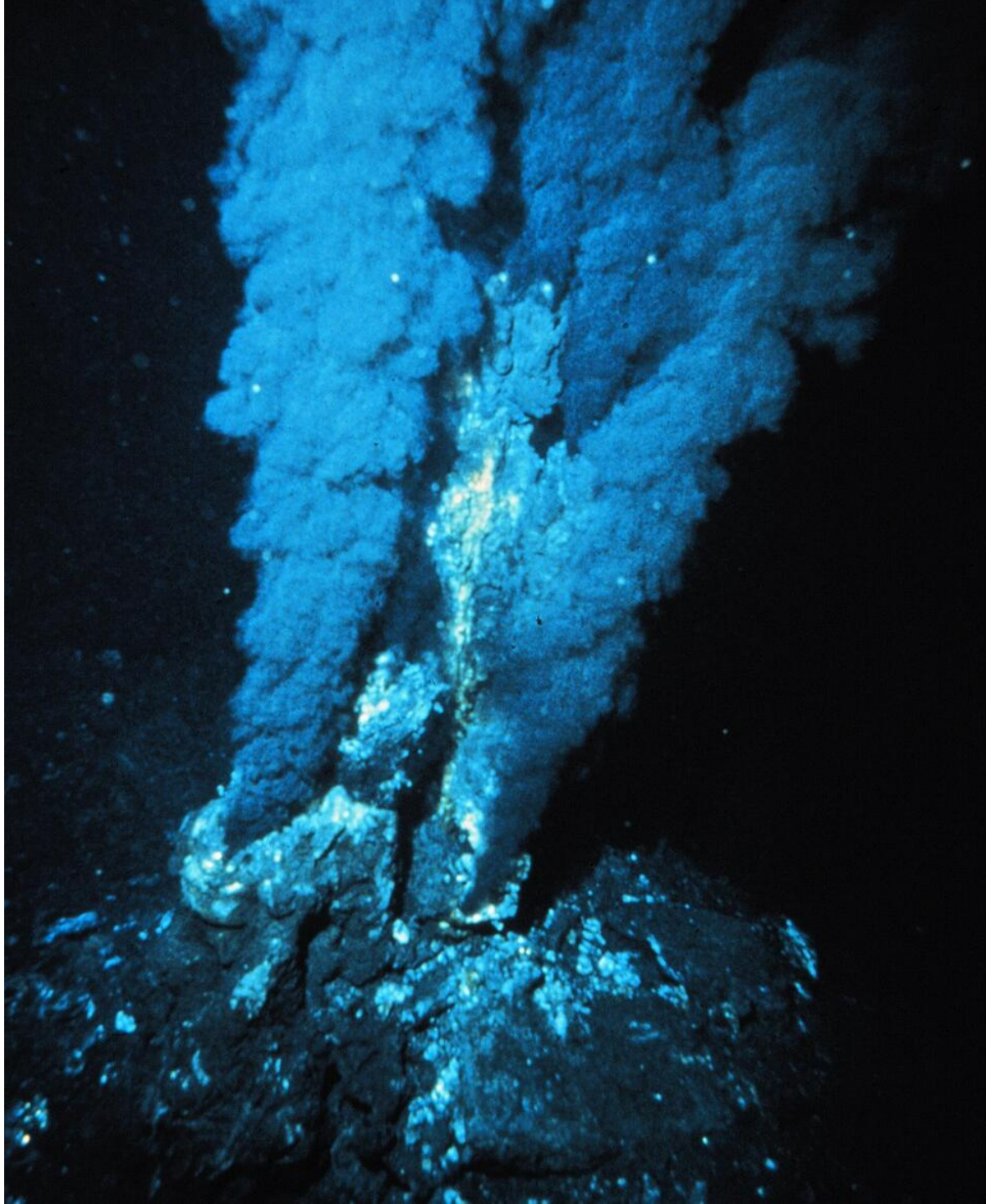
DP Biology – A2.1 (HL only)

Origins of cells

- How could life have begun from non-living matter?
- What stages might lie between simple chemicals and the first cells?

HL statements A2.1.1–9. Textbook pp. 34–47.
Image: a black smoker on the Mid-Atlantic Ridge. P. Rona, NOAA, public domain.



Objectives for each class

Class	Statements	By the end of the class, you can...
1	A2.1.1–2	Describe conditions on the early Earth, and explain why cells are the smallest units of self-sustaining life
2	A2.1.3–4	Explain why the spontaneous origin of cells is hard to explain, and evaluate the Miller–Urey experiment
3	A2.1.5–6	Explain how vesicles form spontaneously, and why RNA may have been the first genetic material
4	A2.1.7–8	Outline the evidence for LUCA, and how the dates of early life are estimated
5	A2.1.9	Evaluate the evidence that LUCA evolved near hydrothermal vents, and review the chapter

Conditions on the early Earth

A2.1.1



Lava fountain, Hawaii. J. D. Griggs, USGS, public domain.

Feature	Early Earth	Today
Free oxygen	Almost none	About 21%
Ozone layer	Absent	Present in the stratosphere
Carbon dioxide and methane	Much higher	Traces
Temperature	Much higher: greenhouse effect	About 15 °C average
UV at the surface	Very high	Mostly absorbed

Cause and effect

With no free oxygen there was no ozone, so ultraviolet light reached the surface. Carbon dioxide and methane trapped heat, so temperatures were higher. Volcanoes released gases, and lightning and UV supplied energy. Earth formed about 4.5 billion years ago, and the oldest evidence of life is at least 3.7 billion years old.

Carbon compounds before life

A2.1.1

- Energy from lightning, UV and volcanic heat could drive reactions between simple gases
- Amino acids, sugars, fatty acids and nucleotide bases could form **without cells or enzymes**
- These reactions do not happen today: oxygen breaks the products down, and living things would eat them
- This idea is called the **primordial soup** hypothesis, proposed by Oparin (1924) and Haldane (1929)



Kilauea eruption. Hawaii Volcanoes NP, public domain.

Discussion

High-energy UV damages large molecules, yet some experiments suggest UV also helps RNA chains form. Was UV more of a problem or a help for the origin of life? What evidence would help you decide?

Cells: the smallest self-sustaining units

A2.1.2

- A cell can carry out all life processes on its own: it is **self-sustaining**
- Its parts, such as a ribosome or a mitochondrion, are not alive on their own
- Living things use energy to keep themselves in a highly ordered state
- NASA working definition: "a self-sustaining chemical system capable of Darwinian evolution"

Every cell has...	So that it can...
A membrane	Keep its chemistry separate
Genetic material	Pass on information
Metabolism	Release energy and grow

Activity

Use the seven life processes (movement, respiration, sensitivity, growth, reproduction, excretion, nutrition) to test a cell, a ribosome, a virus and a crystal of salt that grows in solution. Which are alive? Why is a list of life processes not a complete definition of life?

Why viruses are not considered living

A2.1.2

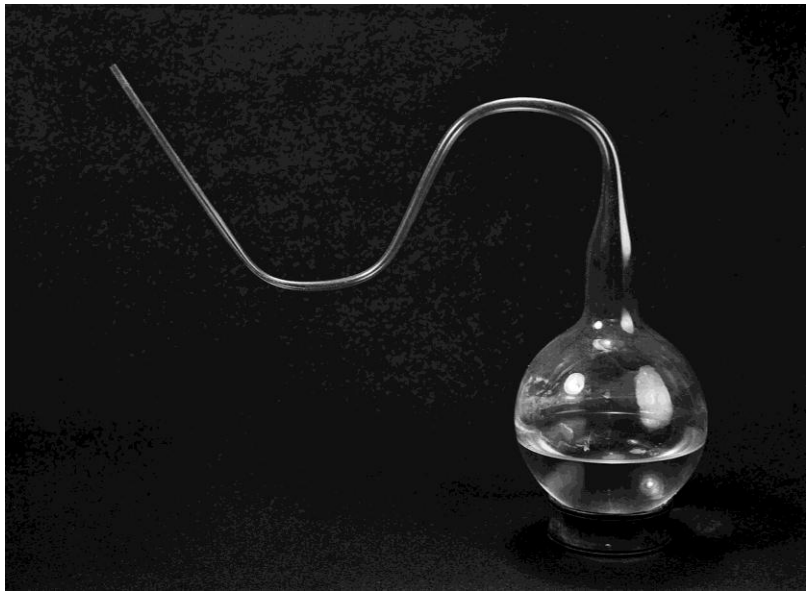
Feature	Cell	Virus
Made of cells	Yes	No: nucleic acid in a protein coat
Own metabolism and ATP	Yes	No
Own ribosomes for protein synthesis	Yes	No
Reproduces	By dividing	Only inside a host cell, using its machinery
Evolves by natural selection	Yes	Yes: mutations, especially in RNA viruses

Key idea

Viruses have genes and evolve, but they cannot sustain themselves. They are usually classed as non-living. Viruses are covered in A2.3.

Cells only come from cells

A2.1.3



Pasteur's swan-necked flask. Wellcome Collection, CC BY 4.0.

Scientist	Experiment
Redi, 1668	Meat in covered jars did not produce maggots; uncovered meat did, because flies laid eggs
Pasteur, 1860s	Boiled broth in a swan-necked flask stayed sterile: air could enter, but microbes settled in the bend. Breaking the neck let microbes in

The challenge

Today, cells are made only by the division of existing cells, so spontaneous generation does not happen now. Yet the very first cells must have formed from non-living materials. Cells are so complex that explaining their first appearance is one of the hardest problems in biology.

Four requirements for the first cells

A2.1.3

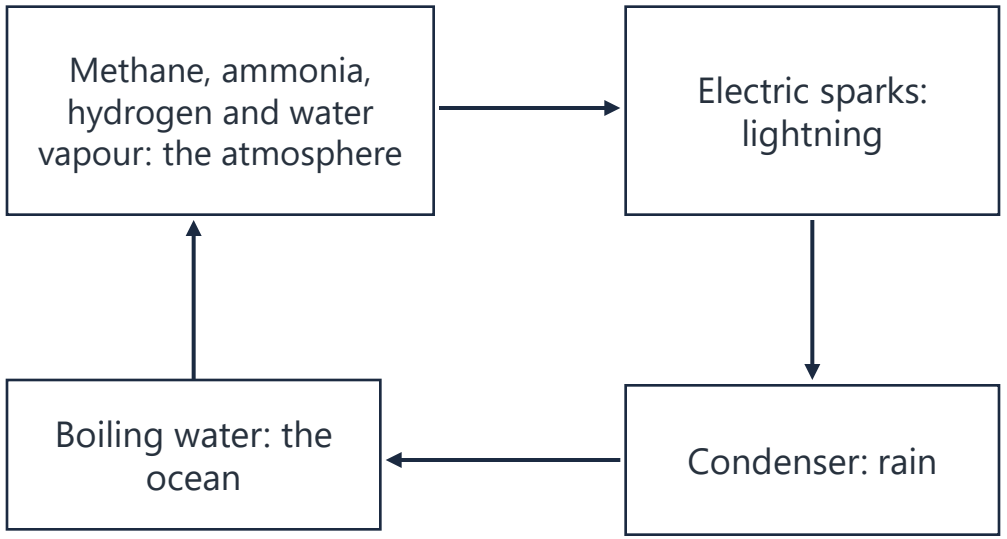
Catalysis	Self-replication	Self-assembly	Compartmentalization
Speed up reactions, so metabolism is possible	Molecules that copy themselves, so information is inherited	Large structures forming on their own, such as membranes	A boundary, so the inside chemistry differs from outside

Hypothesis	Idea
Protocell first	A membrane compartment with simple metabolism came first, and genes came later
Gene first	A self-replicating molecule, probably RNA, came first
Metabolism first	Self-sustaining reactions on mineral surfaces came first

No single hypothesis is proven. The exact conditions cannot be recreated, and the first protocells left no fossils.

The Miller–Urey experiment, 1953

A closed loop of glass. Water vapour carried the gases past electrodes, then condensed and collected the products.



Results

After about a week, the water had turned brown. It contained several amino acids and other organic compounds. Later repeats, with different gases and UV light as the energy source, have produced sugars, fatty acids and nucleotide bases. This showed that the building blocks of life can form outside cells, with no oxygen present.

Evaluating Miller and Urey

A2.1.4

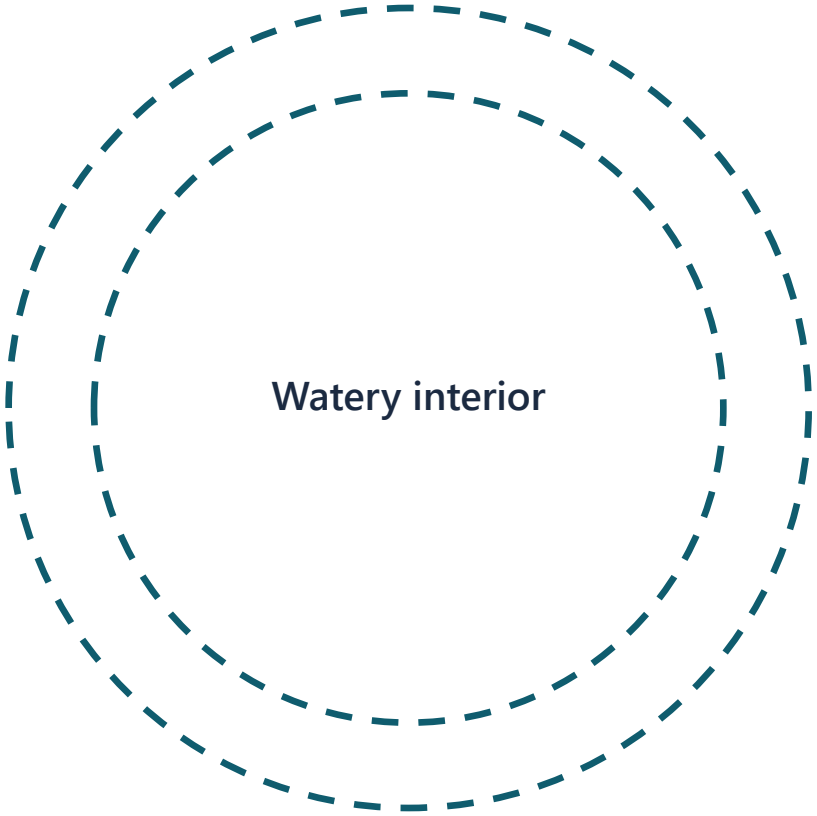
Strengths	Limitations
A closed, controlled system, which can be repeated	The early atmosphere probably had less methane and more carbon dioxide than they used
Clear evidence that organic molecules form without life	Sparks were the energy source, not UV, which was probably more important
Later versions with other gases and energy sources gave similar results	Making monomers is a long way from making polymers or a cell

Activity

Write a short evaluation in three parts: what the experiment showed, two limitations and their effect on the conclusion, and one improvement. Use the words reliable and valid correctly.

Vesicles that form by themselves

A2.1.5



Two layers of fatty acids, with water-loving heads facing the water on both sides.

- Fatty acids are **amphipathic**: one end is attracted to water, the other is repelled
- In water they gather into bilayers, which close into spheres called **vesicles**
- This happens **spontaneously**, without enzymes or cells
- Fatty acids are simpler than phospholipids, so they probably made the first membranes

Why it matters

A membrane-bound compartment lets the chemistry inside become different from outside, and keeps useful molecules together. This is compartmentalization, one of the four requirements.

RNA as the first genetic material

A2.1.6

The problem

Today, DNA needs enzymes to be copied, but enzymes are made using instructions in DNA. Which came first? An RNA world could solve this: one kind of molecule did both jobs.

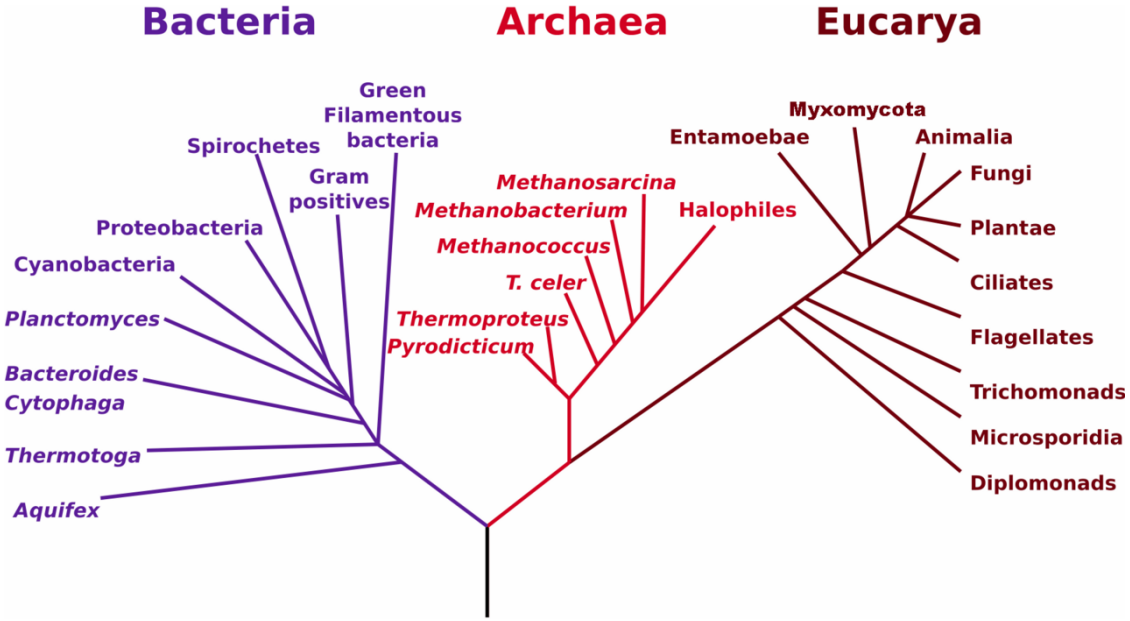
RNA can…	Evidence
Store information	Base sequence, like DNA
Be replicated	Complementary base pairing
Catalyse reactions	Ribozymes: folded RNA with an active site

- In the ribosome, **rRNA** catalyses peptide bond formation: a relic of the RNA world
- Ribose forms easily from methanal, a product of Miller–Urey type reactions; deoxyribose is made from ribose by an enzyme
- DNA later took over storage, as its double helix and thymine make it more stable

Cech and Altman shared the 1989 Nobel Prize in Chemistry for discovering catalytic RNA.

The last universal common ancestor

A2.1.7



Tree of life in three domains. MPF, public domain.

- All life uses the same **genetic code**, the same 20 amino acids and similar ribosomes
- So all organisms descend from one ancestor: **LUCA**, about 4 billion years ago
- Genome studies found 355 protein families shared by bacteria and archaea, probably inherited from LUCA

Other forms of life?

Other early forms of life may have evolved, but became extinct by competing with LUCA and its descendants for resources. A different genetic code would have been possible, so its universality points to a single origin. LUCA was a cell, not a protocell.

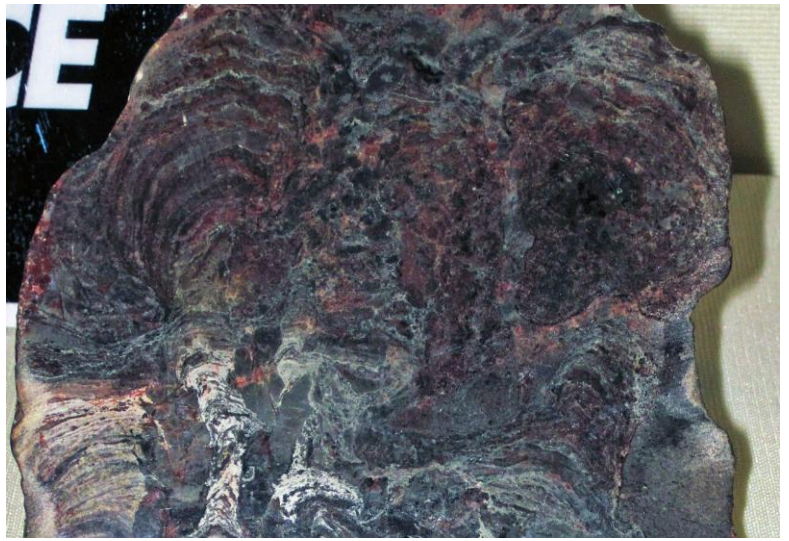
Dating the first cells and LUCA

A2.1.8

Billions of years ago (bya). Approximate dates.



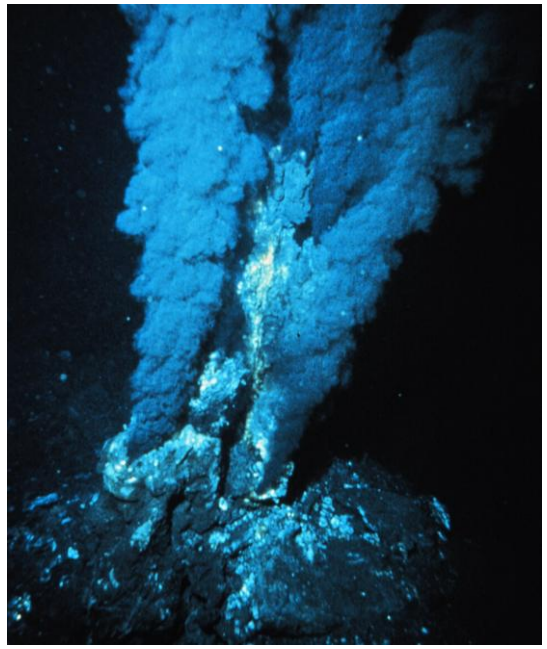
Method	How it works
Fossils	Microfossils and stromatolites in rock layers
Radiometric dating	Decay of isotopes such as uranium to lead dates the rock
Molecular clock	Differences in conserved genes, divided by the rate of mutation, give the time since species shared an ancestor



Fossil stromatolite. James St. John, CC BY 2.0.

Did LUCA live near hydrothermal vents?

A2.1.9



Black smoker. P. Rona, NOAA, public domain.



Nuvvuagittuq rock, Quebec. Daderot, CC0.

Evidence	What it shows
Fossils	Haematite tubes in vent rock at Nuvvuagittuq, at least 3.77 billion years old
Genes	LUCA's likely genes suit heat, no oxygen, and hydrogen as an energy source
Reverse gyrase	An enzyme found in organisms that live above 80 °C

Vents as a cradle

Vents release hot water rich in hydrogen, methane and iron sulfide. These supply energy for chemosynthesis and for joining simple carbon compounds. LUCA was probably anaerobic, fixed carbon dioxide, used hydrogen, and lived at high temperatures.

Check that you can explain

1. How the early atmosphere differed from today, and why
2. How carbon compounds could form before life
3. Why cells are the smallest self-sustaining units, and why viruses are not
4. Why the first cells are hard to explain, and the four requirements
5. What Miller and Urey showed, and the limits of their experiment
6. How fatty acids form vesicles spontaneously
7. Why RNA may have come before DNA and proteins
8. The evidence for LUCA, how early life is dated, and the case for hydrothermal vents

Exit activity: 5 minutes

On your own and without notes. Hand this in as you leave.

1. State two differences between the early atmosphere and today's.
2. Explain why RNA could have acted as both genes and enzymes in the first cells.
3. Give one piece of evidence that all life shares a common ancestor.

Image credits

Blacksmoker in Atlantic Ocean.jpg – P. Rona / OAR/National Undersea Research Program (NURP); NOA – Public domain

Pahoeoe fountain original.jpg – Jim D. Griggs, HVO (USGS) staff photographer[1][2] – Public domain

Kīlauea volcano eruption 20201220.jpg – Hawaii Volcanoes National Park – Public domain

Swan-necked flask used by Pasteur. Wellcome M0012521.jpg – Author not stated – CC BY 4.0

PhylogeneticTree.png – MPF – Public domain

Stromatolites (Bitter Springs Formation, Neoproterozoic, 850 Ma; Amadeus Basin, Australia) 4 (17164764207).jpg – James St. John – CC BY 2.0

Porpoise Cove (Nuvvuagittuq) banded iron formation, northern Quebec, metamorphosed 3.8 billion years ago, magnetite and quartz – Redpath Museum – McGill University – Montreal, Canada – DSC07889.jpg – Daderot – CC0

All from Wikimedia Commons (commons.wikimedia.org, search the file name). Some images are cropped. CC licences: creativecommons.org/licenses