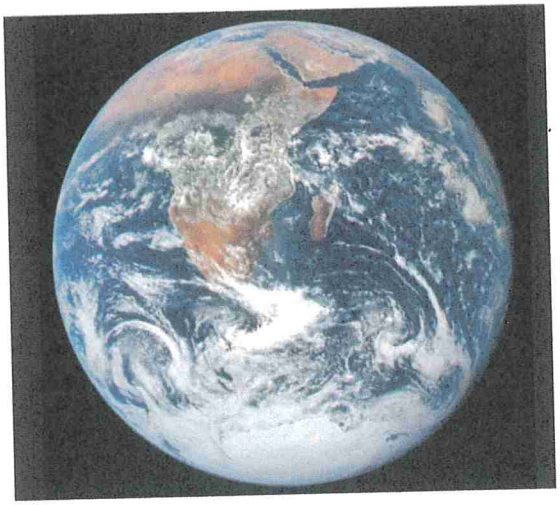
Chapter 1

The conditions for life on Earth

Chapter topics

- Conditions on Earth and how these developed over time
- The physical features of Earth which enabled life to be created
- How the development of life on Earth changed conditions

Early conditions on Earth



This 'Blue marble' image was taken from Apollo 17 while travelling to the Moon in 1972

The Earth was formed about 4.6 billion years ago as gravity pulled rock fragments in space together. The huge amount of energy absorbed as the rocks joined, created heat and produced a ball of molten rock. The surface gradually cooled to produce a surface crust of solid rock.

The physical features of Earth made it suitable for the eventual development of life by controlling the abiotic factors that are needed by living organisms.

Features of Earth that created suitable conditions for life

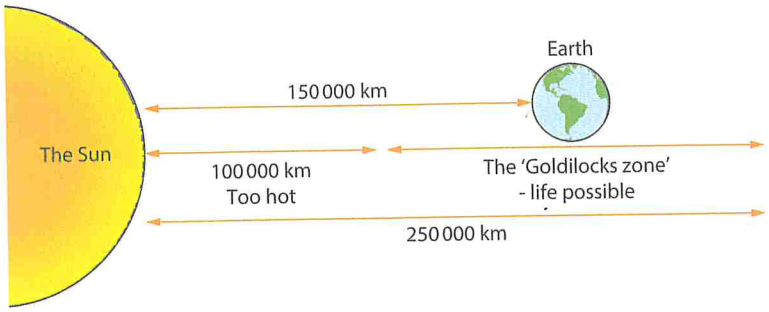
A range of features of the structure, position and behaviour of Earth made the development of life possible.

Mass

The mass of the Earth was great enough to prevent most gases from escaping into space. This atmosphere included the elements essential for life: carbon, hydrogen, oxygen, and nitrogen. They were present in compounds such as methane, ammonia, and carbon dioxide. The atmospheric pressure was high enough to prevent all the liquid water from boiling. Water is vital for living organisms as it is the general physiological solvent in which most biological reactions take place. It is also important in transport and temperature regulation.

Distance from the Sun

The light emitted from the Sun and the distance from the Sun were suitable to produce temperatures on Earth that would be suitable for life. Being too close or too far away from the Sun would prevent liquid water being present. The time taken for the Earth to rotate on its axis produced a day/night cycle that was fast enough to minimise excessive heating or cooling.



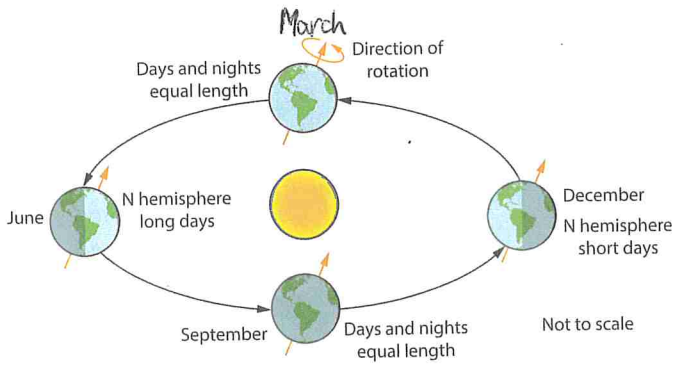
▲ *How Earth's position in the Solar System affects the survival of living organisms*

Axis of rotation

The axis of rotation is at an angle to its orbit around the Sun which produces seasonal variations in conditions as the Earth orbits the Sun.

Speed of rotation

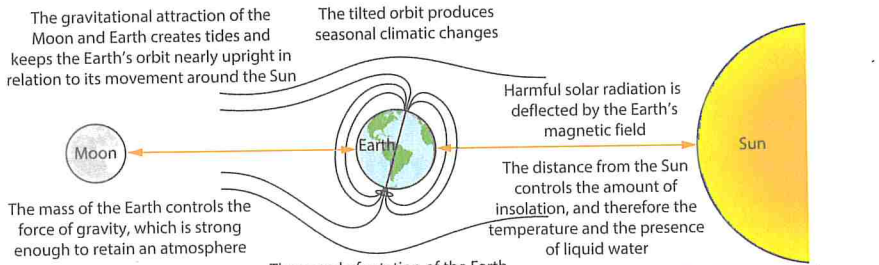
The temperature of the Earth's surface rises when it is exposed to sunlight and falls when it is not. The 24-hour period of rotation of Earth around its axis reduces temperature extremes.



▶ *How the Earth's orbit around the Sun produces seasonal changes.*

Magnetic field

The molten layers beneath the crust produce the Earth's magnetic field that deflects the 'solar wind' and prevents biologically damaging radiation reaching the Earth's surface.



▶ *How the features of the Earth create conditions that are suitable for life*

Distances / km	
Earth to Moon	375 000
Earth to Sun	150 000 000

Diameters / km	
Moon	3 500
Earth	12 700
Sun	1 400 000

Life first developed on Earth about 3.5 billion years ago. The conditions on Earth then were very different from those that exist now. The atmosphere contained some toxic gases, like ammonia, but no oxygen. The solar energy reaching the ground included high levels of ultra-violet radiation.

The chemical composition of the sea included increasingly complex organic molecules.

Development of life on Earth

Eventually, simple single-cells formed, possibly around volcanic geothermal vents on the seabed where the warm temperatures and rich mix of chemicals made biological processes more likely. These Archaea were single-celled organisms similar to bacteria. They still survive in many habitats, especially the oceans. Some are anaerobic, such as the methanogenic archaea that live in intestines and marshes.

Early conditions on Earth that allowed life to develop

After the formation of the Earth about 4.6b years ago, the conditions changed, eventually becoming suitable for life to develop.

Presence of liquid water

All living organisms require water for survival. It performs essential physiological functions and controls many environmental conditions.

- **Solvent water:** the 'general physiological solvent'. Most chemical reactions in living organisms involve reactants that are dissolved in water.
- **Transport within organisms:** water is the solvent in blood and sap where it transports dissolved gases, sugars, amino acids, mineral nutrients, waste products, etc.
- **Temperature control:** the evaporation of water absorbs heat, causing temperatures to decline.
- **Anomalous expansion on freezing:** water is most dense at 4°C so water that is cooler than this floats, stopping the convection current that may have cooled the whole water body.
- **High specific heat capacity:** water warms up and cools down slowly, which helps to moderate the rate and size of temperature changes.
- **Aquatic habitats:** oceans, seas, lakes, marshes, and rivers.
- **Absorption of UV radiation:** this protected living organisms in the oceans before the ozone layer developed which absorbed UV in the stratosphere.

Temperature range

Most areas of Earth have temperatures between 0°C and 35°C, so most areas are warm enough to have liquid water but not hot enough to denature proteins.

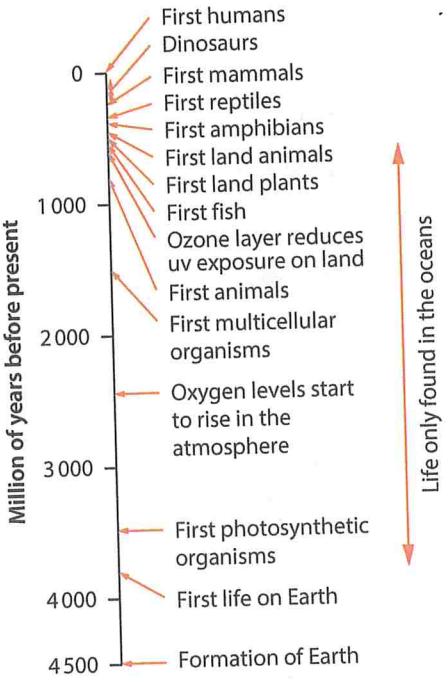
Atmospheric gases

- Carbon dioxide for photosynthesis and the synthesis of carbohydrates, proteins, and lipids.
- Nitrogen for protein synthesis.

Solar insolation

Sunlight provides the energy for photosynthesis. The heat produced by the absorption of sunlight provides the energy that drives the water cycle and warms the Earth's surface and the oceans. The amount of sunlight that is absorbed by the Earth's surface depends upon the albedo of the surface. The composition of the atmosphere controls the amount of infrared energy that is absorbed and converted to heat.

How life on Earth caused environmental change



▲ *A history of life on Earth*

As life developed and became more abundant, it started to change the environmental conditions which eventually made it possible for new life forms to evolve and new habitats to be colonised.

Atmospheric oxygen

By 2.7 billion years ago, some of the Archaea in the oceans had developed the ability to photosynthesise and release oxygen. For millions of years, all the oxygen produced reacted with iron in the oceans. Once all the iron had reacted with oxygen, the surplus dissolved oxygen built up in the oceans. Much of this was released into the atmosphere where concentrations started to rise about 2.45 billion years ago.

Oxygen in the atmosphere absorbed ultra-violet light, producing a dynamic equilibrium of reactions involving O_3, O_2, and O. The absorption of ultra-violet light made life on the Earth's surface possible. The time period when oxygen in the atmosphere was building up lasted until about 540m years ago and was called the Proterozoic. Many anaerobic Archaea and bacteria died out but more complex aerobic organisms evolved including animals and plants.

Carbon sequestration

Carbon dioxide is a greenhouse gas and helps to retain heat energy in the atmosphere. Photosynthetic organisms, photoautotrophs, absorbed carbon dioxide, some of which was stored in geological sediments such as carbonate rocks and fossil fuels. This reduction in atmospheric carbon dioxide levels helped to prevent a long-term temperature rise even though the brightness of the Sun increases by about ten per cent every billion years.

Biogeochemical cycles

As a greater variety of organisms evolved, inter-connected biological processes developed which produced biogeochemical cycles. These meant that relatively small amounts of some nutrient elements could support life over long periods of time without the resources becoming depleted.

Transpiration

Once plants had evolved and colonised the land, transpiration returned water vapour to the atmosphere and increased the amount of rainfall in other areas, making the growth of even more plant life possible.

The development of methods to research past conditions on Earth

Detailed, comprehensive, scientific knowledge of the planet and its past has developed relatively recently. Proxy data is often used as direct measurements of past conditions cannot be taken. This requires an understanding of how natural systems work and the development of new analytical techniques.

Increasing understanding of continental drift, ocean currents, ocean chemistry and atmospheric processes have been very important in understanding why and how conditions changed.

New analytical techniques have been developed that can be used to estimate past climate, for example:

- radioisotope composition can be used to date samples such as the ratio of carbon-12 to carbon-14;
- the ratio of oxygen-18 to oxygen-16 can be used to estimate past temperatures;
- the composition of past atmosphere can be analysed from air bubbles collected from ice cores;
- the ratio of magnesium to calcium in calcite deposits can be used to estimate the temperature. More magnesium is incorporated at higher temperatures.

More details of monitoring techniques can be found in other sections, for example, global climate change and research methods.

Key principles

- The structure and movement of Earth, and its position in the Solar System, control the abiotic conditions on Earth that make life possible.
- The presence of life has changed the conditions on Earth and made it more suitable for life to become more varied and abundant.
- Living systems have responded to environmental changes, such as the increasing intensity of sunlight. This has maintained the conditions that allow living organisms to survive.