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PAST OF THE GREEN WORLD

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This year we celebrated the Birth Centenary of late Professor Birbal Sahni. Professor Sahni was a multifaceted personality, a dedicated researcher, a committed teacher, scholar and above all a great human being. He extensively contributed to the understanding of plant history and stood for an all round development of the science of palaeobotany. He was a rare blend of Botany and Geology. He felt that plant evolution in its true perspective can be understood only through holistics and therefore he practiced an interdisciplinary approach in his researches. Commenting on his own passion - Palaeobotany he wrote "....my own interest in Palaeobotany raises the hope that I may help to bring this fascinating subject more prominently to the notice of my countrymen, and perhaps even succeed inducing a larger number of them to turn their attention to the rich field that it offers for original investigation." He further explained.... "The science of palaeobotany began somewhat like a purely academic pursuit, a study of curios. Gradually the point of view has changed as it always does with time, and has revealed new vistas. The whole outlook has now expanded beyond recognition. Today the study of fossil plants, pursued with modern techniques and with due regard to its repercussions upon all the bordering sciences, already occupies a respectable place among the sciences and fully deserves the support that it is now receiving all over the world. It not only allows us glimpses into the evolutionary history of plants, but helps us more and more accurately to tell the ages of strata and thereby to explore the mineral wealth of the earth, particularly coal and oil." He was so deeply engrossed in palaeobotany that he established an Institute of Palaeobotany at Lucknow, a living monument, unique of its kind, which reminds his true vision. He had an equally devoted partner in Srimati Savitri Sahni who through her undaunted spirit helped to build the temple of learning the Birbal Sahni Institute of Palaeobotany. One can well imagine her great courage and conviction to undertake the task of building the Sahni Institute from brick to brick, when her husband died just a week after the foundation stone laying ceremony. The institute is a beautiful place to work, grow and develop and we are trying to prove worthy of the mantle that we have inherited from the Sahnis and resolve to adhere to hard work, self discipline and noble deeds. Appreciating the idea of establishing a Palaeobotanical Research Institute Professor Alfred Charles Seward, Sahni's *Guru* at Cambridge wrote that Palaeobotany is... "to lift a corner of the veil separating us from the world as it was and view through dimly illuminated vistas the forests and undergrowth of an ancient continent that is now represented by a few widely scattered dismembered pieces", this is indeed what palaeobotanists do.

I chose to talk to you today on "**Past of the green world**" a subject closely connected with palaeobotany. We all want to know our origins. Past is the key to the present and one learns from the past experiences and mistakes. The green world also has experimented, evolved strategies and struggled to build the present. The biosphere we see today is a product of interaction of physical and chemical processes during the geologic past. The inter-related and inter-dependent system comprising various components of lithosphere, hydrosphere and atmosphere directly or indirectly influenced the "PHYTOSPHERE". An insight into these various forces explains the saga of origin and evolution of the past plant life, its strategies and factors responsible for present day green scenario on our planet.

The Earth is a living entity with its own consciousness and may be compared to a space ship. Every one has a stake in its safety. It demands a rationale and sustained utilization and management of space and resources. It may also be considered a global village

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and compared with a small village community where each individual has a role to play (Lovelock, 1979, 1988).

Behind the fragrance of champaka and the frail beauty of jasmine lies the tenaceous life force-the desire to survive and to continue; the alchemy to compound sunlight with inorganic elements and to prepare basic food is the key to greening of the earth. Since the momentous day, billions of years ago, when the first speck of life.. plant protoplasm puffed its first breath of oxygen into the primeval sea the collective energy of the plant has been the force behind their colonizing and conquering the earth. This speck of life has kept the torch of life burning and is the driving force behind evolution of organisms.

Eversince the first cell appeared on the earth the diversity of life has continuously increased both in quality as well as quantity. These qualitative changes infact, are the development of appropriate strategies to face new challenges posed by change of physical conditions. It is not individuals, but populations of organisms that change. They adapt to changing conditions or they leave fewer and fewer replicas eventually becoming extinct. Thus the organism ahead in the evolutionary game is the one that leaves the most offsprings. Yet, there is no single winner in this game.

The initial elementary events which open the gateway to evolution in the living beings are miniscule, fortuous and totally unrelated to whatever may be their effects upon the living system. These changes which are integrated in the living system are retained and transferred to the progeny. If they make the organism more competitive a population of better adapted individuals appear. On the other hand, harmful changes result in the reduced reproductive capacity or extermination of the individual. For example in the course of evolution the herbaceous components successfully exploited the changing environs where as some gigantic woody plants became extinct (e.g. Red wood). On the contrary, cyanobacteria and other living fossils practiced evolutionary conservatism in their morphological diversity and increased their physiological efficiency. Thus function had a priority over structure, whereas in animals form and function went together during the course of evolution (Traverse, 1988). Often organisms of variable characters appear suddenly due to mistakes in the genetic copying process. These changes once made are faithfully copied in subsequent generations. If these changes help the organisms to adapt better to its surroundings then the organisms flourish and diversify often at the cost of its less fortunate partners in the ecosystem. But the harmful changes may result in death of the indivi-dual (Margulis & Sagan, 1986, 1987).

Leuis Agassie has rightly remarked that fossils are the tombstones on which the buried dead wrote their own epitaphs. The scribblings on these epitaphs are deciphered by plant fossil researchers. Plant fossils -- the natural archives were always subjected to myriad forces of nature, the physical, chemical, geological and many others. They are the only reliable evidences which help to unravel hidden treasures of planet earth. The entire story has to be built up from records of organisms as they got buried, and not as they lived, after some ill-defined interval of transportation and decomposition. Thus, the limitation of fossil record is a constraint to reckon with (Venkatachala, 1992).

MANIFESTATION OF LIFE

Life begets life. In whatever manner life might have originated, once it was there, it did not show a going back. An unbroken continuity in evolution has been maintained. All life is cellular. Each one of us start life as a single cell and develops into individuals made up of billions of cells which are inter-related, interacting and intercommunicating. Every cell has been programmed in a manner that is yet not fully understood. Ontogeny reflects phylogeny. The evolutionary history is recapitulated. There is not only physical evolution but evolution of consciousness. One can reasonably assert that in all life there is consciousness, that is there is an awareness of its being what it is and its environment, and that an attempt is made by all living organisms, however, humble to relate themselves to it. Every organism selectively absorbs, assimilates and transforms what it needs from the environment and returns the by-products to the environment. We can conceive of repeated awareness resulting in memory at some point, which means an ability to code, store and retrieve information. It will be a case of cognition leading to recognition. Thus the idea of sequence becomes a possibility for consciousness. Sequence, in turn, leads to consequence, that is the notion of cause and effect. Law of causation becomes an inherent aspect of the operations of organismal consciousness. The abode of consciousness is the individual organism. The organism reflects its genetic potentia-lity and environmental conditioning depending upon (both physical and social) opportunities and constraints. Awareness, selection, absorption, assimilation, transformation and rejection are the activities, functions and characteristics of this consciousness (Margulis, 1982; Hartman *et al.*, 1985; Venkatachala *et al.*, 1988).

EARLY LIFE

The inorganic world brought into being the organic world. The history of plant kingdom is as old as the origin of life itself. The first speck of life must have appeared in calm and deep waters. During the primeval time the atmosphere was not as what it is today, it was hostile to life. Oxygen, the prime requisite of life today, developed only through the activity of life. It is deduced that the inorganic elements, contained in condensed vapour by continuous collision with each other, formed life. The basic energy for activating these reactions and the prolific power of carbon to form chain compounds helped in the formation of the first amino acid and gradually the cell more than 3.5 billion years ago. Further development of organism and the society of organisms was facilitated by enrichment of the originally salt-less waters. As time passed, geysers and eruptions brought vast quantities of minerals into the sea through rivers and springs.

The primeval organisms were dominantly anucleated forms which occupied platform and shallow slope environments. These forms, both with (autotrophs) and without (heterotrophs) the capacity to make their own food dominated earth's biosphere during the first two billion years of its history (Margulis, 1982; Schopf, 1983; John, 1991; Horgan, 1991; Venkatachala, 1993).

The earliest organisms were chemoheterotrophs absorbing necessary nutrients from the surrounding water. The next organisms that appeared were chemoautotrophs. They obtained their energy by degradation of chemical compounds for the synthesis of food molecules. These organisms are found in the Galapagos and deep ocean thermal springs. Analysis of the biological inter-relationship around these springs suggests that geothermally produced hydrogen sulfide is the basic energy source used by chemoautotrophic bacteria to fix carbon. These bacteria not only make their basic food resource but also form the first step in the food chain (Schidlowsky, 1979). Fossilized remains of *Thiobacillus* and some members of Siderocapsaceae which can reduce sulphates are known from >2.6 b.y. old Kudremukh iron ore deposits (Venkatachala *et al.*, 1986). Gradually microbes diversified in many low-lying mud communities. Cells acquired the capability to carry out numerous metabolic strategies, including fermentation, sulphate reduction and anaerobic photosynthesis. It was the appearance of chlorophyll ``A'', the mediator of oxygen producing photosynthesis, as a pigment incorporated in prokaryotic organism known as Cyanobacteria (blue-green algae) which triggered important changes in the atmosphere. A convenient contrivance serving this purpose was the conversion of carbon dioxide to carbohydrates. From the stand point of energy it is affected most economically by the photosynthetic activity of these cyanobacteria. These autotrophic life forms were able to synthesize organic matter from carbon-di-oxide and water with molecular oxygen released as a metabolic byproduct. Besides fixation of nitrogen in the form of nitrate (NO_3), the stage in which it can be used by plants and to set the carbon cycle into motion, was also done by these tiny plants and thus set three important cycles -- the oxygen, nitrogen and carbon cycles into motion. The ultimate result of these changes in the atmosphere was far reaching for a living system. Cyanobacteria represent the highest level of evolution in kingdom Monera. They generated oxygen photosynthetically and appeared in the Archaean. When the oxygen level started rising chemical and biological strategies to cope up with this new situation had to be adapted. Many organisms, unable to tolerate the toxicity of this gas, were permanently driven to anaerobic niches while others first developed tolerance, then facultative use and eventually the obligate use of oxygen in metabolism (Schopf, 1983; Knoll & Bould, 1989; Knoll, 1990; Horgan, 1991). This oxygen, a result of photolysis of water during the photosynthetic process accumulated and led to the evolution of respiring bacteria. These symbiotic forms probably got merged with other bacteria and formed eukaryotic cells which through the course of evolution became multicellular and gave rise to fungi, plants and animals (Margulis & Sagan, 1986).

ORIGIN OF EUKARYOTIC CELL

The first Eukaryotes were probably primitive Protists : aerobic aquatic unicellular organisms whose patterns of cell division and life cycle can vary extremely from one species to another. The fossil acritarchs and vase-shaped microfossils from the Precambrian (1,800 million years) sediments probably represent the earliest records of Protista (Venkatachala *et al.*, 1988; Vidal, 1984; Vidal & Knoll, 1983). Recent discovery of megascopic eukaryotic algae from 2.1 billion year - old Negaunee Iron Formation, Michigan is significant (Tsu-Ming Han & Bruce Runnegar, 1992) and if accepted, will revise the early reports of this event at 1.7 billion years. The advent of eukaryotes at this critical juncture probably was related with increased O_2 levels (Riding, 1992). It is also possible that the missing link between prokaryotes and eukaryotes is either missing or yet to be recovered. Evolution is not anticipatory. Ambiguity in evolution can be traced back to the origin of earlier forms and they appeared as and when the pressures demanded. It is also suggested that the origin of eukaryotic cells involved endosymbiosis, the engulfing of one organism by another, giving rise to cell organelles such as the mitochondrion and chloroplast (Margulis, 1970).

ORIGIN OF SEX

The three defining properties of living system, viz., autopoesis (self maintenance), growth and reproduction can occur in total absence of sex. Perhaps, the evolution of sex was a biological strategy to meet vagaries of environment and an ecological necessity. Or, perhaps at some stage in the distant past certain free-living single-celled organisms exchanged and/or combined genetic material and gained advantage over those that did not. This new means of incorporating adoptive genetic changes presumably helped in rapidly recombining and forming new individuals. This genetic energy is a driving force and forms a continuum. Favourable traits developed in different individuals were brought together in one individual. Thus, the sexual reproduction along with meiosis helped not only in the recombination of characters but also in developing diverse characters in the offspring. Subsequent to the evolution of sex as well as the acquisition of the filamentous habit, another important inevitable event - death - which came to control the future course of life itself was ushered in. The immortal unicell which was capable of several functions, including reproduction gave rise to mortality. However, advanced life forms could not have developed without this gift of death. The birth of death took place atleast 1,300 Ma ago (Margulis & Sagan, 1986).

MULTICELLULAR PHOTOAUTOTROPHS - THE PLANTAE

Metaphytic organisms most probably evolved from unicellular protists. The first stage in the evolution, that is, arrangement of the cells in linear pattern is quite common in several filamentous algae. The next step would have been the formation of plate-like bodies or sheets. Algal sheets are known both in *Vendotaenia*, an alga recorded from ± 1 billion year old sediments of the Vindhyan Supergroup (Shukla *et al.*, 1989, 1991) and *Ulva*, a recent green alga in a marine environment. The earliest unicellular prokaryotes were generalists and could perform all the tasks requisite for survival. As evolution proceeded, different parts of the organisms took over performing of different tasks, thus initiating specialisation and division of labour. This required first specialised tasks being performed by specialised organs with in the cell and then by specialised cells/tissues. This gave rise to specialised organs like, roots for anchorage and absorption of nutrients; leaf for photosynthesis and specialised reproductive organs (Gottlieb, 1968).

How and when the living system adopted the practice of division of labour delegating the work load to specialised cells or group of cells is not known. However, the heterocyst of cyanobacteria takes up the responsibility of reproduction in adverse conditions. The earliest multicellular blue-green algae gradually developed features like branching. They were still inhabiting the aquatic media where nutrients were plenty and easily available to all parts of the organism. They required no foraging roots in a medium containing all the nourishment. Perhaps due to depleting nutritional resources of the early sea the living system must have felt the need to move and occupy land (Pratt *et al.*, 1978; Tiffney, 1985). It is remarkable that a similarity exists in the concentrations of the sea water and our blood. The salts from the sea water were taken by animals while moving from sea to land. Thus what we sweat and cry is nothing but basically sea water (Margulis & Sagan, 1987). As if to remind this ecological necessity the aquatic media is still a pre-requisite for fertilization process to occur.

The Lower Paleozoic flora in the marine realm was dominated by the calcareous and non-calcareous algae. Forms showing characteristic features of Codiaceae, Dasycladaceae and Solenoporaceae appeared in the Ordovician. Sea weeds also developed the power to photosynthesize at greater depths. The algal flora of Ordovician seas persisted into Silurian which was the time of rapid development of calcareous green algae. *Prototaxites* - an enigmatic form with ground mass of small, thin-walled septate, branched, interwoven hyphae and vertical, large thick-walled, aseptate tube appeared in Silurian. It may be related to the brown algae or to a higher plant. But presence of tissues distributed as radially elongated masses that bear crude resemblance to medullary rays, indicates that such forms perhaps represent intermediate stage between true land plants and their ancestors probably green algae.

EARLY LAND PLANTS

The early plants of aquatic system mostly spent their lives attached to the sea-floor and continuously bathed in water. The evolutionary transition from sea to land demanded a variety of adaptive features. The first problem was of support. The atomospheric gases also influenced the respiratory/gas exchange system. The ecological consequences such as the non-availability of food supply in air as compared to its availability in water lead to development and evolution of food supply system. These modifications brought about structural changes in trophic levels, productivity and resource management. The glaciation during the Ordovician probably had an impact on sea level and put more stress on plant life which boldly evolved many vegetative adaptations. The stress tolerant inter-tidal and sub-tidal algae gradually explored terrestrial environments. The pressure variations of oxygen in the earth's atmosphere due to photosynthetic activity of early life forms in aquatic systems possibly helped invasion of land by plants. The circumstances for the extinction of animals at the terminal Ordovician were probably a boon to trigger invasion of primitive green land plants. It is suggested that members of Chlorophyceae and Charophyceae were possible precursors of early land plants as evidenced from molecular genetics. Group II introns are found in the t-RNA genes of all land plants. The distribution of these introns in *Coleochaete, Nitella* and *Spirogyra* corroborates the affinity of these taxa to the lineage that gave rise to land plants. The chloroplast genome of land plants probably acquired these introns more than 400 - 500 million years ago just at the time of land plant origin (Manhart and Palmer, 1990).

The early land plants have horizontal mode of habitat. As early land plants had to grow against the gravity, they evolved structural/prostatic pressure supports such as cuticles and mechanical tissues to stay upright. The underground root system deve- loped for gathering water and nutrients from soil and helped anchorage the plant. The internal transport system and reproductive system were strengthened in response to changing ecological needs. Diffe-rential photosynthetic tissue distribution *vis-a-vis* light availability and water loss controlling adaptability are novel methods through which plants managed a gradual balancing system. The evolution of conducting strands (as seen in non-vascular plants), cuticle for water proofing, stomata for gaseous exchange, xylem (as seen in vascular plants) for better upward flow of water and its strengthening by structural molecule lignin and internal nutrient conducting system through the development of phloem are some of the unique adaptations of plants (Gottlieb, 1968; Knoll & Niklas, 1987). Competition for available light encouraged differential growth patterns and effective adaptations to life in air. This diversification further aided by appearance of herbs, shrubs and finally the trees representing distinctive layers where more organisms could be encompassed within a community (Niklas & O'Rourke, 1982; Knoll *et al.*, 1984; Knoll, 1986; Taylor, 1988). Often associated with sheets of cuticle are recorded a number of microfossils that have been referred to as tube or trancheid like cellls. They have been found in fossils of *Nematothallus* (Edward, 1982), and some types are known to occur within the problematic plant *Prototaxites*. While these ``tubes'' fail to meet the general criteria of a tracheid, the structural organization does suggest a functional role of both conduction and support. Since none of the tubes have been found *in situ*, it is impossible to state whether they belong to land inhabiting embryophytes or some group of aquatic organisms. Like the cuticle, their significance in the fossil record should be viewed as an indication of structural adaptation, and not necessarily of habitat or bilogical affinity (Niklas &

Smocovitis, 1983).

These changes coupled with reproductive adaptations got integrated over a period of time to deal with relatively desiccating environment. In the earlier stages of this evolution, the gametophyte and the sporophyte were more or less in competition, eventually moisture requirements dictated the dominance of sporophyte. The energy management process channelised appearance of micro-and megaspores ultimately leading to the evolution of seed habit. With the passage of time sexual reproduction increased in efficiency as a result of which communities slowly became more diversified. Vegetative adaptations permitted the initial invasion of land while reproductive mechanism followed along by chance or as a response to demanding situation. This resulted gradually into oogamous, archegoniate mode and ecologically haplobiontic diploid life cycle which proved more advantageous (Chaloner, 1970; Chaloner *et al.*, 1977). The evolution of seed was an important breakthrough in land plant reproductive strategies. The discovery of a ``missing link'', a new type of seed in Lower Carboniferous Montagne Noire deposit, France which has no pollen trapping structure or evident access for the pollen to the female gametophyte is significant (Galtier & Rowe, 1989; Chaloner, 1989). It suggests an intermediate evolutionary stage between pteridophytic and gymnospermous reproduction and hence is an important step in evolutionary history.

The early land plant radiation was concentrated in the habitats of swamps, river-banks and floodplains. As plants grew higher, life in air became three dimensional to escape perhaps the ravage of insects; the insects discovered flight very soon. The scenario of early terrestrial life thus was dominated by bryophytes (mosses). pteridophytes and pro-gymnosperms. The development of seed gave the early gymnosperms an additional advantage for quick propagation and spread. Thus the Devonian period produced a variety of morphological structures in both vegetative and reproductive parts (Niklas, 1986; Niklas & O'Rourke, 1982).

The lush vegetation of the low-lying swamp-lands during the succeeding Carboniferous period (355 million years) reflect the evolutionary potential and the vigour inherent in the Devonian precursors. During the Carboniferous tall trees, a form of gigantism, evolved amongst ancestors of plants like *Equisetum* and *Lycopodium*, Plant atlast had conquered land! These were the well-known calamites and lepidodendrids. Ferns recognizable as members of primitive modern families appeared. Seed ferns reached their zenith; other gymnospermous groups, the cordaitales and coniferales, appeared. Heterospory reached a high degree of perfection, and a profusion of primitive seeds evolved. They were soon followed by highly complex seeds. There seems little question that the floras of Devonian and Carboniferous strata represent a continuum initiated at the time of their first appearance and extended by the resulting explosive radiation (Christopher, 1991).

The vast swamp floras of the Carboniferous formed the greatest coal deposits of Northern Hemisphere. Massive tree trunks, buried under sediments, were mummified to develop these coal reserves. In Permian the locus of the great coal swamps populated by the Gondwanic forests was centred in the Southern Hemisphere. After the end of the Palaeozoic, coal development became comparatively restricted all over the globe (Cross & Phillips, 1990; Phillips & Cross, 1991; Christopher, 1991).

In the wake of glaciation of the Late Carboniferous-Early Permian (365-245 m.y.) a unique vegetation - the Glossopteris Flora, arose and spread out far and wide over the Gondwana Supercontinent with subsequent amelioration of climate in the Permian. The amazingly parallel development of the Glossopteris flora in space and time over Gondwana Supercontinent is a strong basis for the assumption that the southern continent including India were formerly close together permiting free intermigration of plants (Sahni, 1935, 1936).

Three new groups of gymnospermous seed plants - the Bennettitales, Cycadales and Ginkgoales evolved during Early Mesozoic (240 million years). This green world of middle ages provided fodder for the dinosaur dominated land animals. The plants perfected the seeds, delayed the germination to expand into new ecological niches. The mosaic of cycads and conifers untill the evolution of flowering plants dominated the green scenarios. The conifers mostly were wind pollinated which was rather expensive. Whereas cycads were mostly insect pollinated (Stewart, 1983). A significant extinction among plant group occurred at the end of Mesozoic. The Bennettitales, cycads and ginkgos that had dominated the Mesozoic flora either died out completely or were markedly reduced in number. Conifers were reduced but managed to survive probably by migration to upland sites and are still vigorous today. Certainly if we view the various orders of gymnosperms as ``experiments'' in evolution, the conifers were the most successful. They have demonstrated sufficient adaptability to survive, whereas the other groups presumably less adaptable, either perished or diminished to little more than relics. Ginkgoales are now represented by a single species, *Ginkgo biloba.* During this time only dinosaurs which dominated the Cretaceous scenarios were obliterated by some reason or the other, such as volcanic eruptions, extraterrestrial impact, hey fever (due to pollen), radioactivity, advent of new herbaceous components effecting dinosaur food habit, etc. (Alvarez *et al.*, 1980, Raup & Sepkowski, 1984; Friis *et al.*, 1987; Wolbach *et al.*, 1988; Buffetaut, 1990).

ORIGIN AND SPREAD OF ANGIOSPERMS

Although a superficial view of the history of plant life shows an apparent steady evolution of new types, a detailed analysis shows that there were periods of vigorous evolutionary activity and others characterized by stability. Evolution has resulted in successively more complex organisms, but the process has been one of intermittent bursts of activity. Each burst of activity can be correlated with evolutionary innovations in the reproductive biology of plants. The last of these evolutionary innovations resulted in the advent of angiosperms. It is not known when this plant group originated, though individual angiospermoid characters can be traced back to Early Mesozoic. At present what we can say conclusively is that angiosperms formed the dominant group by Late Cretaceous (65 million years) and the process of greening came to be stabilized.

When did the first flower open or what flower it was - a palm or perhaps *Magnolia* or some taxa now extinct - is not known but by the Cretaceous period a hundred million years ago, flowering plants were fully established, assisted by insects, whose evolution curiously runs parallel to their own, and further assured by the innovation of a nourishing ovary for their embryos they quickly spread across the globe, evolving into a clan of a quarter of a million species and decorating the landscape in a great mosaic of shapes and colours. The arrival of the flower on the scenario started a magnificient beginning and set up a speedy spread of angiosperms - the flowering plants. Only a few million years after this advent most wild plants we know were established. Since then it has never been a looking back. Flowering plants conquered all nitches on the surface of the earth.

Angiospermy represents a significant evolutionary innovation in plant reproductive biology. Absence of free-living gametophytes; morphological adaptation compiled with reproduction/life cycle modifications, dormancy of seeds and clear dispersal mechanism provided these plants with an edge over the cycads and other gymnosperms which dominated the earth in the Mesozoic. The origin of the flower or clustering of reproductive organs into compact collection of ovule and pollen producing organs was also helpful in increasing the reproductive capacity of these plants. Hence, within the floral diversity the flowering plants the angiosperms increased (Beck, 1976).

The plant is at the mercy of a selective environment which favours the modifications best suited for survival in that environment. The dominance of angiosperms which have a known history of little over 125 million years is a success story of experimentation in several ``character states''. Character state analyses speak much more about the emergence, development, amplification and stabilization of a set of characters or even sets of characters. Each one of these characters is a response to an evolutionary need or an adjustment to changing environmental conditions. The ultimate aim of the experimentation by nature is to make the group a success and to make it succeed in balancing with other conditions. The entire study of fossil history is the understanding of ``character-states''. The development of exine stratification and apertural features of pollen, development of land habit, deposition of cuticle and lignin, the change from herbaceous habitat to an arborescent habit, the development of the seed ultimately leading to angiospermy are only few examples (Vasanthy *et al.*, 1989; Venkatachala, 1992).

The principal driving force in angiosperm evolution is pollination mechanism. The sudden population explosion in Mesozoic Era was also attributed to appearance of primitive mammals, birds and primitive insects, like beetles. Some of the primitive angiosperms probably had large fragrant flowers, where insects assembled to feed and mate. The scents of primitive angiosperms also deter insect chewing so that damage to the flower may minimize as far as possible. The early radiation of angiosperms with much more competetive ability sidelined the contemporaneous gymnosperms. Co-evolutionary interaction between herbivoral insects and host plants is also demonstrated from the fossil records. A 48 million year old Aphid *(Melaphidina)* host plant association from Alaska can be cited as an example (Moran, 1989), even older records are known.

The records of *Archaeanthus* and *Lesqueria* of magnoliodae affinity from the Albian-Cenomanoian beds of Kansas, North America point out the antiquity of Magnoliales (Dilcher & Crane, 1984; Crane & Dilcher, 1984). Two fruits from apocarpous gynoecia were also recovered from the Lower Albian rocks of Virginia (Dilcher, 1979). Besides the record of *Sarcandra chloranthoides* - about 3 mm long flower consisting of a single stamen and a single carpel, a seemingly chloranthoid flower (with *Clavatipollenites* type pollen) from the Late Albian from Maryland, United States of America is significant (Endress, 1987).

It is also suggested that non-magnolian Chloranthaceae and Piperaceae were probably the ancestors of angiosperms and a herbaceous origin of flowering plants is a possibility (Taylor & Hickey, 1992). The record of angiosperms from Aptian times strongly indicates appearance of such forms in much earlier times (Hughes & McDougall, 1988; Taylor & Hickey, 1990; Douglas, 1992). Cladistic analysis of angiosperm pollen from Barremian-Aptian suggest five main clades confirming their antiquity (Doyle & Hotton, 1991). Molecular evidence for a pre-Cretaceous angiosperm origin is also known (Martin & Saedler, 1989).

PHYSIOLOGICAL STRATEGIES

Palaeoecological requirements dictated photosynthetic strategies of flowering plants. The cost of maintaining the leaf during adverse periods is greater than the benefit it provides. This compounded with the cost of re-growing another leaf later is expensive thus Palaeogeographic and palaeoclimatic requirements evolved the decidous habit in some angiosperms for reasons of economy. Changes in the levels of both atmospheric carbon-di-oxide and oxygen lead to alternative systems of carbon assimilation in flowering plants. During the course of evolution C_3, C_4 and CAM (Crassulacean Acid Metabolism) photosynthetic systems evolved in response to these changes. The changes in competetive ability and related phytomass are responses to differential carbon-di-oxide utilization. The C_4 and CAM photosynthesis reflect enhanced water-use efficiency. These strategies are more prevalent in modern day dry habitats. The grasses mostly are C_4 plants and react interestingly to grazing. They alter their growth habit and coevolve with the grazers to produce different reproductive patterns and structures. There exists a mutual dependency of grazed plants and animals. The balance of ecosystem is maintained due to grazing pressures. The first grasses perhaps appeared after the terminal Eocene event and spread widely in the Miocene. Grasses are adapted to face severe grazing. The entire lamina of these plants is photosynthetic and respond quickly to cropping and consists tiny silica fragments (phytoliths) that make them tough to chew. While this was happening on the prairies, the woody dicotyledons in the rain forests responded to excess water by elongated drip tips which help water shedding and limited the growth of epiphyllous forms besides other adoptive strategies (Spicer, 1989). ^{13}C values measured on Late Cretaceous Dinosaurs suggest consumption of C_4 of CAM plants by these gigantic animals (Bocherens *et al.*, 1972).

ENTRAPPED ENERGY

The initial step - the appearance of chlorophyll `A', not only initiated the giant leap towards greening of the earth but also started entrapment of energy by the plant world. The major part of this energy was consumed by plants themselves through respiration during their life cycle. But a small part of the entrapped energy got buried in the sediments and resulted in the fossil fuel hoarding that the earth holds today. Finite amount of these fuels is present in the earth and it is a result of 3 billion years of biological activity. Along with these fossil fuels is also buried a portion of the finite carbon budget of the planet which had been semipermanently withdrawn from circulation and deposition in the crust in the form of organic carbon. Today large part of this buried carbon is being withdrawn from its abode in the crust and pushed back into the atmosphere at a much faster pace than nature would like and tolerate. This is going to effect and influence the oxygen concentration - an essential element for the existence of life today, and increase the CO_2 concentration which may result in the green house effect and consequently increase the temperature of our planet. This increase in temperature may result in melting of ice and increase in sea level. The only hope that mankind has is the natural mechanism of the earth which in the past has withstood such fluctuations with success by evolving appropriate strategies to face new challenges posed by the change of physical conditions, in other words adjusting to newer ecologies (Bazzaz & Fazer, 1992).

CONCLUSIONS

The entire story of greening can also be briefly explained through a geological clock. The history the last 4.8 billion years on earth can be understood if we compare the solar system as only a day old and accordingly one hour of the clock represents a period of 200 million years. The zero hour naturally started around 4.8 billion years B.P. On this time scale the earth came into being about 90 minutes after the solar system was formed, i.e., at 1.30 A.M. curiously the first appearance of life probably occured at 05.00 hours (about 3.8 billion years) followed by the evolution of eukaryotic algae at 15.30 hours (1.7 billion years). Green plants gradually colonized the land by 21.40 hours (450 million years) and the flowering plants at 23.25 hours (120 million years). There was a significant change in the vegetational composition after the rise of Himalaya at 23.53 hours (1.5 million years). *Homo sapiens*, the most evolved animal appeared at 23.59.30 hours (about 1 million years) and Indus Valley civilization is only 10^{-5} seconds old (Ca. 2500 - Ca. 1750 B.C.) (Venkatachala *et al.*, 1988).

Albeit man made his appearance so late in the evolutionary ladder (about 1 million year BP), yet he is trying to conquer nature, in the process disturbing the homeostatis. It has taken over 3500 million years of preparation (appearance of life) and over 120 million years (Cretaceous) of adaptation for the greening process to stabilise and give shape to the earth today. We are here only for a million years but have already started disturbing the global environmental balance of Large scale inefficient utilisation of fossil fuels is resulting in gradual but steady increase of carbon (as carbon dioxide) in the atmosphere. The finite forest resources are being systematically reduced resulting in depletion of biological diversity. The synergistic edifice built by nature for billions of years is progressively deteriorating due to the superbrain of the little human. It is not necessary for us to destroy or mutilate the living world for our survival and comfort. For, there could not be animals untill there were plants on which they could feed, or cornivores before there were other animals to feed upon, or decomposers before there were some thing to decompose. The potential of one depends on the potential of the other, each being part of the total living system. The potential of the whole is important. So the need of the hour is to conserve nature and natural resources. If we do not understand this today there may not be a tomorrow. For, what is the use of being a peer when there is not one to do your bidding. Genetic process is slow. However, man is trying to manipulate and hurry this process through genetic engineering. It is feared that he may storm nature through new varieties of life which may or may not be beneficial. The fate of wild varieties would be at stake. Conservation of biodiversity is utmost needed. Evolution is an expression of creative urge - a fulfilment of novel ends produced inventively during a passage of time. It implies a real presistence of the past in the present, a duration which is, as it were, a hyphen, a connecting link. It would be futile to try to assign life to an end in the human sense of end. There is no end to the process of evolution. New strategies to meet new challenges give rise to new organisms. It's not predictable (Bergson, 1944). Evolution as viewed from a hind sight is not entirely ``the survivor of the fittest'' as picturised by Charles Darwin but ``Symbiosis'' - coexistence. From the appearance of the nucleated cell which was formed by the engulfing of the parasitic organism by the host cell over 1500 million years ago to the plant world in the ecosystem that we see today, is a testimony of harmonious living of not two or ten but hundreds/thousands of organisms. The ones that adjusted and lived well, succeeded, those who didn't, perished. The law of nature thus is symbiosis and the art to live and let live.

Our ancestors have rightly stressed the reverence with which they held ``Mother Earth'' and the respect they gave not only in worshipping her but in protecting also. I end this lecture with this prayer.

SAMUDRA-VASANE DEVI PARVATASTANA MANDALE

VISNUPATNI NAMASTUBHYAM PADASPARSAM KHSAMASVA ME

``O! Mother! with the resplendent sea as your outer garment, the lovely rolling mountainland as your body, pardon me my indiscretion of treading on you with my feet''

I am extremely thankful to the Indian Botanical Society for awarding me this prestigious medal instituted in memory of Professor Birbal Sahni.

I have drawn material for this interesting story from several published and unpublished sources. I have been fascinated by some of the thoughts which are indeed stimulating. I am sharing these thoughts with you. I am sure this will stimulate many of you.

I am thankful to my colleagues Drs. A. Rajanikanth and Manoj Shukla for their help in preparing this lecture and Dr. H.K. Maheshwari for various suggestions.

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