



## SPECIATION IN EVOLUTION, OFF BONDING DOMAINS

\*John Barnabas and #Andrew Lamb

\* Centre for R&amp;D in Life Science; Microbiology Research Laboratory &amp; \*Post-Graduate Department of Microbiology, Dr. C.D. Sagar Centre for Life Sciences, Dayananda Sagar Institutions, Shavige Malleleshwara Hills, Kumarswamy Layout, Bangalore-560078 India.

#University of Bolton, Centre for Materials Research and Innovation, Deane Road, Bolton, BL3 5AB, U.K.

**ABSTRACT**

Evolution of a species is an incessant process when perceived on unremitting length of time. Perspicacity- at a certain point in time, a species appears more as a stilled organism. The evolution of an organism appears in time and space as a still biont and also as that of a continuous wave like motion (speciation). The consequence of speciation is the facility to break down barriers and bridge across kingdom/domains or genus or species, to generate higher probability into a course that is fitting for a species to evolve relating to external and internal factors thus leaving behind foot prints of each metamorphosis that has led into next phenotype of the same. Traces of a transcending species of its speciation are showing in microorganisms of the modern day *e.g* between prokaryotic bacteria and eukaryotic algae, common structural, metabolic and genetic characteristics institute in cyanobacteria as photosynthesis. An account of these common characteristics of organisms between kingdom/domain represent their phenotypic footprints of evolution, hence common characteristics between organisms of different kingdom/domain is the precipitated resultant nature of a species journey through evolution, presenting that they are motile flowing with time breaking down kingdom/domain barriers. Time has been established in science as the ultimate measuring scale for any event in the universe, irrespective to the magnitude of an event. All entities are studied as subjects of time. Biological processes are ultimately measured with it, the causes and effects are its attributes. When large scale biological processes such as evolution are conferred on time, the view is rather dissimilar in comparison to the smaller scale biological events (Irwin *et al.* 2001) such as biological events happening within the life span of an organism. These large scale biological processes are observed as a mobile processes running parallel and perpendicular to time. In the big picture over a large scale of time, evolution of organisms on earth can be observed as continuous processes such as speciation, these processes in relation to the universe are motile, streaming with time, acquiring genetic and phenotypic traits, ever changing, overlapping bridging kingdom domains dodging taxonomy. Common characteristics in microorganisms that belong to altogether different kingdom domains depict these phenomenal foot prints of evolution.

**KEY WORDS:** Evolution, species, speciation, photosynthesis, cyanobacteria, algae

It has been proved since 1944 that DNA directs the synthesis of essential organic molecules for an organism and it is the hereditary genetic material (Avery, MacLeod, and McCarty, 1944). Environmental factors are key inducers for triggering genetic material to synthesize necessary macromolecules in accordance to the necessity of an organism to survive in a specific environment. The concept of evolution relies profoundly on two factors, the genetic and environmental (Roff, 1997) and this is further discussed at the back drop that genetic and environmental factors are accountable to bring about a gradual change, evolving an organism into the next stage of evolution and that this change is observed more as a flow rather than distinct steps in the evolution of organisms, but the flow as such do not show by default, since the observation occurs at a specific point in time and circumstance (Irwin *et al.* 2001; Mary.E.,1942;Wake *et al.*,1989; Wake and Schneider.1998).This flow is observed externally as a 'phenotypic' or 'morphologic' change(Irwin *et al.* 2001; Mary.E.,1942;Wake *et al.*,1989; Wake and

Schneider.1998) which is acknowledged as an aerodynamic icon favored by nature to deal with evolution of a species according to the changing environment, besides it is the 'driving force' selected by nature to the current of evolution. Phenotype of an organism is affected by internal (genetic) (Christophe Fraser *et.al* 2007; Taylor, McPhail, 2000; Albert Jeltsch, 2003) and external (environmental) factors (Roff, 1997; Darwin,1959; Schluter D, 2009; Price.T 2008), the sum total of these two(Cohan,2002), and it is precipitated by these two factors (Oyama, Griffiths, and Gary, 2001), a neutralized state, where in organisms evolved into superior forms. The significance of morphology in evolution is factual for microorganisms such as bacteria (Siefert, and Fox, 1998; Gupta, 2000; Tamames, *et al.*, 2001; Young, 2006; Ausmees, Kuhn, and Wagner, 2003; Takeuchi, DiLuzio, Weibel, *et al.*, 2005) in the present case. Morphology is heavily affected by speciation which is obviously sculptured by natural selection and common ancestry of species (Darwin &Wallace 1858).

A species or speciation (Cook, 1906, 1908) is a 'defined entity' at a specific point in time, when reflected at, over a significant period of time (Grant, P. R., and B. R. Grant., 2002; Reznick, *et al.* 1997), its 'wave-like' nature of movement (evolution) is conceived. A species moves along, in motion with time, acquiring new traits (Kingsley, 2009) and changing or in the reverse, decline (Byrne and Nichols, 1999) and become extinct. In the context of 'the present' the species appears more or less a package of energy such as a stilled biont, which is seldom, a reality since on larger scale of time the species is actually evolving. The wave nature is properly conceived in the facet on a large scale of time, a species moving or changing with any given length of time. The still nature of a species is the resultant and the manifestation of the wave nature of an organism in specific time and it is temporary, limited to that epoch, since sooner or later the species would acquire new traits and change (Irwin *et al.* 2001), this is a movement towards traits that are to be acquired. A defined species is an evolving species as of itself. The movement of these 'species' from one phase to the next can be visualized by tracing the forms below and above it, which is a resultant consequence of biodiversity (Baker, 2005). Species acquiring new traits is characteristic of their 'wave like speciation', for the reason that a wave is characterized with motion, and seldom found stationary, this acquisition and exhibition of new characteristics is the wave nature of a species, it formulates an organism to jump from species to species or genus to genus or kingdom to kingdom, this is further sustained by the concept of edosymbiosis (Kutschera and Niklas 2005; Fares, Moya and Barrio, 2004).

Further, the acquisition of new traits depends on the environmental, genetic factors and the interaction between them (Wolf and Wade, 2000). A speciation of an organism is an entire entity, this is reflected in the species; it carries with it all the previously acquired characteristics along in expression or in a dormant state, as it moves along evolutionary time consequently in the future tense, a species carries with it an ability to acquire new traits, to mutate to acquire and to evolve into new species.

A species is seldom observed to travel in the opposite direction of evolution so as recognized of time, if they did they become extinct. The wave nature of a species by default harbor traces in their genetics of their speciation nature; e.g in the microorganisms that exist in the modern day, the species in the three kingdom domains; prokaryotes, eukaryotes and the archae, represent both their species stillness and mobility any given time, since the higher and lower forms of a defined species are especially observable in the microorganisms.

The speciation between the domains "prokaryotes" and "eukaryotes" can be observed in the existing microorganisms in the modern day. Organisms from primitive to complex; have been observed in close proximity to dissociate into higher forms, acquiring new traits to be called 'species'. Species acquire new traits to become new species. Not all members of a species have been experiential to evolve into new species, some have remained, some to evolve and some have faded, in order that a chain of organisms lingered behind to make a continuous wave pattern of evolution of that species,

consequently remained defined at any given point of time. In the discrete life forms such as microorganisms, the wave nature is stamped in the organisms that are pragmatic in the modern day. It is conceptualized that the speciation of an organism is responsible for the jump between kingdom domains, given considerations their characteristics morphing with time.

In the intimate observation there is a gradual movement of species from their primitive organization; from domain prokaryote to the domain eukaryote. This jump is basically characterized as a pattern of speciation in a course of time, in the big picture it is observed as a 'continuous wave pattern' against time. It is therefore highly likely that evolution does not have barriers such as species barrier, or genus barrier or kingdom barrier or domain barrier any or all of these are broken down by evolution at any point of time to evolve into any form that is of nature's selection (Duve, 1996; Niklas, 1997; Cavalier-Smith, 2000; Kutschera and Niklas, 2005; Martin, Hoffmeister, Rotte, Henze, 2001; Woese, 2002; Knoll, 2003; Keeling and Doolittle, 1996). The kingdom/ domain jump is noted as the most remarkable event in the cellular evolution, consequently, it is considered that higher multi-cellular organisms evolved hence forth.

Bacteria were considered as primitive organisms, they commonly exists as spherical or rod shaped or helical, they have not evolved into something intangible from the single celled organization, the jump from the prokaryotic to the eukaryotic kingdom has been paused at various points by retaining the structural integrity of its previous forms to more complex forms (Bergman, J, 1999), from a single cell bacteria to a cyanobacteria, the vast bridge between the kingdoms has been imprinted in these 'transitional organisms' which have been residual and having their own species identity.

In the course of evolution certain, species such as in archae are perhaps the first sign of complex eukaryotic organization, which had been around for 7 million years within the evolutionary/uniformitarianism timescale (Brocks *et al.*, J.J.; 1999., Knoll; 1999) a have stood still with the tolerable characteristics of extreme climatic conditions, which was the earliest earth. Archaeobacteria have been accepted as an off-shoot in the evolutionary tree, a safety valve to sustain evolutionary processes in relation to extreme environmental conditional threats.

It has been understood that photosynthesis evolved early in evolution, when microorganisms dominated the planet in an atmosphere that was abundant with carbon dioxide. It is estimated that 3,500 million years ago the photosynthetic organisms appeared which were using inorganic substances as their source of electrons instead of water (Olson, 2006). The appearance of cyanobacteria is estimated about 3,000 million years ago, which were held responsible to create oxygen in the atmosphere (Buick, 2008). Earliest cyanobacterial symbiosis with earliest protists has been well documented (Rodríguez-Ezpeleta, 2005) and the chloroplasts has been thought of, as a result of cyanobacterial endosymbiosis (Gould, 2008). The evidence of photosynthesis have been classified into three major folds such as chemical markers, stromatolite fossils, and microfossils of ancient organisms. With the chemical markers the ratio of  $^{13}\text{C}/^{12}\text{C}$  in

sedimentary organic carbon (kerogen) indicates a incessant evidence of biological CO<sub>2</sub> fixation that dates 3.5–3.8Ga (Schidlowski et al. 1983; Schidlowski 1988). Organic carbon is depleted in <sup>13</sup>C, while inorganic carbonate is not. The difference between these two forms

of carbon is expressed as the relative depletion of <sup>13</sup>C in a sample (Olson and Blankenship, 2004);

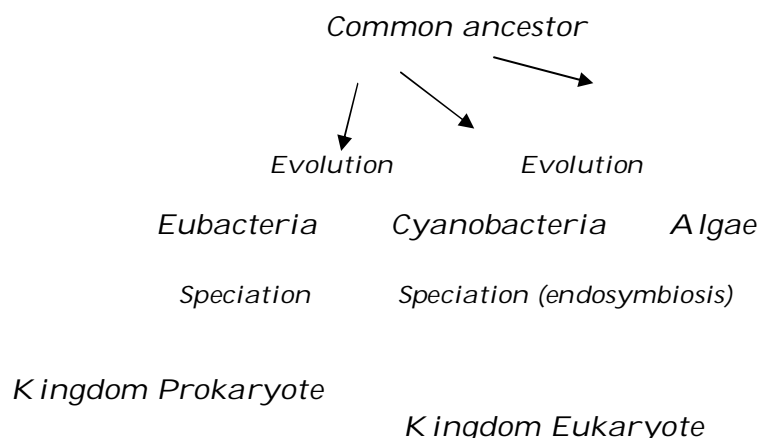
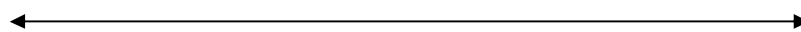
$$\delta_{13}\text{C} = \frac{[(^{13}\text{C}/^{12}\text{C})_{\text{sample}} - 1]}{[(^{13}\text{C}/^{12}\text{C})_{\text{standard}}]} \times 103$$

---

‘Speciation’ Between Kingdom Domains: Cyanobacteria

---

*Photosynthetic apparatus: Photosynthesis*



**Figure1.** Speciation from eubacteria to algae through cyanobacteria represents movement of photosynthesis from kingdom prokaryote to kingdom eukaryote

The geological account demonstrate a constant value of  $-27 \pm 7$  ‰ for organic carbon and a habitual value of  $+0.4 \pm 2.6$  ‰ for carbonate carbon. This evidence was found to be reliable with biological CO<sub>2</sub> fixation dominated by RuBP carboxylase (Schidlowski et al. 1983), but is also consistent with other fixation mechanisms and does not reveal whether the CO<sub>2</sub> fixation was photosynthetic. (Olson and Blankenship, 2004) Stromatolites are encrusted formation of arrangement consisting of interchanging layers of mat-forming organisms and sediment. Extant stromatolites more or less at all times hold filamentous photosynthetic bacteria and/or cyanobacteria. It has been observed that there is a continuous fossil record of stromatolites from 2.8 Ga to the present, with evidence of previous structures dated at 3.1 and 3.5Ga (Walter 1983). The stromatolites that are present in the modern day nearly always contain filamentous photosynthetic bacteria and/or cyanobacteria (Olson and Blankenship, 2004). There is a continuous fossil record of stromatolites from 2.8 Ga to the present, with evidence of earlier structures dated at 3.1 and 3.5Ga (Walter 1983). A number of the some of the oldest microfossils (0.9 Ga) that evidently appeared like current cyanobacteria had been observed at Bitter Springs Formation in Australia (Schopf 1968; Schopf and Blacic 1971). Nevertheless, microfossils were in general acknowledged as coming from really ancient cyanobacteria have been dated at 2.0Ga (Schopf 1974; Hofmann and Schopf 1983). Strong evidence that cyanobacterial-like organisms existed even before 2.5 Ga comes from chemical biomarkers (2-methylhopanoids) found in ancient rocks (Summons et al. 1999). Lookalike modern cyanobacteria come from the Bitter Springs

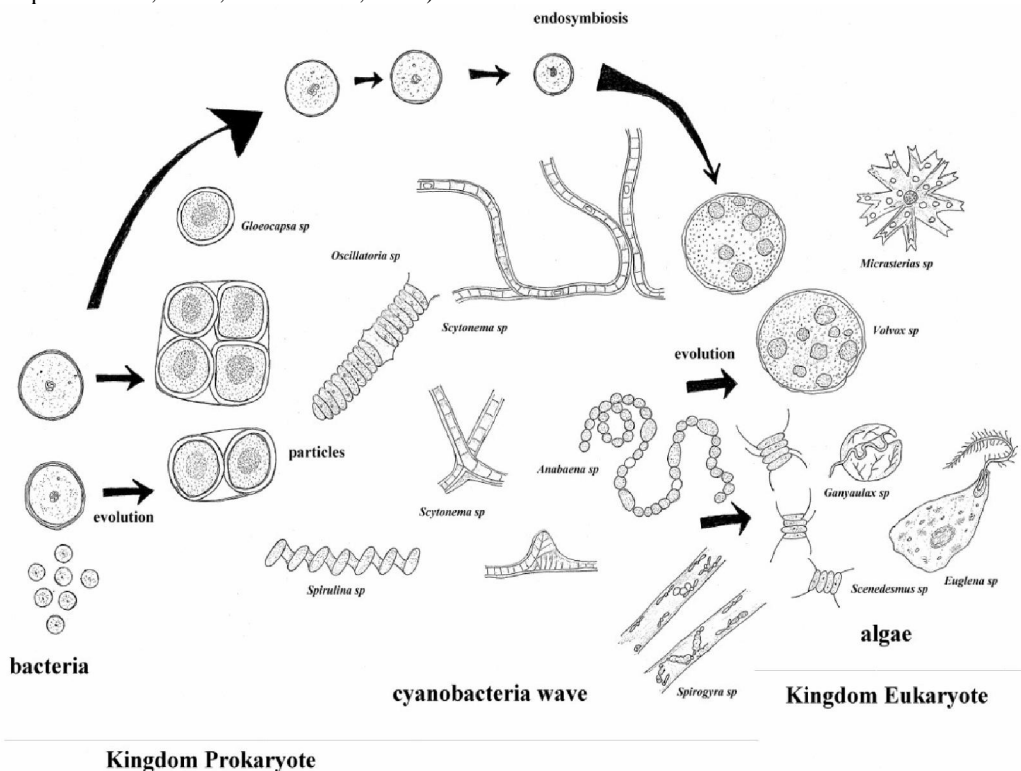
Formation in Australia (Schopf 1968; Schopf and Blacic 1971). Nevertheless, microfossils are generally accepted as coming from truly ancient cyanobacteria have been dated at 2.0Ga (Schopf 1974; Hofmann and Schopf 1983). Profound evidence that cyanobacterial-like organisms existed even before 2.5 Ga from chemical biomarkers (2-methylhopanoids) found in ancient rocks (Summons *et al.*, 1999; Olson and Blankenship, 2004).

Cyanobacteria are typically prokaryotic in approach commonly termed as blue green algae, they share common characteristics with eukaryotic algae, consequently photosynthesis is a common heavy factor between the two, hence they are termed here as transitional organisms. Cyanobacteria are Gram negative, cell organelle lacking, bacteria which are classified into the prokaryotic domain, they are photosynthetically synonymous with eukaryotic algae. The true bacteria (eubacteria) morphing into the eukaryotic algae through cyanobacteria is a heavy incidence of transition through the photosynthesis between the two kingdom domains. Due to their similarity of plastids as well, prokaryotic cyanobacteria have been classified together with eukaryotic algae (Bhattacharya and Medlin, 1998). This leap from eubacteria to eukaryotic algae is formulated in that, an exodus of bacteria gathering photosynthetic traits in cyanobacteria evolving into eukaryotic algae through edosymbiosis (Mereschkowski, 1905; McFadden, 2001; McFadden and Dooren, 2004; Gould *et al.*, 2008) concept which draws profoundly on this. The linkage of cyanobacteria with algae and higher chlorophyll containing organisms has been well documented (Schimper, 1883). Further detailed electron microscopic studies between cyanobacteria and

chloroplasts has drawn lot of interest (Ris H, 1961) adding to the fact that the plastids contain their own DNA (Stocking and Gifford, 1959) and similarities with photosynthetic bacteria include a circular chromosome, prokaryotic-type ribosomes, and similar proteins in the photosynthetic reaction center (Douglas, 1998; Reyes-Prieto *et al* , 2007), and the genetic similarities of chloroplast DNA with cyanobacteria (Raven and Allen, 2003). As well as their similarities with the plastids of marine algae (Herrero and Flores, 2008) Culminating evidence for the endosymbiotic origin of chloroplasts attained from comparative genomics of chloroplasts and cyanobacteria. It was found that in almost all cases for sequence comparisons that were analyzed , chloroplast genes clustered with homologous genes from cyanobacteria in a phylogenetic tree. This existing substantiation positioned the facade of eukaryotic photosynthetic microorganisms (and chloroplasts) at about 2Ga (Han and Runnegar 1992; Knoll 1992), further it was investigated at molecular level and proved that bacteriochlorophyll evolved much before the chlorophyll biosynthesis (Jin Xiong *et al*, 2000)

Within algae speciation is noted in decisive precision, as they are both prokaryotic and eukaryotic photosynthetic algae. Photosynthesis due to cyanobacteria (Buick, 2008; Rodríguez-Ezpeleta *et al*, 2005; Gould *et al*, 2008) is a

vital phenomenon achieved between kingdoms, and this is strongly supported by the endosymbiosis concept (McFadden, 2001; Moreira, Guyander, and Phillippe, 2000) and the molecular evidence of photosynthesis (Blankenship, 2001). The solar energy was accessed, to make the jump at a much earlier level in the evolution of organisms where-in eubacteria from the domain kingdom prokaryote acquired photosynthetic parameters and spread vastly among organisms, hence the characteristic photosynthesis is not observed to be confined to a single kingdom, a very strong connection across kingdom domains makes a 'species wave nature' which are observed discreetly as speciation particles in the modern day. Since there are photosynthetic prokaryotes existing in the modern day, it determines that the solar connection was made much before the evolutionary jump of prokaryotic blue green algae to eukaryotic algae (Moreira, Guyander, and Phillippe, 2000). The accumulation of characteristics of species from primitive prokaryotic kingdom to eukaryotic kingdom in the evolution is responsible for the photosynthetic kingdom shift. This nature has been referred to as 'wave' nature of a species in evolution and this is highly evident in the case of cyanobacteria which is argued as bridge or domain shift between prokaryotic and eukaryotic photosynthesis.



**FIGURE 2.** In addition to the concept of endosymbiosis, photosynthetic movement from kingdom prokaryote to kingdom eukaryote, is showing. Speciation creates 'wave' between kingdom domains.

In the evolution of species over time, there is a clear representation of new traits that have been acquired, due to factors external and internal. This acquisition of new traits gives a new definition to a defined organisms to become species. In the above context examples of microorganisms

convey, that species tend to evolve into higher forms acquiring new characteristics over a period of time bridging domains. This occurs as an unstoppable flow of evolution which is a totally a continuous process. Of what has been discussed in the kingdom shift and from the

examples discussed, it is evident that there are common characteristics between kingdom prokaryote and eukaryote, in certain microorganisms, which are considered as stages or 'still nature' of speciation creating a 'species wave' between kingdom domains. In the systems that have been discussed, it is observed that single prokaryotic cells evolving higher into eukaryotic single celled and multi-cellular eukaryotes, and eukaryotic algae, through a common phenomenal footage of endosymbiosis. On the larger scale of time, these 'intermediate organisms' have evolved from one species to another leading to the kingdom barrier which got dismantled, this steady shift is observed as a continuous species 'wave' over a great period of time (Wessen,1991). The critical leap made between the prokaryotes to the eukaryotes, is the resultant of higher characteristics that have been acquired between the prokaryotic and eukaryotic domain

It is apparent that the kingdom shift due to the formation of chlorophyll and mitochondria in eukaryotes by endosymbiosis is the most important high point that has been attained by evolution at a much earlier stage, which become a potential state for multi-cellular organisms to emerge. Ever since this evolutionary jump from prokaryote to eukaryote, over an immense period of time, there has been no other kingdom jump from eukaryotic to any other domain that is established. It is well acknowledged that with-in the kingdom eukaryote there has been large scale developments leading to complex multicellular organisms. There is good lot of significant evidence present as 'evolutionary foot prints' between domains. It is therefore evident that some organisms linger as defined species indicating transitional organisms that bridge kingdom domains at any given time, consequently favored ones selected by nature, enter the progressive speciation, into the next stage of evolution.

**DEDICATION:** This original publication is dedicated to Dr.P. S.Rao, Vice-President & Director, Life Sciences and Engineering, Dayananda Sagar institutions, Dr.C.D.Sagar Centre for Life Sciences, Shavige Malleshwara Hills, Kumarawamy Layout, Bangalore-560078,India.,for His Life-Time-Achievement, His Contribution To Science and therefore to the Society. And also acknowledge the encouragement and support, in carrying out the above work.

## REFERENCES

Albert Jeltsch (2003) Maintenance of species identity and controlling speciation of bacteria: a new function for restriction/modification systems? *Gene* Volume 317, 23 October 2003, Pages 13-16

Ausmees, N., J. R. Kuhn, and C. Jacobs-Wagner (2003) The bacterial cytoskeleton: an intermediate filament-like function in cell shape. *Cell* 115:705–713

Audery M. Glauert and David A. Hopwood(1961) The Fine Structure of *Streptomyces violaceoruber* (*S. coelicolor*): III. The Walls of the Mycelium and Spores. *The Journal of Biophysical and Biochemical Cytology* Volume 10: 505-516.

Avery, O. T., MacLeod, C. M., and McCarty, M. (1944) "Studies on the chemical nature of the substance inducing

transformation of pneumococcal types." *Journal of Experimental Medicine* 79, 137- 158.

Baker.J.M (2005) Adaptive speciation: The role of natural selection in mechanisms of geographic and non-geographic speciation". *Studies in History and Philosophy of Biological and Biomedical Sciences* 36 (2): 303–326

Bergman, J.,(1999) The putative evolution of the animal eukaryote cell ultrastructure, *Creation Research Society Quarterly* 35(4):221231

Brocks, J.J., Logan, G.A., Buick, R. and Summons, R.E., Archean molecular fossils and the early rise of eukaryotes, *Science* 285:10331036, 1999.

Bhattacharya, D.; Medlin, L. (1998) "Algal Phylogeny and the Origin of Land Plants". *Plant Physiology* 116 (1): 9–15

Buick R (August 2008) "When did oxygenic photosynthesis evolve?". *Philosophy. Transaction. Royal. Society of London., B, Biol. Sci.* 363 (1504): 2731–43.

Cavalier-Smith,T. (2000) Membrane heredity and early chloroplast evolution. *Trends In Plant Sciences.*5, 174-182.

Christophe Fraser, William P. Hanage, Brian G. Spratt (2007) Recombination and the Nature of Bacterial Speciation *Science* 26. Vol. 315. no. 5811, pp. 476 – 480

Cohan FM. (2002).Sexual isolation and speciation in bacteria. *Genetica.* ;116(2-3):359-70

Cook, O. F. (1906) Factors of species-formation. *Science* 23:506-507.

Cook, O. F. (1908) Evolution without isolation. *American Naturalist* 42:727-731

Darwin C., Wallace A. R. (1858) On the tendency of species to form varieties; and on the perpetuation of varieties and species by natural means of selection. *Journal Proceedings of Linean Society. London.* . 3, 46–50.

Darwin C. (1859) In On the origin of species by means of natural selection or the preservation of favoured races in the struggle for life. London, UK: John Murray.

De Duve, C. (1996) The birth of complex cells. *Scientific American.*274 (4), 38-45.

Douglas SE (December 1998) "Plastid evolution: origins, diversity, trends". *Current Opinion. Genetic. Deviation.* 8 (6): 655–61.

Fares Ali Mario, Andres Moya and Eladio Barrio (2004) ELSEVIER, TRENDS in *Genetics*, Vol.20 No.9.

- Grant, P. R., and B. R. Grant. (2002) "Unpredictable evolution in a 30-year study of Darwin's finches." *Science* 296: 707-711.
- Gould SB, Waller RF, McFadden GI (2008) "Plastid evolution". *Annual Review of Plant Biology* 59: 491–517
- Gupta, R. S. (2000) The phylogeny of proteobacteria: relationships to other eubacterial phyla and eukaryotes. *Federation of European Microbiological Society. Microbiology Reviews*. 24:367–402.
- Han T-M and Runnegar B (1992) Megascopic eukaryotic algae from the 2.1 billion-year-old Negaunee iron formation, Michigan. *Science* 257: 232–235
- Herrero A and Flores E (editor). (2008) *The Cyanobacteria: Molecular Biology, Genomics and Evolution* (1st ed.). Caister Academic Press
- Hofmann HJ and Schopf JW (1983) Early proterozoic microfossils. In: Schopf JW (ed) *Earth's Earliest Biosphere*, pp 321–360.
- Irwin, D.E., S. Bensch, and T.D. Price. (2001) Speciation in a ring. *Nature* 409: 333-337.
- Jin Xiong, William M. Fischer, Kazuhito Inoue, Masaaki Nakahara, Carl E. Bauer. 2000: *Science* 8 September Vol. 289. no. 5485, pp. 1724 – 1730
- John M. Olson and Robert E. Blankenship (2004) Thinking about the evolution of photosynthesis. *Photosynthesis Research* 80: 373–386
- Katharine Byrne and Richard A Nichols (1999) "Culex pipiens in London Underground tunnels: differentiation between surface and subterranean populations. *Heredity* (1999) 82, 7–15;
- Keeling, P.J. (2004) Diversity and evolutionary history of plastids and their host. *American Journal of Botany* .91, 1481-1493.
- Knoll A (1992) The early evolution of eukaryotes: a geological perspective. *Science* 256: 622–627
- Knoll, A.H., (1999) A new molecular window on early life, *Science* 285:1025-1026.
- Knoll, A.H.(2003) Life on a young planet: The First Billion Years of Evolution on Earth. *Princeton University Press*, Princeton, NJ.
- Kingsley, D.M. (January 2009) "From Atoms to Traits," *Scientific American*, p. 57
- Kutschera. U and Niklas (2005) Endosymbiosis, cell evolution, and speciation. *Elsevier, Theory in Biosciences* 124(2005)1-24.
- Niklas, K.J.(1997) *The Evolutionary Biology of Plants. The University of Chicago Press*, Chicago and London.
- Mary.E.(1942) *Systematics and the Origin of Species. Dover*. New York.
- Martin, W., Hoffmeister, M., Rotte, C., Henze, K. (2001) An overview of endosymbiotic models for the origins of eukaryotes, their ATP-producing organelles (mitochondria and hydrogenosomes), and their heterotrophic lifestyle, *Biological Chemistry*. 382, 1521-1539.
- Mereschkowski C (1905) "Über Natur und Ursprung der Chromatophoren im Pflanzenreiche". *Biological Centralbl* 25: 593–604
- McFadden, GI (2001) Primary & secondary endosymbiosis and the origin of plastids" *Journal of Phycology*. 37: 951-959.
- McFadden GI, van Dooren GG (July 2004) "Evolution: red algal genome affirms a common origin of all plastids". *Current Biology*. 14 (13): R514–6.
- Moreira A, D., H. Le Guyander, and H. Phillippe. (2000) The origin of red algae and the evolution of chloroplasts. *Nature* 405:69–72.
- "Monophyly of primary photosynthetic eukaryotes: green plants, red algae, and glaucophytes". *Current Biology*:15 (14): 1325–1330
- Olson JM (May 2006)"Photosynthesis in the Archean era". *Photosynthesis Resesarch*. 88 (2): 109–17.
- Oyama S., Griffiths, P. E. & Gray, R. D. (2001) *Cycles of Contingency: Developmental Systems and Evolution (Massachusetts Institute of Technology Press, Cambridge, MA)*.
- Price.T (2008) *Speciation in Birds Roberts and Co. Greenwood Village, CO. Roberts and Company CO: Roberts & Company*.
- Princeton University Press, Princeton, New Jersey Summons RE, Jahnke LL, Hope JM and Logan GA (1999) 2-Methylhopanoids as biomarkers for cyanobacterial oxygenic photosynthesis. *Nature* 400: 554–557
- Reznick, D. N., F. H. Shaw, F. H. Rodd, and R. G. Shaw (1997) "Evaluation of the rate of evolution in natural populations of guppies (*Poecilia reticulata*)." *Science* 275: 1934-1937.
- Ris H, Singh RN (January 1961) "Electron microscope studies on blue-green algae". *Journal of Biophysical Biochemistry and Cytology* 9 (1): 63–80
- Raven JA, Allen JF (2003) "Genomics and chloroplast evolution: what did cyanobacteria do for plants?". *Genome Biology*. 4 (3): 209



- Reyes-Prieto A, Weber AP, Bhattacharya D (2007) "The origin and establishment of the plastid in algae and plants". *Annual. Review of Genetics*. 41: 147–68.
- Robert E. Blankenship(2001) Molecular evidence for the evolution of photosynthesis. *Trends in Plant. Science*. Volume 6, Issue 1, Pages 4-6
- Rodríguez-Ezpeleta, Naiara; Henner Brinkmann, Suzanne C Burey, Béatrice Roure, Gertraud Burger, Wolfgang Löffelhardt, Hans J Bohnert, Hervé Philippe, B Franz Lang (2005) "Monophyly of primary photosynthetic eukaryotes: green plants, red algae, and glaucophytes". *Current Biology: CB* 15 (14): 1325–1330.
- Roff D. A., (1997) *Evolutionary Quantitative Genetics (Chapman & Hall, NewYork)*.
- Schimper AFW (1883) "Über die Entwicklung der Chlorophyllkörner und Farbkörper". *Botany. Zeitung* 41: 105–14, 121–31, 137–46, 153–62.
- Schopf JW (1968) Microflora of the Bitter Springs Formation, LatePrecambrian, Central Australia. *Journal of Paleontology* 42: 651–68
- Schopf JW and Blacic JM (1971) New microorganisms from the Bitter Springs Formation (Late Precambrian) of the north-central Amadeus Basin, Australia. *Journal of Paleontology* 45: 925–960
- Schopf JW (1974) Paleobiology of the Precambrian: The age of blue-green algae. *Evolutionary Biology* 7: 1–38
- Schluter D(2009) Evidence for ecological speciation and its alternative. *Science* 323:737–741
- Schidlowski M, Hayes JMand Kaplan IR (1983) Isotopic inferences of ancient biochemistries: carbon, sulfur, hydrogen and nitrogen. In: Schopf JW (ed) *Earth's Earliest Biosphere*, pp 149–185. Princeton University Press, Princeton, New Jersey
- Schidlowski M (1988) A 3800-million-year isotopic record of life from carbon in sedimentary rocks. *Nature* 333: 313–318
- Siefert, J. L., and G. E. Fox(1998) Phylogenetic mapping of bacterial morphology. *Microbiology* 144:2803–2808.
- Stocking C and Gifford E (1959) "Incorporation of thymidine into chloroplasts of *Spirogyra*". *Biochemistry and Biophysics. Research. Communication*. 1: 159–64
- Sullia S.B and Shantharam. S (2005) *General Microbiology*, second edition. Oxford and IBH Publishing Co.Pvt.Ltd. New Delhi. (Images redrawn from)
- Takeuchi, S., W. R. DiLuzio, D. B. Weibel, and G. M. Whitesides. (2005) Controlling the shape of filamentous cells of *Escherichia coli*. *Nano Letters*.5:1819–1823.
- Tamames, J., M. Gonzalez-Moreno, J. Mingorance, A. Valencia, and M. Vicente (2001) Bringing gene order into bacterial shape. *Trends in Genetics*.17:124–126
- Tylor E.B and McPhail J.D. (2000) "Historical contingency and determinism interact to prime speciation in sticklebacks". *Proceedings of the Royal Society of London Series B* 267 (1460): 2375–2384.
- Wake D.B., Yanev.K.P., and Freelow.M.M.(1989) in specization and its consequences(edds. Otte,D & Endler, J(134-157) *Sinauer*, Sunderland, MA
- Wake D.B. Schneider.C.J (1998) Taxonomy of the plethodontid salamander genus *Ensatina*. *Herpetologica*. 54.279-298.
- Walter MR (1983) Archean stromatolites: evidence of the Earth's earliest benthos. In: Schopf JW (ed) *Earth's Earliest Biosphere*, pp 187–213. *Princeton University Press*, Princeton, New Jersey
- Wesson,(1991). R., *Beyond Natural Selection*, MIT Press, Cambridge, Massachusetts, p.57
- Wolf J. B., Brodie, E. D., III & Wade, M. J., (2000) *Epistasis and the Evolutionary Process* (Oxford Univ. Press, New York).
- Woese, C.R., (2002) On the evolution of cells. *Proceedings of National Academy of Science. USA* 99, 8742-8747.
- Wake D.B. Schneider.C.J. (1998)Taxonomy of the plethodontid salamander genus *Ensatina* *Herpetologica*. 54.279-298.
- Young. K. D. (2006) The Selective Value of Bacterial Shape. *Microbiology and Molecular Biology Reviews*, p. 660–703.