Life: Complexity and Diversity

2. The Expanding Biosphere

Madhav Gadgil

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Early life on earth arose in an environment without oxygen. In an atmosphere with increasing oxygen concentrations, co-operation among teams of biomolecules led to the emergence of multicellular organisms which over time evolved to give rise to higher plants and animals.

Early Life

Life expands continuously. It constantly draws in non-living matter and energy and converts them into living matter. Living creatures produce more and more living creatures like themselves. The efficacy with which any living creature accomplishes these two tasks depends on how good its team of proteins, nucleic acids and lipids is at making more copies of itself and of other associated molecules (*Figure 1*). The key to the quality of this performance lies in the efficacy of the instructions resident in the nucleic acids,for assembling proteins and in turn a whole range of other molecules. These instructions are passed largely intact from a cell to its daughter cells,

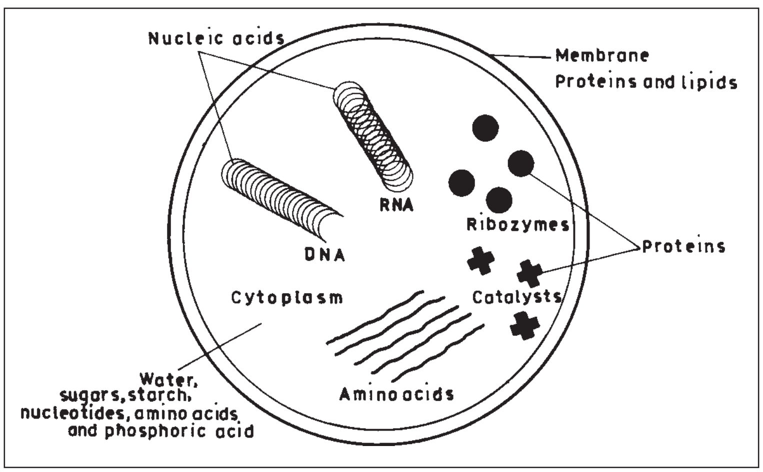

***Figure 1** Living organisms are basically teams of mutually co-operating molecules.*

from one living creature to its offspring. They thus constitute the hereditary material or the genetic constitution of an organism. The better an organism's hereditary abilities are tuned to its setting, the more effectively it converts non-living matter into more copies of its own self. This sets up a game in which organisms get ever better at adapting to and populating the world. This is what Darwin termed "survival of the fittest". This process of natural selection has produced an ever greater number of organisms fitted to increasingly diverse environments for life.

Organisms need resources of matter and energy to keep their molecular teams in good repair, and to replicate them. Three and a half billion years ago life probably originated in shallow warm seas out of a soup of organic molecules that had been produced through the action of a variety of non-biological agents on the early earth. As we have seen in the previous article (*Resonance*, 1(1)), a few hundreds of simple building blocks make up the tremendous variety of living organisms on the earth today. Essentially the same form of basic instructions set down in the nucleic acids orchestrate the functions of all the diverse forms of life. This strongly suggests that all life had a single, common origin. It is very likely that in the beginning there was just one simple kind of living organism. It lived in the soup of organic molecules in the warm, shallow primeval seas, making up the world's earliest ecosystem and using the simple organic molecules in its environment as raw materials to repair and replicate itself. The chemical bonds between carbon, hydrogen, oxygen, nitrogen and phosphorus in these molecules supplied the energy to sustain this activity. There was essentially no free oxygen in this early world. This presumed early life may then be visualized as resembling anaerobic bacteria living in the thick slurry of organic molecules in the bowels of a biogas plant.

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Over time, life has managed to invade almost every type of habitat on the earth, forever extending the limits of the biosphere. It is out in the open ocean and in the deepest trenches of the ocean floor. It is in little pools in the Antarctic ice cap and in the hot, sulphurous springs on land. It has come out of the waters onto land, colonizing not only the warm moist niches, but thriving in the driest of deserts and on cold mountain tops. It has taken to air, as pollen grains of flowering plants and spiders with their little balloons; as flying lizards gliding from tree to tree and birds flying from the Arctic to the Antarctic. This of course has happened at a slow pace over billions of years in small steps, with living organisms progressing to habitats more and more different from their ancestral homes in the warm, shallow seas.

New Ways of Life

Living organisms have also taken to new ways of tapping resources for, every organism must necessarily maintain a flow of energy and materials through its body to keep itself going. Thus green plants absorb the sun's rays and give out heat. Their roots take in water which is lost through the leaves. The roots absorb nitrogen, phosphorus, potassium and molybdenum, which are eventually returned to the earth with drying leaves and roots. Animals feed on other plants or animals, breathe in air and drink water. They excrete dung and urine and breathe out air. Without exception, all living organisms must thus maintain a flux of energy or energy rich matter through their bodies.

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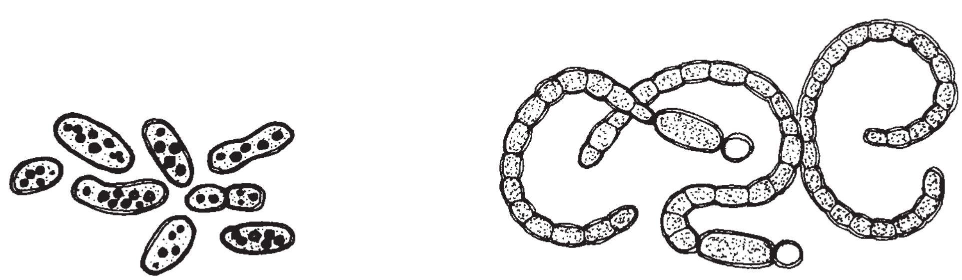
Living organisms have been elaborating increasingly complex ways of achieving this over their evolutionary history. The earliest organisms were born in an organic soup; so for them these organic molecules served at once as the source of matter and energy. They simply lapped up what had been formed through physical processes over the first billion years of the history of the earth. We still have certain bacteria and fungi that grow in rotting wood or in corpses of animals, which follow this route. These decomposers take in preformed organic molecules available for free in their surroundings. That was the only way in which life was practised for a very long time, perhaps for the first billion years. Over this period the supply of preformed energy rich organic molecules must have begun to run low. In any case, there came on the scene, new organisms that began to exploit an entirely new source of energy - sunlight. Amongst the earliest to do so were sulphur bacteria which use the energy of sunlight to split hydrogen sulphide. The hydrogen atoms produced may then be combined with carbon dioxide to produce organic molecules that form the raw material for the fabrication of living organisms. The early environments of the earth were relatively rich in hydrogen sulphide discharged from the then active volcanoes. But a far richer source of hydrogen is dihydrogen oxide - water. Breaking the hydrogen-oxygen bonds in water however requires more energy. This feat was achieved by cyanobacteria or bluegreen algae that appear to be descendants of sulphur bacteria. With the help of special pigments they learnt to use more energy-rich sunlight of shorter wavelength, to produce simple organic molecules from the abundantly available molecules of water and carbon dioxide. In the process of making sugar from carbon dioxide and water, they produced oxygen, as do the green plants today (*Figure 2*).

The early organisms were adapted to exist in an oxygen-free environment.

For the next billion or more years of evolutionary history there existed on earth simple bluegreen algae and bacterial decomposers. But now the environment on earth was being radically transformed. In the beginning there was little free oxygen, either in the air, or dissolved in the water. The early organisms were in fact adapted to exist in an oxygen-free environment. Since oxygen is a highly reactive element, it rapidly combines with organic molecules. This is after all what happens when wood or a candle burns. The machinery of early organisms could not, in fact, tolerate free oxygen. But this did not keep bluegreen algae (which are really bacteria) from splitting off oxygen from water molecules and combining hydrogen



$$2CO_2 + 2H_2S \xrightarrow{\text{Sunlight}} 2(CH_2O) + 2S + O_2$$

$$CO_2 + H_2O \longrightarrow (CH_2O) + O_2$$

***Figure 2** Sulphur bacteria use sunlight to split hydrogen sulphide ; cyanobacteria use it to split water to synthesize simple carbohydrates.*

atoms with carbon dioxide to produce sugars. So the concentration of oxygen in air and water kept increasing. Living organisms had to somehow deal with this new situation.

Quickening Pace

To protect their molecules from combining too rapidly with the oxygen in the environment, bluegreen algae evolved special structures and enzymes. But as oxygen concentrations increased another more attractive possibility was exploited; this was to use oxygen to speed up the flux of energy through the bodies of living organisms. This is what most organisms, including human beings, do today. We eat energy-rich food, breathe in oxygen, use the oxygen to release the energy trapped in food molecules, use this energy to maintain our machinery to grow and reproduce. But this ability to use oxygen to facilitate energy fluxes came only after a long history of a billion and a half years of evolution.

The important ability of using oxygen to speed up living processes was the consequence of a new kind of mutualism. This was the formation of a single organism out of the merger of two different kinds of bacteria.

Life originated by the elaboration of co-operation amongst teams of molecules - proteins, nucleic acids, lipids. The important new ability of using oxygen to speed up living processes was similarly a consequence of a new kind of mutualism. This was the formation of

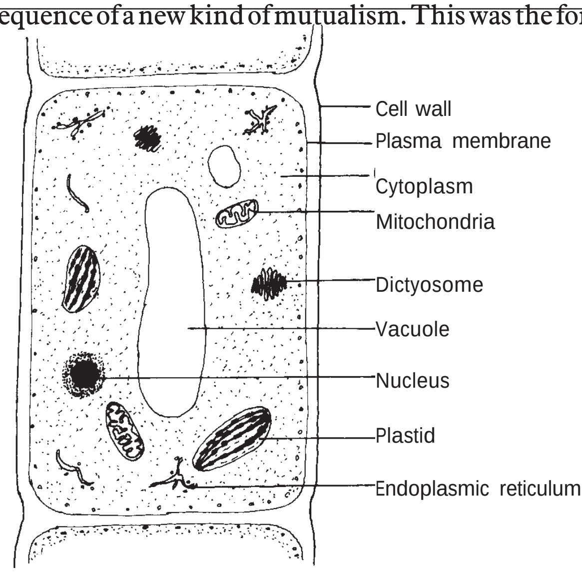
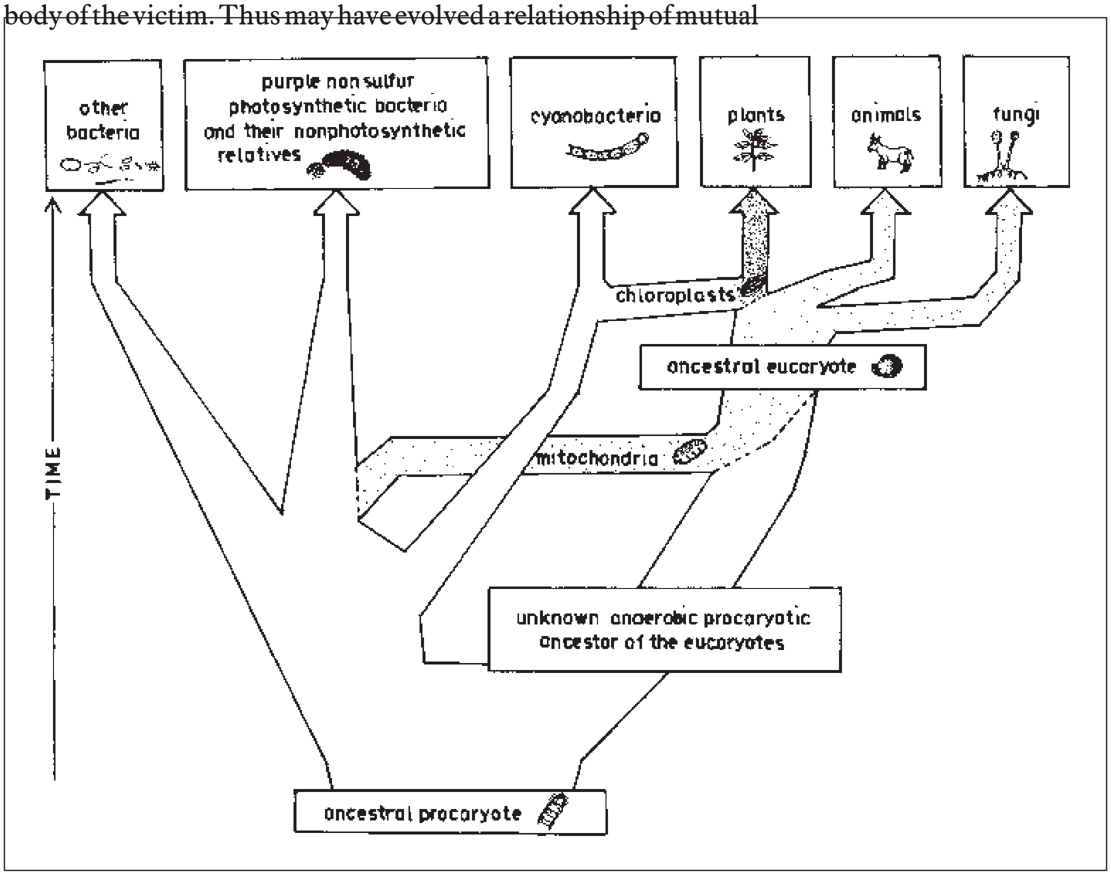


***Figure 3** Cells of higher organisms, such as flowering plants are far more complex than the earlier simpler bacterial cells. They are believed to have arisen as co-operatives of several cells from different evolutionary lineages that came together to constitute the more complex entities.*

a single organism out of a merger of two different kinds of bacteria (*Figure 3*). The partners in the merger probably related to each other as prey and predator. The prey bacterium may have been a tough organism - like *Thermoplasma* surviving the hot and acidic waters such as those of the hot springs of the Yellowstone National Park, USA. The predator may have been a bacterium that had the ability to use oxygen, like *Bdellovibrio* which attaches to and then enters its victim's innards by rotating like a whirling drill. After they have used the material resources of their prey to make their own proteins and nucleic acids, *Bdellovibrio* come out by rupturing the empty cellular bags of their ruined hosts.

It appears that some descendants of such predators evolved to practice restraint. They contented themselves by consuming the expendable waste products, such as oxygen, rather than the entire body of the victim. Thus may have evolved a relationship of mutual

***Figure 4** Presumed pathways of evolution of the more complex cells that constitute the bodies of fungi, plants and animals.*



It is now generally accepted that mitochondria must have been independent, aerobic bacteria that have now become an integral part of the confederation with their larger former victims who provide the cytoplasm and the nucleus.

advantage, with the former predators helping the host get rid of unwelcome oxygen. Inside the cells of higher plants and animals, oxygen is used in organelles called mitochondria. These mitochondria are wrapped inside their own membranes, have their own nucleic acids and divide independent of the whole cells. It is now generally accepted that these mitochondria must have been independent, aerobic bacteria that have now become an integral part of the confederation with their larger former victims who provide the cytoplasm and the nucleus (*Figure 4*).

Higher plants also have another kind of organelle inside their cells — plastids which house the green pigments used in trapping light energy to split a molecule of water into hydrogen and oxygen. The

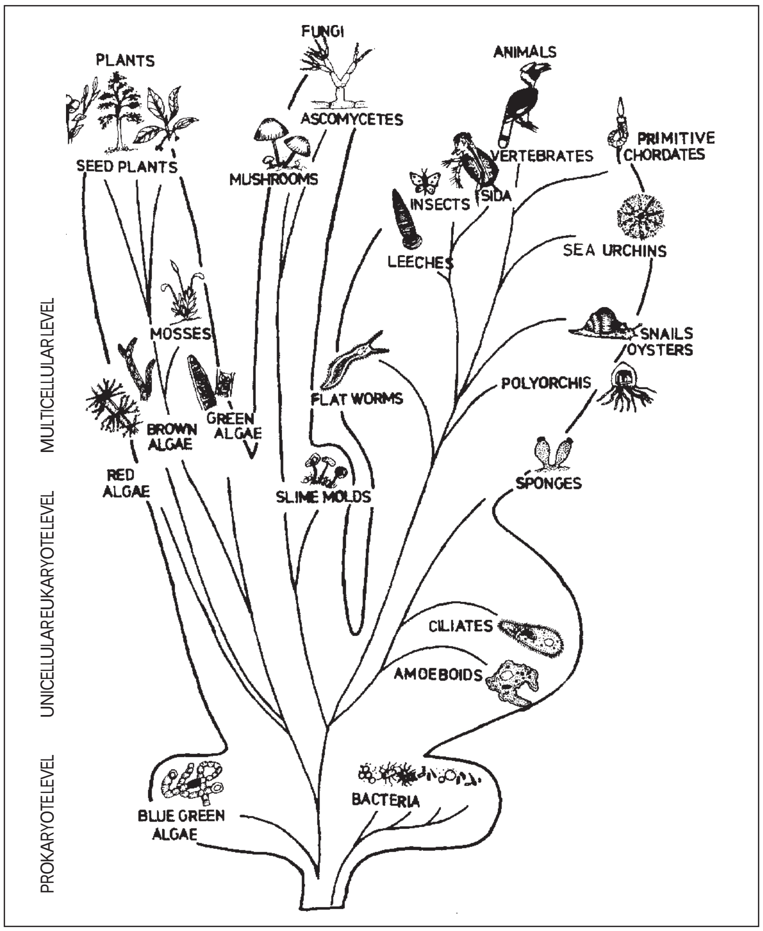


Figure 5 Evolutionary tree of life. All the major groups of simpler organisms that arose in the remote past continue to survive along with the more complex, more recently evolved groups, resulting in an ever increasing diversity of designs.

Suggested Reading

Lynn Margulis, Dorion Sagan. Microcosmos: Four Billion Years of Microbial Evolution. Allen & Unwin, London. 1987. pp 301.

plastids seem to be descendants of grass-green bacteria like the *Prochloron*. *Prochloron* is an enormous bacterium loaded with green pigments similar to those of higher plants. Today *Prochloron* coats the sedentary, lemon-shaped marine animals called *sea squirts*, and possibly supplies them with some nutrients. Perhaps relatives of *Prochloron* were eaten by many kinds of bacteria. Some of the victims must have resisted digestion, and those that stayed alive, eventually evolved into plastids. Today this co-operative partnership has achieved tremendous success, with green plants being the most abundant form of life over most of the landmass (*Figure 5*).

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The ability to use oxygen greatly quickened the pace of life. This added yet another major way of life to the repertoire of living organisms. Some of the oxygen imbibing creatures could now actively feed on other organisms. So along with decomposers and photosynthesizers, the earth began to support organisms that grazed or preyed on others.

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Precaution in time of cholera epidemics ... "The Allahabad *Pioneer Mail* says that an experiment is in progress in several of the larger gaols of the Punjab, which may have important results in the future. It has been one of the ordinary precautions in time of cholera epidemics to boil the drinking water supplied to prisoners. To ascertain whether it might not be advisable always to boil the drinking water, the Lieutenant-Governor has ordered that a certain number of the prisoners should be given boiled, and an equal number unboiled, water the results being reported at the end of the year. If these are as expected, the reduction in the fever death-rate should be followed by a similar reduction in mortality from dysentery and diarrhoea."

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