The Origin of Life

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About the Author – Hugh Rollinson

Hugh Rollinson holds a personal chair in Geology and is a member of the Geography and Environmental Management Research Unit (GEMRU) at Cheltenham and Gloucester College of Higher Education, where he has responsibility for projects relating to Mineral Resources and Geochemistry. Hugh also runs GEMRU's Geochemistry Laboratories which house the newly installed ICP spectrometer.

Hugh's long-term career interest is the early history of Planet Earth and much of his work has centred on the petrology and geochemistry of Archaean rocks. After graduating he was employed for nearly four years as a geologist with the geological survey of Sierra Leone mapping Archaean greenstone belts and basement gneisses. This was followed by PhD studies at Leicester University on the geochemistry of the Lewisian Gneisses of Scotland. A two-year post-doc at Leeds took Hugh back to West Africa and provided the chance to follow up geochemically work started in his Survey days. A teaching position at Cheltenham followed, broken by a spell (1990-1993) when he was appointed associate Professor of Geology at the University of Zimbabwe and subsequently chairman of the Department. More recently Hugh has been working in west Greenland in the Isua Greenstone Belt on the metamorphic petrology of 3.8 Ga sediments and volcanic rocks. Along with research interests in the Archaean he also has research interests in mineralisation, mathematical geology and geological pedagogy.

Introduction

> "To the honest man ... the origin of life appears ... to be almost a miracle, so many are the conditions which would have to be satisfied to get it going"
>
> Francis Crick — Biochemist, discoverer of the structure of the DNA molecule

> "Life is improbable, and it may be unique to this planet, but nevertheless it did begin and it is thus our task to discover how the miracle happened"
>
> Euan Nisbet (The Young Earth, 1987)

This module is about the origin of Life — one of the most fascinating of all subjects of enquiry. It is one of the most profound (and difficult) scientific questions that we can address. But it is much more than that, for the answers we find to this scientific question have a bearing on our own search for identity.

The module is in three parts. The **first part** sets the scene and explores theoretically the steps that we need to go through in order to create something living from something that is non-living. The **second part** of the module introduces the reader to 'what we know' — a discussion of the more fruitful lines of evidence which point towards the origin of life. These lines of evidence tend to be biased towards what is known from the Earth Sciences. **Thirdly**, the module examines what is currently a very popular hypothesis for the likely location of the origin of life on Earth: hydrothermal vents, forming today on the floor of the oceans, are thought to be a very likely environment within which the first life evolved.

Understanding the origin of life on Earth is but a part of a larger field of enquiry — that of the search for Life in the Universe. This is the major theme of NASA's astrobiology programme (sometimes the North Americans call this science 'exo-biology'). You will find a wealth of useful materials on their web site at http://astrobiology.arc.nasa.gov/. A good starting place for a search of this web site is the research goals which are described at http://astrobiology.arc.nasa.gov/roadmap/goals/index.html.

Other useful links are at:

- http://web99.arc.nasa.gov/~astrochm/originlinks.html
- http://www.geocities.com/CapeCanaveral/Lab/2948/originoflife.html
- http://www.resa.net/nasa/origins_life.htm#extreme

1 Steps to the Formation of Life

Before we consider the detail of constructing a living cell, you may wish to first ponder the question 'What exactly is Life?'. How can life be defined? Spend a moment jotting down some notes, on what properties you think define life. Then you may wish to consult the following web site for their ideas: http://www.panspermia.org/whatis2.htm.

A single cell may seem extremely simple compared with the biological complexity of the higher mammals. This is not in fact the case. Cells are extremely complex, and to construct a living cell from non-living material is effectively to solve the problem of the origin of life. In this section of the module we examine the six steps that lie between non-living (inorganic) molecules and the formation of a self-replicating, self-sustaining, living cell. It will quickly become clear that the chemical complexities involved in the formation of a single cell are enormous, and the probability that these are driven by random processes is extremely low.

Step 1: A Biotic Synthesis

A first step in the formation of a living cell is to begin to assemble the complex molecules from which that cell is constructed. Our starting materials are very simple, for we are restricted to those molecules which are naturally occurring in the oceans and atmosphere. These are therefore:

CO_2 — Carbon dioxide

CO — Carbon monoxide

H_2O — Water

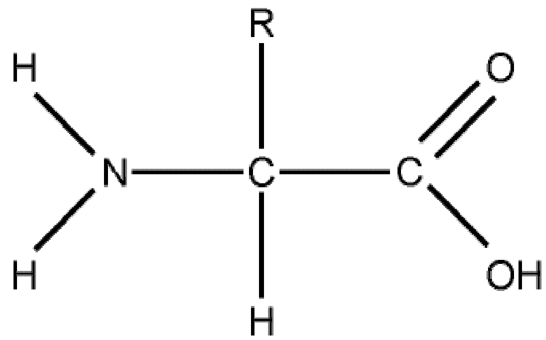
N_2 — Nitrogen

CH_4 — Methane

NH_3 — Ammonia

Clearly, the precise mix of molecules depends upon the environment, and it is important to remember that in the early Earth the composition of the atmosphere was very different from that at present. To a lesser extent the oceans also had a different chemical composition. An illustration of the nature of the pre-biotic Earth is given at http://cmex-www.arc.nasa.gov/VikingCD/Puzzle/Prebiot.htm.

A first step in a-biotic synthesis is the formation of molecules known as amino acids from simpler molecules. An amino acid has a structure illustrated below:



Amino acids vary from one another in the occupancy of the 'R' position. The simplest amino acid is glycine, and has a hydrogen atom in this position.

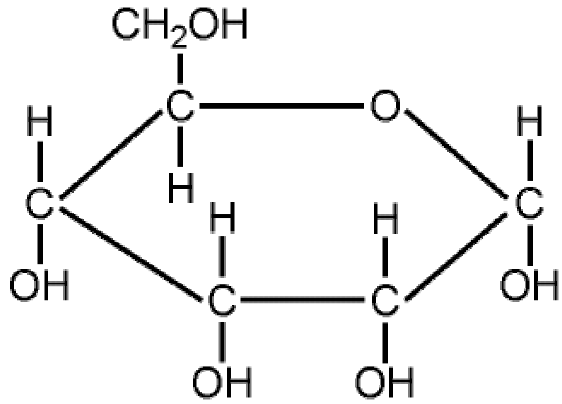
An early experiment, conducted to test whether or not more complex molecules can be made from simpler molecules was conducted by Miller and Urey in the 1950s. Scroll down the following web pages to find details of their experiment: http://www.worc.ac.uk/departs/envman/Staff/Mike/env103web/L2life.html#orig and more recent results http://exobio.ucsd.edu/miller.htm.

An electrical discharge, to simulate lightening, was passed through a mixture of 'atmospheric gases', in a glass chamber in order to investigate which molecules might be generated by this process. In these early experiments the Earth's atmosphere was thought to be a mixture of the gases steam-hydrogen-ammonia-methane. The results were very positive and amino acids and purines (a component of DNA) were formed.

More recent research, in part based on our knowledge of the atmospheres of the other terrestrial planets, suggests that the Earth's early atmosphere was carbon-dioxide rich. Unfortunately, the Miller-Urey experiment does not produce amino acids from a carbon-dioxide atmosphere. This means that the quest is still on for a process to produce amino acids from simpler molecules.

Step 2: Pre-biotic Synthesis

The next stage in complexity, in the construction of more complex molecules is the formation of sugars. The structure of the sugar glucose, built upon a carbon ring, is illustrated below.



Step 3: Synthesis of Proteins and Nucleic Acids

Ultimately the goal of molecular synthesis is to form complex molecules such as proteins and nucleic acids.

Proteins

Proteins form long, chain-like molecules called polymers, and are made up from amino acids. As an example the protein insulin is made from 51 amino acids. Proteins are the main structural and functional agents in a cell. An illustration of a complex protein may be viewed by scrolling to the bottom of page http://www.biochem.ucl.ac.uk/bsm/pdbsum/9wga/main.html.

In the game of molecular synthesis, proteins are extremely important because one group of proteins, known as enzymes, are biological catalysts. They have the function of delivering the right chemicals to right place for organic synthesis.

Nucleic Acids

If molecules are to be useful in the 'life-business' they need to be able to copy themselves, for self-replication is one of the essential characteristics of living organisms. Important here are the two nuclei acids DNA (deoxyribonucleic acid) and RNA (ribonucleic acid).

DNA (deoxyribonucleic acid) is a very important biological compound. It occurs in the nuclei of cells and is the principal component of chromosomes. DNA contains, in encrypted form, the instructions for the manufacture of proteins. Encoded within DNA of an organism, is the order in which amino acids should be strung together to form all the necessary proteins. The key to understanding DNA is in its molecular structure. This can be viewed at: http://www.biochem.ucl.ac.uk/bsm/pdbsum/103d/main.html. Click on the images to the top left for an enlargement. The vital feature here is that DNA forms a double helix — you will see that the structure forms two spiral staircase-like structures which are inter-twined. It is this structure which is the key to its ability to replicate. Details of the DNA molecule are described in the text at http://www.sigmaxi.org/amsci/articles/95articles/cdeduve.html.

RNA (ribonucleic acid) is a close relative of DNA. It can both act as a catalyst and can create a copy of itself from raw materials. Details of what RNA is and its structure can be found at http://www.rnabase.org/primer/. Some scientists think that RNA may precede DNA in the evolutionary process and that once the world of molecular biology was dominated by the RNA molecule. Details are given at http://www.panspermia.org/rnaworld.htm.

Step 4: Synthesis of a Process of Replication

How the first biological systems first became capable of replication and translation is one of the major problems in the study of the origins of life. At the present time we are unclear of the details and there are a number of competing theories.

What is clear, however, is that at a molecular level to process of replication is well illustrated by the molecule DNA. As already stated, DNA molecules are formed from two strands of DNA that spiral around each other in a formation called a double helix. The two strands are held together by bonds which is quite specific, so that bonds are always partnered in the same way. This complementarity is crucial for faithful replication of the DNA strands prior to cell division.

During DNA replication, the DNA strands are separated, and each strand serves as a template for the replication of its complementary strand. It is as if the molecule has positive and negative halves, each which produce their opposite during replication, yielding two identical molecules from one original.

Step 5: Formation of a Simple Cell

Cells are of two basic types. There are cells without a nucleus, these are the most primitive type of cell and are called prokaryotes. Cell with a nucleus, the cells of plant and animals, are called eukaryotes. [See the section cells in http://www.panspermia.org/whatis2.htm.] Common to both types of cell are:

a) the presence of a cell membrane, a cell wall, and
b) the aqueous interior of the cell.

The aqueous interior of a cell indicates that cell evolved in an aqueous environment.

The mechanism whereby the cell wall evolved is an important step in the emergence of living organisms (see http://cmex-www.arc.nasa.gov/VikingCD/Puzzle/Early.htm).

One model is that small bubbles of iron sulphide material, were the precursors to biological cells.

An alternative explanation is that there is an interstellar origin for organic molecules and cell like shapes. (See http://www.seti.org/science/clues_origin_life.html.)

Step 6: Energy for Sustaining Unicellular Life

Once a living cell has evolved the final stage in its survival is the ability to sustain itself. Nowadays many organisms require light energy to sustain them. This mechanism is known as phototrophy and includes the process of photosynthesis. Alternatively, and maybe more primitive is chemotrophy

> 'Systems of metabolism in which energy is derived from endogenous chemical reactions rather than from food or light-energy, e.g. in deep-sea hot-spring organisms.'

There are two types of chemotrophy. Autotrophy uses inorganic substances as building blocks, while heterotrophy uses organic molecules.

It is possible that the earliest organisms obtained their energy through chemotrophy, maybe utilising methane as an energy source.

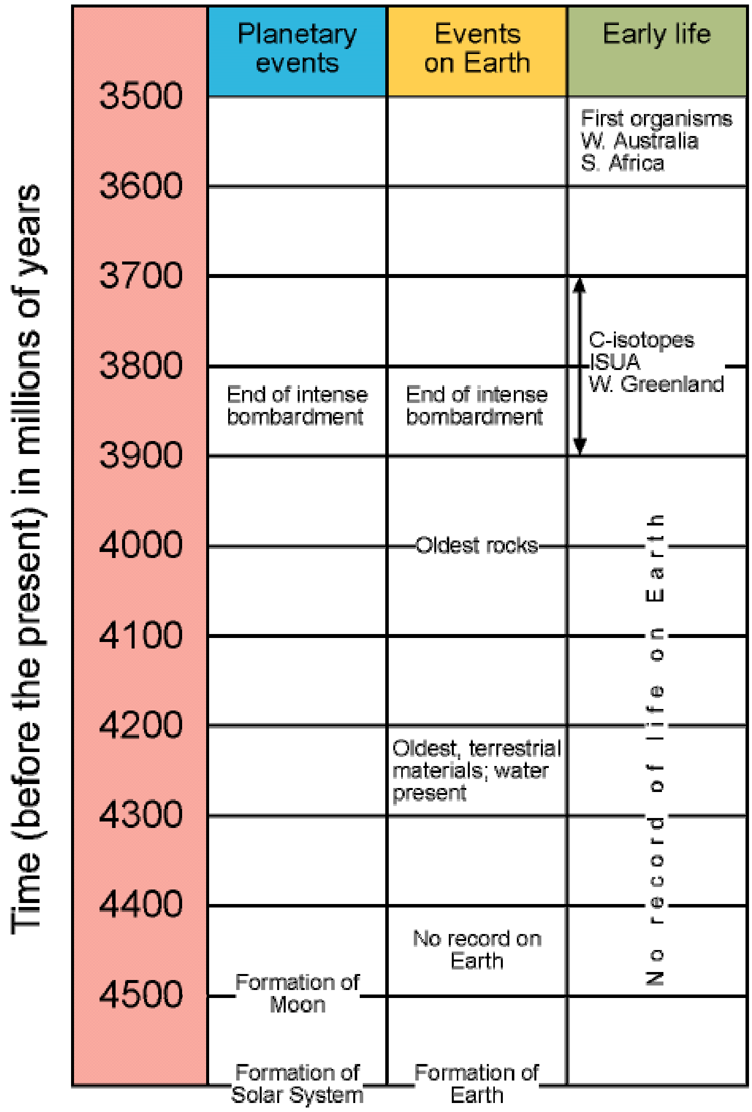
Postscript: The Cosmic Ancestry of Organic Matter

An alternative hypothesis to that outlined above, is that the process of organic synthesis took place not on Earth, but during the process of stellar or planetary formation. It may be that quite complex organic molecules were delivered to earth already formed. There is some evidence to support this hypothesis, for some interstellar dust particles and some meteorites contain complex organic molecules. The topic of a cosmic ancestry for life has been given the grand title 'panspermia' and there is a helpful web site at http://www.panspermia.org/index.htm (see especially http://www.panspermia.org/oseti.htm).

2 Evidences for the Earliest Life on Earth

The earliest evidence for life on Earth is found either as fossils, or as chemical signals representing the former existence of life. The best evidence comes from only a few localities worldwide — from the Barberton Mountain Land of northern South Africa, the Pilbara area of western Australia and the Isua Region of west Greenland.

The time-line given below for the first billion years of Earth history illustrates the principal events described in the text below.



2.1 The Earth's Oldest Rocks

The most ancient fossils represent very simple, single celled, life-forms preserved in very fine grained sediments. They are often very difficult to recognise and the scientific literature is scattered with arguments over whether a particular set of microscopic objects do or do not represent former living cells. One of the most convincing evidences come from the study of stromatolites. Stromatolites are structures which form from colonies of bacteria. These colonial structures form 'mats' (http://nai.arc.nasa.gov/index.cfm?page=focus1, http://nai.arc.nasa.gov/_global/shockwave/g3_matgallery.swf) or mounds, which trap fine-grained limestone sediment. The bacteria themselves decay away but the fine-grained limestone mud preserves the detailed structure of the algal mat as evidence of former living organisms. They form today in warm salty shallow marine conditions. Examples of stromatolites from the geological record are found at

- http://www.wmnh.com/wmel0000.htm
- http://www.petrifiedseagardens.org/main.htm.

The oldest authenticated stromatolites are from the rocks of the North Pole region of the Pilbara area, western Australia. They are contained in a sequence of unmetamorphosed sediments and lavas 3500 million years old. The sediments are thought to represent shallow water sands and evaporites (see http://www.carleton.ca/~tpatters/teaching/intro/precambrian/precambrian7.html). Stromatolites are also reported from the ca. 3400 million year Barberton area in south Africa and from 2900 million-year rocks in the Belingwe area of Zimbabwe.

2.2 Chemical Signals of Former Life on Earth

Kerogen, a tar-like substance associated with sedimentary rocks preserved throughout the geological record, is thought to be evidence of organic matter of biological origin. The best evidence, however, comes from the study of carbon isotopes in kerogen or in the carbon mineral graphite. In a nutshell, the separation, or fractionation, of carbon isotopes of different mass can be used to detect former photosynthesis, and hence is good evidence for the existence of former life. If you want to know the details of this process go to 'Understanding Carbon Isotopes' (Box 1), or to the web site http://hjs.geol.uib.no/marinegeology/chapter7-4-2.shtml.

In 1988 Manfred Schildlowski from the University of Mainz, in Germany showed that primitive carbon, which comes from the Earth's mantle, has a value of –6 ‰ (parts per thousand) on the carbon isotope scale. In contrast carbon in limestone, forming in the oceans, has a value of about zero, whereas carbon in living organisms has very low values in the range -20 to -30 ‰. This complementary separation of carbon isotopes into an oceanic limestone 'reservoir' and a biomass 'reservoir' is thought to be the product of living organisms.

The most exciting part of Schidlowski's 1988 discovery is that the separation between the organic and inorganic carbon isotope reservoirs appears to have been almost constant through time from the earliest preserved sediments to the present day, indicating that life has been present on earth from as far back as the sedimentary rock record can go. The Earth's earliest preserved sediments are at Isua in west Greenland and are between 3700 and 3900 million years old and these very ancient sediments preserve a carbon isotope record indicative of former life. Thus there is carbon isotope evidence for life on Earth from as far back as 3.7-3.9 billion years.

Box 1 Understanding Carbon Isotopes

Almost all elements are made up of more than one isotope, i.e. atoms of the same element but which have different masses. In fact this is why most quoted atomic weights are not whole numbers, because they are averages of a number of different atomic masses. Carbon is no exception and is made up of isotopes with masses 12, 13 and 14 (written ^{12}C, ^{13}C, ^{14}C, but read carbon-12 etc.).

In geology, isotopes are used in two quite different ways. Some isotopes are radioactive and decay to produce isotopes of a different element over time. The study of *radiogenic isotopes* is the basis of many geological dating techniques and is also an important branch of igneous geochemistry. Many other elements are made up of isotopes which are stable — they do no experience radioactive decay. *Stable isotopes* can become preferentially concentrated because of differences in their mass. This makes them useful in geochemical fingerprinting, and allows us to identify reaction pathways and ultimately distinguish between different types of geological process. Where the mass difference is large, greater is the likelihood of fractionation. Thus in the case of hydrogen, ^{2}H is double the mass of ^{1}H and isotopic fractionation is extensive. Normally, the mass difference is not as great as this. In the case of carbon isotopes, ^{13}C is 8.3% heavier than the isotope ^{12}C.

Rather confusingly the isotopes of carbon include both radiogenic (^{14}C) and stable isotopes (^{12}C, ^{13}C). It is the stable isotopes of carbon which are the focus here. Isotope mass fractionation may take place in two ways. It may be the result of an entirely physical process, such as evaporation. The conversion of water to water-vapour will tend to physically separate the heavy and light isotopes of oxygen in water. In this way water with light oxygen will tend to become water vapour, whereas water with heavy oxygen will tend to remain as liquid water.

Alternatively, isotopic fractionation takes place during a chemical reaction. In this case it is the speed of the reaction which is important. In other words there is a kinetic control on the fractionation. In detail the strength of a chemical bond is dependent upon atomic mass, such that bond strength increases with the substitution of heavier isotopes. In biological processes, when inorganic carbon is used to make organic compounds, ^{12}C is more weakly bonded and reacts more readily than ^{13}C, because of its lighter mass. This means that organic matter tends to become enriched in ^{12}C relative to the reservoir of inorganic carbon from which it has been drawn.

Stable isotopic fractionations are measured relative to a standard. In the case of carbon the standard is a fossil belemnite (the PDB standard). Isotopic fractionations are normally small and so values are measured in parts per thousand (‰) and expressed as $\delta^{13}C$ values as follows:

$$\delta^{13}C\ ‰ = [(^{13}C/^{12}C_{sample} — {}^{13}C/^{12}C_{standard}) / (^{13}C/^{12}C_{standard})] * 1000$$

The crucial reaction for detecting biogenic activity in ancient graphite, is thought to be oxygenic photosynthesis involving the enzyme 'Rubisco'. For example, within a cyanobacterial cell, the conversion of bicarbonate (inorganic carbon) to carbon dioxide (en route to becoming organic carbon) is speeded up in the vicinity of Rubisco producing a carbon isotope fractionation of -22 ‰.

2.3 So When Did the First Life Appear on Earth?

Answering the question 'When did life first appear on Earth?' is extremely difficult, because all that we can say from the fossil and chemical evidence is that life was already in existence, when we find the first sedimentary rocks. The oldest sedimentary rocks, however, formed at least 600 million years after the formation of the planet. If there was photosynthesis at 3.7-3.9 billion years ago, then more primitive life forms must have existed well before this time.

An comparison between the history of the Early Earth and the history of the Moon shows that there was an important period of meteorite bombardment which ceased between 3.9 and 3.8 billion years ago. This is the same time interval as that of the Isua sediments, the Earth's earliest record of life. Meteorite bombardment of the young Earth would have generated sufficient energy to vaporise the surface layer of the oceans and thereby sterilise the Earth, killing all emergent life. It is possible therefore, that despite many attempts, life was unable to emerge on the Earth until after the 'late heavy bombardment' had ceased at about 3.8 Ga.

3 Hydrothermal Vents — Where it all Begins?

Currently many scientists think that life may have begun on Earth in the vicinity of deep-oceanic, hydrothermal vents. This type of environment was anticipated by Charles Darwin, some 150 years before, who wrote:

> 'But if we could conceive in some warm little pond, with all sorts of ammonia and phosphoric salts, light, heat electricity etc, present'

Hydrothermal vents represent discharges of hot, sometimes super-heated water, onto the ocean floor deep beneath the surface oceans. Hydrothermal vents tend to be found close to mid-ocean ridges. It is thought that the water is heated from contact with the hot, newly-formed oceanic lithosphere of oceanic spreading centres. For more detail see http://www.ocean.washington.edu/people/grads/scottv/exploraquarium/vent/intro.htm.

Hydrothermal vents are of a number of types, but the most spectacular are 'black smokers', where mineral-laden, super-heated water is discharged into cold ocean floor water creating a black, smoke-like plume. Vents of this type were first discovered in the late 1970s with the aid of small submarines capable of operating under several kilometers of ocean water. The best known of these is the submersible ALVIN. For images of hydrothermal vents and their exploration see http://www.pmel.noaa.gov/vents/chemocean.html (then select 'image gallery').

See also:

- American Museum of Natural History web site (http://www.amnh.org/nationalcenter/expeditions/blacksmokers/home.html)
- Natural History Museum, London web site (http://www.nhm.ac.uk/mineralogy/intro/project5/)
- and http://www.divediscover.whoi.edu/infomods/vents/index.html.

Below, seven lines of evidence are given, which support the view that hydrothermal vents are where life first formed on Earth:

1. Evidence from the family tree of bacteria
2. Protected from impacting
3. A source of Thermal energy
4. A source of mineral-rich solutions
5. A source of reducing fluids
6. The importance of mineral surfaces to facilitate chemical reactions
7. An environment in which the cell wall could evolve

3.1 Evidence from the Family Tree of Bacteria

One of the most exciting discoveries made at hydrothermal vents was the presence of an abundant and exotic fauna in the dark, cold part of the ocean, where little life was thought to exist. You can find images of some of these creatures in the image gallery identified above. More important still have been the discoveries of the micro-fauna which exist at hydrothermal vents.

It is now known that certain bacteria can exist in very hot natural waters. These bacteria like the hot-water environment and have been termed 'thermophyllic bacteria'. Much of the research on organisms of this type has been done in hot springs found at the Earth's surface in places such as Yellowstone National Park, USA (http://www.spaceref.com/redirect.html?id=0&url=www.bact.wisc.edu/bact303/b1, http://whyfiles.org/022critters/hot_bact.html) but the results of this work apply equally to studies of deep ocean hydrothermal vents. [For more detail visit the site http://helios.bto.ed.ac.uk/bto/microbes/thermo.htm.]

Studies of the different types of organisms have recently shown that there are three principal domains of life (see http://www.ucmp.berkeley.edu/alllife/threedomains.html), the most primitive of which is the Archaea (http://phylogeny.arizona.edu/tree/life.html and follow the links). Evidence from the RNA evolutionary tree shows that the Archaea are the most primitive of all organisms. All live in extreme environments and some are thermophyllic (http://www.bmb.psu.edu/Courses/micro401/Archaea.JPG). This suggests that life began at high temperatures, or at least very early in its history life passed through a high temperature stage.

3.2 Protected from Impacting

In Section 2.3 the link between a late impacting event and the emergence of life at about 3.8 billion years ago was discussed. The logic of the argument was based upon the volatilisation of the upper levels of the ocean. However, if life was evolving in the deeper parts of the oceans it is possible that it was unscathed by all but the hugest asteroid impact, of the type which led to the formation of the moon at about 4.4 billion years ago. Thus during the late heavy bombardment, between 3.8-3.9 billion years ago life at the bottom of the oceans would have been protected from the impacting.

In addition, the evidence for photosynthesis at about 3.8 billion years ago implies a long prior evolutionary history. This requires an environment protected from impacting and is consistent with a deep oceanic environment.

3.3 A Source of Thermal Energy

Many modern organisms derive their energy either directly or indirectly from sunlight. This may not always have been so, particularly in the earlier steps of evolution when the simpler molecules were being synthesised. An alternative therefore to photosynthesis is the derivation of energy from a thermal source. The ready supply of heat energy at hydrothermal vents, supplied by the hot water, could be this source. Thus creatures which can sense heat (light of a specific wave length) develop an advantage in the very hot to very cold gradients of hot springs.

For more details visit the web site http://www.pbs.org/wgbh/nova/abyss/life/extremes.html.

There is some debate about how hot vents should be to foster the development of life. It is perhaps unlikely that super-hot vents are the likely site, since the high temperatures (400°C) are likely to destroy organic molecules, rather than permit them to form. Cooler vents (~ 100°C), forming away from the main axial ridge of an oceanic spreading system are perhaps a more likely environment.

3.4 A Source of Mineral-rich Solutions

In addition to the principal ingredients of carbon, hydrogen, oxygen, nitrogen and phosphorus, living organisms also utilise a vast array of trace metals such as Fe, Mg, Zn, Ni, Mo, Cu, Se. Hydrothermal vent solutions are derived from hot ocean water filtering through the basalts of the ocean floor (see http://www.pmel.noaa.gov/vents/chemocean.html). In the process of flowing through ocean-floor basalt the hot water solutions dissolve from the basalts small amounts of metals. This process, known as leaching, gives rise to metal-rich solutions which vent onto the ocean floor. In some circumstances they create metal-rich mineral deposits, but in addition these metal rich solutions can become the nutrients for living organisms. It is in this nutrient-rich environment that organic molecules with specific metal contents may have first been manufactured. For example, Rubisco — the catalyst which is at the core of photosynthesis incorporates at its heart iron sulphide (FeS), a mineral which is common at oceanic hydrothermal springs.

3.5 A Source of Reducing Fluids

One of the problems of abiotic and pre-biotic synthesis is that the Earth's early atmosphere was carbon dioxide-rich, that is, it was oxidising. Experimental studies, such as the lightning discharge experiment of Miller and Urey, require a mix of gases or fluids which is much less oxygen-rich than that expected in the Earth's primitive atmosphere in order to synthesis amino acids and the like. One possible resolution of this paradox is that the process of organic synthesis did not take place at the Earth's surface in a primitive oxidising atmosphere, but rather took place in an environment which was reducing (more hydrogen-rich). The evidence from modern hydrothermal vents is that the solutions which are vented onto the ocean floor are alkaline and reducing — see http://www.gla.ac.uk/projects/originoflife/html/2001/index.htm (select 'critical aspects' and then Fig. 1).

It is possible therefore that early hydrothermal vents supplied the appropriate fluids for the synthesis of the amino acids necessary for the formation of RNA and DNA.

3.6 The Importance of Mineral Surfaces to Facilitate Chemical Reactions

The problems of synthesising complex molecules from simple has already been discussed in this module. Laboratory experiments of this type sometimes use the presence of other materials to physically assist a chemical reaction. One such agent is thought to be the surfaces of some minerals, where free electrons may be used to enable a reaction to take place. There is evidence to suggest that sulphide mineral surfaces are particularly useful in this respect. Hydrothermal vents contain an abundance of the sulphides of iron and of copper which would have been available in the early Earth to facilitate biosynthesis reactions.

Another great difficulty in synthesising complex organic molecules, such as RNA and DNA is the initiation of the self-replication process. An ingenious idea suggested by Cairns-Smith, formerly of the University of Glasgow, is that clay minerals play a part in the replication process. Clay minerals are not living, but have a chemical structure which is characterised by endless repetition and Cairns-Smith proposed that organic molecules might have 'learned' the idea of self-replication from clays. Clays are a common alteration product of ocean-floor basalt adjacent to hydrothermal vents and are formed by the degradation of basalt by the hydrothermal solutions.

3.7 An Environment in which the Cell Wall Could Evolve

A final difficulty in starting the life-process is the formation of the first living cell. Mike Russell of the University of Glasgow has proposed that such a process may have had a non-living counterpart in the sulphide bubbles which form at hydrothermal vents. He has suggested that iron sulphide (FeS) can in some circumstances form a chemical membrane. This non-living chemical membrane forms a base from which organic molecules can 'learn' to form an organic membrane and thereby form a sac in which the vital molecules of DNA can be safely stored. For details see http://www.gla.ac.uk/projects/originoflife/html/2001/index.htm (go to 'show origin of life model', bottom right of figure; for greater detail go to the section on 'Organic Membrane').