly being **transferred** from one of the Earth's spheres to another, ***why those systems seem so stable?***

Why should the composition of the atmosphere be constant?

Why doesn't the sea become saltier, or fresher?

This is because the Earth's natural processes follow **cyclic paths**. Materials flow from one system to another, but the systems themselves don't change much because the ***different parts of the flow paths balance each other***:

i.e. ***the amounts added equal the amounts removed***.

A few basic cycles can serve to **illustrate** most of the **Earth processes** that are of importance in environmental geology.

These include

- The Energy Cycle
- The Hydrologic Cycle
- The Biogeochemical Cycles
- The Rock Cycle

1. The Energy Cycle

The **energy cycle** encompasses the great engines – **the external and internal energy sources** – that **drive the Earth system and all its cycles**.

The **energy cycle** could be thought of as a "**budget**": energy may be added to or subtracted from the budget and may be transferred from one *storage place* to another, but overall the additions and subtractions and transfers must ***balance*** each other.

If a balance did not exist, the Earth would either **heat up** or **cool down** until a **balance** was reached.

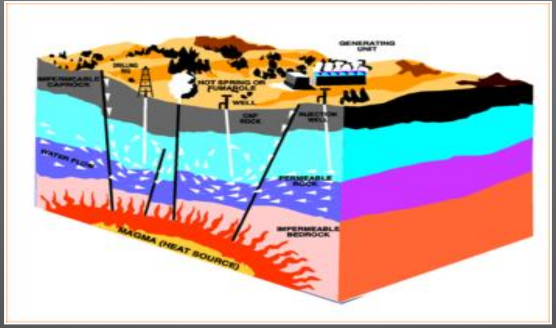
Energy Inputs

The total amount of energy flowing into the Earth's energy budget is more than

174,000 terawatts (or 174,000 x 10^{12} watts).

There are **three main sources** from which energy flows into the Earth system:

Solar Radiation	Geothermal Energy	Tidal Energy
99.986%	0.013%	0.002%



Solar Radiation

Short-Wavelength Solar Radiation

Some of this influx powers the winds, rainfall, ocean currents, waves, and other processes in the ***hydrologic cycle***.

Some is used for ***photosynthesis*** and is temporarily stored in the biosphere in the form of plant and animal life. When plants die and are buried, some of the solar energy is stored in rocks; when we burn coal, oil, or natural gas, we release stored solar energy.

Geothermal Energy

The Earth's Internal Heat Energy

Geothermal comes from the Greek words geo (Earth) and therme (heat). So, geothermal means Earth heat.

At Earth's core – 4000 miles deep – temperatures may reach over 9,000ºF.

Geothermal energy finds its way to the surface of the Earth, primarily via ***volcanic pathways***.

It drives the ***rock cycle*** and is therefore the source of the energy that uplifts mountains, causes earthquakes and volcanic eruptions, and generally shapes the face of the Earth.

Tidal Energy

The Kinetic Energy of the Earth's Rotation

Tides are caused by the **gravitational attraction** of the ***Moon*** and ***Sun*** acting upon the **oceans** of the **rotating Earth**.

The relative motions of these bodies cause **the surface of the oceans** to be **raised** and **lowered periodically**.

Energy Loss

The Earth loses energy from the cycle in **two main ways**:

- Reflection
- Degradation and Reradiation

Reflection

About **40%** of **incoming solar radiation** is simply **reflected**, unchanged, back into space, by the clouds, the sea, and other surfaces.

For any planetary body, ***the percentage of incoming radiation that is reflected is called the albedo***.

Ice is more reflectant than vegetation; and forested land reflects light differently than agricultural land.

Thus, if large expanses of land are ***converted*** from forest to plowed land, or from forest to city, the actual reflectivity of the Earth's surface, and hence its **albedo**, may be altered.

Any change in the **albedo** will have an effect on the Earth's energy budget.

Degradation and Reradiation

The portion of incoming ***solar energy that is not reflected*** back into space, along with ***tidal*** and ***geothermal energy***, is **absorbed** by materials at the surface of the Earth.

This energy undergoes a series of **irreversible degradations** in which it is transferred from one reservoir to another and converted from one form to another.

The energy that is absorbed, utilized, transferred, and degraded ends up as **heat**, in which form it is **reradiated** back into space as **long-wavelength infrared radiation**.

Weather patterns are a manifestation of energy transfer and degradation.

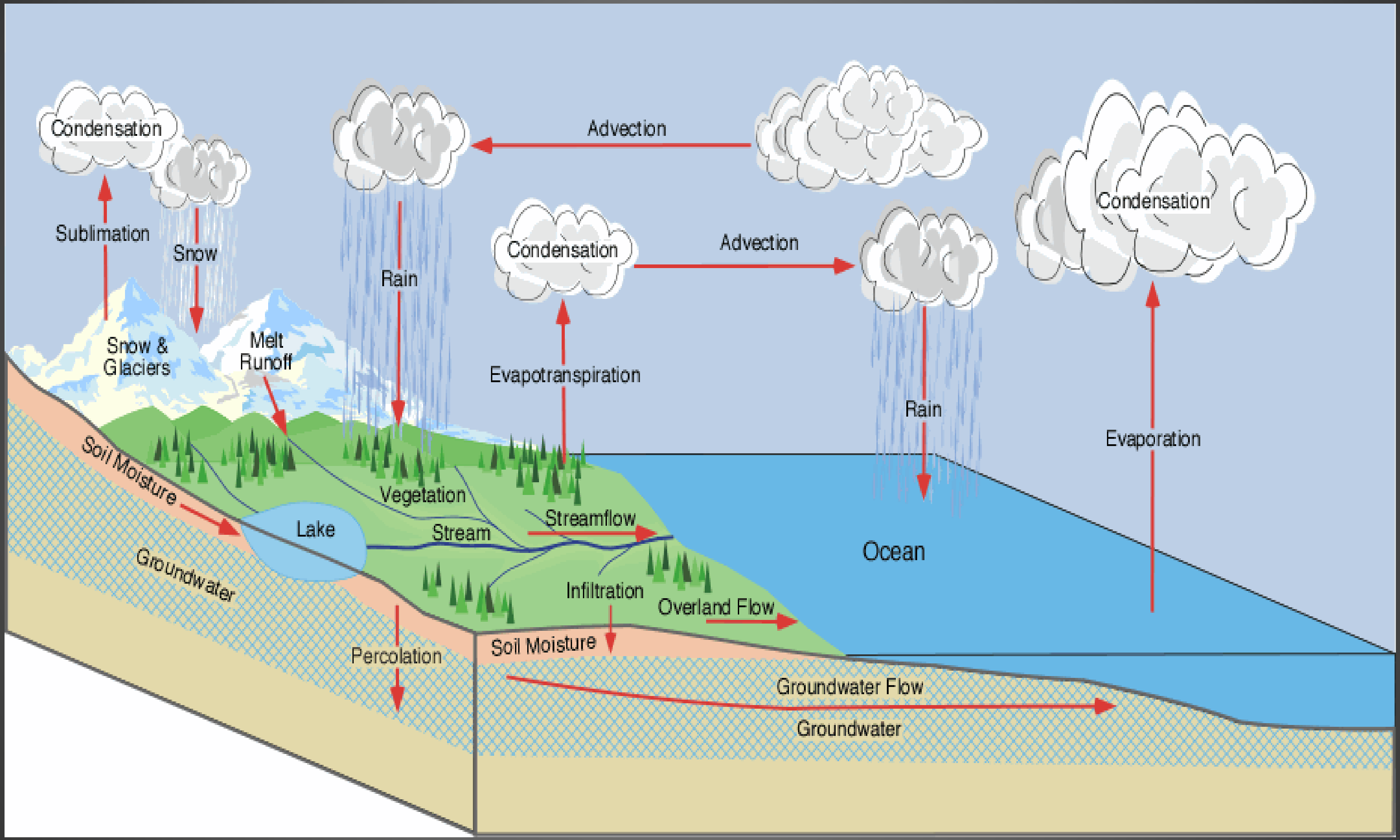
2. The Hydrologic Cycle

It describes the **fluxes of water** between the various **reservoirs** of the **hydrosphere**.

The **hydrologic cycle** is composed of

pathways, ***the various processes by which water is cycled around in the outer part of the Earth***, and

reservoirs, or storage tanks, ***where water may be held for varying lengths of time***.



Condensation
Sublimation
Snow
Advection
Rain
Condensation
Advection
Condensation
Snow & Glaciers
Melt Runoff
Evapotranspiration
Rain
Evaporation
Soil Moisture
Vegetation
Lake
Streamflow
Stream
Ocean
Groundwater
Infiltration
Overland Flow
Percolation
Soil Moisture
Groundwater Flow
Groundwater

Pathways

The movement of water in the **hydrologic cycle** is powered by **heat** from the Sun, which causes **evaporation** of water from the ocean and land surfaces.

The **water vapor** enters the **atmosphere** and moves with the **flowing air**.

Some of the **water vapor condenses** and falls as **precipitation** (either rain or snow) on the land or ocean.

Rain falling on land may be **evaporated** directly or it may be **intercepted** by vegetation, eventually being returned to the atmosphere through their leaves by **transpiration**.

Or it may drain off into stream channels, becoming **surface runoff**.

Or it may **infiltrate** the soil, eventually **percolating** down into the ground to become part of the **groundwater**.

Snow may remain on the ground for one or more seasons until it **melts** and melt water flows away.

Reservoirs

The largest **reservoir** for water is the **ocean**, which contains more than **97.5%** of all the water in the system.

This means that most of the water in the cycle is saline, not freshwater.

The largest **reservoir** of **freshwater** is the permanently **frozen polar ice sheets**, which contain almost **74%** of all freshwater.

Of the remaining unfrozen freshwater, almost **98.5%** resides in the next largest reservoir, **groundwater**.

Only a very small fraction of the water passing through the hydrologic cycle resides in the **atmosphere** or in surface freshwater bodies such as **streams** and **lakes**.

3. The Biogeochemical Cycles

A **biogeochemical cycle** ***describes the movement of any chemical element or chemical compound among interrelated biologic and geologic systems***.

This means that *biologic processes* such as respiration, photosynthesis, and decomposition act alongside and in association with such *nonbiologic processes* as weathering, soil formation, and sedimentation in the cycling of chemical elements or compounds.

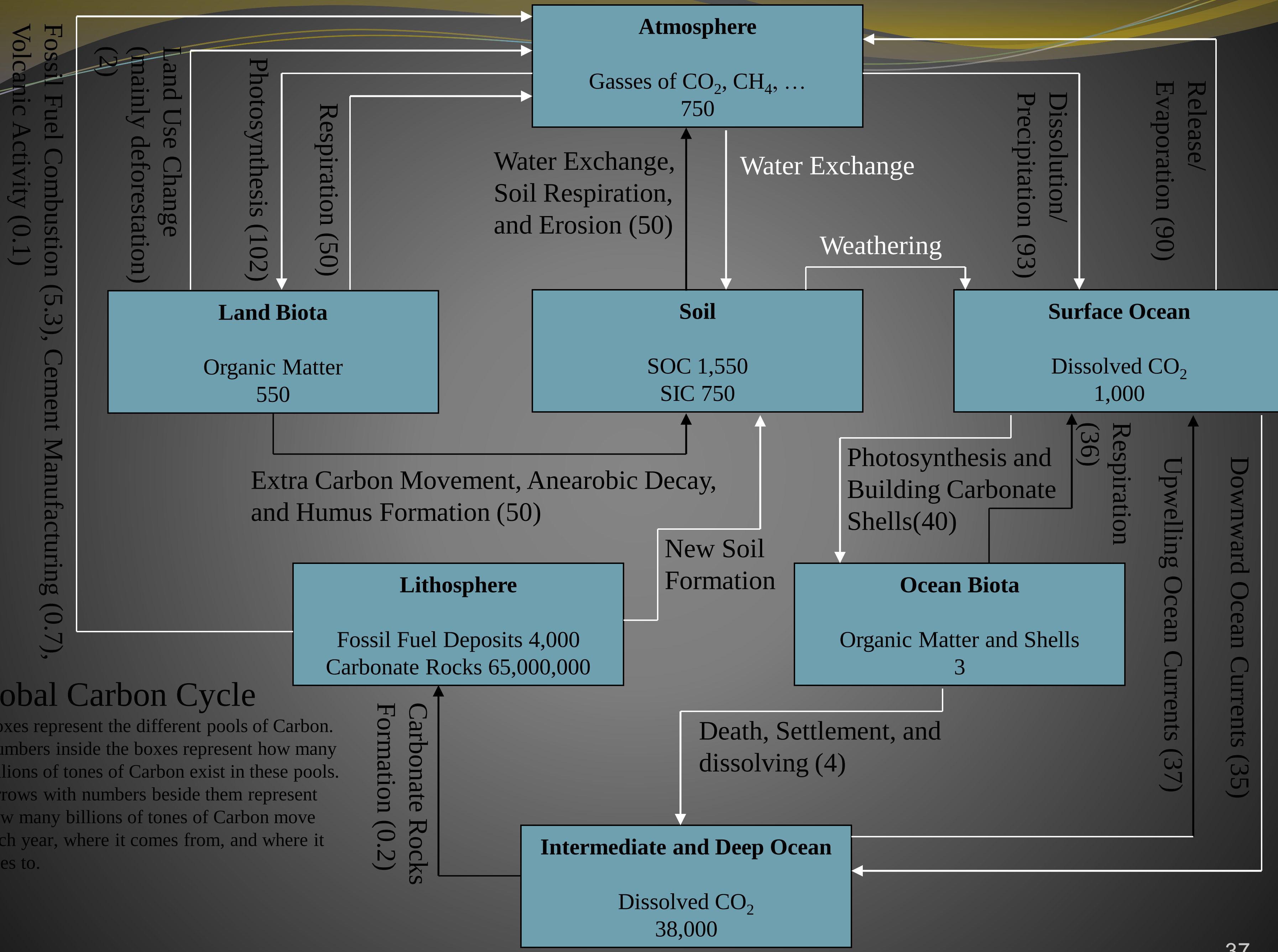
This means that living organisms can be important storage reservoirs for some elements.

The **carbon cycle** is an important biogeochemical cycle; so are the **nitrogen**, **sulfur**, and **phosphorus cycles**, because each of these elements is critical for the maintenance of life.

The Carbon Cycle

Carbon is essential for every life form, comprising approximately ***50% of all living tissues***. In the form of CO_2, it is necessary for photosynthesis and, through the absorption of longwave radiation, helps to sustain Earth's climate.

It is found in *all spheres of the Earth* – the **atmosphere** (as the gasses of CO_2, methane (CH_4), and several other compounds), the **hydrosphere** (as dissolved CO_2), the **lithosphere** (as calcium carbonate ($CaCO_3$) that was originally deposited on the seafloor, as kerogene dispersed in rocks, and as deposits of coal, oil, and gas), the **pedosphere** (as soil organic carbon and soil inorganic carbon), and the **biosphere** (as biomass)



Global Carbon Cycle

- Boxes represent the different pools of Carbon.
- Numbers inside the boxes represent how many billions of tones of Carbon exist in these pools.
- Arrows with numbers beside them represent how many billions of tones of Carbon move each year, where it comes from, and where it goes to.

Carbon cycles through these pools in different time scales as:

- **short-term cycling**
- **medium-term cycling**
- **long-term cycling.**

Short-Term Cycling

Plants on land and **Phytoplankton** in ocean absorb **Carbon** from the **atmosphere** in the form CO_2 and release Oxygen gas into the atmosphere in the process of Photosynthesis.

After Photosynthesis, **animals** eat **plants** and **Carbon** in the form of organic matter in **plants** tissues moves to the **animals**.

Plants and **animals**, then, absorb Oxygen from the atmosphere and release **Carbon** into the **atmosphere** in the form of CO_2 in the process of Respiration and the cycle starts again.

Long-Term Cycling

Limestone rocks are composed mainly of $CaCO_3$. They hold most of the **Carbon** found near the surface of the earth.

Weathering and Erosion of carbonate rocks and rocks contain $CaSiO_3$ result in dissolved Ca, C, SiO_2. These substances transport to the **oceans** through **rivers**.

In the **ocean** some **benthic organisms** and **planktons** use these substances to build there own **inorganic skeletons**.

After the death of **marine animals** and **plants**, their remains settle down at the **sea floor surface**. The organic matter of these **dead plants** and **animals** decompose by decomposers and the shells dissolve. As a result, **Carbon** is released into the **deep ocean**. This **Carbon** may ***remain for hundreds of years*** there before it goes to the **atmosphere** by upwelling ocean currents.

The **Carbon** escaped degradation becomes part of the **sediments** of the **sea floor**. Through the process of sea-floor-spreading, this **Carbon** moves to the **Subduction Zones**. In the **Subduction Zones**, metamorphism releases CO_2 which finds its way to the **atmosphere** through Volcanic Eruptions.

This CO_2 in the **atmosphere** combines with rain drops and falls down on the **land surface** and dissolves **carbonate rocks** and the cycle starts again.

Medium-Term Cycling

Plants absorb CO_2 from the **atmosphere** and release O_2 into the **atmosphere** in the process of Photosynthesis. **Animals** feed on **plants** and then **Carbon** moves from **plants** to **animals**.

After the death of these **animals** and **plants**, their remains become part of the **surface sediments**.

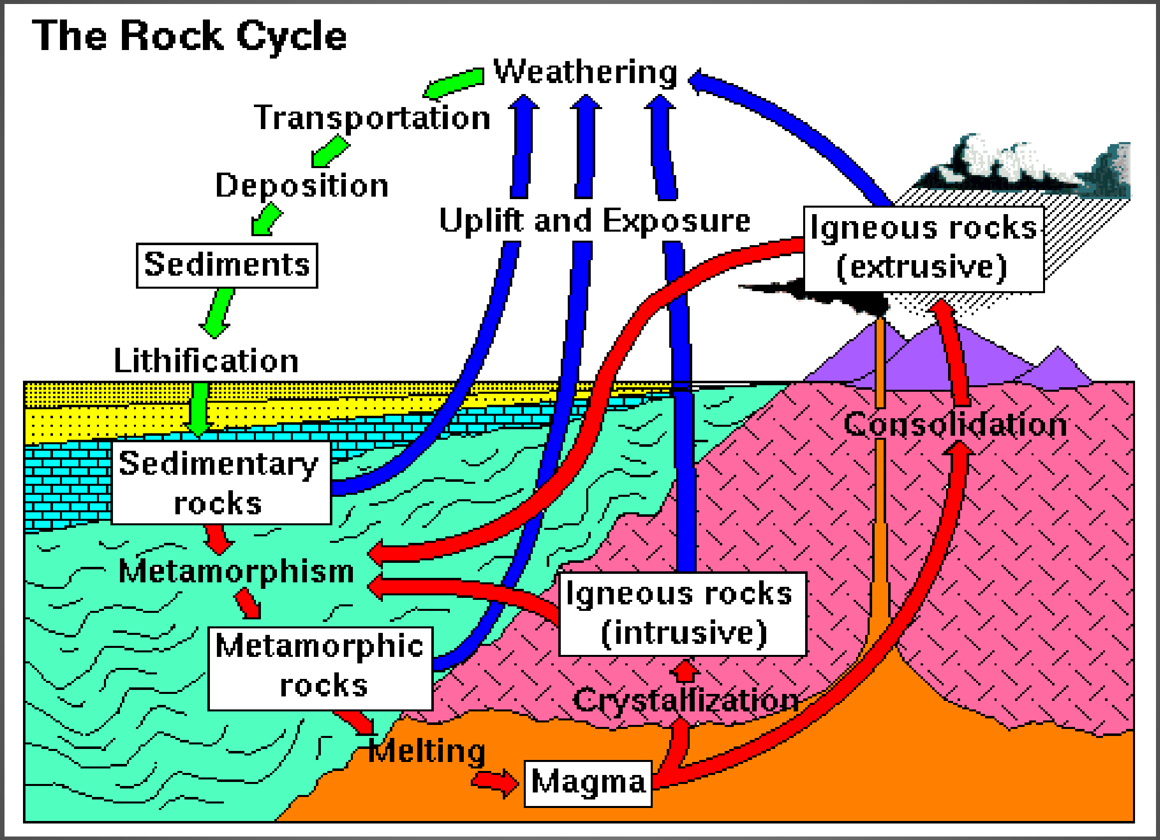
Under different conditions of burial (i.e., depth, temperature, and pressure) **organic matter** decomposes and **Coal** (Peat, Bituminous Coal, Anthracite) and **Oil** and **Gas** form.

Through the process of Plate Tectonics, these reserves are uplifted and exposed to the **surface**. At the **surface**, the reserves react with the atmospheric Oxygen (Oxidative Decay) and CO_2 is released back to the **atmosphere** and the cycle starts again.

Anthropogenic activities affect the **Carbon cycle** by increasing **Carbon** concentration into the **atmosphere**. These activities include fossil fuel combustion, cement manufacturing, land-use change, and deforestation.

4. The Rock Cycle

Solar Energy



Internal (Geothermal) Energy

The **rock cycle** is a general model that describes how various geological processes **create**, **modify**, and **influence rocks**.

This model suggests that the **origin of all rocks** can be ultimately traced back to the **solidification of molten magma**.

Magma consists of a partially melted mixture of elements and compounds commonly found in rocks. Magma exists just beneath the solid crust of the Earth in an interior zone known as the **mantle**.

Igneous rocks form from the **cooling and crystallization of magma** as it migrates closer to the Earth's surface.
If the crystallization process occurs at the Earth's surface, the rocks created are called **extrusive igneous rocks**.
Intrusive igneous rocks are rocks that form within the Earth's solid **lithosphere**. Intrusive igneous rocks can be brought to the surface of the Earth by a variety of **tectonic processes**.

All rock types can be **physically** and **chemically decomposed** by a variety of surface processes collectively known as **weathering**.
The debris that is created by weathering is often **transported** through the landscape by **erosional** processes via streams, glaciers, wind, and gravity.
When this debris is **deposited** as a permanent **sediment**, the processes of **burial**, **compression**, and **chemical alteration** can modify these materials over long periods of time to produce **sedimentary rocks**.

A number of geologic processes, like **tectonic folding** and **faulting**, can exert heat and pressure on both **igneous** and **sedimentary** rocks causing them to be **altered physically or chemically**. Rocks modified in this way are termed **metamorphic rocks**.
All of the rock types described above can be returned to the Earth's interior by **tectonic** forces at areas known as **subduction zones**. Once in the Earth's interior, extreme pressures and temperatures **melt** the rock back into **magma** to begin the rock cycle again.

Uniformitarianism

The present is the key to the past

Uniformitarianism is one of the most important concepts in the geosciences.

The ideas behind **uniformitarianism** originated with the work of the Scottish geologist ***James Hutton***.

In 1785, Hutton presented at the meetings of the Royal Society of Edinburgh that the ***Earth had a long history and that this history could be interpreted in terms of processes currently observed***.

He also suggested that ***supernatural theories were not needed to explain the geologic history of the Earth***.

This idea was **diametrically opposed** to the ideas of that time period which were ***based on a biblical interpretation of the history of the Earth***.

The prevailing view at that time was that ***the Earth was created through supernatural means and had been affected by a series of catastrophic events such as the biblical Flood***.
This theory is called **catastrophism**.

Hutton's ideas did not gain major support of the scientific community until the work of ***Sir Charles Lyell***. In the three volume publication **Principles of Geology** (1830-1833), ***Lyell*** presented a variety of geologic evidence to prove ***Hutton's*** ideas correct and to reject the theory of **catastrophism**.

The term **uniformitarianism** was first used in 1832 by ***William Whewell***, a University of Cambridge scholar, to present an alternative explanation for the origin of the Earth.

Uniformitarianism suggests that ***we can study present Earth processes in order to understand the processes that have shaped our environment in the past***.

For example, deep soil profiles were formed by the weathering of bedrock over thousands of years.

Today, most theories of landscape evolution use the concept of **uniformitarianism** to describe how the various landforms of the Earth came to be.

Uniformitarianism is a powerful principle, but should we abandon **catastrophism** as a totally incorrect hypothesis?

Recent discoveries suggest not.

For example, the impact of a large meteorite may have been responsible for the extinction of the dinosaurs 66 million years ago.

Neo-catastrophism recognizes **uniformitarianism** as the guiding principle in understanding Earth processes while acknowledging the role of infrequent, sporadic **catastrophic** events in generating ***massive, far-reaching environmental changes on a very short time scale***.