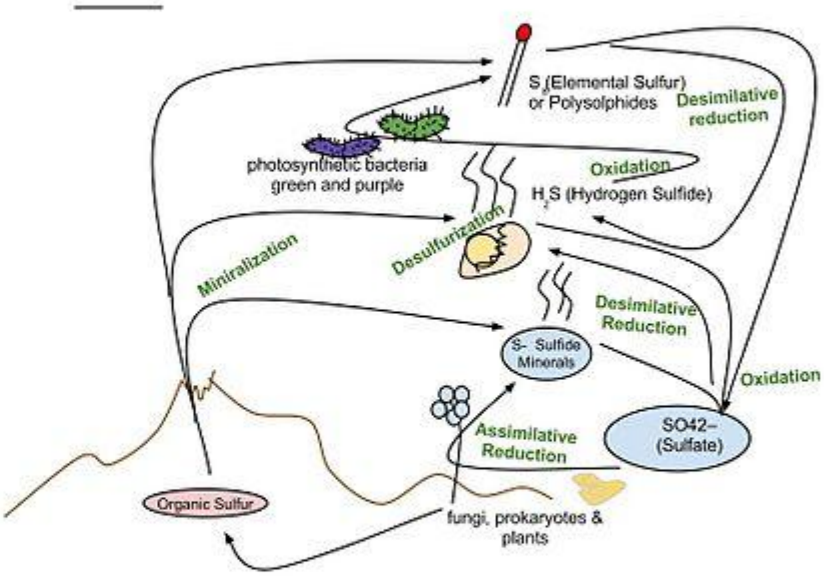
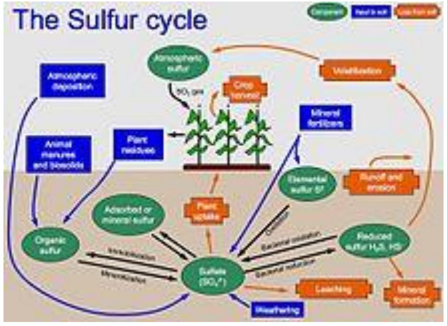
The **sulfur cycle**

is the collection of processes by which sulfur moves to and from rock, waterways and living systems. Such biogeochemical cycles are important in geology because they affect many minerals. Biochemical cycles are also important for life because sulfur is an essential element, being a constituent of many proteins and cofactors.



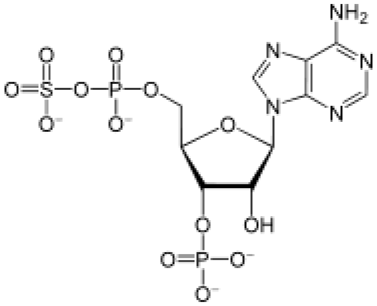
The Sulfur cycle (in general)



Steps of the **sulfur cycle** are:

- Mineralization of organic sulfur into inorganic forms, such as hydrogen sulfide (H_2S), elemental sulfur, as well as sulfide minerals.

- Oxidation of hydrogen sulfide, sulfide, and elemental sulfur (S) to sulfate (SO_4^{2-}).
- Reduction of sulfate to sulfide.
- Incorporation of sulfide into organic compounds (including metal-containing derivatives).



Structure of 3'-phosphoadenosine-5'-phosphosulfate, a key intermediate in the sulfur cycle.

These are often termed as follows:

Assimilative sulfate reduction (see also sulfur assimilation) in which sulfate (SO_4^{2-}) is reduced by plants, fungi and various prokaryotes. The oxidation states of sulfur are +6 in sulfate and –2 in R–SH.
Desulfurization in which organic molecules containing sulfur can be desulfurized, producing hydrogen sulfide gas (H_2S, oxidation state = –2). An analogous process for organic nitrogen compounds is deamination.
Oxidation of hydrogen sulfide produces elemental sulfur (S_8), oxidation state = 0. This reaction occurs in the photosynthetic green and purple sulfur bacteria and some chemolithotrophs. Often the elemental sulfur is stored as polysulfides.
Oxidation in elemental sulfur by sulfur oxidizers produces sulfate.
Dissimilative sulfur reduction in which elemental sulfur can be reduced to hydrogen sulfide.
Dissimilative sulfate reduction in which sulfate reducers generate hydrogen sulfide from sulfate.

Sulfur can be reduced both biologically and thermochemically. Dissimilatory sulfate reduction has two different definitions:[5]

1. the microbial process that converts sulfate to sulfide for energy gain, and

2. a set of forward and reverse pathways that progress from the uptake and release of sulfate by the cell to its conversion to various sulfur intermediates, and ultimately to sulfide which is released from the cell.

Sulfide and thiosulfate are the most abundant reduced inorganic sulfur species in the environments and are converted to sulfate, primarily by bacterial action, in the oxidative half of the sulfur cycle. Bacterial sulfate reduction (BSR) can only occur at temperature from 0 up to 60–80 °C because above that temperature almost all sulfate-reducing microbes can no longer metabolize. Few microbes can form H2S at higher temperatures but appear to be very rare and do not metabolize in settings where normal bacterial sulfate reduction is occurring. BSR is geologically instantaneous happening on the order of hundreds to thousands of years. Thermochemical sulfate reduction (TSR) occurs at much higher temperatures (160–180 °C) and over longer time intervals, several tens of thousands to a few million years.

The main difference between these two reactions is obvious, one is organically driven and the other is chemically driven. Therefore, the temperature for thermochemical sulfate reduction is much higher due to the activation energy required to reduce sulfate.[clarification needed] Bacterial sulfate reductions requires lower temperatures because the sulfur reducing bacteria can only live at relatively low temperature (below 60 °C). BSR also requires a relatively open system; otherwise the bacteria will poison themselves when the sulfate levels rise above 5–10%.[further explanation needed]

The organic reactants involved in BSR are organic acids which are distinctive from the organic reactants needed for TSR. In both cases sulfate is usually derived from the dissolution of gypsum or taken directly out of the seawater. The factors that control whether BSR or TSR will occur are temperature, which is generally a product of depth, with BSR occurring in shallower levels than TSR. Both can occur within the oil window.[further explanation needed] Their solid products are similar but can be distinguished from one another petrographically, due to their differing crystal sizes, shapes and reflectivity.]

Human activities have a major effect on the global sulfur cycle. The burning of coal, natural gas, and other fossil fuels has greatly increased the amount of S in the atmosphere and ocean and depleted the sedimentary rock sink. Without human impact sulfur would stay tied up in rocks for millions of years until it was uplifted through tectonic events and then released through erosion and weathering processes. Instead it is being drilled, pumped and burned at a steadily increasing rate. Over the most polluted areas there has been a 30-fold increase in sulfate deposition.

When SO2 is emitted as an air pollutant, it forms sulfuric acid through reactions with water in the atmosphere. Once the acid is completely dissociated in water the pH can drop to 4.3 or lower causing damage to both man-made and natural systems. According to the EPA, acid rain is a broad term referring to a mixture of wet and dry deposition (deposited material) from the atmosphere containing higher than normal amounts of nitric and sulfuric acids. Distilled water (water without any dissolved constituents), which contains no carbon dioxide, has a neutral pH of 7. Rain naturally has a slightly acidic pH of 5.6, because carbon dioxide and water in the air react together to form carbonic acid, a very weak acid. Around Washington, D.C., however, the average rain pH is between 4.2 and 4.4. Since pH is on a log scale dropping by 1 (the difference between normal rain water and acid rain) has a dramatic effect on the strength of the acid. In the United States, roughly 2/3 of all SO2 and 1/4 of all NO3 come from electric power generation that relies on burning fossil fuels, like coal.