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SIXTEENTH BIRBAL SAHNI MEMORIAL LECTURE

Our oldest rocks and the early record of life

B. P. Radhakrishna

The Geological Society of India, Bangalore-560 019, India

NEARLY fifty years ago, while still a student, I had the privilege of hearing Professor Birbal Sahni, one of the greatest scientists India has produced. I remember him as a most charming personality who thrilled the audience with his exposition of the theory of drifting continents. Professor Sahni's interest was largely centred round the study of extinct plants and this lead him on to take a keen interest in geology. His contributions to the Indian geology are as profound as those to Botany. The twin sciences of geology and botany suffered a grievous loss in the untimely death of this distinguished scientist.

I am grateful to the Director of this Institute for the honour he has done in inviting me to deliver the Founder's Day lecture. The subject I have chosen for my talk is on 'Our oldest rocks and the early record of life.' It is one of great interest to both geologists and botanists. Rapid advances are being made in this multi-disciplinary field in which geologists, biologists, organic chemists, and geochronologists are working together to unveil the mystery of the origin of life. It will be my object to unfold this fascinating story as best as I can. The story of the origin of life is inseparably tied up with the early evolution of the planet Earth itself. It is inevitable, therefore, that to gain a correct understanding of the beginnings of life, we should go back into Earth history and understand how Earth emerged as a separate entity in the solar system and how it evolved through time. An understanding of how the atmosphere and hydrosphere initially developed is also a necessary part of such a study. Evidences for constructing the early history of Earth, the recognition of the major events which led to the beginning of life have to be looked for in our oldest rocks.

There are, however, serious limitations to such studies. Rocks older than 3800 m.y. have not come to light. We really do not know what happened during the first 1,000 m.y. of the birth of the earth as it is shrouded in mystery. Secondly, the oldest sedimentary rocks that could have preserved traces of life are in a highly altered and metamorphosed state. We have to work with such fragmentary data in order to piece together scraps of information and try to construct a history of past events.

Schopf, one of the most active palaeobiologists of the present day has suggested classifying all available evidences relating to early life into four categories: (i) compelling evidence, (ii) presumptive evidence, (iii) Evidence of permissive or possible category, and (iv) Evidences that are completely missing. As we go along tracing the early history of the Earth we will see that the evidences which have so far come to light on the vexed question of the origin of life are only of the permissive or possible category. A great deal of further search for the missing evidence has to continue before we are in a position to quantify our evidence as compelling.

We in India are in an advantageous position to carry out palaeobiological studies. Nearly a third part of our country is covered by the oldest rocks. Every part is easily accessible. Some of the largest Proterozoic sedimentary basins of the world containing sediments which have not suffered from subsequent metamorphism are to be found in India. We have, therefore, rocks ranging in age from 3,800 to 600 m.y —the entire Precambrian—the period during which life evolved and diversified. This country, then, should be capable of contributing substantially to the evidence that is being gathered from all parts of the world to trace the beginnings of life on this planet.

In spite of such excellent opportunities, palaeobiological research in India has not made much headway. Text books and monographic studies on Early Life which have appeared in recent years do not make even a mention of India or of Indian material. This is surprising since possibly the first record of fossil stromatolite came from the Indian Precambrian. There is urgent need to intensify study of our oldest rocks and bring to light evidences that lie hidden in them—evidences so compelling as to make the rest of the world take notice and give due credit.

EVOLUTION OF THE PLANET EARTH

Our story begins with the origin of the Earth. Latest advances in astronomy point to a time when there was no Sun, Earth or any of the other planets of the Solar System It is said, at the very beginning, there was some primordial substance which burst with a big bang 13,000 m.y. ago and released elementary particles into empty space. These elementary particles later combined to form a variety of atoms of heavier nucleii of which the simplest and the most abundant are hydrogen and helium. Over 95 per cent of the universe is made up of two elements—hydrogen and helium. The rest of the elements are believed to have evolved out of hydrogen through a series of complex thermo-nuclear reactions at high temperature and pressure. Hydrogen burned to produce helium and helium produced carbon and oxygen. At still higher temperature silicon and other heavier elements like iron and nickel were produced. Such reactions took place in the supernovae long before the accretion of the Earth.

The Solar System as such came into being through gravitational collapse of an interstellar cloud of gas and dust. The Earth formed through accretion of planetissimals made up of a mixture of silicate and metal particles similar to the present day chondritic meteorites. The meteorites falling from outer space reflect the composition of planetissimals which gathered together to form the primitive earth.

EVOLUTION OF THE ATMOSPHERE

The Earth when it was first formed was devoid of an atmosphere and was also waterless and lifeless. There was no differentiation into continents and oceans. The outer surface of the mantle itself formed the crust. This was bombarded by meteorites which destroyed this crust and allowed for differentiation to take place. Great floods of lava erupted and covered the surface of the earth.

As the planet further evolved, the gases originally trapped inside the earth were released to form the earth's initial atmosphere. The gases so released initially were lighter, like hydrogen, helium and argon. These being light did not stick to the earth but escaped into outer space. A secondary atmosphere developed which was rich in methane, ammonia and water vapour. Even this was transitional and changed to one of carbon dioxide and nitrogen. Such a stage had been reached by 3,800 m.y. ago. The inner planets like Venus and Mars, however, have been observed to preserve such an atmosphere even today. On Earth, there was a further change as a result of photosynthesis. Oxygen was produced by green algae (cyanobacteria). Carbon dioxide got fixed in photosynthetic algae and carbonate rocks. Oxygen content which was originally nil or present only in minor amount in the atmosphere steadily increased through time. Oxygen and nitrogen, it should be remembered, form 99 per cent of the present day atmosphere. Biological activity, therefore, played a decisive role in the build up of oxygen in the atmosphere on Earth. No other planet in the Solar System has either free water or free oxygen in their atmosphere except the Earth. The formation of oxygen-rich atmosphere is a landmark in the history of the planet Earth, as it formed the starting point for the diversification of life forms.

The rock record confirms many of these changes. The lack of oxygen in the early atmosphere is supported by the occurrence of fresh unaltered grains of uraninite and pyrite in the oldest conglomerates of the Archaean (~ 3,000 m.y.). The beginning of life and the first release of oxygen is documented by the deposition of banded iron formation rich in oxide minerals of iron. The steady increase of oxygen in the atmosphere and the onset of processes of oxidation and weathering is confirmed by the first appearance of continental red beds around 2,000 m.y. ago.

EVOLUTION OF THE HYDROSPHERE

We have already noted that the first billion years of Earth's existence witnessed profuse degassing of water vapour from the earth's interior. This vapour condensed and poured out as rain on Earth's surface and collected to form the first water bodies on Earth. There were no real oceans to start with but only shallow warm seas developed around hydrothermal vents. Whether this happened gradually as a result of continuous volcanic outgassing or whether it was sudden and catastrophic, happening at an early stage in the history of the earth, is not clear. The oceans are believed to have reached their present volume 2,000 m.y. ago and since then there has not been much of a change. The early seas were probably more acidic because of dissolved carbon dioxide.

OUR OLDEST ROCKS

Although the age of the earth is put down at 4,500 m.y. on the basis of radiometric data, oldest rocks so far identified on earth do not go beyond 3,800 m.y. Such old rocks are extremely rare. They were till recently known only from Greenland (Moorbath *et al.*, 1973), but several occurrences have come to light in recent years. Rock strata described as Older Metamorphics in the Singhbhum region of Bihar (India) may prove to be still older, as the gneisses intruding them have given an age of 3,800 m.y. (Basu *et al.*, 1981). It is claimed that unpublished work in progress is indicative of rocks of still older ages existing in the Dharwar Craton of Peninsular India (Monrad *et al.*, 1982). The Indian Precambrian shield, therefore, may prove to be one of the oldest continental fragments of the world.

The oldest dated rock in South India is a migmatitic gneiss giving an age of 3,358 ± 66 m.y. (Beckinsale *et al.*, 1980). These gneisses are intrusive into still older sediments including graphitic schists originally of the nature of carbonaceous shales to which the name 'Sargur Supracrustals' has been given (Swami Nath & Ramakrishna). No direct estimation of the age of the sediments has yet been made. They are in all probability older than 3,400 m.y.

There have been recently claims of still older ages of 4,200 m.y. for zircon grains in a 3,100 m.y. old gneisses from Pilbara, Western Australia (Froude *et al.*, 1983). These older ages, however, have not been accepted (Moorbath, 1983; Sharer & Allegre, 1985). Rocks dated at 3,800 m.y., therefore, are the oldest so far known and it has not been possible to extend earth history, as recorded in rocks, beyond 3,800 m.y. The search for identifying still older rocks, however, will continue, but the success ratio is going to be limited. So far as geological record is concerned the first billion years (the missing billion), remains blank and evidence of what happened during this period probably has to be pieced together from a study of other planets.

CONDITIONS 3,800 m.y. AGO AS REVEALED BY THE ROCK RECORD

Prior to 4,000 m.y. ago we may presume that conditions on earth were not particularly hospitable to life. The temperature was high. There was neither atmosphere nor hydrosphere.

The study of oldest known sediments indicates the existence of shallow oceans. Continental masses at that period were probably very few. Processes of erosion, transport and deposition had no doubt set in, and deposition of clastic and chemical sediments had just started. The atmosphere was deficient in oxygen and particularly enriched in carbon dioxide and nitrogen. Volcanism was active with release of abundant gases. The landscape was studded with volcanoes belching smoke and lava. The seas were warm and acidic. Sediments that were being deposited were mostly immature mixtures of crustal and volcanic material. These were the conditions under which life on earth appears to have made its beginning.

LIFE IN OUTER SPACE—COSMIC ORIGIN OF LIFE?

Carbonaceous meteorites are known to contain not only amorphous carbon but also various hydrocarbons. The earth too must have contained hydrocarbons from the very beginning and could have formed the basic material for the origin of life.

Modern thinking appears to be in favour of considering the origin of life as involving a lengthy process of chemical evolution which first generated simple organic compounds in the early atmosphere. These primary products became increasingly complex culminating in the evolution of polymeric structure, i.e. number of repeated basic units held together by chemical bonds having capabilities of self-replication (Chang *et al.*, 1983). Chemical evolution is thus believed to have preceded biologic evolution. The energy available for promoting these chemical reactions was probably that provided by sunlight, electric discharges, thunder and lightening. Proteins and nucleic acids must have been synthesized in such an environment. Such transformation probably took place in the atmosphere and the seas of that period and in their boundary with the land surface. The preservation of abundant carbonaceous material in earliest Archaean sediments lends support to this view. Organic matter thus started gathering and accumulated in the shallow oceans of that period. Life appears to have got cooked in such a primitive broth of organic compounds (Sylvester Bradley, 1972).

The idea that life originated in outer space is now being put forward forcefully. Hoyle and Wickramsinghe (1986) have projected the idea that a swarm of comet-like bodies were present towards the outer margins of the Solar System in its early history and were the sites of early biological replication. They feel that such bodies are more favourable venues for the development of life than the initially sterile surface of a small planet like the earth. Following this idea, they predicted that dust expelled from Halley comet would be organic in composition. Surprisingly, astronomers have reported material from comet Halley which looks organic like coaltar. Since Earth is perpetually embedded in a halo of cometary material, bacteria from outer space could have landed softly on earth without being destroyed by heat. These observations add a new dimension to the origin of early life.

HOW DID LIFE ORIGINATE 3,800 m.y. AGO

While there may be organic particles of carbon and hydrocarbons in other planets and in space, it is only on earth structures which have the capacity to replicate and transmit genetic characteristics to their descendents are found. The initial life forms were microscopic, mostly unicellular, in the form of minute spheres probably indistinguishable from carbon particles of non-biological origin (Schopf, 1978).

Microscopic carbonaceous objects resembling filamentous bacteria have now been found in a chert barite unit from North Pole, western Australia (Groves *et al.*, 1981). These are undoubtedly fossils, but it has not been possible to definitely prove that they were original and not contaminants. After five years of intense searching, the authors have admitted of their failure to discover more reliable evidence of life at North Pole. They do not deny that life existed before 3,500 m.y. ago but affirm that unequivocal evidence of its existence has probably not been preserved.

A recent discovery of some importance is the identification of giant clams at a depth of 5,640 m on the steep inner wall of the Japanese trench. Similar clams have been noted close to hot springs. This is very significant as it points to development of ecosystems on geothermal rather than on solar energy (Jennesch & Mottl, 1985). This lends support to the hypothesis that early life probably originated first near hydrothermal vents.

The division between life and non-life is stated to be an artificial one. According to Ponnamperuma the animate and inanimate are to be seen as lying in a continuum rather than as being one or the other. On such a scale, a virus which cannot replicate on its own would be somewhere near the middle as might some unknown proto cell that became the ancestor of life on earth.'

Growing crystals of clay are stated to have formed the first replicating evolving systems and ushered in the age of organic cells. The earliest known organisms are considered by Schopf to be similar to the type of bacteria known today—blue green algae, that unlike other bacteria produce oxygen through photosynthesis.

According to Margulis, the story of life on earth is overwhelmingly a story of bacteria, microscopic cells that lack nuclei. For two billion years, i.e. more than half the time that life has been on earth, the bacteria or prokaryotes had the planet to themselves. They altered the atmosphere and evolved all of life's miniaturised chemical systems—achievements that so far humanity has not approached.

THE NATURE OF THE EARLY LIFE FORMS

Schopf (1983) a leading palaeobiologist of the present day speculates that early life inhabited an aqueous and presumably benthonic environment, the muds and silts of bottom sediments beneath wave base where organic detritus could accumulate. The early life forms were morphologically simple, undifferentiated, non-mobile, non-colonial and presumably spheroid organisms. It is one of the marvels of nature that the diversity of life forms of the present day started from such humble beginnings. All life on earth, from bacteria to the banyan tree, or even man, evolved originally from a single ancestral cell!

STROMATOLITES

Stromatolites are organo-sedimentary structures produced by the trapping of sediments by metabolic activity of micro-organisms. They thus represent the only undisputed fossils in Archaean rocks (Walter, 1983; Krumbein, 1983). Their first appearance in the geological record is a pointer to the presence of photosynthetic bacteria. They are not regular fossil organisms but are related to the algae in the same way as coral reefs are related to coral organisms. Surrounding environment had a significant role to play in the growth of stromatolitic structure. A number of varieties are now recognised such as mound-shaped stromatolites, branched columnar stromatolites (Baicalia) and conically laminated stromatolites (Conophyton). These have formed in a variety of depositional settings and provide an opportunity for studying palaeoenvironmental conditions and identifying ancient shore lines.

Stromatolitic structures were first identified in the Proterozoic Vindhyan rocks as early as 1872 (King, 1872, p. 164). The algal character of such structure was pointed out by Srinivasa Rao (1943). A list of earlier references to stromatolitic structure in the Proterozoic of India is given by Raha and Sastry (1982). Reports of Archaean stromatolites, however, are rare. Rarity of these structures is attributed to their obliteration through metamorphism.

Many more structures are likely to be identified in the coming years through careful field work. These stromatolites, when identified, have to be subjected to a careful study of their microbiota, since it is the microbe community which generated layered, domed and columnar structures so characteristic of stromatolites. Such studies are likely to provide valuable clues to the early evolution of life forms and to the mode of their preservation.

The Late Archaean and Early Proterozoic witnessed a change from a mobile environment to one of stable platforms in which bulk deposition of carbonate sequences became possible. These carbonates appear to have favoured the development of stromatolites. There was at that time a marked invasion and perhaps more effective utilization of such an environment (Walter, 1976). Stromatolitic structures have been found to be ubiquitous components of carbonate facies environments throughout the world (Schopf & Walter, 1983). A gradual but marked increase in mean diameter and size range and taxonomic diversity has been noticed during the Proterozoic (Schopf, 1977).

Russian geologists have made extensive studies and have used stromatolites to classify the Late Proterozoic and erect stromatolite biostratigraphy. Raha and Sastry (1982) have made a preliminary attempt in this direction for the Proterozoic sequences in India. Study of stromatolites, their morphology, morphogenesis and microbiology should, however, gain in momentum in this country. The need for improving descriptive methods and making use of numerical techniques has to be emphasized. Significant changes in microfossil assemblages have been noted at boundaries between Early, Middle and Late Proterozoic. Stromatolites of differing ages were probably formed by distinctively differing microbiota and could be stratigraphically useful. The Proterozoic sedimentary basins of India contain a rich harvest of stromatolites awaiting detailed examination. For a country of the size of India and with such abundant material available, there are very few palaeontologists who are interested in the study of early life, compared to the large number of geochemists, structural geologists and the like.

ARCHAEAN MICROBIOTA

There have been several sporadic attempts at identifying microfossils in rocks of Archaean age. Most of these finds on critical examination have been found to be not genuine. Schopf and Walter (1983) have formulated a set of criteria which have to be satisfied before the authenticity of Archaean microfossils can be accepted. These are:

Geological age—That the rocks containing microfossils are to be precisely dated and shown to be Archaean in age.

Syngenetic character—That the fossil-like objects are demonstrably syngenetic, physically imbedded in the rock and not extraneously induced contaminants.

Biogenicity—That the fossils are actually biogenic and not laboratory produced artifacts.

The last criterion is the most difficult to satisfy since a wide variety of non-biologic objects can imitate biologic microbiota. Cloud (1973) and Schopf (1975) are of the opinion that the bulk of the Precambrian microfossils are either artifacts of non-biologic origin or recent bacterial contaminants. Only two occurrences have so far been accepted as satisfying the above criteria: (i) microbiota from bedded stromatolitic cherts of the 3,500 m.y. old Warrawoona Group, Pilbara Block of Western Australia (Walter *et al.*, 1980), and (ii) the 2,800 m.y. old Fortescue Group of Hamersley Basin, also in Western Australia.

The Warrawoona microfossils, as described, are structurally complex, more advanced and indicate that the beginnings of life on earth must have occurred very much earlier. Recently well-preserved stromatolites from 3,300 to 3,500 m.y. old rocks in chert layers within the Fig Tree Group of Swaziland Supergroup in South Africa have been reported (Byerley *et al.*, 1986), which are morphologically complex but biogenically convincing. They are stated to be morphologically advanced. They are described as stratiform growing on a substrate of komatiitic lava and sediments deposited on the lava surface and covered by later komatiitic flows. Abundant fine-grained tourmaline included in the fine-grained laminae is suggestive of an environment dominated by boron-rich hot spring emissions and evaporite brines. Chert layers in between komatiitic flows elsewhere, should be carefully searched for stromatolite structure and Archaean microbiota. It is conjectured that life when it first appeared diversified rapidly and in all probability explored and occupied most, if not all, habitable ecological zones (Awramik, 1986).

We in India have to give more attention to the study of Archaean microbiota. Exposures are in no way inferior to those of Western Australia and South Africa. There is scope for making important discoveries in the older rocks after taking all due precautions.

CHRONOLOGY OF THE BEGINNINGS OF LIFE

Evidence from the geological record points to the presence of spheroidal prokaryotes as the earliest forms of life. Their energy requirement was probably met by fermentation of organic material of non-biologic origin—a stage reached during chemical evolution. Oxygen producing photosynthetic cells probably appeared earlier than 3,000 m.y. ago. These are believed to have lived in mat-like communities in shallow water and gave rise to the first stromatolite columns.

Filamentous fossil bacteria have been identified in thin sections of the laminated carbonate cherts from the Fortescue Group, Western Australia (Awramik *et al.*, 1983). These are claimed, as of today, the oldest undoubted fossils known in the geological record. The complexity of these forms indicates that life must have appeared much earlier.

The oldest stromatolites reported from India are those from the Karnataka (Dharwar) Craton. One is from Sandur (Murthy & Krishna Reddy, 1984) and the other from Dodguni by Boral (1986). Suresh (1982) has reported microfossils from Dodguni cherts.

The rate of change of biota during the first 1,000 to 1,500 m.y., after the first appearance of life was so slow that not much of a change in evolutionary pattern is noticed. Since 1,500 m.y. however, evolutionary changes have been rapid leading to increased taxonomic diversity (Schopf, 1975). Characterization of the fossil record in the period of approximately 900 m.y. prior to Cambrian time, and its ordering into biochronologic sequence is going to be a major challenge to palaeontologists in the comming years (James, 1981).

Schopf (1978) says that the style and tempo of evolution in the Precambrian was distinctly different from that of the later Phanerozoic era. The Precambrian was an age in which the dominant organisms were microscopic and prokaryotic, and until near the end of the era, the ratio of evolutionary change was limited by the absence of advanced sexual reproduction. It was an age in which the bench-marks in the history of life were the result of biochemical and metabolic innovations rather than morphological changes.

MAJOR STEPS IN THE EVOLUTION OF LIFE

Eight major steps have been recognised in the early evolution of life (Cloud, 1983). These are:

1. Origin of life around 3,800 m.y. ago.
2. Appearance of first stromatolites pointing to the

existence of some type of microbial life forms around hydrothermal vents feeding on sulphur (> 3,500 m.y. ago).

3. Photosynthesis: Further development of stromatolites, precursors of blue-green algae, producing molecular oxygen as a result of photosynthesis (3,000 m.y. ago).
4. Appearance of enlarged cells and oxygen tolerating blue-green algae. Continental red beds pointing to presence of free oxygen in the atmosphere (2,000 m.y. ago).
5. Eukaryotic cells: Development of larger cells with nucleus (1,400 m.y. ago).
6. Appearance of Metazoa: Ediacara fauna—first appearance of multicellular aquatic animals.
7. Appearance of metazoa with shells—dawn of the Cambrian (550 m.y. ago).
8. Fully oxic conditions (100%)—the first appearance of fish and land plants. Biospheric evolution to the present day world—life filling almost all parts of the planet. It should be noted that in the first two stages oxygen was deficient. There was a gradual build up in oxygen content in atmosphere from 1 per cent around 3,000 m.y. ago to 100 per cent by 500 m.y. ago.

ECONOMIC IMPORTANCE OF PALAEOBIOLOGICAL STUDIES

Petroleum exploration—The study of palaeobiology is not without economic interest. For example, it has an important bearing on petroleum exploration. Kerogen is a geochemically altered organic matter present in sedimentary rocks formed millions of years ago. It is conjectured that oil or gas originated from kerogen. Petroleum is found in source beds which contained organic matter and the oil later migrated to reservoir rocks. The attention of petroleum geologists has been concentrated mostly on reservoir rocks and little attention has been given to the study of organic matter in source rocks. Organic matter has now been traced to the most ancient rocks. It is but right, therefore that attention should be turned to the study of life forms trapped in the oldest rocks and trace the changes in composition that have occurred as a function of time and temperature.

Petroleum source rocks have now been identified in the Precambrian of McArthur Basin, North Australia ranging in age from 1,400 to 1,700 m.y. (Jackson *et al.*, 1986). The rock types consist of stromatolitic and evaporitic carbonates and inter-bedded carbonaceous shales. Because of their low degree of thermal alteration they provide a valuable resource for the study of primitive biota. The hydrocarbon composition of the oil in these strata is stated to be consistent with a derivation from organic matter of prokaryotic origin. This opens up possibilities of striking oil in middle Proterozoic sediments so well represented in the sedimentary basins of India.

Another interesting development may be noted. Liquid oil has now been reported or trapped in fluid inclusions in calcite veins cutting across a cupriferous shale deposit at White Pine, Michigan (Kelley & Nishioka, 1985). Oil is known to have impregnated all rock types. The hydrocarbon content of None such shales is stated to be similar to those of Phanerozoic source rocks. A Precambrian age and indigenous origin is ascribed for the oil on the basis of chemical similarity. These are stray evidences, no doubt, but indicate biological activity in Precambrian leading to the production of hydrocarbons similar to those formed in more recent sediments.

Mention should be made here of the other extreme view held by Gold (1980, 1982) and some of the Russian geologists challenging the 'fossil fuel' theory and holding to the belief that hydrocarbon gases are abiogenic in origin, produced through the hydrolysis of metal carbides trapped in the Earth's mantle (Zvi Sofar, 1985). According to these authors gas is being formed in other planets and that primordial materials cooking near the planets cores have slowly seeped upward through cracks in the crust. Important accumulations of oil, according to them, can accumulate in regions of continental faulting. Very little is known about this aspect yet. A 3 to 5 km deep hole is being drilled by the Swedish Power Board to test whether abiogenic methane is being expelled from the mantle to produce gas fields where satisfactory cap rocks exist. Some of the test wells drilled have indeed showed evidences of the presence of methane. Progress on this subject is being watched with interest.

Recent news reports (The Times, London, 17th September 1986) point to the discovery of solid methane hydrate (a bluish ice-like substance)—a new kind of gas deposit, in some of the deep holes being drilled in the Arctic. The methane hydrate is described as a chemically bound mixture of methane gas and water that occur as vast sheets or lenses. It is stable when cold but readily decomposes on warming. A cubic yard of hydrate is stated to be capable of yielding 5,000 cubic feet of natural gas. This will be a new energy source for the future.

In these matters it would appear not wise to be over conservative and blind to understanding of what still remains unknown. If what Gold predicted comes true, the implications are startling. We can then expect huge gas reserves in regions affected by deep crustal faults. Regions which are presumably written off now as barren of oil may prove to be rich. The importance of carrying out research in this field at once becomes apparent (Radhakrishna, 1984).

MICROORGANISMS AND HEAVY METAL CONCENTRATION

Study of the metal content of living organisms of almost all types shows large concentration factors for a very wide range of metals. Microorganisms are known to interact with heavy metals and play an active part in the mobilization, transportation and deposition of metals like gold, uranium and iron The Precambrian is known for its rich accumulation of gold, uranium and iron in stratified deposits. Fossils of earliest living forms have been traced in rocks formed just before the deposition of iron formations. The appearance of stromatolites in the geological record is indicative of the presence of oxygen producing cyanobacteria and the dominant role played by them in the deposition of iron. An array of organisms are now known to precipitate minerals (Lowenstem, 1980). The processes by which biological heavy metal transfer, transportation and accumulation can take place has recently been reviewed by Dexter Dyer *et al.* (1984). Biological processes presumably have played a major role in differential enrichment of specific metals. Gold contained in trace amounts in volcanic rocks of komatiitic composition which dominated in the Archaean was removed in solution during the weathering process. Its precipitation close to the edge of the sedimentary basin of deposition was aided by biological activity (Reimer, 1984). Degradation of organic matter, has been shown to dissolve gold, enrich it in the biological system and redeposit in a concentrated form. Similarly, uranium concentration in sediments has been shown to be related to biological activity. Experiments continue to be conducted to test enrichment of uranium by micro-organisms as a method of concentrating it from low-grade ores. These experiments are expected to throw new light on the origin of uranium deposits and open up new pathways for exploration.

FUTURE STUDIES

Although not a palaeontologist, you will pardon me if I venture to make a few suggestions regarding the direction in which future studies should be pursued. First and foremost, interest in palaeontological studies has to be revived. The weakest section in many of our university geology departments is the Palaeontology wing and suffers both from want of qualified men and equipment. These should be strengthened and young intelligent scholars attracted to join. We have some of the largest sedimentary basins in India ranging in age from 3,000 m.y. to the present. A careful search in the older sedimentary basins is sure to reveal a whole range of fossil remains to reconstruct the early history of life on earth.

Study of microbiota from stromatolitic structures is likely to show local peculiarities and some apparent evolutionary trends which can be made use of in stratigraphic correlations. More concentrated search for stromatolites especially in rocks older than 2,500 m.y. should be undertaken.

Carbon isotopic ratios have indicated the biological nature of carbon in ancient sediments as old as 3,800 m.y. These sediments should be searched for evidence of primitive life forms.

Unmetamorphosed banded iron formations and associated cherts require to be more intensively studied. The relation of photosynthetic oxygen to the deposition of banded iron formation should be evaluated. The following major biological innovations have been identified: (i) origin of life (> 3,800 m.y. ago), (ii) bacterial photosynthesis (> 3,400 m.y. ago), (iii) appearance of eukaryotes (2,000 to 1,300 m.y. ago), and (iv) dawn of Metazoa (~ 600 m.y. ago). Evidences in support of this chronology from the Indian geological record have to be collected. There should be sustained search for evidence of fossil remains in our oldest rocks. In my opinion two specialist groups should be constituted, one for Archaean microbiota and the other for the stromatolites of Proterozoic.

Micropalaeontological study of the Precambrian is one of the most rapidly developing branches of current research. Such studies have yet to gain in tempo in India. This Institute which bears the honoured name of Professor Birbal Sahni should specialise in all inter-disciplinary studies in which Biology and Earth Sciences are concerned and give a lead to micropalaeontological research in the country. Sedimentologists, geochronologists, geochemists, palaeontologists, organic chemists and molecular biologists should shift their attention to the Archaean-Proterozoic record. They should together make a supreme effort at understanding the process of early evolution of biological system on Earth.

There is still a long way to go in solving the mystery of the origin of life. The emergence of life we have seen is only one stage in the larger history of cosmic changes and the result of constant assembly of matter since it was created with a big bang. The broad goal is to arrive at an intellectually satisfying account of how living forms emerged step by step from inanimate matter (Dickenson, 1978).

There emerges from these studies an increasing awareness of the supreme truth embodied in our ancient texts—*the Upanishads* that there is a thread which runs through all things and holds them together and that the universe is the result of a gradual unfolding of the creative power inherent in the primordial substance.

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