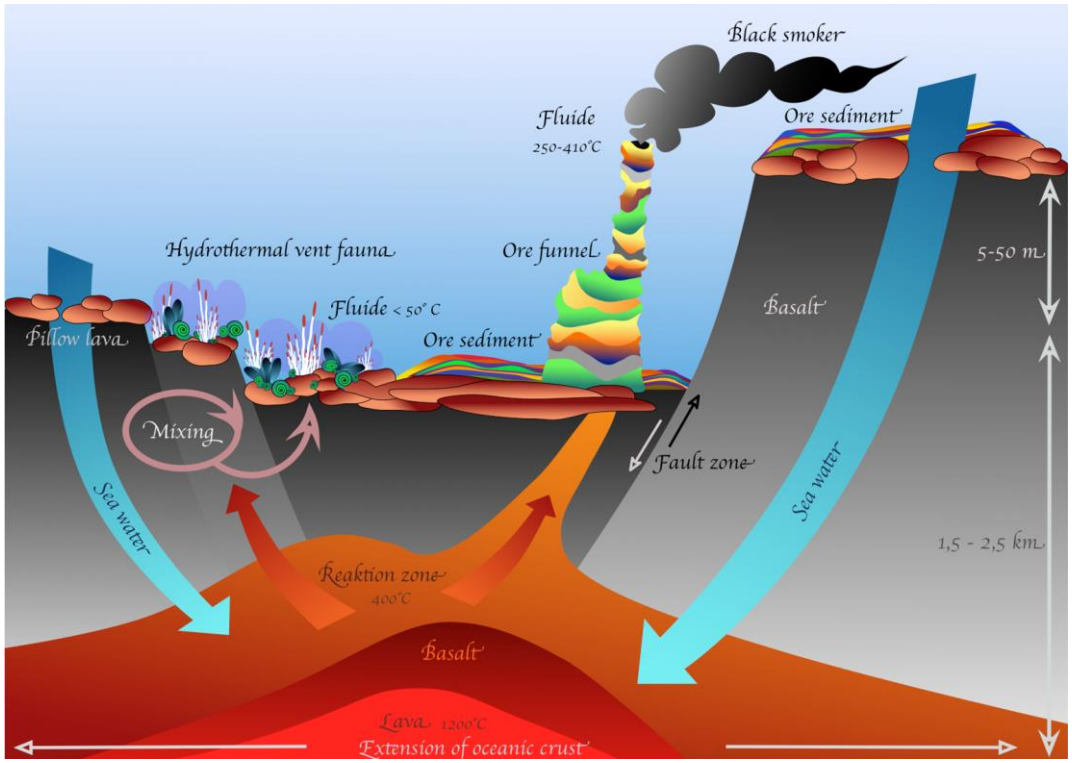
When did the chemicals of life arise?

- The solar system formed about 4.6 Ga ("giga ago" = billion years ago).
- Isotopic evidence of life based on ratios of Carbon-12 and Carbon-13 in graphite from Labrador dated 3.95 Ga and Jack Hills dated 4.1 Ga.
- Oldest known cell fossils are found in rocks dated 3.5 Ga.

It is probable that chemical evolution began around 4 Ga and resulted in cells by 3.5 Ga.

The environment of hydrothermal vents

Deep sea vents are under tremendous pressure and are extremely hot. Hydrothermal vents account for appx. 10% of heat loss from the entire Earth. At high pressure, water can be heated up to 450°C and remain in liquid form. The superheated water dissolves compounds of iron, sulfur, nickel and reduced carbon. As this water flows out of volcanic vents it encounters water at 4°C and deposits the dissolved compounds forming “black smokers.”

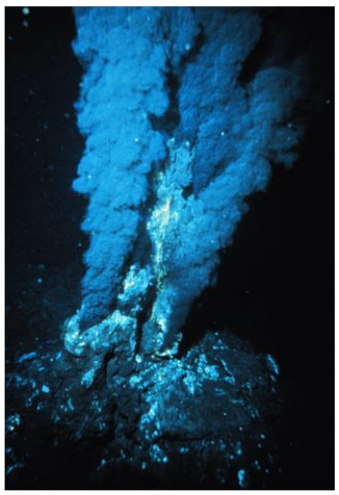


Hydrothermal circulation at a mid-ocean ridge system generates hot vents and a fauna independent from sunlight. (H Grobe/AWI 2015, Wikimedia Creative Commons)

Black Smokers Reading

Life around hydrothermal vents

The ecosystems around hydrothermal vents are based on chemosynthesis. Bacteria use chemical energy to make sugar molecules (food). The reaction between hydrogen sulfide (H_2S) from the vent and oxygen from sea water can power this reaction. Chemosynthetic bacteria are the basis of modern hydrothermal ecosystems.



Black smoker at a mid-ocean ridge (P Rona/ OAR/ NOAA, public domain)

Evidence for chemical evolution around hydrothermal vents

Observations

- Genetic studies suggest that the most recent common ancestor of life is an aquatic microbe that lived at extremely high temperatures – just like those around hydrothermal vents.
- Fossils of microbial communities around shallow continental hot springs suggest that early life thrived in the presence of chemical and heat energy from the early Earth.

Experiments

- The alkaline waters flowing from vents create a proton gradient when they encounter more acidic ocean water. This is similar to the way cells store energy. This energy could have eventually led to true cells with membranes.
- Fatty acids readily form simple membranes and protocells in experimental conditions like those around early hydrothermal vents, further supporting the “black smoker” location for the origin of life.
- Experiments replicating the water chemistry and heat around vents in early Earth result in the formation of amino acids and alpha hydroxy acids.

Could vents host life on other worlds?

Enceladus, a moon of Saturn, has a coating of ice on the surface with salty ocean underneath. The Cassini mission discovered geyser-like jets erupting from its surface. This suggests the presence of hydrothermal vents around which life might evolve.

Jupiter’s moon Europa is another possible body with hydrothermal activity. The Hubble space telescope has spotted possible water plumes erupting from the surface. NASA scientists study hydrothermal vents to gain a better understanding of how and where life might arise on other planets.

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