Biogeochemical cycles – Geological, Chemical and Biological Evolution on Earth

- **Geological Evolution** – the Earth has a significant atmosphere with winds and precipitation and also has large amounts of solid and flowing water. This means that weathering of the original surface rocks occurs readily to produce particulates which can be carried by water or wind motion and lead to the formation of sedimentary rocks such as mudstones, limestones, sandstones and the formation of various clay minerals.
- Such sedimentary rocks can be **silicate-derived** (from igneous rocks); **hydroxide-based** via hydrolysis of released metal ions (mostly clay minerals) or **carbonate-based** and mostly derived from the sedimentation of calcium carbonate biominerals. Incorporation of phosphate or sulphate into minerals is also possible.

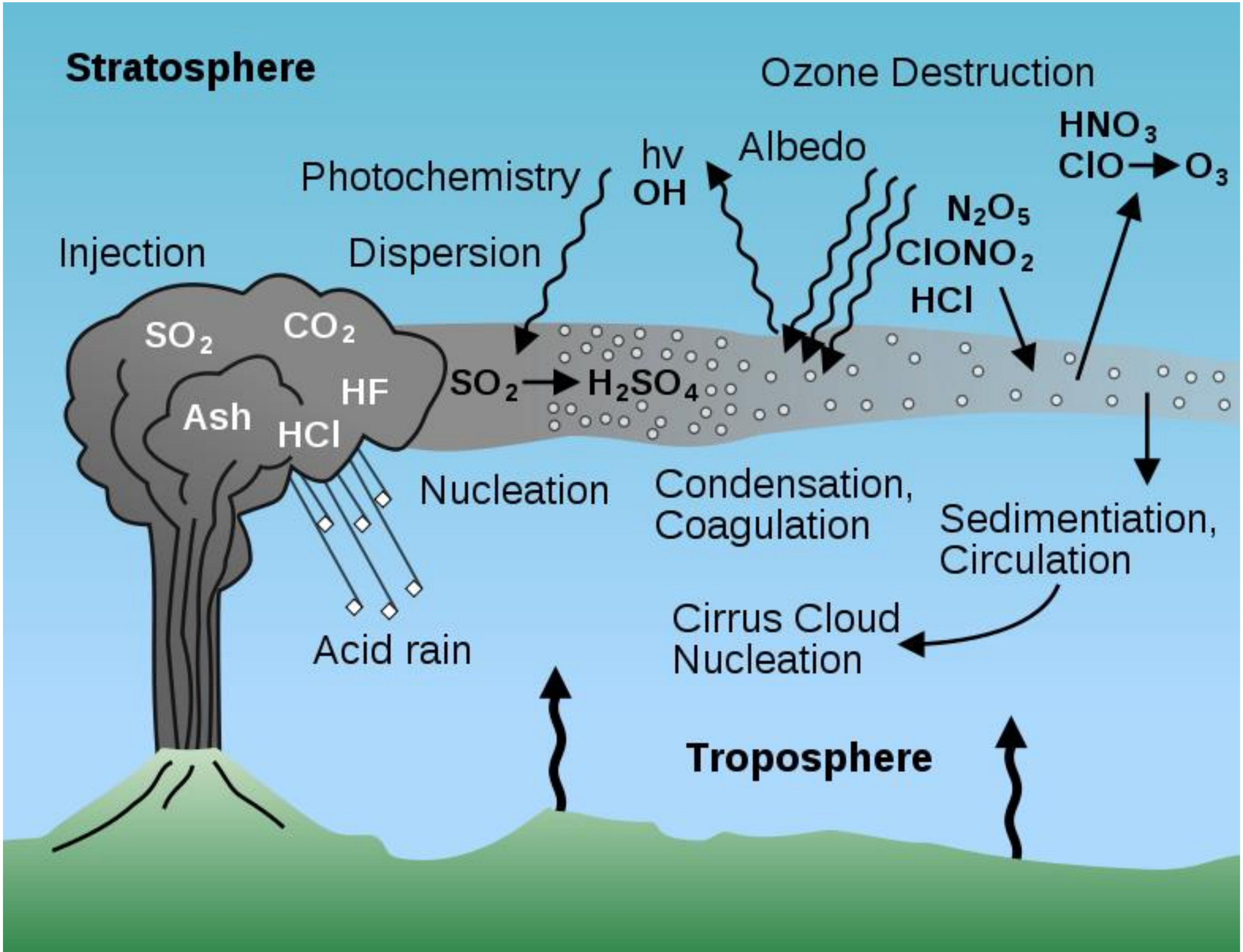
Biogeochemical cycles – Geological, Chemical and Biological Evolution on Earth

- **Geological Evolution**
- The thermodynamic end product of most hydroxide based minerals is the most stable oxide of the system, e.g. haematite (α-Fe_2O_3) for iron systems.
- Modification of such sedimentary rocks (or even igneous rocks) through heat and/or pressure usually resulting from seismic action gives metamorphic rocks such as marble (modified $CaCO_3$) and granite (modified aluminosilicate).
- Seismic activity plays a key role in steering geological, and therefore chemical and biological evolution.
- Seismic action can release huge amounts of dust into the atmosphere as well as providing elements such as S and P in outgassing.
- Under the ocean the added aspects of different temperatures and pressure alter the whole chemistry and even so, life persists!

Cleveland Volcano Alaska photographed from the ISS, May 2006

Pinatubo ash plume

The Effects of Volcanic Activity on the Environment



Biogeochemical cycles – Geological, Chemical and Biological Evolution on Earth

- **Chemical Evolution** – In comparison with Earth's neighbouring planets of Venus and Mars, chemistry even without the presence of life was more complex than appears to be the case on either of these two planets.
- Several factors may have contributed to this.
- Geologically, heavy seismic activity brought core elements to the surface of the Earth as part of molten rock (magma) and gases (usually very rich in sulphur).
- Very early life-forms evolved which feed on purely "inorganic" substances and give rise to the idea of ABIOGENESIS (or **biopoiesis)** which probably occurred between 3.9 and 3.5 billion years ago, in the Eoarchean era, which succeeded the Hadean era when the Earth was essentially molten.

Stromatolites – the world's first trolls?

These look like rocks : they are "living rocks" combined with photosynthesising cyanobacteria and have been extant for over 3.5 billion years

Biogeochemical cycles – Geological, Chemical and Biological Evolution on Earth

- **Chemical Evolution**
- Atmospherically, the high water content and windy nature of the atmosphere gives rise to large electrostatic interactions between rain-filled clouds resulting in thunderstorms accompanied by lightning and heavy rain – this is a way of producing metastable small molecules such as NO and bringing these to the surface of the Earth.
- The initial fixation of nitrogen by such high energy reactions, able to overcome a significant activation barrier to product formation and thereby trapping them in metastable states, is a noteworthy feature characteristic of much chemistry on Earth.

Biogeochemical cycles – Geological, Chemical and Biological Evolution on Earth

- **Chemical Evolution**
- There are many metastable compounds on Earth.
- Aspects of living organisms can be described in terms of metastable states or dynamic equilibria – kinetic theory applies to metabolism but not to overall life processes – this is a very complicated topic if we stay within the bounds of classical thermodynamics and kinetics.
- We need to remember that chemical reactions are dependent on conditions – not everything happens at STP!
- For example, humans operate at about 37 ^{o}C and pH 7.2.
- Extremophiles live at extremely high pressures and temperatures with very low local pH.

Biogeochemical cycles – Geological, Chemical and Biological Evolution on Earth

- Maybe the important point is that Geology, Biology and Chemistry can all produce metastable, long-lived (maybe trapped) systems on Earth.
- It is easy to forget that most life relies on symbiosis – if you don't have the right bacteria in your gut, for example to help you digest cheese, you get nightmares!
- And what do they eat when you keel over and die and stop eating cheese?!
- Note that this also applies to the mouse model…

Biogeochemical cycles – Geological, Chemical and Biological Evolution on Earth

- **Chemical Evolution**
- Species such as particulates of FeS_2 (iron pyrites) might act as templates for organic transformations leading to the first molecules for biology.
- Once biology comes into play, the chemistry becomes ever more intricate and task-specific.

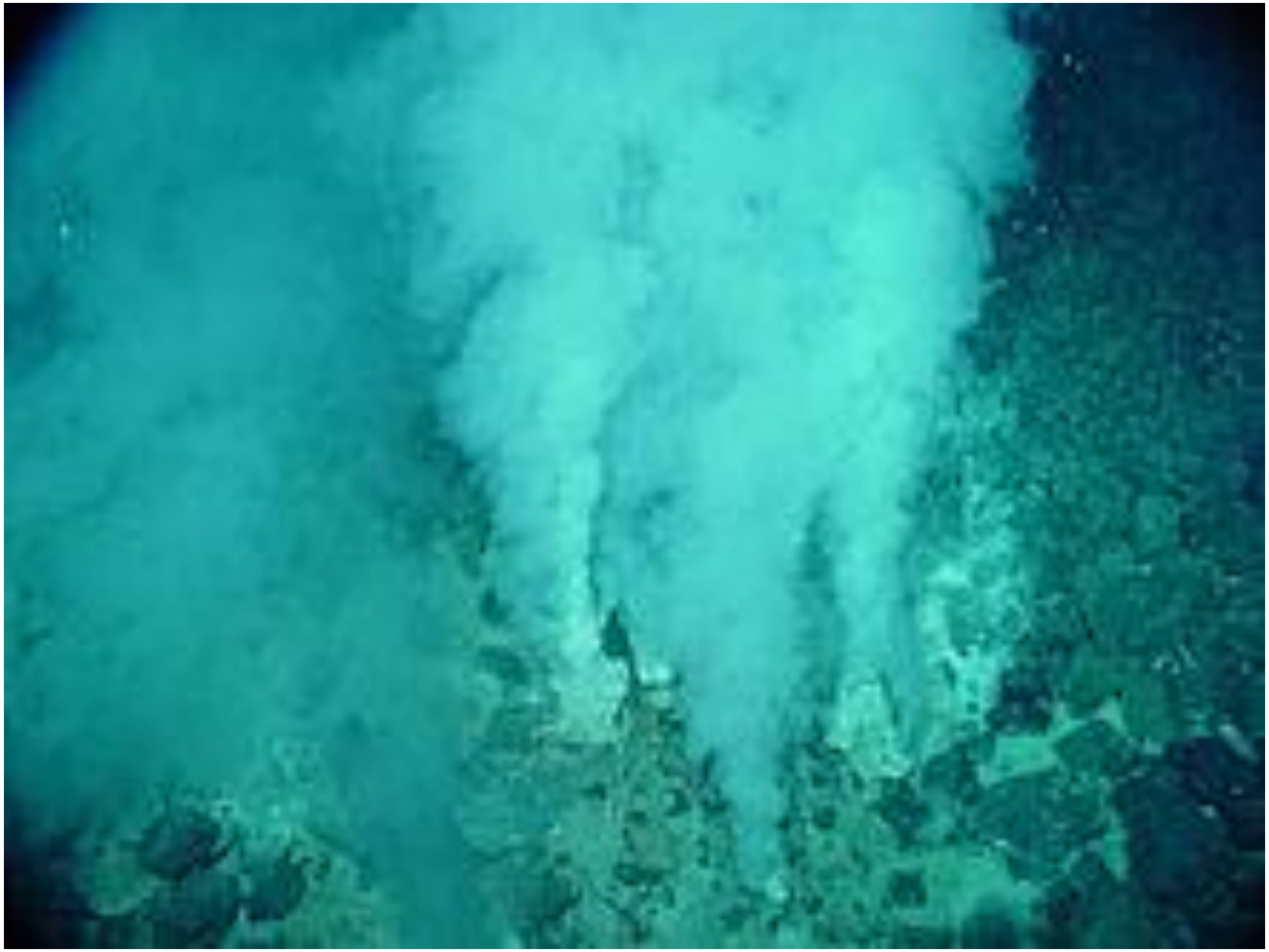
Biogeochemical cycles – Geological, Chemical and Biological Evolution on Earth

- **Biological Evolution** – all the conditions on Earth today seem ideally suited for sustaining life, but we have to bear in mind that what we see is the result of successful adaptations by living organisms to their environment.
- The fact that environmental factors have nearly destroyed life on several occasions in the Earth's history reminds us that the life we see around us represents a compromise adapted to its environment along the lines of "Survival of the fittest" - not Darwin's phrase but quoted by him and first used by Herbert Spencer.
- This refers the system best fitted to adapt to its surroundings and used by Darwin when referring to the specialised adaptations of the bills of finches in the Galapagos enabling them to eat only certain specific foods. The message here is not so much that the finches have remarkable adaptive skills, but rather that they are doomed if their specialised food source disappears as then their adaptation will have led them to a dead-end.

Biogeochemical cycles – the Interplay of Geology, Chemistry and Biology

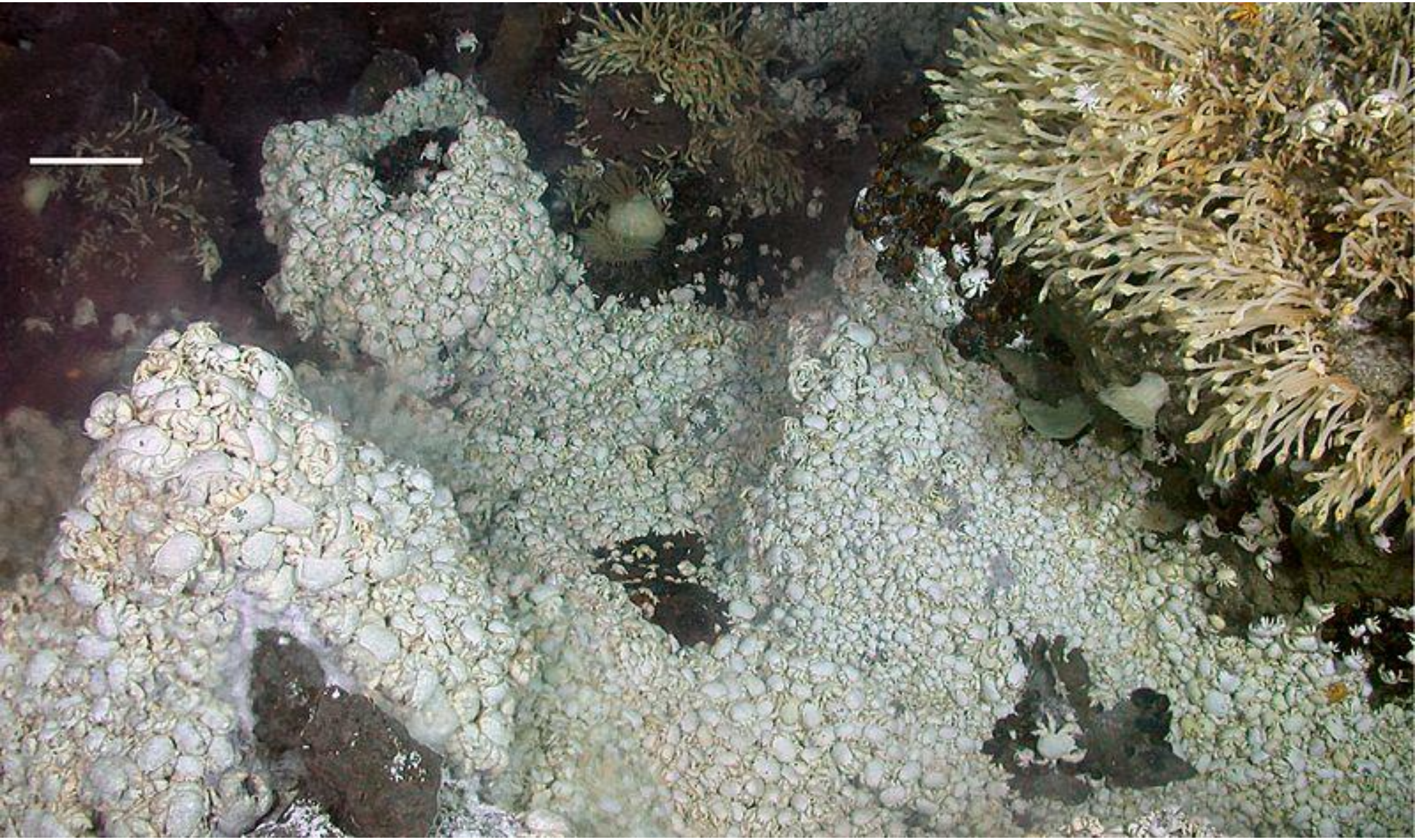
- Growing evidence that what we like to separate out as Geology, Chemistry and Biology actually act in concert to favour or disfavour conditions for life – this more easily imagined as the result of tipping a delicately posed set of dynamic equilibria.
- Evidence is given by periodic catastrophic environmental events often leading to mass extinctions (the demise of the dinosaurs is an obvious example).
- Need to correlate geological events (tectonic plate movements) with biological (evolutionary) changes and recognise that often the catastrophe is the result of a prevailing unfavourable local chemistry.
- Some life-forms, however, seem to be virtually indestructible!
- So-called extremophile bacteria can withstand very high or very low pressures, survive on nothing more than rocks and if life had ever formed on Mars or Venus may well be still present there.

Geological Influences



The so-called “Champagne Vent” Northwest Eifuku volcano, Marianas Trench Marine National Monument white smoker

Unexpected multicelled life near hydrothermal vents



Dense mass of anomuran crab Kiwa around deep-sea hydrothermal vent