IX
Life on Earth

http://sgoodwin.staff.shef.ac.uk/phy229.html
Life exists on the surface layers of the Earth.

We cannot consider life and the planet separately: they interact with one another and change each other.

Indeed, as we will see, the way to detect alien life is to look for the changes to a planet's surface and atmosphere caused by life.

First we will look at what we know about the evolution of life on Earth...
9.1 The history of life on Earth

The Earth is the one example of life that we have and so provides the only (good??) example of how life forms and develops.

Palaeontology is the study of the development and history of life on Earth based on the fossil record.
9.1 Rocks

There are three types of rock:

**IGNEOUS**: formed from the cooling of molten rock (magma) either below the surface (plutonic rock) or on the surface (volcanic rock).

**SEDIMENTARY**: which form 75% of the Earth's *continental* surface and are formed from the deposition of a) sediments, b) results of biological activity e.g. limestone or chalk, c) weathered remains of other rocks e.g. sandstone, or d) precipitation.

**METAMORPHIC**: a rock (of any type) subjected to extreme temperatures and pressures changing its structure (but not melting it).

(See basic geology from PHY106.)
The most important type of rock from our perspective are sedimentary rocks as they contain fossils.

Typically fossilisation preserves parts of the body that were partially mineralised in life (e.g. bones or exoskeletons), however footprints and faeces can also be fossilised. Of particular interest for exobiology (e.g. the Allan Hills meteorite) is the preservation of biochemical signatures of life (microfossils or products of life).

It was first noticed by William Smith (1769-1839) that stratified rocks contain different fossils in particular orders and that these orders are the same everywhere – the basis of geological categorisation.
The Earth's history is divided into Eons, Eras, Periods and Epochs. Divides in the timescale are often delineated by major palaeontological events (such as mass extinctions).
We need only really concern ourselves with Eons:

**HADEAN (4600-4000 mya):** very few rocks from this era exist and it is thought to be the period of heavy bombardment after the formation of the Solar System.

Some zircons dating to 4400 mya have been found which suggest the Earth was cool and wet at this point, and *maybe* contain evidence for life...
9.2 Archean

**ARCHEAN (4000-2500 mya)**: mostly igneous rocks remain, but fossils of cyanobacterial mats (stromatolites) are common throughout the late Archean. Eukaryotic fossils are not present, only simple non-nucleated single-celled organisms are found.
9.2 The Proterozoic

The eon encompassing the move from prokaryotic cells to multicellular organisms.

**PROTEROZOIC (2500-545 mya)**: The geological age before the abundance of complex life on Earth. Three major events occurred during the proterzoic:

- The atmosphere oxygenated during the mesoproterzoic (2500-2100 mya) which coincides with the rise of the eukaryotic cells (2100 mya).
- Several major glaciations – possibly including 'snowball Earth' – during the late Neoproterozoic (800-650 mya)
- The development of numerous soft-bodied multicellular organisms 750-550 mya (including the Edicarian biota).
9.2 The Phanerozoic

The **Phanerozoic (545 mya - now)** covers the time during which animal and plant life have been abundant on the Earth.

It covers the development of marine life, the expansion of planet and then animal life onto land, the age of the dinosaurs and currently the Cenozoic era (65 mya – today).

Given the large numbers of fossils due to animals developing shells, exoskeletons and bones, the rise and fall of different animal types is very obvious in this eon and mass extinction events are obvious in the fossil record.
9.3 The KT mass extinction

The most famous mass extinction is the KT boundary event that marked the end of the dinosaurs 65 mya. This is thought to have been caused by the impact of a 10km asteroid or comet.

The Chicxulub crater in Mexico, dated at 65 mya.

Iridium (a rare earth more common in asteroids) is found in extremely high concentrations in the dark KT boundary (thought to be carbon deposits from a global firestorm).
9.3 The KT mass extinction

In the KT event ~50% of species died-out.

Straight after the impact vast quantities of dust from the main impact and soot from a global firestorm started by secondary impacts would have created a nuclear winter causing temperature to plummet and photosynthesis to stop for several years.

The vast quantities of CO$_2$ released by the firestorm would then have caused an extreme greenhouse effect which would have lasted a few hundred thousand years.

The impact might also have initiated the Deccan Traps volcanism in India which would release even more CO$_2$. 
There have been several mass extinctions, including the 'big 5'.

The change in species present and so fossils left allows mass extinctions to be used to mark geological boundaries.
The most extreme event was the PT mass extinction ~250 mya that killed possibly more than 80% of species alive at the time within less than 1 my. Possible causes are:

- extreme **volcanism** (Siberian Traps – the largest volcanism event in Earth's history),
- an **impact** with a 50km asteroid (possible crater in Antarctica),
- **continental drift** (climate change associated with the formation of the supercontinent Pangaea),
- a nearby **supernova** (bathing the Earth in high energy cosmic rays),
- the release of **methane clathrates** leading to massive global warming.

and many others...
Generically what might cause mass extinctions? A species will become extinct when it is unable to feed itself and/or reproduce. This may occur if its habitat changes, or if a planet or animal it relies on becomes extinct or very rare. Whole ecosystems can collapse if one or more steps in the food chain are removed (e.g. plankton from the marine food chain).

Another possible cause is the lack of vital chemicals, e.g. phosphorus or organically usable nitrogen, which are required for biochemistry.

Probably the main cause of such changes is climate change. This can be associated with major volcanism (the 11 known major volcanism events are all associated with mass extinctions), continental drift, changes in sea level, impacts, ice ages, global warming...
9.3 Periodic mass extinctions?

Some suggest a 26-30 Myr cycle? (Not sure I believe it.)
Is the extinction rate falling with time?
9.4 Ice ages – an aside

The global climate can be changed significantly, very quickly and from very small perturbations.

The current global continental configuration is rather unusual. We have large land masses surrounding the north pole. Ice ages can begin due to a few cool summers. Snow falling on the land at high latitudes normally melts in the summer (e.g. Siberia, Alaska), however a cool summer will cause the snow to remain. This increases the Earth's albedo and makes for a cold winter with snow cover spreading. A few cold winters together can push the Earth's equilibrium towards permanent snow/ice cover at high latitudes which locks-away water, dries-out southern latitudes and lowers sea levels.

Antarctica only froze about 10 Myr ago, and the North Pole less than 1-2 Myr ago. (Good IoT about this).
The history of the Earth can be divided into 4 major eons:

**HADEAN** (4600-4000 mya): very little information, maybe no life?

**ARCHEAN** (4000-2500 mya): only prokaryotic cells.

**PROTEROZOIC** (2500-545 mya): eukaryotes develop.

**PHANEROZOIC** (545 mya – now): advanced multi-cellular life develops.

In the phanerozoic eras, periods and epochs are divided by mass extinctions where many organisms disappear from the fossil record (presumably these happened before but aren't in the fossil record).
Geologists often use a slightly different way of denoting time.

In astronomy we tend to talk about 'Gyr' and 'Myr', but in geology quite often these are given as 'gya' (giga years ago) and 'mya' (mega years ago).

I will flip between these fairly randomly I fear...