



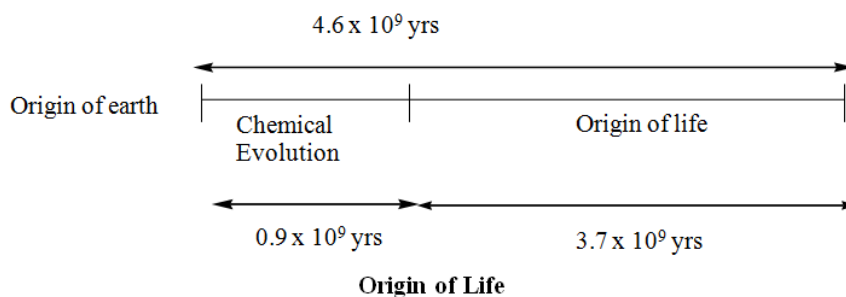
Chemical Evolution and Origin of Life: A Review

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ABSTRACT



Life has evolved approximately 3.7 billion years ago on Earth while the Earth itself was formed some 4.6 billion years ago. So it was the time of 0.9 billion years in which chemical reactions took place and formation of first living cell occurred. There are various views on origin of life. This review discusses and compares these theories with respect to chemical evolution and origin of life.

Keywords: Chemical evolution, Origin of life, metal oxides, clay, cyano complexes

INTRODUCTION

"If it were given to me to look beyond the abyss of geologically recorded time ... I should expect to be a witness of the evolution of living protoplasm from non living matter ... I should expect to see it appear under forms of great simplicity, endowed ... with the power of determining the formation of new protoplasm from such matters as ammonium carbonates, oxalates and tartrates, alkaline and earthy phosphates, and water, without the aid of light". In these words Thomas Huxley saw the emergence of life from simple prebiotic materials" (Huxley 1870).¹

Different viewpoints, many with deep philosophical and historical roots, have shaped the scientific study of the origin of life. Some of these argue that primeval life was based on simple anaerobic microorganisms able to use a wide inventory of abiotic organic materials (i.e., a heterotrophic origin), whereas, others involve a more sophisticated organization, one that thrived on simple inorganic molecules (i.e., an autotrophic origin). While many scientists assume that life started as a self-replicative molecule, the first gene, a primitive self-catalytic metabolic network has also been proposed as a starting point. Deducing the mechanism of the origin of life on Earth has always remained a fascinating but unsolved puzzle. Some have even considered it too difficult for scientific study, because the direct evidence is long gone and we can only work by plausible inference. Although this is indeed a very difficult problem to approach experimentally. A number of striking observations over the years have allowed the formulation of plausible scenarios for the prebiotic synthesis of various important biomolecules. During the last 50 years a lot of work has been done and it is resulted that life on the Earth must have evolved through a number of chemical reactions, which took place on

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the Earth. The complexity of the reactions was raised step by step leading to the formation of more complex materials, which produced the first living cell on the Earth. Many biomolecules were needed to make up the first autocatalytic biochemical pathways and the first living cell. At the beginning of chemical evolution these biomolecules must have been available to interact and chemically evolve. It is of great importance for the understanding of our basic roots to know or to have at least credible theoretical and experimental indications how this path of chemical evolution might have started. Besides the considerations that life evolved on the Earth, scientists also believe that the life evolved somewhere else outside our planet in the space. A number of experiments are being conducted under simulated atmosphere of several planets and their moons.²⁻⁵ Kobayashi⁶ has discussed chemical evolution and origin of biological system in the universe. Delaye et al.⁷ has discussed about the leap from biochemical monomers and small oligomers to living cells. Lazcano⁸ has discussed about the early evolution of Life, prebiotic chemistry, the pre-RNA world, and time.

The process by which all these chemical reactions had given the life on Earth is known as Chemical Evolution. The ocean received organic matter from the land and the atmosphere, as well as from infalling meteorites and comets. Substances such as water, carbon dioxide, methane, and hydrogen cyanide formed key molecules such as sugars, amino acids, and nucleotides. Such molecules are the building blocks of proteins and nucleic acids, compounds ubiquitous to all living organisms. A critical early triumph was the development of RNA and DNA molecules, which directed biological processes and preserved life's "operation instructions" for future generations. These helices formed some of the living threads, however, other threads derived from planetary processes such as ocean chemistry and volcanic activity. This evolving bundle of threads thus arose from a variety of sources, illustrating that the origin of life was triggered not only by special molecules such as RNA or DNA, but also by the chemical and physical properties of the Earth's primitive environments. Ever since the historical contributions by Aleksandr I. Oparin, in the 1920s, the intellectual challenge of the origin of life enigma has unfolded based on the assumption that life originated on Earth through physicochemical processes that can be supposed, comprehended, and simulated; that is, there were neither miracles nor spontaneous generations. Haldane (1929) and Oparin (1953) proposed that the early ocean was a prebiotic soup, a rich diversity of organic and inorganic compounds for assembly into more complex precursors of true life forms. Miller and Urey addressed this by subjecting a mixture of ammonia, methane, hydrogen and water to heat and electric discharge, and saw the production of hydrogen cyanide; aldehydes and amino acids.⁹ These can be further converted to nucleotide bases (from HCN and methane) and sugars (from HCHO).¹⁰⁻¹³ In turn, polymerization can generate polypeptides and, notably, polynucleotides.¹⁰

THE PRIMITIVE EARTH

Once the level of meteoric bombardment had dropped and the rapid cooling process to form the Earth's crust was complete (ca. 4.0×10^9 years ago) it is proposed that bodies of water were formed and organic chemistry became established. The oldest known fossils date back to ca. 3.6×10^9 years ago and show resemblance to modern blue-green algae. The complex translational apparatus found in these organisms suggests that by this time cellular life must have already been well established. Biogenesis from organic chemistry to a primitive cell must therefore have occurred in the relatively small time (at least in the geological sense) of 0.4×10^9 years. On the basis of theoretical and experimental considerations, scientists have proposed the early oceans as probable starting place of life on Earth. One of the considerations strongly supporting the early oceans as primeval locale for chemical evolution is that organic compounds, once formed and settled in the ocean were protected from their degradation due to strong ultraviolet light on primitive Earth. In addition to the above consideration, the hypothesis of chemical evolution in the primeval seas is more favorable because the seas would have provided the wealth of catalytic surfaces consisting of inorganic minerals, source of transportation and mixing of intermediate products. The different steps of chemical evolution through which life has originated on Earth, right from the formation of Earth core and primitive Earth's atmosphere may be summarized as follows. The first step involved the formation of core and primitive atmosphere. The red – hot ($5000 - 6000^\circ\text{C}$) gaseous cloud consists of innumerable free atoms of several elements (such as hydrogen, oxygen, carbon, nitrogen, sulphur and phosphorous etc.) began to rotate. As the rotation, gravitation and heat of this cloud slowly lost, the atoms of this cloud segregated and heat of this cloud slowly lost, the atoms of this cloud segregated into three concentric masses depending upon their atomic weights. The heaviest metallic atoms (Fe, Ni, Cu etc) collected in the centre and formed hot lava on the core of future Earth. Medium weight atoms (Na, K, Si, I, Mg, Cl, F, S, Al, P, etc.) formed lithosphere in later stage. The light atomic weight atoms (N, H, O, Ar, C etc.) formed the primitive atmosphere which was highly reducing because of hydrogen atoms were numerous and most reactive.

The second step involved the origin of molecules and inorganic compounds. Numerous atoms of primitive atmosphere were spread in the space due to high temperature but as the temperature gradually decreased, these free atoms combined to form molecules of same elements (H_2 , N_2 , O_2 etc) and as well as of different elements giving rise to simple inorganic compounds. Later on these molecules condensed into solid matter forming hard lithosphere. Combining of H with O and N produced H_2O and NH_3 , respectively, which were probably the first inorganic compound formed on the primitive Earth.

The third step of the hypothesis describes the evolution of organic compounds. The hard lithosphere was studded with actively erupting volcano's as a result of which hot metal lava of the core was poured with gases like CO_2 , CO, N_2 and H_2 etc. and thus metallic atoms of lava could form their carbides and

nitrides which later formed the crust of the Earth. Hot water vapors reacted with metallic carbides and nitrides to form simplest compounds such as CH₄ and NH₃, respectively. Both the CH₄ and NH₃ under prebiotic environment could have formed HCN. As the temperature fall down, the water vapors came down upon lithosphere as torrential rains, but it turned into vapors as soon as it touched the hot ground. Again there became such torrential rain which evaporated further from hot ground. The process was continued for million years. As the Earth cooled down below 100°C, it holds the rain water and it was emerged in vast primitive oceans. The oceanic water contained large amount of NH₃, CH₄, HCN, nitrides, carbides and various gasses and elements which could freely moved and colloid to form complex molecules. Methane like saturated hydrocarbons, ethylene and acetylene on further reaction could have formed aldehyde, ketones, alcohols and organic acids at later stage. Using the energies of UV – rays of sunlight, electricity of thunderstorms during the rains and heat of volcanic eruptions, the various organic molecules present in the oceanic water continued becoming more and more complex molecules like amino acids, sugars, fatty acids and nitrogenous organic bases etc. Since the atmosphere was reducing in nature these complex molecules could not be oxidized but they continued further reaction and ultimately they polymerized forming large linear polymers or macromolecules such as proteins, carbohydrate and fats, which are the main constituents of protoplasm. At the same stage of chemical evolution the oceanic water was rich in these organic polymers and formed a soup of organic compounds.

The fourth step involved the formation of colloids and coacervates. Oceanic macromolecules having full freedom of movement and collisions, formed small cell like colloid sphere in the form of insoluble droplets. Due to being charged and viscous, minute water drops used to stick their surfaces.

Fifth step describes the origin of autocatalytic systems, genes and primordial life. In the due time nucleic acids (deoxyribose nucleic and ribose nucleic acids) gradually evolved in primitive oceans. Nucleotides formed in the primitive oceanic water by the combination of nitrogenous organic bases with pentose sugars and phosphoric acid.

Under similar conditions as that of primitive atmosphere researches are going on to trace the pathways of chemical evolution. Scientists have performed reactions taking the same environment and they have got good results showing the synthesis of various biomonomers from simpler starting material. Some of the important experiments done in the field have been summarized here in brief.

Urey and Miller⁹, pioneer in the field of origin of life performed an experiment and synthesized a series of amino acids by electric discharge in an atmosphere of NH₃, CH₄ and H₂O and they confirmed formation of almost forty organic molecules. Harada and Fox¹⁰ synthesized natural amino acids from HCN under primitive atmospheric conditions. Gabel¹¹ reported the synthesis of monosaccharide from formaldehyde. Oro synthesized the purines and pyrimidines from HCN.¹²⁻¹³ Ponnamperna et al.¹⁴ was able to synthesize adenine by

electron irradiation of methane, ammonia and water. Palm and Calvin¹⁵ proposed that molecules like amino acids, purines, pyrimidines and pentose sugar formed on the primitive Earth were readily available for further transformation during the course of chemical evolution.

It is now believed that a number of biomonomers such as amino acids, nucleotides and pentose sugars could have formed their dilute aqueous solutions in primeval seas. The biomonomers produced biopolymers as a result of several reactions such as condensation, oligomerization, polymerization and redox reactions etc. Before such reactions to take place, the biomonomers must had to be concentrated from their dilute aqueous solutions so that they might have come closer. Thus the means through which biomonomers could have concentrated from their dilute aqueous solutions in primeval seas seems to be the key steps for further prebiotic synthesis in primeval seas, but it is not well established as how the biomonomers might have concentrated from dilute aqueous solutions and polymerized to give large complex molecule. However, clay and clay minerals seem to have played important role in concentrating the biomonomers during the course of chemical evolution¹⁶⁻¹⁹. Biomonomers concentrated on the solid surfaces were transformed into biopolymers through a series of chemical reactions, which must have catalyzed by certain catalysts. Ferris and coworkers proposed clay and clay minerals as possible catalysts in prebiotic synthesis.²⁰⁻²⁶ Brack studied the catalytic activities of polypeptides. Perello et al.²⁷ correlated the catalytic activity of basic oligopeptides to form α -helix in water. Barbier and Brack²⁸ investigated the catalytic role of β -sheets of basic polypeptides in hydrolysis of oligoribonucleotides. Hydrolysis of ribonucleic acids have been catalyzed using polycationic polypeptides consists of arginine or lysin and hydrophobic amino acids.²⁹ Pelerin et al. proposed the basic peptides to be efficient in enhancing the rate of hydrolysis of ribonucleic acids.³⁰ Based on plausible early motif evolution and also on results from both biochemical and geological investigations, emphasizing the emergence of selected homopolymers as probably being significant intermediate stages between monomers and heteropolymers in connection with the origin of life, a tentative, detailed outline of a stepwise molecular origin and evolution of biological energy conservation, with emphasis on its early phosphate metabolism. Importance of inorganic phosphates as energy donor species has been studied³¹⁻³². Baltscheffsky studied the molecular origin and evolution of the metabolism of phosphate compounds, particularly proton-pumping inorganic pyrophosphatases which are directly involved in bioenergy conversion.³³ The role of radiation in origins of life has been discussed by Kobayashi.³⁴ Spark discharges, UV light (UV) and heat have been considered major energy sources. Formation of amino acids from mixtures of methanol, ammonia and water in various phases by γ -rays and UV irradiation were quantified. Formation and decomposition of organic compounds by ultraviolet light in simulated interstellar environments has also been discussed by Kobayashi et al.³⁵ Energy for the origin of life has been reviewed by Baltscheffsky et al.³⁶ Lazcano³⁷ has discussed about

the cosmic and primitive Earth environments, particularly those in which life is thought to have originated. Discussed are extraterrestrial organic syntheses in interstellar clouds, comets, and meteorites, the early evolution of the atmosphere together with the prebiotic formation of organic molecules essential to life, and the processes that led to the appearance of the 1st cells in the archaean Earth and the early evolution of biological systems. Oro et al.³⁸ has discussed the role of comets in origin of life in universe.

Almost all polymerization reactions took place under prebiotic conditions were of condensing type. Exact mechanism through which these biomonomers might have condensed under prebiotic conditions is still a matter of debate. But the following suggestions have been put to suggest the probable ways which might have taken place

1. Reaction conditions could have arisen in evaporating ponds.³⁹
2. Reactions could have taken place when biomonomers come in contact with suitable mineral surface.⁴⁰
3. Condensing agents could have been involved in condensation reactions under consideration.⁴¹

The condensation of biomonomers in presence of different metal clays, zirconium phosphate, activated carbon and condensing agents under fluctuating environment has been studied. It is described here in brief under following headings.

1. Fluctuating, clay water system
2. Role of condensing agents
3. Role of clays and clay minerals
4. Role of metal oxides

FLUCTUATING, CLAY - WATER SYSTEM

The importance of dynamic fluctuating environment in condensation process has been discussed.⁴²⁻⁴⁶ Lahav and Chang⁴⁷ have also examined the possible role of solid surfaces in prebiotic condensation process. The above studies suggest that the oligomerization reactions in ocean sediment systems were less favored in dehydrated systems but more favorable in fluctuating system. The fluctuating clay-water system involved the redistribution mechanism i.e., adsorbed oligomers and monomers were desorbed and redistributed on the solid surfaces during the next hydration – dehydration cycle. Fluctuating clay – water systems seem to be capable of dynamic interaction with simple precursors to form some oligomers of prebiotic relevance. Amino acids oligomerise in fluctuating clay – water system without any activated monomers, condensing agents and even at moderate temperature. Polymerization of amino acids in presence of kaolinite or bentonite under conditions of cyclic temperature fluctuations along with redissolution has been studied.⁴⁸ Reaction in presence of kaolinite yielded up to pentapeptide products. The polymerization of aspartic acid in presence of kaolinite at 90°C has been studied by Degan et al.⁴⁹ Reactions under redissolution condition showed better yield than temperature fluctuating condition alone. Clays and clay minerals concentrated the biomonomers through adsorption processes to initialize the proton exchange and to suppress the ionic repulsions. Montmorillonite clay catalyzed synthesis of RNA oligomers has been done by Ferris et al.⁵⁰ Reaction of

activated monomers of nucleotides in pH 8 aqueous solution containing Mg^{2+} in the presence of montmorillonite yields 6-14 mers. Sequence- and regio-selectivity in the montmorillonite-catalyzed synthesis of RNA has been studied by Ertem and Ferris.⁵¹ The six binary montmorillonite clay-catalyzed reactions of the 5'-phosphorimidazolides of adenosine, cytidine, guanosine and uridine were performed and the eight dimers from each reaction were separated and analyzed by HPLC. A 16-51-fold higher yield of the 5'-purine-pyrimidine dimers over that of the 5'-pyrimidine-purines was observed. The total yield of the 5'-purine-pyrimidine dimers was in the 50-70% range while that of the 5'-pyrimidine-purine dimers was 1.3-7.0%. The reaction takes place at the clay interlayer. The catalyst controls the synthesis of RNA oligomers in that a limited number of sequences are formed, there is control on the selectivity of phosphodiester bond formation and there is homochiral selectivity. Oligomers of length greater than 40 mers can be formed in reactions where the activated monomer is added daily to a primer. The need for catalysis in prebiotic synthesis is discussed (Figure 1). Methyladenine and adenine N-phosphoryl derivatives of adenosine 5'-monophosphate (5'-AMP) and uridine 5'-monophosphate (5'-UMP) are synthesized using clay and their structures are elucidated by Prabhakar and Ferris.⁵² The oligomerization of adenosine 5'-phosphoro-4-(dimethylamino)pyridinium (4-(CH_3)₂-NpypA) and diadenosine 5',5'-pyrophosphate (A5'ppA) (9:1) on Na(+)-montmorillonite has been studied by Ferris and Prabhakar.⁵³ Clay catalyzed oligonucleotide formation has been studied by Kawamura and Ferris.⁵⁴ Synthesis of RNA oligomers on heterogeneous templates has been done by Ertem and Ferris.⁵⁵ Oligomerization reactions of deoxyribonucleotides on montmorillonite clay has been studied by Ferris and Kamaluddin.⁵⁶

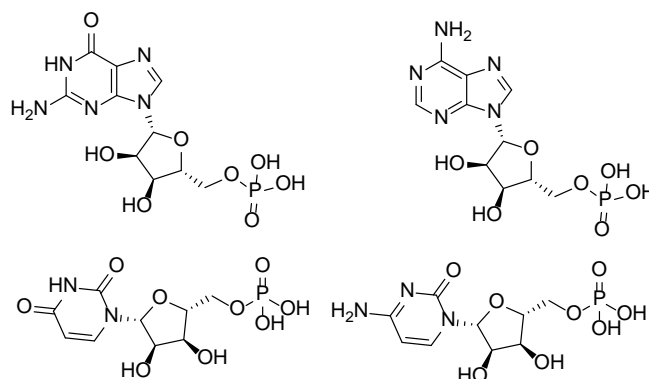


Figure 1: Various monomers present in primitive ponds

CONDENSING AGENTS

Polymerization of biomonomers into biopolymers involved the dehydration type condensation reactions which seem very unlikely to take place spontaneously in aqueous solutions as the solvent shifts the reaction equilibrium towards the reactants. But the experimental studies have shown that the coupling of dehydration reactions with condensing agents could have facilitated the biopolymerization in aqueous solution.

Biopolymers such as peptides, nucleosides, nucleotides have been synthesized in such coupled reactions using certain prebiotic condensing agents. Certain compounds have been proposed as efficient prebiotic condensing agents and some of them have been shown in figure 2:

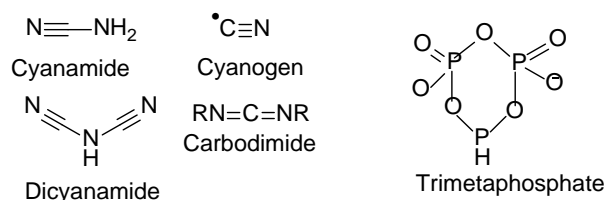


Figure 2. prebiotic condensing agents

Khurana⁵⁷ proposed the mechanism of condensation of amino acids using carbodimide as a condensing agent. Steps are given in figure 3.

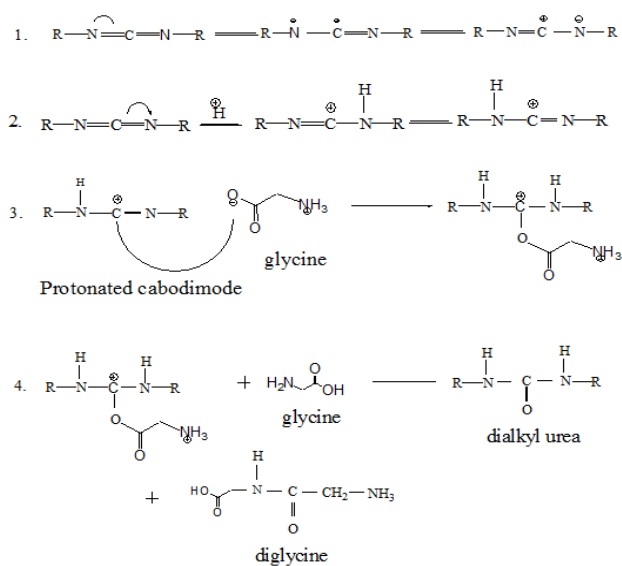


Figure 3

Yamanaka⁵⁸ proposed Trimetaphosphate in condensation of oligoglycines in aqueous solutions (Figure 4).

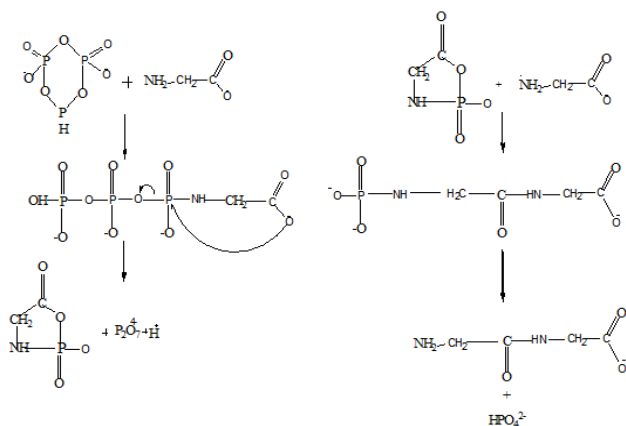


Figure 4: Trimetaphosphate in condensation of oligoglycines

Cyclization and dimerization of hexanucleotides containing guanine and cytosine with water-soluble carbodiimide has been done by Kawamura et al.⁵⁹ Amino acetonitrile has also been used as prebiotic condensing agent for dipeptide synthesis from amino acids.⁶⁰ Odom^{61,62} have studied the oligomerization of nucleotides in presence of kaolinite, ammonium chloride and cyanamide and suggested that cyanamide is only responsible in the condensation processes. Halmann⁶³ also used cyanamide as the condensing agent in formation of diglycine from glycine.

ROLE OF CLAYS IN CHEMICAL EVOLUTION

Clays are widely distributed on Earth surface. They have high surface area, strong affinity for organic compounds, specific distribution of surface charge, property to associate with exchangeable metal ions. Clays have strong adsorption capacity and are found to be good catalysts. Bernal⁶⁴ was the first to propose the role of clays and minerals in chemical evolution. Bernal proposed that clay minerals could have catalyzed the polymerization of biomonomers from their aqueous solutions and also a number of chemical reactions of prebiotic importance from which life could have evolved on the primitive Earth. Many researchers showed that the clay mineral in the process of chemical evolution adsorbed an organic compound, concentrated it and acted as a catalyst to synthesize an organic molecule from inorganic molecules and also to polymerize them.

According to the Bernal's hypothesis, clay minerals helped in chemical evolution in the following sequences:

- (i) Clay minerals could have catalyzed the synthesis of biomonomers from gases of primordial atmosphere
- (ii) Clay minerals adsorbed biomonomers formed on their surfaces providing a highly concentrated system having biomonomers in specific orientation
- (iii) Clay minerals facilitated condensation reactions between adsorbed biomonomers from biopolymers

Marco Franchi and Enzo Gallori studied possibility of development of the RNA world on a clay substrate by investigating the capacity of different RNA molecules adsorbed/bound on the clay minerals montmorillonite (M) and kaolinite (K) to persist in the presence of a degrading agent (RNase-A), to interact specifically with complementary RNA strands, and to transmit the information contained in their nucleotide sequences.⁶⁵ Oligomerization of the 5-phosphorimidazolide of uridine (ImpU) in the presence of montmorillonite clay has been also studied.⁶⁶ The role of catalysis in prebiotic synthesis is illustrated using the montmorillonite clay catalyzed synthesis of RNA oligomers.⁶⁷ Reaction of activated monomers of nucleotides in pH 8 aqueous solution containing Mg^{2+} in the presence of montmorillonite yields 6–14 mers. The reaction takes place at the clay interlayer. The catalyst controls the synthesis of RNA oligomers in that a limited number of sequences are formed. The catalytic efficiency in peptide bond formation of various clays has been tested.⁶⁸ Mg-rich trioctahedral clays hectorite smectite and talc are found to be most efficient catalysts. Juraj Bujdak studied the reaction conditions on montmorillonite-catalysed peptide

formation.⁶⁹ Clay catalyzed polymerization of amino acid adenylates has been discussed.⁷⁰ Role of metal ions in chemical evolution has been studied for the polymerization of alanine and glycine.⁷¹ Five proteinaceous and six nonproteinaceous amino acids were synthesized from a CH₄-N₂ atmosphere exposed to an electric discharge in the presence of Na⁺-montmorillonite in water. Glycine, DL-alanine, DL- α -aminobutyric acid, and sarcosine were the 4 major amino acids produced.⁷² The adsorption of protein and nonprotein amino acids by Na⁺-montmorillonite was studied at pH 3, 7, and 10. Five pairs of amino acids, containing 2-6 C atoms were used at concentrations equal to 100% of the clay cation exchange capacity. The following pairs of protein and nonprotein amino acids were used: glycine and sarcosine, α -alanine and β -alanine, α -aminobutyric and λ -aminobutyric acids, valine and norvaline, L-isoleucine and D-alloisoleucine. No selective adsorption of protein amino acids occurred at any H⁺ concentrations. Adsorption of β - and γ -amino acids was 3- and 4-fold greater, respectively, than that of α -amino acids under acidic and neutral conditions.⁷³ Peptides were formed from aspartic acid, glutamine, glycine, alanine, valine, isoleucine, leucine, phenylalanine, lysine, histidine, and arginine with a kaolinite or montmorillonite catalyst under fluctuating moisture conditions (dehydration followed by hydration) at temperatures below the b.p. of H₂O. The amino acid distribution of the peptides formed (apprx. 500-5000 Daltons) was close to that of natural peptide.⁷⁴ The adsorption of ATP and ADP on montmorillonite, kaolinite, and Al(OH)₃ was studied as a function of pH, and for montmorillonite and kaolinite, as a function of the ionic composition of the system. The three minerals exhibited different adsorption characteristics. Mg²⁺ and Zn²⁺ montmorillonite adsorbed ATP and ADP more than Na⁺ montmorillonite.⁷⁵ Clay-mediated oxidation of diaminomaleonitrile has been studied by Ferris and coworkers.⁷⁶

ROLE OF METAL-CYANOGEN COMPLEXES IN CHEMICAL EVOLUTION

Cyanide has been reported as an important product in almost all the simulated prebiotic experiments and is supposed to readily available under prebiotic environment. It is assumed that cyanide ions might have formed a number of soluble and insoluble complexes with transition metal ions present in primeval seas. So, a hypothesis has been proposed that cyano complexes had worked as catalyst in reactions of prebiotic importance. Orgel⁷⁷ have supported the formation of cyano complexes of transition metals, which could have played very important role in chemical evolution. Beck⁷⁸ proposed that cyanide ion which was presumably present on the prebiotic environment might have formed stable complexes with transition metals present in the primeval seas. Taking all these concepts in view, a number of metal cyano complexes have been tested for their role in chemical evolution. Interaction studies of nucleotides and amino acids with several of the cyano complexes have been studied by Kamaluddin et al.⁷⁹⁻⁸² Adsorption of adenine, adenosine, and adenosine nucleotides on nickel (II) hexacyanoferrate (II) has been studied by Viladkar et

al.⁸³ Adsorption of ribose and 2'-deoxyribose 5'-nucleotides on metal ferrocyanides has been studied by Kamaluddin et al.⁸⁴ and their role in chemical evolution has been discussed.

ROLE OF METAL OXIDES IN CHEMICAL EVOLUTION

As Bernal proposed the role of clays in chemical evolution, search of new solid surfaces and their possible involvement in chemical evolution also started. It is proposed that all substances which act as good adsorbent for organic molecules, could have helped in concentrating these organic molecules and subsequently helped in the formation of first cell.

Table 1: The Ten Most Abundant Compounds in the Earth's Crust

Compound	Formula	Abundance Percent/Weight	Abundance Parts per million by weight
Silicone dioxide	SiO ₂	42.86	428,600
Magnesium oxide	MgO	35.07	350,700
Ferrous oxide	FeO	8.97	89,700
Aluminium oxide	Al ₂ O ₃	6.99	69,900
Calcium oxide	CaO	4.37	43,700
Sodium oxide	Na ₂ O	0.45	4,500
Ferric oxide	Fe ₂ O ₃	0.36	3,600
Titanium dioxide	TiO ₂	0.33	3,300
Chromic oxide	Cr ₂ O ₃	0.18	1,800
Manganese dioxide	MnO ₂	0.14	1,400

Source: Exploring Chemical Elements and their Compounds; David L. Heiserman, 1992

Egami correlated the concentrations of minor transition metals with their biological behavior in primeval seas⁸⁵. It is proposed that transition metal ions abundantly present in primeval seas might have formed complexes with simple molecules readily available to them and had played crucial role in chemical evolution. Kobayashi studied the importance of transition metals in chemical evolution.⁸⁶⁻⁸⁸ Metal oxides constitute an important component of Earth crust and other planets. Hence their possibility of catalyzing different important reactions in the course of chemical evolution and origin of life cannot be ruled out. Alumina, Silica, Iron oxide, zinc oxide and a number of metal oxides are found to be present on different planets such as Mars. Research is in progress for understanding the role of metal oxides in chemical evolution. Prebiotic synthesis of purine, adenine, cytosine, and 4(3H)-pyrimidinone from formamide has been found to be catalyzed by inorganic oxides, namely, calcium carbonate, silica, alumina, kaolin, and zeolite and its application in the origin of life has been discussed.⁸⁹ Under mild conditions, alumina is found to catalyze peptide formation. Alumina has also been found as a good catalyst for the peptide formation of alanine. All three forms of alumina, acidic, neutral and basic are used for the formation of Ala₂, Ala₃ and cyclic alanine.⁹⁰ Adsorption and thermal condensation of glycine on silica has also been studied by Ming and coworkers.⁹¹ The interaction between glycine and alumina has been studied by Tzvetkov et al.⁹² It is proposed that metal

oxides present on primitive Earth could have provided surfaces onto which biomonomers could have been concentrated through the means of selective adsorption. Matrujit and Blanot⁹³ used synthetic ferrihydrite as amino acid adsorbent and a promoter of peptide bond formation. They studied polymerization of alanine, glycine and norvaline using ferrihydrite as catalyst. Hematite is present on Mars and studies have been done for knowing climatic evolution on Mars. Iron (III) hydroxide oxide [FeO(OH)] catalyzes the condensation of DL- glyceraldehydes to ketohexoses. Formation of sorbose, fructose, psicose, tagatose and dendrokotose occur.⁹⁴ Activated alumina has been used as an energy source for peptide bond formation by Bujdak and Rode.⁹⁵ They have used various forms of alumina for alanine dimerization. Highest yield of Ala₂ was obtained with neutral alumina. Bujdak and Rode also studied the alumina-catalyzed peptide bond formation and they found that yield of peptide decreases for trimers and tetramers.⁹⁶ Peptide bond formation on the surface of activated alumina has been studied by Bujdak and Rode.⁹⁷ They studied reactions of the dipeptides and glycine oligopeptides on activated alumina and obtained longer chain oligomers up to (Gly)₁₁.

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