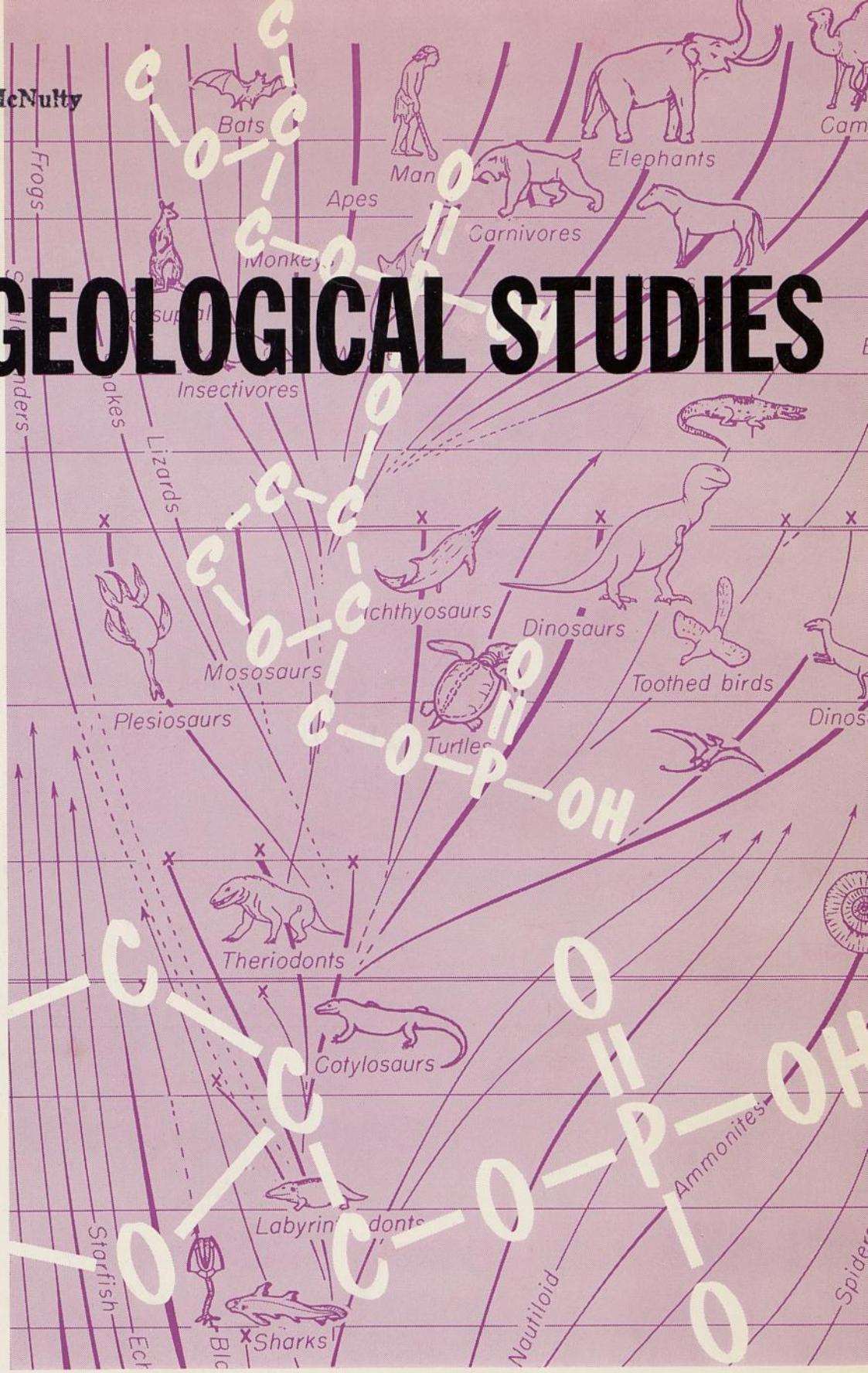

BAYLOR GEOLOGICAL STUDIES

FALL 1964

Bulletin No. 7

BAYLOR UNIVERSITY - WACO, TEXAS
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Geologic Factors Controlling Mutation and Evolution - - A Review

JEAN M. SPENCER

"Creative thinking is more important than elaborate equipment--"

FRANK CARNEY, PH.D.
PROFESSOR OF GEOLOGY
BAYLOR UNIVERSITY
1929-1934

Objectives of Geological Training at Baylor

The training of a geologist in a university covers but a few years; his education continues throughout his active life. The purposes of training geologists at Baylor University are to provide a sound basis of understanding and to foster a truly geological point of view, both of which are essential for continued professional growth. The staff considers geology to be unique among sciences since it is primarily a field science. All geologic research including that done in laboratories must be firmly supported by field observations. The student is encouraged to develop an inquiring objective attitude and to examine critically all geological concepts and principles. The development of a mature and professional attitude toward geology and geological research is a principal concern of the department.

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BAYLOR UNIVERSITY
Department of Geology
Waco, Texas
Fall, 1964

Baylor Geological Studies

The Baylor Geological Studies Bulletin is published semi-annually, Spring and Fall, by the Department of Geology at Baylor University. The Bulletin is specifically dedicated to the dissemination of geologic knowledge for the benefit of the people of Texas. The publication is designed to present the results of both pure and applied research which will ultimately be important in the economic and cultural growth of the State.

Additional copies of this bulletin can be obtained from the Department of Geology, Baylor University, Waco, Texas. $1.00 postpaid.

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The generalized evolutionary chart on the cover was modified from Figure 8 of C. O. Dunbar's HISTORICAL GEOLOGY (2nd Edition) with permission of John Wiley & Sons, Inc., New York. Cover design by Jerry L. Goodson, Baylor University.

Geologic Factors Controlling Mutation and Evolution - - A Review

JEAN M. SPENCER

ABSTRACT

Hereditary mutations originate in DNA molecules in nuclei of reproductive cells. Permanent alteration of a DNA molecule of such cells will be transferred to successive offspring; permanent alteration of a DNA molecule of somatic cells will result in effects limited to the organism experiencing the alteration.

One of the few factors present in the natural environment which possesses the energy to break or alter DNA structure without destroying the entire cell is radiation. Present levels of radiation are not sufficiently high to promote abundant and widespread mutations; however, in the two billion years since life has been on earth there have probably been extended periods of increased radiation which not only altered genetic DNA of many organisms but also, possibly in combination with other factors such as environmental changes, caused extinction of many vulnerable organisms. The sources of these radiation increases may include changes in the atmospheric composition, changes in the earth's magnetic field, and areas of high cosmic ray density related to supernovae explosions.

The purpose of this study was to review for the geologist current research in the various interdisciplinary areas—for example, geophysics, biophysics, biochemistry, molecular biology, and genetics—which have been contributing so much fundamental knowledge to the progress of evolutionary concepts.

INTRODUCTION[1]

Geologic history is largely the history of the development of life primarily through the past half-billion years. Much of the foundation for the modern evolutionary theory is based on the fossil record, a fact which has placed geologists among the principal historians of evolutionary change and among the principal benefactors of evolutionary discoveries.

Within the past few years rapid developments in molecular biology have produced an explanation for the actual process of mutation in evolution. This area of knowledge is largely alien to geologists. Therefore, the purpose of this investigation has been to synthesize for geologists recent discoveries in various areas of science which pertain to the evolutionary mechanism; to correlate these studies with the geologic record; and to determine what factors may have been present in the natural environment to influence the evolutionary mechanism. This review and synthesis is not only intended for the geologist who is dependent in so many ways upon the significance of the fossil record, but also for the non-geologist interested in the role of mutation in evolution—and its relationship to geology, biology, chemistry and physics.

Life has not made a smooth transition through geologic time. Repeatedly throughout the geologic past groups of organisms have become modified, have become extinct, and new groups of organisms have appeared.

Two or possibly three methods of speciation (multiplication of species) take place. One method is by *isolation*. As a result of new environmental pressures and genetic drift, a population may reach a point when reproduction with other populations of the same species is impossible; the isolated population is then considered a distinct species. If, however, reproductive isolation

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[1]A thesis submitted in partial fulfillment of the requirements for the M. S. degree in Geology, Baylor University, 1964. Professors O. T. Hayward and L. F. Brown, Jr., Department of Geology, and Professor T. J. Bond, Department of Chemistry, Baylor University, were consulted during the research and manuscript preparation. Professors F. R. Gehlbach, Department of Biology, and R. G. Packard, Department of Physics, Baylor University, as well as Capt. John R. Morgan, Jr., Nuclear Research Officer, U. S. Air Force, Directorate of Nuclear Safety, Kirtland Air Force Base, New Mexico, reviewed the manuscript. Alice K. Praisnar, Baylor University, drafted the final illustrations.

is not achieved, hybridization between populations may take place with more favorable genes dispersed among the species members (Merrell, 1962, p. 294).

Phyletic evolution is the shift in the characteristics of a population in response to environmental pressures; it does not involve the development of several different species but rather the adaptation of one particular species. Phyletic evolution is thought to lead eventually to new genera and families (*idem*).

Quantum evolution refers to a rapid change in population characteristics which are unlike those of the ancestral characters. This type of change leads to the development of new taxonomic categories and may lead to new orders and classes. It is doubtful that a single mutation could produce the many differences which divide orders and classes; such differences are the result of the "reorganization of the entire genotype rather than a single mutation" (*idem*, pp. 295-296). Since new orders and classes generally appear in the fossil record with no evidence of a gradual development, the idea of quantum evolution arose; however, no systemic mutations have been demonstrated among living organisms (*idem*). Quantum evolution may, nevertheless, reflect the effects of many small mutations taking place within individuals of a population in a relatively short period of time. By recombination, environmental pressures, and possibly other factors, these small mutations may combine to produce more rapid changes in a population.

These then are the methods which apparently produce variations in organisms and which have been responsible for the trend in evolutionary development throughout the past. Let us now briefly consider some of the broader aspects of the history of life as it is reflected in the fossil record.

DEVELOPMENT OF LIFE: A SUMMARY

Animal phyla undoubtedly originated in a marine environment and later entered fresh water and terrestrial environments. Four main lines of evidence point to a greater age for marine animals than for fresh water or land animals: "(1) general composition of present-day faunas, (2) similarity in the chemical composition of body fluids and sea water, (3) life histories, and (4) paleontological relationships" (Sverdrup *et al.*, 1961, p. 282). In addition all animal phyla are represented in the marine environment with five phyla exclusively marine: Ctenophora, Echinodermata, Phoronidea, Brachiopoda, and Chaetognatha (*idem*).

The principal record of life commenced with the beginning of the Cambrian Period (table 1) when abundant advanced types of invertebrate animals present in the late Precambrian developed hard parts capable of preservation. Nearly 500 animal species have been described from lower Cambrian rocks and this group includes representatives from seven phyla (Rhodes, 1962, pp. 78-79). Although the long line of organisms which led up to those of the Cambrian Period left few fossilized remains, enough have been found to indicate a varied and advanced fauna (Glaessner, 1961, pp. 72-78; Rutten, 1962, p. 77). The early part of the Cambrian Period was a time of rapid and fundamental evolution with this diversity of animals increasing rapidly through the Cambrian and Ordovician periods (Simpson, 1962, p. 292). During this span of 100 to 150 million years representatives of all of the recognized animal phyla appeared on earth; no new animal phyla developed after this time. The general trend throughout the remainder of geologic time has been toward diversification with only the lesser types within phyla becoming extinct (*idem*, pp. 295-296).

The plant kingdom, with a more ancient history of development than the animal kingdom, developed into complex forms in the middle Paleozoic; however, fossil plants, both one-celled and relatively simple multicellular types, occur in late Precambrian and early Paleozoic rocks.

The Devonian Period apparently marked another milestone in the development of life. It was a time of diversification of new types such as the vertebrates, whose rapid evolution produced several of the great orders of fishes before the end of this period. The appearance of primitive land animals (amphibians) which closely followed the "rapid evolution" of air-breathing fishes occurred in the late Devonian Period. Land invertebrates such as spiders, mites, and primitive insects also appeared about this time.

Land plant life was evidently scarce before the Devonian Period; the oldest known land plants are fragments from the Ordovician of Poland and the Appalachian region in the United States. Better preserved are the Silurian land plants of Victoria, Australia (Rhodes, 1962, p. 144). From middle Devonian to the end of the Paleozoic Era a diversified flora developed which included primitive representatives of the Tracheophyta (vascular plants) belonging to the Lycopsida (club mosses), Sphenopsida (horsetails), Pteropsida, Filicineae (ferns), and Gymnospermae (conifers). The primitive Psilopsida is represented by Silurian and Devonian fossils (Merrell, 1962, p. 152). No fossil wood has been recognized in rocks older than those deposited during the Devonian Period.

As the Paleozoic Era drew to a close other important developments occurred (Newell, 1952, p. 381). Many groups of animals became extinct during the Permian Period; during this period some animals, for example, the brachiopods *Prorichthofenia* and *Leptodus*, developed unusual skeletal forms before extinction.

The Mesozoic Era saw the rise and development of new types of creatures. Vertebrate land animals developed into many groups such as the dominant dinosaurs and the flying and swimming reptiles. Birds and mammals, although not yet dominant, originated and developed during this time. Among invertebrates, certain cephalopods (Ammonoidea) underwent a rapid expansion in varieties and numbers. As the era closed most reptiles disappeared; all the dinosaurs became extinct at this time. Only marine turtles and smaller reptiles survived into the Cenozoic Era. This "great dying" also included other groups of animals (such as the ammonoid cephalopods) with wide varieties of habitats and characteristics. However, many other animals made the Mesozoic-Cenozoic transition to develop species which characterize modern life.

Table 1. Geologic time scale.

ERA	PERIOD
CENOZOIC	QUATERNARY
	TERTIARY
MESOZOIC	CRETACEOUS
	JURASSIC
	TRIASSIC
PALEOZOIC	PERMIAN
	PENNSYLVANIAN
	MISSISSIPPIAN
	DEVONIAN
	SILURIAN
	ORDOVICIAN
	CAMBRIAN
PRECAMBRIAN EON	

The flora of the Mesozoic Era was dominantly ferns and gymnosperms; however, by middle Cretaceous Period angiosperms had become dominant (Axelrod, 1952, p. 29), having increased with "explosive rapidity" (Laubenfels, 1956, p. 207). It is evident that angiosperms had attained considerable diversity by the Jurassic Period (Axelrod, 1952, p. 32) but no ancestral type has been recognized which indicates a line of development (*idem*, p. 29). Axelrod (p. 57) stated that angiosperms were in existence during Permo-Triassic time and were "undergoing quantum evolution from proangiosperms" living in upland regions.

Mammal-like reptiles existed in the late Paleozoic Era; however, the first true mammalian fossils occur in Triassic deposits (Merrell, 1962, p. 46). The phenomenal rise and development of mammals occurred during the Tertiary Period (Dobzhansky, 1951, p. 282) and paralleled the rapid angiosperm development.

In summary, the major development of most invertebrates took place during the Paleozoic Era after which time invertebrates held a relatively conservative pace with respect to major evolutionary trends. Vertebrates increased during late Paleozoic times culminating in the dominance of Mesozoic reptiles, and Cenozoic mammals and birds. Each of the major groups of plants apparently originated with a short period of rapid evolution followed by a long period of relative evolutionary stability (Kummel, 1961, p. 51). Changes in the plant kingdom do not appear to coincide chronologically with changes in the animal kingdom, a factor which could indicate independent causes (Schindewolf, 1954, p. 463).

Slow continuous changes occur in living populations as observed in gradations between subspecies. Many of these changes reflect alterations in the gene pool of a species. Such genetic variations are part of the genetic code and are passed among individuals of the species. Many of these changes reflect differing utilization of characteristics present within the genotype of the species. The expressed genotype (phenotype) is acted upon by the changing environment which selects from the better adapted phenotypes. Genotypes which are not expressed are not acted upon by the environment.

Because the cell is basic to all living things, it is the key to the development of life and to changes in organisms. An understanding of the structure of cells, both in gross and molecular aspects, is necessary in order to determine what factors may cause changes in the cell and eventually in the individual.

GENETIC MECHANISM: THE SITE OF MUTATION

THE CELL

Theories of the primeval development of hydrocarbons, organic molecules, and the cell have been discussed by many authors such as Ross (1962), Petersil'ye (1962), Haldane (1961), Barghoorn (1957), Oparin (1953), and Blum (1951). Because of the universal character of all cells, a common origin is implied. The basic cell has undoubtedly remained essentially the same type of structure since its development, with some cells altering to develop specialized functions. Therefore, basic cellular activity may be assumed to have utilized the same chemical reactions ever since the cell has been a biochemical unit, and factors which influence cellular development today may be assumed, with reasonable certainty, to have affected cellular activity in a similar manner throughout the past. Thus a study of biochemical genetics may be extended to the past in order to postulate probable biochemical causes for mutations and evolution.

The cell is the basic unit of all life (excluding bacteria and virus). Cells are ultimately responsible for the growth and development of the whole organism; the reaction of each cell to the environment determines how well these functions will be carried out. Nutrients, temperature, and many other environmental factors affect the activity of body cells. Within the nucleus of the cell is the hereditary material which enables each cell to divide (become two equivalent cells) or to carry out various physiological functions (such as secretion) which are necessary for the maintenance of life and the development of the organism. The efficiency and apparent ease with which each cell carries out its chemical reactions belies the complexity of these operations.

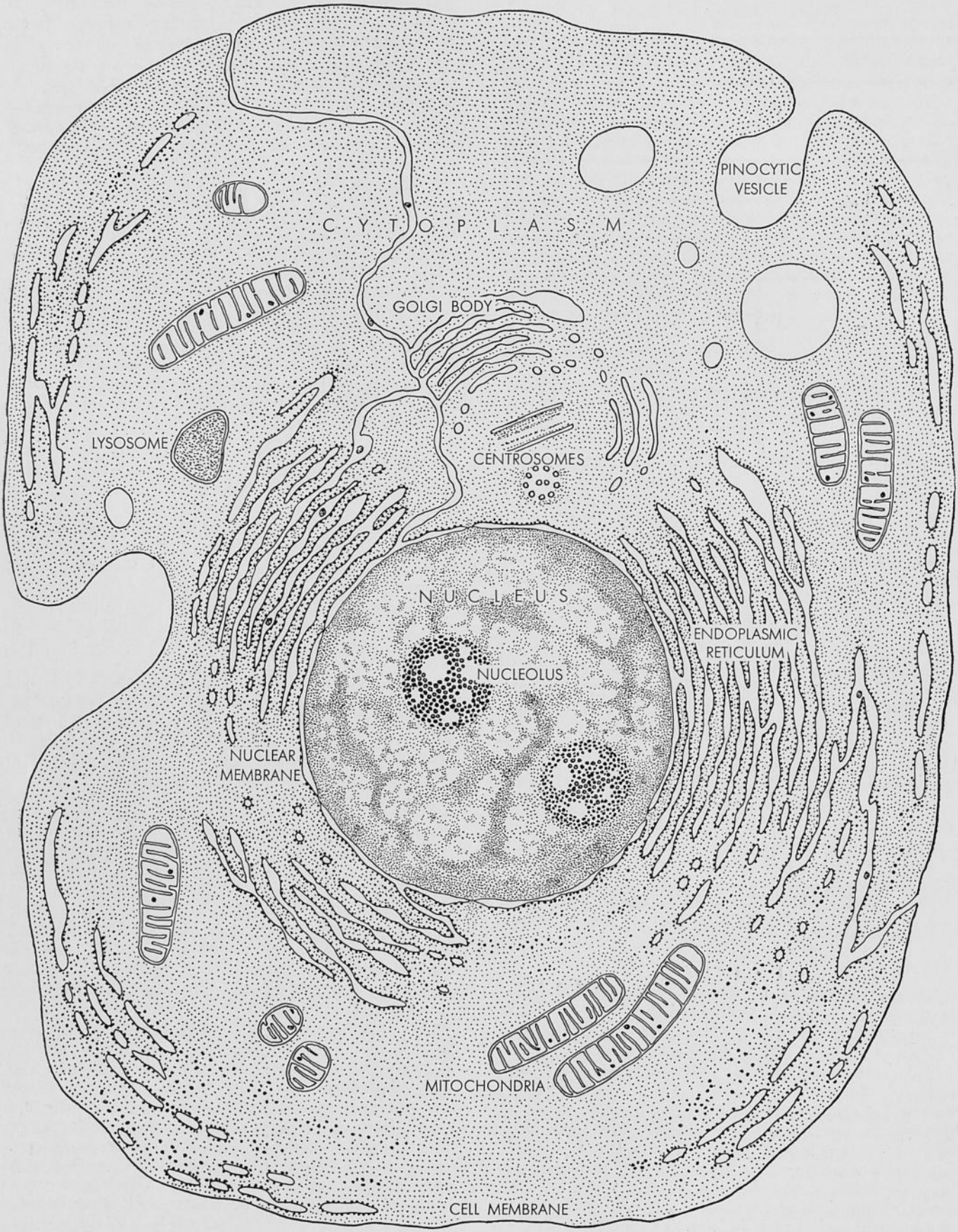


Fig. 1. The cell. *From* Jean Brachet (1961) The living cell: Scientific American, vol. 205, no. 3, p. 55. Reprinted with permission.

The functions of many subcellular units are not completely understood; each unit, however, carries out its own activities in cooperation with every other subcellular unit and the individual activities function together to perform the role of the individual cell.

The cell consists essentially of two main parts—the cytoplasm and the nucleus which both contain a number of smaller bodies. Because the cell is an integral unit, the activities of the nuclear and cytoplasmic bodies affect one another. Thus, although the genetic code is contained within the nucleus, the production of proteins indicated by the code is carried out in cytoplasmic bodies. Conversely, it is apparent that materials and activity in the cytoplasm control nuclear activity; for example, an enzyme deficiency stimulates the nucleus to direct production of the needed enzyme. An adequate supply of a particular protein in the cytoplasm is thought to suppress direction for that protein by the nucleus. Thus a "feedback" of information from cytoplasm to nucleus is demonstrated (Mirsky, 1955, pp. 116-117; Waddington, 1962, p. 6).

It is entirely possible that cytoplasmic activities affect transmission of hereditary material during cellular division and that conditions which adversely affect the cytoplasm could, in turn, cause subsequent changes in the structure of the genetic code.

Perhaps the most important cellular function is that of reproduction; to specialized reproductive cells is entrusted the continuity of the species, and all changes, including the evolutionary process, begin within these cells. All cellular organisms, whether large or small, develop from a single cell. All the information for growth and development of an individual must be encoded within the initial cell. During ordinary cell division (mitosis) each cell duplicates itself so that two identical cells are formed. When a single-celled organism (such as an amoeba) divides, each daughter cell normally receives exactly the same information to make it identical with the parent cell; this mechanism may allow for little if any variation from generation to generation. This factor may explain the apparent "permanence" of some simpler species through the geologic record.

During the formation of gametes (eggs and sperm) of metazoa, cell division (meiosis) permits half of the available material to enter each gamete. Thus, the zygote (fertilized egg) receives half of the necessary information for the new individual from each gamete, and subsequently the completed cell may begin the process of division and development to form the individual. After the individual has been developed, each cell must work to carry out its life processes.

Although cells vary according to their functions and do not each contain all the same materials, a composite cell has been drawn from information obtained by the electron microscope (fig. 1).

The cytoplasm is a watery material that fills the interior portion of the cell; it is surrounded by a membrane that is approximately 100 Angströms thick, which is capable of separating ions and allowing some to enter the cell while barring others. Structures found in the cytoplasm include the cell membrane, ribosomes, mitochondria, lysosomes, and golgi bodies. In addition, smaller constituents of the cytoplasm include molecules of protein, carbohydrate, and fat, as well as salt ions and water molecules.

The cell membrane extends into the cell to form channel-like structures which provide the cell with openings to the outside. These structures are the endoplasmic reticulum through which material is thought to travel from the outer portion of the cell to the nucleus (Brachet, 1961, p. 57).

Golgi bodies are small networks made of smooth membrane which are often continuous with the endoplasmic reticulum. These bodies are thought to produce cellular secretions and may possibly be responsible for producing new cellular membrane (*idem*).

Ribosomes, which contain a high ribonucleic acid (RNA) content, are important protein producers of the cell. These small bodies are located along the endoplasmic reticulum. Amino acids first appear in the cell in peptide linkages associated with ribosomes. Magnesium and calcium ions are important to the maintenance of ribosomes which dissociate to smaller subunits in the absence of these ions (Hoagland, 1961, p. 10).

Lysosomes contain digestive enzymes that break down large molecules such as fats, proteins, and nucleic acids into smaller units so they can be utilized by other components of the cell, such as the oxidizing enzymes of the mitochondria. Because of their destructive capacity lysosomes would dissolve the interior portion of their cells if their confining membrane were broken and the enzymes were released into the cytoplasm.

Mitochondria produce the energy-yielding molecules necessary for cellular function; they may be considered the "power plants" of the cell and thus of all life since the geological beginning of cellular organisms, for they are present in both plant and animal cells. In the mitochondria the formation of the chemical adenosine triphosphate (ATP) from nutrients stores energy for the cell (fig. 2). The ATP molecule consists of three phosphate groups attached to an adenosine molecule—the first with a low-energy bond, the last two with high-energy bonds. Chemical energy is given up by loss of the terminal phosphate (by hydrolysis) which joins the molecule utilizing the energy. Thus ATP, by the loss of a terminal phosphate, becomes adenosine diphosphate (ADP) and the molecule which has been joined by the terminal phosphate becomes a monophosphate molecule. This bond is exothermic and yields free energy in the form of heat (Fruton and Simmonds, 1961, p. 374). The restoration of a terminal phosphate atom to ADP to reconstruct ATP is made possible by the oxidation of glucose which provides the necessary energy (Asimov, 1962, p. 75) This reaction is extremely critical as it not only provides the energy for muscular movement and other activity but also for growth, as it is utilized in the formation of deoxyribonucleic acid chains which determine the activity of the cell.

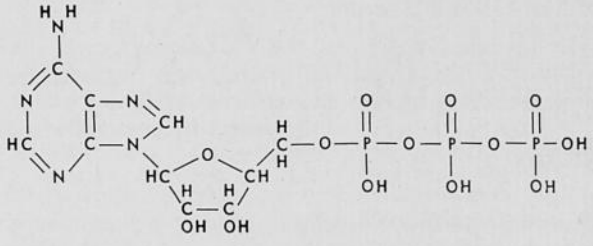


Fig. 2. Adenosine triphosphate molecule.

Centrosomes lie in the center of the cell close to the nucleus. This is a rather dense area of protoplasm in the center of which lie two small bodies, the centrioles; the centrosome, the dense area surrounding the centrioles, is, in turn, surrounded by a clear region, the centrosphere. The centrioles take an active part in mitosis. During the first stages of cell division (prophase) they move to opposite ends of the cell placing the nucleus between them. Delicate fibers form a spindle between

these two points or poles. It is on this fibrous spindle that the chromosomes align themselves during the metaphase of mitosis and subsequently migrate to poles formed by the centrioles.

The nucleus is the source of information for the type of material that will be produced by the cell. It is surrounded by a membrane that allows communication with the cytoplasm. Components of the nucleus include nucleoli, chromatin, and proteinaceous liquid.

The nucleoli are spherical bodies inside the nucleus; they appear to be packed with tiny granules and are rich in ribonucleic acid (RNA).

Chromatin, which contains the deoxyribonucleic acid (DNA) of the cell, is diffused throughout the nucleus when the cell is not dividing; this probably allows the DNA contact with other material of the nucleus. When the cell divides the chromatin forms chromosomes by coiling, and an equal number of chromosomes become a part of each new cell.

A proteinaceous liquid makes up the remainder of the nucleus.

Other structures may yet be discovered in the nucleus and cytoplasm as investigations of the cell are carried further.

In all forms of life growth is characterized by cell division whereby each daughter cell normally receives equal and identical units of matter from those units in the parent cell. Attention was early focused on the chromosome as the source of hereditary characteristics, since there is almost equal cleavage and distribution of chromosomes when cells divide. Chromosomes, residing in the nucleus of the cell, have been proven beyond all reasonable doubt to contain in the genes, structures which are responsible for cellular duplication (Ross, 1962, p. 43) and mutation.

Genes are located on the chromosomes in linear formation (Demerec, 1962, p. 167). In the late 1940's it was established by a number of researchers that DNA is the essential material of the gene (Allfrey and Mirsky, 1961, p. 74).

Every creature carries genetic material derived from the parent (nonsexual reproduction) or parents (sexual reproduction). The gametes, each of which contains half of the information for a new individual, are usually produced in far larger numbers than will be utilized to form new individuals. The chromosomes that go into each gamete are determined in large measure by chance, since only half of the available information is utilized for each gamete. Likewise, the small number of gametes utilized eliminates part of the possible chromosomal combinations and the union of gametes to form zygotes, which is entirely a matter of chance, also significantly reduces the number of possible combinations.

Mayr (1962, p. 4) noted stages in a life cycle when the development of variations is unusually favorable:

a. Mutation at one or several loci (in the chromosome)
b. Crossing over of chromosomes
c. Distribution of chromosomes during reduction division
d. Success of gametes
   Choice of partner
   Choice of gamete
e. Success of zygote

These represent the various processes whereby the characteristics of an individual can be varied within a species; these processes are "partially or largely accidental" (*idem*). The success of the zygote and ultimately that of the individual will be dependent upon the relation of the characteristics that it has inherited to the environment in which it finds itself; this fact may explain the enormously rapid multiplication of certain forms at specific times in the geologic record.

The possibilities for combinations in bisexual reproduction are enormous. For example, in an organism with 1000 genes, each of which can demonstrate 10 different variations, 10^{1000} homozygous gene combinations are possible. "This number is vastly greater than the estimated number of electrons and protons in the visible universe" (Dobzhansky, 1951, p. 254).

In the human zygote there are 46 chromosomes, each gamete having contributed 23. The number of combinations of chromosomes possible for one pair of human parents is over 70 thousand billion (Smith, H. W., 1959, p. 15). Because each chromosome is composed of many genes (many with variations), it is possible for one set of human parents to have 2^{1000} genetic combinations in their offspring (*idem*). This figure is determined by assuming 1000 genes each with two variations.

It is from this vast array of genetic variations (genotypes) of each species that many types of individuals (phenotypes) can form; however, the majority of individuals of a species will approximate a mean or average type which is best adapted to the environment. If the environment should change, this mean or average type may alter to a different average utilizing the genetic material already available in the gene pool of the species.

Thus, the environment presents a controlling selective factor in the determination of which characteristics will continue and which characteristics will be eliminated due to inability to adapt to the environment. Because of the vast reserve of genetic possibilities, a species can make gradual changes to adapt to environmental modifications by natural selection. This type of adaptation can explain, to some extent at least, gradual changes of species throughout geologic time. The genetic possibilities are already present in the population and all that is needed to develop them is a combination of characteristics compatible with the environment.

But how do such a wide variety of genotypes come about? Within the chromosomes lie the genes which are composed primarily of deoxyribonucleic acid (DNA). This is the actual coding material for characteristics of every living organism, both plant and animal. The basic molecular structure of DNA is apparently the same in all organisms. Because of its universal character DNA must have developed prior to the development of the first cell and before life was possible on earth.

DEOXYRIBONUCLEIC ACID

In 1953, J. D. Watson and F. H. C. Crick proposed a structure for DNA molecules (Jordan, 1960, p. 159). With but few alterations this structure has been widely adopted as the best of the many proposed models. This structure consists of long chains of alternating sugar (deoxyribose) and phosphate molecules (Allfrey and Mirsky, 1961, p. 74). To each sugar unit, one of four nitrogen bases (either a purine or pyrimidine) is attached.

Two polynucleotide chains, joined by hydrogen bonding between nitrogen bases, are coiled around the same axis with both following right-hand helices. The sugar-phosphate atoms (C_1-C_2-C_3-C_4-C_5-O-P-O) run in opposite directions in each chain so that if one chain were reversed with the last atoms opposite the first atoms of the other chain, the atoms would be exactly alike in sequence (fig. 3).

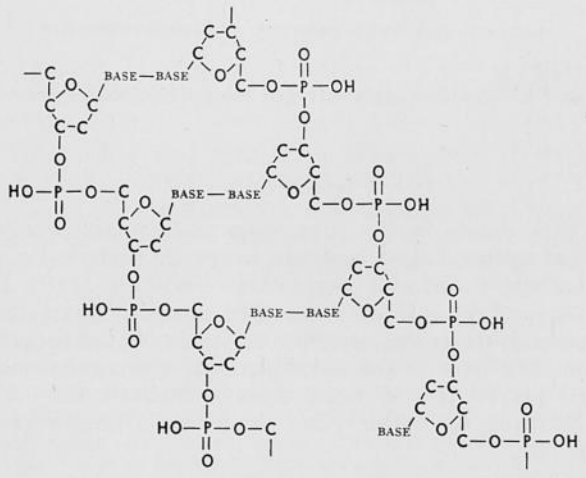


Fig. 3. The polynucleotide chain.

The nitrogen bases are complementary rather than matching so there is always an equal number of purines and pyrimidines. These chains are normally about 10,000 nucleotide units long (Kornberg, 1962, p. 246) and are held together by hydrogen bonds between the purines and pyrimidines (Jordan, 1960, p. 3; Wilkins, 1963, p. 943). These bonds present definite geometrical restrictions resulting in the orderly pairing and distribution of nitrogen bases (Pimentel and McClellan, 1960, p. 321).

The sequence of nitrogen bases—*the code*—is the first step in the determination of the protein (basic unit of all living matter) that will ultimately be formed. Alterations in this code are rare, but they can and do occur. The effects of these alterations may be insignificant or they may be important. For example, the deletion of a critical enzyme may handicap an individual. The substitution of one atom for another in a molecular structure may have either beneficial or disastrous results.

Among reptiles and birds the alteration in the composition of the medium for nitrogen elimination provided the animals greater adaptability to arid environments than those which did not experience the alteration, *e.g.* amphibians and mammals. Thus the change from the formation of urea to uric acid (fig. 4) allows nitrogen (the end product of protein metabolism) elimination with a decrease in the amount of water needed for

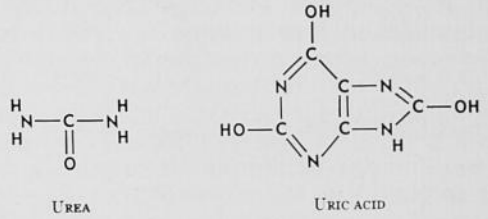


Fig. 4. Comparison of urea and uric acid molecules.

excretion. Therefore, reptiles, which made this change, were able to conserve their limited water supply away from water sources by doubling the amount of nitrogen excreted per molecule (Smith, H. W., 1959, p. 129).

The development of uric acid as the primary material for nitrogen excretion undoubtedly came before the separation of birds from reptiles and after the appearance of true mammals, since the uric acid-excreting habit is not found (except in very small amounts) in any other known animals (Fruton and Simmonds, 1961, p. 847; Smith, H. W., 1959, p. 130). The primary nitrogen excretion product for all other terrestrial vertebrates is urea. The change from urea to uric acid gave the reptiles a tremendous advantage in certain environments over their ancestors, the amphibians.

Likewise, other basic physiologic changes when combined with favorable environments were determining factors in the success of various new stocks.

The long DNA chain is composed of structurally smaller units, nucleotides, which are formed from one phosphate group, one sugar molecule and one nitrogen base. The nitrogen bases of DNA which appear to be the actual determinants of genetic selection belong to one of two groups: pyrimidines or purines. Hydrogen bonds between the pyrimidines and purines on each chain hold the double DNA chain together (Jordan, 1960, p. 3).

Pyrimidines are structurally the smaller of the two types of nitrogen bases present in the nucleic acid. They are six-membered heterocyclic rings which contain four carbon and two nitrogen atoms. Pyrimidines are represented in DNA by thymine and cytosine (fig. 5).

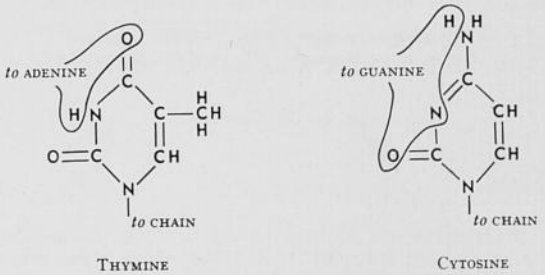
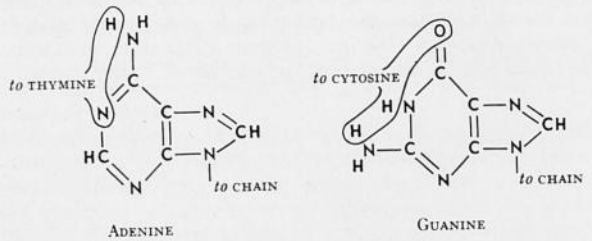


Fig. 5. Pyrimidines.

Purines, larger than pyrimidines, are structurally two heterocyclic ring systems which are fused (Cram and Hammond, 1959, p. 484). Two types of purines are present in DNA—adenine and guanine (fig. 6).



ADENINE GUANINE

Fig. 6. Purines.

The carbohydrate portion of nucleic acid DNA is 2-deoxy-D-ribose (Fruton and Simmonds, 1961, p. 191). This is a monosaccharide unit which is a five-membered furanose ring (fig. 7).

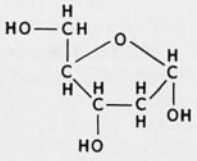
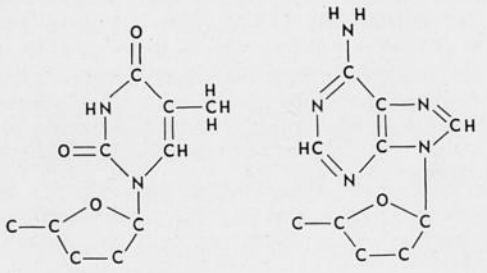


Fig. 7. 2-Deoxy-D-ribose molecule.

When joined together the nitrogen bases and carbohydrate groups form nucleosides (purine and pyrimidine glycosides). These structures are joined in the manner shown in Figure 8.



PYRIMIDINE GLYCOSIDE
THYMINE DEOXYRIBOSIDE

PURINE GLYCOSIDE
ADENINE DEOXYRIBOSIDE

Fig. 8. Nucleosides.

The nucleosides are in turn joined to form nucleotides by phospho-ester links (fig. 9). In DNA these structures join the C_3 of one nucleoside to the C_5 position of the next nucleoside (Jordan, 1960, p. 156).

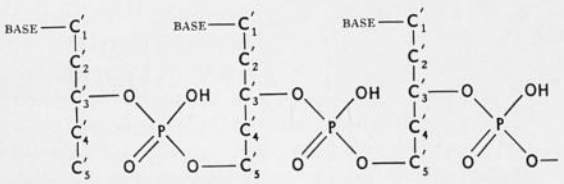


Fig. 9. Junction of nucleosides by phospho-ester links.

The joined purines and pyrimidines do not match from chain to chain but are complementary (fig. 10). Thus, no matter in what order they occur along a single chain, the other chain will have the complement: adenine-thymine; guanine-cytosine.

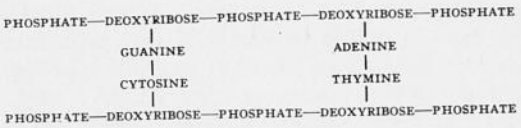


Fig. 10. Complementary nitrogen bases in nucleotides chains.

DNA exists in the gene as a paired coil spiraled around a central axis; however, in certain bacteriophages it has been found as a single chain (Wilkins, M. H. F., 1963, p. 945). Each nucleotide remains in its own plane with the complementary nucleotide of the opposite chain held to it in the same plane by hydrogen bonds. Each set of paired nucleotides is rotated from the neighboring nucleotide pairs producing a double helix (fig. 11).

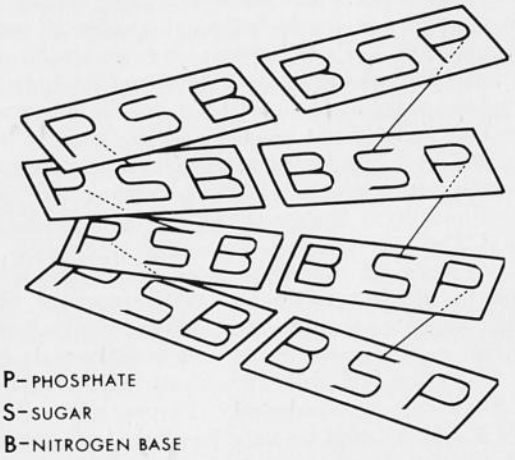


Fig. 11. Structure of a portion of a double nucleotide chain. *Adapted from* PHYSICIAN'S BULLETIN, [vol. XXVII, no. 3, p. 53, September, 1962] a publication of Eli Lilly and Company; S. O. Waife, Editor. Used with permission.

Three configurations of DNA have been observed. In the *A* form, one revolution of the chain is completed for each 11 nucleotide pairs and the joined bases tilt 20° from the horizontal axis of the molecule. The *B* form consists of 10 nucleotide pairs for each completed revolution; the joined bases lie 3.4 A from the pair above and the pair below and are perpendicular to the axis of the molecule (Wilkins, M. H. F., 1963, p. 943). The *C* form of DNA has about 9⅓ nucleotide pairs per completed turn; the base pairs are inclined about -5° from the horizontal axis (*idem*, p. 946). Only the *B* form has been observed *in vivo;* the *A* form, which was the first to be observed, is similar to the configuration of RNA. The *C* form is thought to be produced by partial drying of the molecule (*idem*).

The phosphate ester linkages which hold the nucleotides of each plane together are covalent and stronger than the hydrogen bonds which unite the nitrogen bases of the nucleotides. Therefore, when the two strands unlink, the hydrogen bonds yield to give two single chains. These chains then form complementary chains by attaching to themselves the proper nucleotide molecules until each is again a double chain. The additional nucleosides are activated by ATP and become deoxynucleoside 5'-triphosphate. This unit then reacts with the 3'-hydroxyl group at the growing end of the nucleotide chain; the last two phosphate units are removed as the organic portion of the molecule joins the chain as a unit (Kornberg, 1961, pp. 8-9) to form an additional link in the chain.

Thus the same sequence of nitrogen bases can be carried from one cell to another, as it has from the beginning of cellular life, transmitting characteristics by an endless series of complementary chains.

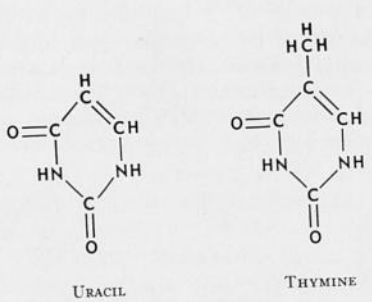
The second step in protein formation is the transfer of the base sequence from DNA to RNA which subsequently carries it from the nucleus of the cell to the ribosomes where proteins are formed. Since the base sequence of RNA is critical to the type of protein which will be formed, alterations in its sequence will lead to changes in the resulting protein.

Changes in RNA will affect the individual, possibly producing an aberrant organism; however, if the DNA remains unchanged the hereditary line will not follow the RNA-produced aberrant but will continue to produce the original type of individual. Thus such a change may appear in the fossil record as a somewhat varied individual among a more homogeneous group.

RIBONUCLEIC ACID

Ribonucleic acid (RNA) is present both in the nucleus and cytoplasm of cells, while DNA is found only in the nucleus. An RNA unit consists of a 5-carbon sugar (D-ribose), a phosphoric acid, and a nitrogen base. These units are arranged in a chain similar to the DNA chain.

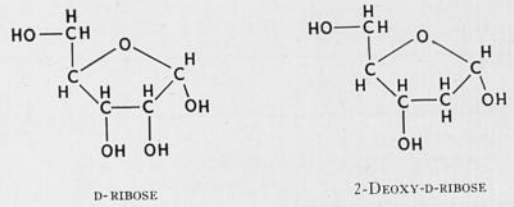
The nitrogen bases of the RNA molecule are the same as those of the DNA molecule with one exception—thymine appears only in DNA and uracil only in RNA. Therefore, the nitrogen bases of RNA are adenine, guanine, cytosine, and uracil. Structures of uracil and thymine are shown in Figure 12. These bases are similar except that thymine has a methyl group (CH_3) in the C'_5 position and uracil has only a hydrogen ion at this position.



URACIL THYMINE

Fig. 12. Comparison of uracil and thymine molecules.

The sugar unit of the RNA molecule is the 5-carbon sugar D-ribose (fig. 13). The ribose structure in RNA is a 5-membered furanose ring (Fruton and Simmonds, 1961, p. 188). This ring is composed of four carbon atoms from a five-carbon chain and one oxygen atom from a hydroxyl group (Asimov, 1963, p. 110). This ribose molecule contains one more oxygen atom than does the deoxyribose of DNA. This difference in sugars between RNA and DNA may be responsible for the main difference between these two molecules (Mirsky, 1955, p. 111) since up to 48 percent of nucleic acid is sugar and this sugar unit is centrally located within the acid. The names of the two acid groups correspond to the names of their respective sugar units: ribose in ribonucleic acid and deoxyribose in deoxyribonucleic acid. Each sugar is characteristic of and only present in its respective acid.



D-RIBOSE 2-DEOXY-D-RIBOSE

Fig. 13. Comparison of RNA and DNA carbohydrate units.

The pyrimidines and purines are joined to the ribose molecule to form nucleotides. Pyrimidines are joined from the C_3 and purines are joined from the C_9 to the C_1 of the ribose furan ring in the same manner as pyrimidines and purines of DNA join the deoxyribose molecule (fig. 8).

The nucleosides are joined, in turn, by phosphate ester links to form nucleotides. These links join the C_2 or C_3 position of one nucleotide with a C_5 position of the next nucleotide (Jordan, 1960, p. 147). The RNA nucleotides, linked by phosphate groups, form long chains (fig. 14) similar to those of DNA (Allfrey and Mirsky, 1961, p. 78).

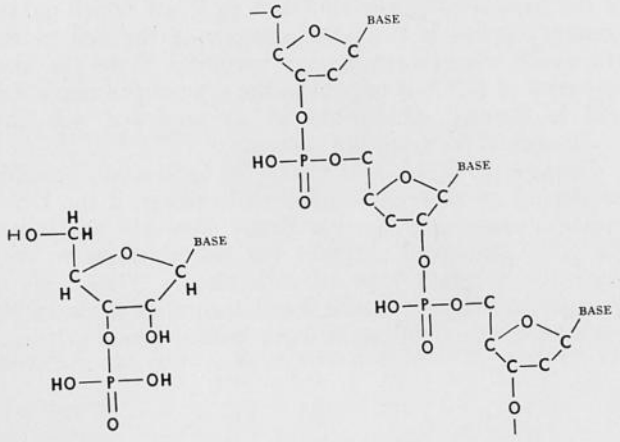


Fig. 14. RNA nucleotide and RNA nucleotide chain.

The structure of RNA in the nucleus of the cell is determined by the structure of DNA. DNA can produce either identical DNA molecules (for cell division) or RNA molecules (to serve as patterns for subsequent protein synthesis in the cytoplasm). The complementary nucleotide pairing of two DNA chains also appears to control the development of the complementary RNA molecule. For example, if a DNA chain is composed exclusively of a nucleotide containing a series of thymine bases, the RNA developed from it would be a complementary chain containing only adenine bases. All bases of DNA are joined by a complement in RNA except adenine which is joined by uracil.

Several types of RNA are found in the cell (Sinsheimer, 1962, p. 233; Waddington, 1962, p. 12). One type forms from DNA in the nucleus and passes from the chromosomes of the nucleus into the cytoplasm. This is messenger-RNA (*m*RNA) which has a high molecular weight and is apparently encoded by DNA. In microsomal particles of the cytoplasm, template (or microsomal) -RNA (*t*RNA) acts as the template along which amino acids are joined by peptide bonds and arranged to form protein molecules, the basic structural units of protoplasm. The *t*RNA is encoded by the *m*RNA from the chromosome. Both have high molecular weights but *m*RNA is more heterogeneous. A third type of RNA, referred to as soluble (or transfer) -RNA (*s*RNA) activates the amino acids which move to the ribosomes where they are joined in proper sequence. The *s*RNA, in contrast to *m*RNA and *t*RNA, is of relatively low molecular weight.

This, then, is the key process whereby life has continued throughout time and continues today. Factors which can influence the sequence from DNA to RNA to protein may ultimately guide the evolutionary sequence.

PROTEIN PRODUCTION

Many of the basic structural units of cells are proteins; they form hormones (which regulate metabolic processes), enzymes (which act as catalysts for most cellular reactions), and many other compounds. The myosin of muscles and collagen of muscles, cartilage, and bones are proteins. In addition, the green pigment of plants (chlorophyll) and the red pigment of mammalian blood (hemin) are attached to proteins.

Proteins are composed of chains of amino acids, the sequence of which is determined by the DNA code. If an amino group were altered, omitted, or added to, the entire function of a particular protein might be drastically changed. If this alteration were indicated in the DNA code so that it were a part of the hereditary construction of the organism, then it would be a genetic mutation transmissable to offspring which could consequently develop, propagate, and perhaps leave fossilized remains. Most mutations are disadvantageous; however, occasionally a mutation will enable an individual to adapt better to its environment, in which case it will thrive and its progeny multiply because of their advantageous characteristics. Thus the occurrence of such mutations may be preserved in the fossil record as a "burst" in development of a particular group.

Since proteins have played a major role in the structure and function of all living matter for all geologic time, a discussion of these compounds follows.

Proteins are long complex polypeptide chains which are composed of amino acids. To date (1964) 20 to 25 different amino acids have been derived from proteins. Amino acid molecules (fig. 15) are composed of a central carbon atom bound to a

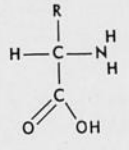


Fig. 15. Basic amino acid unit.

basic amino group ($-NH_2$) and an acidic carboxyl group (-COOH). A characteristic residue R forms the other point of attachment. This residue may be a hydrogen ion, as in glycine, or may be a more complex chain carrying a positive

or negative charge; the residue may be composed of long hydrocarbon chains or aromatic linkages. The side chains are fairly reactive which explains the innumerable varieties of proteins that amino acid combinations can form (Borsook, 1956, p. 5). The amino acid is classified as neutral if it contains one amino and one carboxyl group; acidic if it contains one amino and two carboxyl groups; or basic if it contains two amino and one carboxyl groups (Cram and Hammond, 1959, p. 527).

Amino acids unite, base to acid, lose a molecule of water at each junction, and form peptide chains (fig. 16). Each peptide chain has a definite alignment of carbon and nitrogen atoms (-N-C-C-N-C-C-) with characteristic residues, as well as hydrogen and oxygen atoms extending from it (fig. 17). The sequence of amino acids along the peptide chain determines the type of protein formed, and thus its role in life.

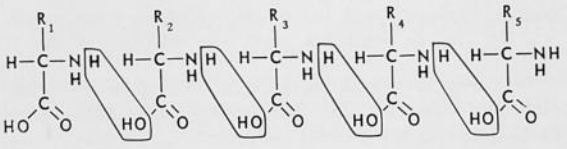


Fig. 16. Formation of a peptide chain.

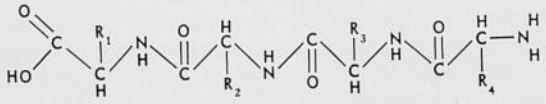


Fig. 17. Peptide chain alignment.

Since there are about 20 known amino acids and only four possible nitrogen bases, there must be enough combinations of these bases to develop all of the amino acids. Groups of two nitrogen bases along a chain would yield only 16 varients ($4^2=16$), an insufficient number. F. H. C. Crick and colleagues have carried out experiments which point to a sequence of three or, less probably, multiples of three nitrogen bases (Crick, 1962, p. 66).

Sequences of three nitrogen bases could yield as many as 64 possible combinations ($4^3=64$)—over twice the number needed to utilize the known amino acids. Of these 64 possible combinations 20 are definite enough to be distinguished from other combinations.

Table 2 is a summary of the codes representing various amino acids as they have been determined at the present time (1963) by the two research groups listed. The original announcement of corresponding RNA and an amino acid was made by Marshall Nirenberg in August, 1961. He stated that polyuridylic acid synthesized phenylalanine into acid-insoluble peptide linkages. Since that time work has proceeded rapidly in this field (Abelson, 1963, p. 774).

DNA does not function as an active protein producer; it encodes the message (base sequence) which is utilized by RNA to produce protein. The messenger-RNA forms along a DNA chain in the same manner as a duplicate DNA molecule would form; the main difference, however, is that the structural sugar in the RNA chain is ribose and the RNA base uracil is utilized in place of DNA base thymine. Thus the base sequence is carried over in the complementary sequence by RNA (fig. 18).

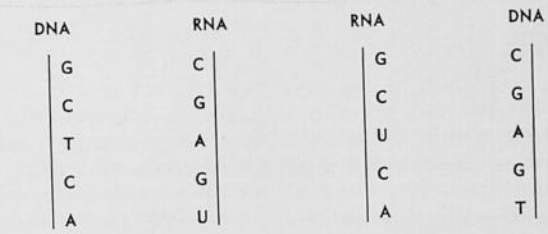


Fig. 18. Transfer of information from DNA to RNA. A-adenine, C-cytosine, G-guanine, T-thymine, U-uracil.

Since DNA is joined to a protein structure in the chromosome and does not leave this area, RNA must transfer the base sequence to ribosomes in the cytoplasm where protein is manufactured (Hoagland, 1961, pp. 10-11).

Amino acids to be joined in the peptide chain are first activated by adenosine triphosphate (ATP), produced in the mitochondria (figs. 1, 2) and a specific enzyme. ATP is an adenosine molecule with three phosphate groups attached. Two of the phosphate groups are released and the remaining adenosine monophosphate (AMP) joins the amino acid at its acidic carboxyl unit (Allfrey and Mirsky, 1961, p. 78; Fruton and Simmonds, 1961, p. 484). This addition activates the amino acid which joins the soluble RNA, and it subsequently moves to the ribosome where it is aligned in the proper position along the peptide chain.

Table 2. The amino acid code.[1]

Amino acid	Code Word	
	National Institutes of Health	New York University
Alanine	CCG	CUG CAG CCG
Arginine	CGC	GUC GAA GCC
Asparagine[2]	ACA	UAA CUA CAA
Aspartic acid[2]	ACA	GUA GCA
Cysteine[3]	UUG or UGG	GUU
Glutamic acid[4]	ACA AGA AUG	AAG AUG
Glutamine[4]	ACA	AGG ACA
Glycine	UGG	GUG GAG GCG
Histidine	ACC	AUC ACC
Isoleucine	UUA	UUA AAU
Leucine[5]	GUU CUU AUU (UUU)	UAU UUC UGU
Lysine	AAA AAC AAG AAU	AUA AAA
Methionine	UGA	UGA
Phenylalanine	UUU	UUU UUC
Proline	CCC CCU CCA CCG	CUC CCC CAC
Serine	UCG UUC UCC	CUU CCU ACG
Threonine	CAC CAA	UCA ACA CGC
Tryptophan	UGG	UGG
Tyrosine	UAU	AUU
Valine	UGU	UUG

1From Abelson (1963) Transfer of genetic information: **Science**, vol. 139, no. 3556, p. 775. Used with permission.
[Sequence of nucleotides within code words was not determined experimentally except for tyrosine (AUU) by the New York University group.]
2The NIH group cannot as yet determine whether ACA represents aspartic acid or asparagine.
3It is not clear yet which of these possibilities is correct.
4The NIH group cannot as yet determine whether ACA represents glutamic acid or glutamine.
5Poly U will serve as a template for leucine in the absence of phenylalanine.

The seat of coded information for the production of proteins, and thus for the major portion of cellular constituents, rests with the sequence of bases in the DNA. This coded sequence is a triplet; that is, three bases determine a specific amino acid. A sequence of triplets determines the order in which the amino acids will be arranged to form a peptide chain and finally a protein.

This sequence of events is evidently similar in all living organisms. The universality of the code implies a common origin and thus a constant and similar type of activity throughout geologic time. Therefore, the DNA code as it functions in modern organisms may be interpreted to have reacted in the past as it does in the present.

John Abelson (1963, p. 774) described the code as follows:

> "1) The code is specific; amino acids are only incorporated into proteins by templates which contain their code words. There is a very low incidence of mistakes in reading the RNA template.
>
> "2) The code is degenerate; that is, there is more than one code word for many of the amino acids.
>
> "3) The fact that nearly all synthetic polynucleotides so far examined are active in coding for at least one amino acid suggests that most of the nucleotide sequences in these synthetic polymers may be meaningful.
>
> "4) Hypoxanthine will replace guanine in templates containing G, so the 2-amino group of G is apparently superfluous in so far as the code is concerned.
>
> "5) Many of the amino acids may be coded by polymers having only two bases; exactly what the doublet code theory might predict. Roberts [1962] reported that this theory had predicted 93 percent of the experimental results found subsequent to its publication. This successful prediction lends support to the idea that if code words are triplets, two of the bases carry the majority of the information.
>
> "6) Lengyel [1962] pointed out that many of the degenerate code words differ by a single base. This base can be U, A, or C, but it is not so for G.
>
> "7) The order of nucleotides has been determined for very few code words, but possibilities exist for solving this problem."

MUTATION AND SURVIVAL

The fossils of the geologic past are largely representative of successful adaptation of populations, for it is unlikely that a markedly destructive mutation would appear in sufficient numbers of organisms to be preserved in the paleontologic record. Thus the fossil record is largely the history of locally and temporarily successful mutations. The key to the external form and function of the organism is the DNA code in the nucleus of each cell. In the past, as in the present, no fundamental change in a group of animals was possible without a change in the code—*a mutation*—which was subsequently selected or rejected by the environment.

A mutation may be formed if a single nitrogen base is removed from its position along the nucleotide chain since this would destroy the sequence for a particular amino acid and possibly also the sequence for amino acids beyond the site of the missing base. Thus, after the deletion the code would continue to be read in triplet but not necessarily the proper triplets unless another base is added along the chain to restore the original sequence (fig. 19). The code could be destroyed for those amino acids located between the missing base and the added base.

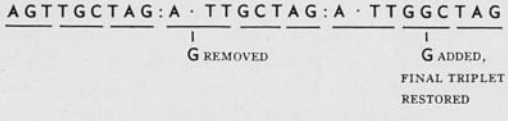


Fig. 19. Deletion and addition of nitrogen bases in nucleotide chain.

In the event of substitution of one nitrogen base for another, either the triplet with the substitution will become garbled and meaningless or it will indicate a different amino acid which may help but will normally hinder the organism. An example of substitution is shown in Figure 20.

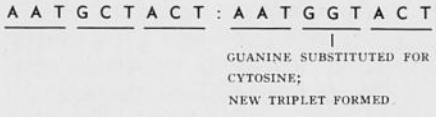


Fig. 20. Substitution of nitrogen base in nucleotide chain.

Such a substitution has been found to cause sickle-cell anemia, a hemoglobin abnormality peculiar to the Negro race (Kolmer, 1943, p. 651) which appears to confer a type of immunity against malaria when in the heterozygous state (one sickle-cell gene and one normal gene) and death when in the homozygous state (two sickle-cell genes) (Merrell, 1962, p. 342; Ross, 1962, p. 102). One of the peptides from sickle-cell anemia hemoglobin has one extra valine and one less glutamic acid than normal hemoglobin (Jukes, 1963, p. 231). The normal RNA code sequences for these amino acids are A, U, and G for glutamic acid and U, U, and G for valine. Thus in the sickle-cell condition a uracil is substituted for an adenine in a particular location in the coding triplet (*idem*). Another hemoglobin abnormality exists which can be traced to the replacement of the guanine, in the same triplet, by an adenine, resulting in a substitution of the amino acid lysine for the normal glutamic acid (*idem*).

Mutation-causing deletions and/or substitutions can occur in more than one position along the nucleotide chain. That is, there could be two or more deletions of nitrogen bases in the sequences in which case the effect on the cell or organism would be increasingly more severe. If three adjacent bases are removed the normal sequence is retained even though one or two amino acids have been lost. If, however, three bases are removed at various positions along the nucleotide chain, the distance between the first and last loss may be affected; after the removal of the third base the original triplet sequence will probably be restored. For this reason, the greater the distance separating the first and last base removed, the more serious could be the effect on the cell or organism since more of the code would be involved. Such large alterations would, in most cases, be lethal; however, regardless of how small

the possibility, some such alterations could conceivably have led to macromutations (lethal or non-lethal) during the two billion years while life has developed. The hypothetical removal of three bases in a sequence is illustrated in Figure 21.

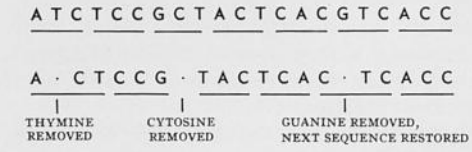


Fig. 21. Removal of three bases from nucleotide chain.

The mutation will be restricted to the affected individual if the mutation occurs in any cells except the reproductive cells (Sievert, 1959, p. 63). However, if the reproductive cells (eggs and sperm) or organs which produce them receive these modifications, they can faithfully carry the alterations to offspring which will be modified according to the new code (Alexander, 1959, p. 117). Since this modification is a part of the new individual, subsequent offspring will also carry the modification from this parent either as a dominant or as a recessive character.

Most new mutations are recessive with less than 1 in 100 mutants being fully dominant (Merrell, 1962, p. 351). If the characteristic is dominant, it will be apparent in the individual which has developed from the modified nucleotide or gene; if it is recessive, it will remain unnoticed for several generations until two individuals, both carrying this modification as a recessive character, produce offspring. Their offspring have one chance out of three of demonstrating the modification in some form.

For example, if a true-breeding black guinea pig and a white guinea pig produce offspring, all the offspring of the first (F_1) generation will be black because black is the dominant characteristic and white the recessive. However, if the hybrids of the F_1 generation produce offspring, the second (F_2) generation will be ¾ black and ¼ white—on the average. If the F_2 white guinea pigs are mated, all their offspring will be white since no dominant black genes are present in them to produce black offspring.

If the F_2 black guinea pigs are mated ⅓ will produce only blacks and the other ⅔ will produce black and white individuals as in the F_2 generation. This follows Mendel's first genetic law that factors for a pair of characters are segregated. If one character is dominant, offspring are segregated in an average ratio of 3:1. This occurs since each parent donates half the genetic material of an individual and it may be explained diagrammatically (fig. 22).

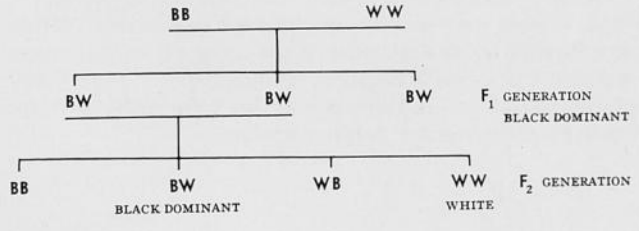


Fig. 22. Illustration of Mendel's first genetic law.

A recessive mutation may not appear in a population for many generations because it must be transmitted to offspring and, as a recessive, will not show up in a population until two gametes, each carrying the new recessive characteristic, unite (*e.g.* the white guinea pigs). Although mating may occur among members of the F_1 generation who do not show the mutation, of their offspring one in three may demonstrate the change.

Therefore, in a fossil or living population individuals with environmentally adaptive dominant characteristics will appear more quickly than their recessive counterparts; however, if the recessive characteristic is better adapted it will appear but at a more gradual rate.

In large populations several generations may elapse before two individuals carrying the mutation mate. Thus in small isolated groups individuals carrying a recessive character would have a greater possibility of mating than individuals in a large, widespread population, and recessive characteristics would be demonstrated sooner in the smaller group. This factor may explain the existence of small isolated groups of somewhat unique fossil assemblages.

When the recessive mutant finally does manifest itself, it may be as a lethal factor in which case the individual normally will not reach maturity.

Such lethals are known in *Mus musculus* (Arey, 1941, p. 181; Storer and Usinger, 1955, p. 179), a yellow house mouse which dies as an embryo if it is a homozygous yellow (yellow factor from both parents). Lethals are also known in *Drosophilia* (the fruit fly), cattle, sheep, hogs, and horses (Storer and Usinger, *idem*).

If the alteration does not produce a lethal mutant, its expression within a population may be determined by the environment. Greater adaptability to surroundings tends to allow those individuals with such favorable characteristics to survive and reproduce in a larger proportion than those without the successful mutant.

Environment is a major contributing factor in the expression of characteristics in many organisms. Factors such as food supply, pH or salinity of water environment, temperature, or other conditions play a direct role in determining which plants and animals are best suited for a particular environment. Such factors may be major contributors to minor variations within a species—either living or fossil.

Environmental influence is seen in the relationship between collagen type and temperature in fish. In warmer water fish collagen allows for greater expansion (shrinkage temperature) before rupture of hydrogen bonds and subsequent rearrangement of the collagen to form gelatin; this maximum temperature is lower in fish collagen of cooler waters. An "amazing linear relationship" between environmental temperature and the presence of the amino acid hydroxyproline exists in fish collagen (Anfinsen, 1959, pp. 215-216) demonstrating a definite influence of the environment on the production of an amino acid. "Collagen shrinkage temperatures seem to fall about 15° or 20° above the highest temperatures likely to be encountered by a species," thus providing a safety margin for a normal environment (*idem*, p. 216).

High salinity can cause dwarfing of aquatic animals. For example, many species of Mediterranean (salinity 39 grams salt per kilogram water or 39,000 parts per million—ppm) organisms are smaller than their counterparts, which live in open water along the British and Spanish coasts (Grabau, 1913, p. 1067) with a salinity of about 35,000 ppm (Sverdrup *et al.*, 1961, p. 55). Various salts present in a marine environment may also be responsible for altering the appearance of organisms.

Such dwarfing is occasionally caused by the presence of iron in excessive amounts in an environment. This fact has been demonstrated by experiments on fishes and tadpoles which were retarded 3 to 5 millimeters in eight months in an environment with excess iron salts (Grabau, *idem*). Dwarf fauna of the Upper Devonian System of New York occur in the "Pyrite layer" (iron sulfide) which replaces the Tully

Limestone in the Genesee Valley and westward. In this fauna 45 species average 1/15 the size of the normal form with the dwarfing probably caused by the presence of a large amount of soluble ferrous (iron) carbonate in the Devonian sea (*idem*). Pyritized dwarf fauna also occur in the Upper Cretaceous Del Rio Formation of Central Texas. Such a dwarfing effect would be somatic rather than genetic and could lead to new species or subspecies only if individuals carrying a particular genotype became better suited for, or more adapted to, the particular environment—hence, by natural selection.

That "species change" can come about due to changes in food supply has been demonstrated by experiments with plants. For example, the ferns *Asplenium adulterinum* and *A. serpentinum* were studied by Sadebek in 1871 (Nesvetaylova, 1961, p. 609; Varming, 1902, p. 53). These ferns grow in areas containing serpentinite and probably utilize the magnesium. Sadebek grew these ferns in serpentinite-free soils and observed that in the sixth generation they had developed into *Asplenium adiantum nigrum* and *A. verida* which are more common fern species. This adaptive change is also noted in other plants which apparently change species when grown on soils containing different elements (Nesvetaylova, 1961, p. 609). These changes are probably produced by utilization of characteristics already present in the hereditary makeup of the plants which need only the environmental pressures to develop from one type to another. Would this, then, be considered a true species change?

Artemia, the brine shrimp, has been studied in relation to development of its eggs in various salt solutions. It has been found that salinity has a considerable effect on the proportional sizes of thorax and abdomen as well as on other features. The thorax is short when salinity is high and becomes progressively longer as salinity decreases; the reverse is true for the abdomen.

The English sparrow, *Passer domesticus*, which was introduced into North America from England and Germany about 110 years ago, has spread over the United States, south into Mexico, and north into Canada. These birds have generally increased in size and, being subject to many types of climatic conditions, have subsequently developed many characteristics in relation to environmental pressures (Dobzhansky, 1951, p. 96; Calhoun, 1947, p. 203). For example, sparrows of Death Valley are lighter in color than other sparrows and contain more white feathers; other changes in size and color have been discovered in various environments (Calhoun, 1947; Univ. Kansas Newsletter, 1962; Johnston and Selander, 1964).

Protective coloration (adaptation) allows survival of a larger number of animals possessing these characteristics, thus changing the population to an average better adapted to the environment (Dobzhansky, 1951, p. 102).

Moths in industrial areas of Europe appear to be altering from light to darker forms while lighter forms remain predominant in nonindustrial areas. *Boarmia repandata* is such an example (Ross, 1962, p. 104).

Moths in England have changed from predominantly light to predominantly dark gray or black to better blend with the soot-covered trees, resulting from increased industrialization. The darker color affords the moths better protection from birds. H. B. D. Kettlewell of the University of Oxford (1959) has conducted a study primarily on *Biston betularia* and its darker form *B. carbonaria*. The dark form was first reported in England in 1848; in 1953, 90 percent of the moths caught in the Birmingham woods were the dark form.

Kettlewell (1959, pp. 52-53) noted that when a new mutation occurs it takes from one to fifty years to appear in a population; however, once the mutants increase to one percent of the population they will increase rapidly if they are a more advantageous form. After a mutation appears in a population natural selection controls its subsequent development (*idem*).

In human genes a very rough estimate sets mutation frequencies between 1 in 10,000 and 1 in about 250,000. About one sex cell in each 50,000 from a normal person, not exposed to any special radiation agents, has a gene mutation for retinoblastoma, cancer of the eye (Dobzhansky, 1960, p. 206).

During the great span of geologic time even slow accumulations of various biologic mutants could appear as relatively sudden bursts in the fossil record. What may appear as a sudden development of a new species may actually be the result of long genetic changes unless, of course, it represents an invasion of the already developed species from a foreign source.

Of the many mutations that have occurred during the course of organic development, only a small fraction have been preserved because they were beneficial or were not detrimental. Thus the majority of genetic mutations have been eliminated by natural selection (*idem*, p. 207).

Therefore, in summary, genetic mutations take place in the nucleus of the cell and affect the code which determines the cellular activity. This has apparently been true throughout the history of cellular life. Such a mutation consists of an alteration in the DNA sequence which is subsequently transmitted, via RNA, to the cytoplasm where the code is acted upon. Mutations which affect any cells except those of reproduction will be restricted to the individual which has experienced the mutation. If, however, the mutation affects cells of reproduction, the mutation may be faithfully transmitted to offspring and could become a part of the hereditary heritage of the species. Its subsequent selection and development will depend upon the environment.

Because of the number of nitrogen bases (10,000 units per DNA chain) in each gene (Kornberg, 1962, p. 246) and the large number of genes per chromosome, the nucleus of each cell contains a vast number of loci for alterations in the normal sequence of nitrogen bases. The chance of alteration in the gene is greatest during mitosis when the chromosomes condense for cell division. During this stage the DNA double helix apparently forms and this tightly packed structure is more susceptible to alteration. An alteration at this time could affect corresponding points on the complementary strands causing a more permanent change than if only one base were destroyed or altered (Muller, 1959, pp. 29-30).

Various factors can affect the developing embryo. These factors may lead to an aberrant organism. When these factors affect cells other than those of reproduction (somatic cells) such changes do not become hereditary but the individual organism may be sufficiently distinctive to be mistaken for another species.

EMBRYONIC DEVELOPMENT AND MUTATION

The development of an organism from the zygote or fertilized ovum takes place by means of an orderly series of events, each triggered by chemical reactions. It is apparent that each step has a definite time of development with rapid cell multiplication. If this schedule is interferred with so that development does not take place, another opportunity will not arise and the retarded part will remain unchanged while subsequent portions develop according to their schedule (Arey, 1941, pp. 178-179).

At the microscopic or intracellular level during the development of any organism, chromosomal activity occurs. On the chromosomes certain loci apparently enlarge to form characteristic "puff" or "Balbian-ring" structures when they are directing cellular activity, decreasing in size when their function is terminated. Such enlargements appear to have a definite sequence indicating an orderly series of instructions to the developing cell (Waddington, 1962, p. 51). Subsequent instructions to the nucleus from within the cytoplasm may trigger the next stage of cellular activity. Another group of puff structures then develop to direct further growth while the preceding set of puff structures, their function complete, decrease in size.

At the macroscopic level the orderly embryonic growth of an organism can be observed from the initial development of the zygote. There is a definite embryonic growth sequence and if there is interference at any particular stage, the organs or other structures, whose growth is synchronous with this stage, will not develop even if the interference is later removed so that subsequent development is normal.

Both chemical and physical interference are possible. Such chemical agents as thalidomide, although not present in the natural environment, may cause a depressing influence on the development of the extremities in the human embryo, if present during the period of normal development of these extremities. Such suppressions can result in *phocomelus* whereby extremities are missing or hands and feet appear to grow directly from the trunk (Arey, 1941, p. 160; Taussig, 1962, p. 29).

A cause for many developmental suppressions may be a reduced metabolism resulting in a reduction of oxidation necessary to the development rate (Arey, 1941, p. 178); however, no malformation occurs until the oxygen level falls to about three-fourths that normally required (Snider, 1963, p. 81). In the oxygen-deprived chick embryo, one of the first effects is an increased absorption of water which causes engorged blood vessels and increased blood pressure. This increase in water content may amount to as much as 10 times the normal quantity and may possibly initiate later developmental changes (*idem*). Factors which cause oxygen reduction include subnormal temperature and a reduced oxygen supply (Arey, 1941, p. 178); the result is arrested development of the affected organism.

Such changes would not be hereditary but would affect only the individuals whose development was altered. For this reason an isolated group of organisms (living or fossilized) may appear structurally different from similar organisms but may be the same genotype, though development has been affected by the physical and chemical restrictions of the local environment. When and if young from such a group develop apart from this environment, they can differ in appearance from other members of their species. The dwarf fauna of the Upper Devonian System of New York and the Cretaceous System (Del Rio Clay) of Central Texas are such examples (p. 18).

Thus a group of organisms will develop according to the capacity of its genetic makeup within the restrictions of the environment; the resulting phenotype can then be preserved as the fossil record in the rocks deposited within that environment.

ENERGY EFFECTS ON MOLECULAR STRUCTURE

Hereditary mutations, which have resulted in a changing fossil record, can occur only within the restricting limits of the molecular pattern of DNA and the thermodynamic properties of the system (Blum, 1951, p. 155). Therefore, in order to occur, mutations must follow certain biochemical mechanisms.

Most spontaneous mutations probably result from ordinary physiological processes such as the utilization of altered nitrogen bases in DNA chains or abnormal cross-linkages between chains. The causes of such spontaneous mutations are difficult to assign; however, background radiation, which is probably responsible for a small fraction of natural mutations (Alexander, 1959, p. 128), has surely made an important contribution to mutations throughout the vast history of life.

The amount of energy needed to break bonds within the DNA molecule, to effect substitutions, or to destroy any part of the structure is important. The energies (in kilogram calories per mole) needed to break some of the important bond combinations found in organic molecules are listed below (Gilreath, 1958; Cram and Hammond, 1959).

O-H	110 kcal/mole
H-H	103
C-H	94
C-C	58
O-O	38
hydrogen bond	5-10
peptide bond	2.75

The bonds joining atoms are stronger than the bonds joining molecules so less energy is needed to separate molecules than atoms. The Van der Waals forces which hold molecules together generally are of energies of less than 10 kcal/mole (Blum, 1951, p. 121). Because energy is lost in the formation of these bonds this energy must be supplied to break them. The more energy lost in bond formation, the stronger the bond.

More energy is needed to remove completely an electron from an atom, to ionize it, than is needed to break bonds. For example, 312 kcal/gm-atom are required to remove an electron from a hydrogen atom (Gilreath, 1958, p. 168), while 103 kcal/mole will break a H-H bond. Therefore, bond rupture is achieved at lower energies or before ionization occurs.

In order to produce mutations by disruption of DNA, energy in amounts large enough to break nucleotide bonds must be made available. This energy must be capable of entering the nucleus of the reproductive cells and giving up energy without destroying the cells or their functions. An obvious source of this energy is the radiation from radioactive isotopes present in the earth and atmosphere as well as from solar and cosmic radiation. This radiation can penetrate cells and transfer the energy needed to produce bond rupture and mutation. Types of molecular excitation caused by electromagnetic radiation of various wavelengths are shown in Figure 23.

Heat is a second factor which may produce genetic changes. In general, heat of sufficient intensity to rupture readily nucleic acid bonds would not be restricted to the cell nucleus but would also rupture bonds of other cellular components and probably impede function of the entire cell.

Heat may be transferred by infrared radiation with wavelengths from about 8000 A to 50 microns. The shorter of these infrared radiations possesses sufficient energy to rupture molecular bonds. A wavelength of 8000 A produces about 36 kcal/mole of heat—enough to break molecular but not atomic bonds. Generally, near-infrared radiation, which excites molecules to higher vibration levels, produces a bending or stretching of molecular bonds (Cram and Hammond, 1959, p. 615). Therefore, although it does not possess the higher energy of shorter electromagnetic radiation, infrared radiation must be taken into account as a possible agent in continuous mutations during the long period of geologic time.

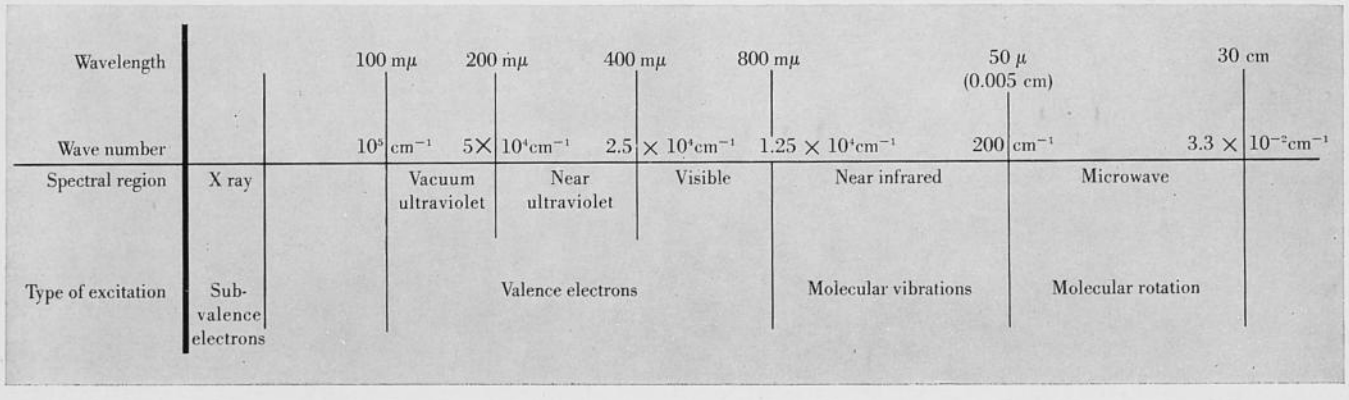


Fig. 23. Correlation between spectroscopic regions and types of molecular excitation. *From* ORGANIC CHEMISTRY [p. 616] by Cram and Hammond. Copyright 1959. McGraw-Hill Book Company. Used by permission.

IONIZING RADIATION

GENERAL PROPERTIES

Ionizing radiation—considered a principal energy source for mutation—consists of electromagnetic waves and subatomic particles which produce ionization of material by giving up quanta of energy to atoms or moleclues from which electrons are ejected, leaving the atom or molecule positively charged (ionized). The dislodged electrons or beta particles join other atoms or molecules causing them to become negatively ionized. The resulting positive and negative ions are called an *ion pair* (Alexander, 1959, p. 21).

Energy of radiation is expressed in electron-volts (eV). (1,000 eV=1 keV; 1,000 keV=1 MeV; 1 eV = 1.60 x 10^{-12} ergs; 1 eV/ molecule = 23.05 kcal/mole).

For electromagnetic radiation the quantum energy in ergs is dependent upon the frequency or wavelength according to the following relations:

$$q = h\nu = h\frac{c}{\lambda}$$

where q= energy of the quantum in ergs, h = Planck's constant (6.6236 x 10^{-27} erg-second), (Nu) ν = frequency, c = velocity of light (3.0 x 10^{10} centimeters per second), and (lambda) λ = wavelength. The quantum energy, determined in ergs, must be multiplied by the number of molecules in a mole (Avagadro's number—6.0227 x 10^{23}) and by the factor to convert ergs to kilogram-calories (0.239 x 10^{-10}) to give the energy in kilogram-calories/mole.

Thus a wavelength of 9,500 A (Angströms) would yield about 30 kcal/mole of heat while a shorter wavelength of 6,800 A would yield about 41 kcal/mole.

The quanta or energy, in electron volts (eV), given up by electromagnetic radiation, may also be expressed as 12,400/λ, where λ is the wavelength in Angströms (Alexander, 1959, p. 28). The shorter the wavelength the greater is the energy available in electron volts and the deeper the penetrating power (fig. 24).

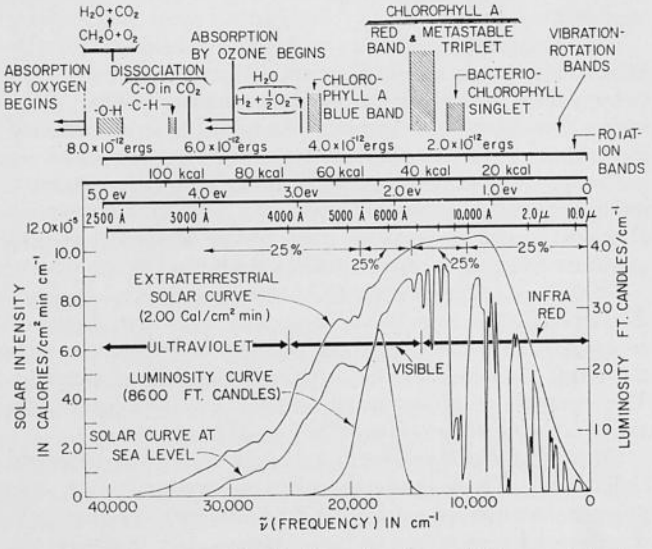


Fig. 24. Frequency distribution of solar radiation and its interpretation in terms of biologically significant reactions. *From* D. M. Gates (1963) The energy environment in which we live: AMERICAN SCIENTIST, vol. 51, p. 332. Used with permission.

Two types of energy relationships are illustrated in Figure 24. The intensity of radiation is represented on the ordinate. The frequency scale is noted at the bottom of the diagram and the corresponding energy per mole quanta is represented by three horizontal scales with the energy given in ergs/mole, kcal/mole, and eV/mole; a fourth horizontal scale gives corresponding wavelengths. Photochemically important reactions are listed above the chart including the dissociation of C-O, C-H, and O-H bonds, the absorption of radiation by oxygen and ozone, as well as the absorption bands for chlorophyll. It may be noted that solar radiation reaches maximum intensity at the earth's surface in the near-infrared (Gates, 1963, pp. 332-333).

Ultraviolet light consists of electromagnetic waves shorter than 4000 A; these are longer than x-rays (wavelengths normally less than 1 A) and shorter than the shortest waves of the visible spectrum. Purine and pyrimidine molecules (pp. 11-12) are excited by 2537 A of ultraviolet light energy (Errera, 1959, p. 700). Wavelengths of approximately 2600 A of ultraviolet light have been effective in producing genetic changes in the liverwort *Sphaerocarpus* (Knapp and Schreiber, 1939, *in* Errera, p. 716) and endosperm deficiencies in maize (Stadler and Uber, 1942, *in* Errera, 1959, p. 716). This energy is probably taken up by the nucleic acids (Errera, *idem*) of the cell; ultraviolet irradiation may cause the breakage of hydrogen bonds, peptide bonds, amide bonds, and disulfide bonds to form organic radicals which may or may not reform the original molecule (*idem*, p. 701). The energy produced by such wavelengths is about 110 kcal/mole and is enough to break many of the important bonds of organic molecules (p. 20).

Thus electromagnetic radiation bursts or factors which might increase electromagnetic radiation such as elevation (partial elimination of atmospheric absorbers) should increase mutation rates. Therefore, following times in the geologic past when electromagnetic radiation may have increased, a subsequent increase in biologic varieties would be expected.

X-rays are shorter than ultraviolet rays (x-rays are longer than gamma rays). Probably because of their shorter wavelength and therefore greater ionizing capability, x-rays cause more mutations than ultraviolet light, but even at low doses they have 200 times more lethal effect than ultraviolet (*idem*, p. 717). Therefore, even a slight increase of x-rays would cause not only the possibility of new forms (mutations) but also possibly widespread deaths which would be reflected in the fossil record by the disappearance or marked reduction in representatives of certain groups. Wavelengths longer than x-rays normally do not cause ionization; instead they cause excitation of electrons which return to their original stable state if an immediate reaction does not take place (Alexander, 1959, pp. 1, 20).

The closest source of extraterrestrial electromagnetic radiation is the sun. Electromagnetic waves include those of the visible spectrum as well as shorter and longer emissions. Solar emission also consists of particles such as protons and electrons (Sullivan, 1961, p. 204).

Ultraviolet radiation is screened from the surface of the earth by oxygen and nitrogen of the atmosphere. The absorption of solar ultraviolet radiation with wavelengths of about 2400 A to 1000 A by molecular oxygen dissociates the oxygen molecules (Tousey, 1961, p. 2; Nicolet, 1952, p. 193); these atoms collide with molecular oxygen to form ozone (O_3). The shorter wavelength of 910 A ionizes oxygen atoms (*idem*, p. 211). Ozone absorbs radiation with wavelengths from 2000 A to 3000 A and is dissociated photochemically (Tousey, 1961, pp. 1-2). Thus atmospheric oxygen acts as an effective screen against ultraviolet penetration. Radiation with a wavelength below 1000 A is absorbed primarily by molecular nitrogen (*idem*, p. 2).

There are bands of maximum absorption for electromagnetic radiations due to dissociation of molecules and ionization of atoms. Between these bands are areas or "windows" where radiation of various wavelengths can penetrate to the lower atmosphere (Nicolet, 1952, p. 208).

Were it not for the screening effect of the oxygen and nitrogen of the atmosphere, the earth would be bathed in a much greater amount of short electromagnetic radiation (such as ultraviolet light) which would have an adverse effect on the present type of life. If most atmospheric oxygen has been derived from the photosynthetic activity of plants, the atmospheric shield of oxygen could not have existed prior to the development of photosynthesis (Gulick, 1955, p. 481; Rutten, 1962, pp. 48, 113). This would have allowed ultraviolet penetration to reach the surface of the earth and this energy would have been available to stimulate chemical reactions.

The early atmosphere is generally thought to have been without free oxygen; however, two hypotheses concern the major compounds present. Some investigators conclude that the primitive atmosphere consisted primarily of methane and ammonia (Rutten, 1962, p. 48; Haldane, 1961, p. 289; Mason, 1960, pp. 201-204). Another group does not believe that the supply of hydrogen was sufficient to form these compounds and cites their unstable nature with even traces of oxygen present, such as might result from the dissociation of water molecules (Rubey, 1962, p. 383). This group also envisions an atmosphere consisting primarily of carbon dioxide and nitrogen gas (Rubey, 1962, pp. 363, 383; Mason, 1960, *idem*).

The lack of oxygen in the early atmosphere probably allowed electromagnetic radiation to penetrate to the earth's surface to provide energy for chemical reactions and molecular excitations. However, when oxygen reached an atmospheric content of one part per 100,000, it would produce an ozone layer capable of one-half of the shielding capacity of the present ozone layer (Kuiper, 1961, p. 26). Thus a protective shield would develop at an early stage against ultraviolet radiation. This would provide a protection against dissociation for organic molecules near the earth's surface (p. 20; fig. 24), since ultraviolet radiation possesses the energy necessary to break such bonds as C-O, C-H, and O-H (Gates, 1963, p. 333).

Molecular nitrogen, which absorbs radiation of less than 1000 A, would have restricted radiation of the shorter wavelengths if it were present in the original atmosphere. If molecular nitrogen were absent, then this radiation of less than 1000 A would not have been screened and it too would have penetrated to the earth's surface providing adequate energy for the chemical reactions necessary for mutation.

The development of an oxygenic atmosphere and, therefore, an oxygen-saturated hydrosphere, probably occurred between one and two billion years ago (Rutten, 1962, p. 113) in late Precambrian time; the Cambrian atmosphere almost certainly contained a significant oxygen content.

Organisms present before late Precambrian may have been anaerobic and possibly were subjected to a much higher ultraviolet radiation level than is experienced today. However, organisms below certain water depths were screened from ultraviolet radiation by the water even before the atmosphere became oxygenic. Later, ultraviolet radiation became screened from the earth when the atmosphere contained sufficient oxygen, and any mutating effects of higher doses decreased.

At the other end of the spectrum, solar infrared radiation is screened from the earth's surface by water vapor and carbon dioxide in the earth's atmosphere. These atmospheric components equalize the intense heat of the sunlit side of the earth and the extreme cold of the nighttime side (Gates, 1963, p. 335). Most plants and animals confine their biological activity to a temperature range of O° C to 60° C; therefore, a specific temperature range is normally necessary for growth and development (*idem*, p. 328). Should the temperature drop too low, all biochemical reactions would cease and if the temperature should become too high organic molecules would be destroyed causing death of the organism (*idem*, p. 348).

In the case of high velocity subatomic particles the depth of penetration is dependent upon the velocity, mass, and charge of the particle as well as on the atomic weight of the material penetrated. The higher the velocity the deeper the penetration; however, the more mass the particle contains the less deeply it can penetrate, but the greater is its ionizing capacity per distance traveled.

By giving up quanta of energy to electrons of the material through which they are passing, radiation particles excite and eject electrons from their paths. Materials experiencing electron-loss are ionized (primary ionization). Such an ionized state leaves the atom or molecule chemically active and it can subsequently enter into other chemical reactions. These subsequent chemical reactions produce most of the biological effects attributed to radiation—including mutation.

If the ejected electrons have received enough energy during primary ionization they may, in turn, produce secondary ionization in atoms along paths which branch off from the track of the primary ionization particle. The secondary electrons produced by this ionization are called delta rays (Lea, 1962, p. 27).

Organic substances form radicals when subjected to radiation. These radicals always appear when the same substance is subjected to radiation. Since primary ionization is a random process, the uniform results in the radicals produced must be the stable end product of reactions which are initiated by primary ionization (Smith, D. E., 1962, p. 584). Studies car-

ried out on irradiated organic crystals by electron spin resonance (ESR) demonstrate these uniform results (*idem*, p. 577; Cook and Wiffen, 1962, p. 292).

It is apparent that the enzymes containing the sulfhydryl (SH) group are the most radiation-sensitive enzymes (Errera, 1959, p. 700; Smith, D. E., 1962, p. 581). Even after small radiation doses, adjacent sulfhydryl groups can be oxidized and recombined to form disulfide (SS) groups. Thus adjacent molecules may be combined (Alexander, 1959, p. 187). Although the sulfhydryl group may not necessarily be altered by primary radiation, secondary electrons (radiation) may still cause molecular changes. Proteins containing the sulfhydryl group are essential in cell division (Hammett, 1929, and Rapkine, 1931 *in* Briggs and King, 1959, p. 562). The nucleus of the ovum is rich in proteins containing the sulfhydryl group (Briggs and King, *idem*). Three amino acids (cysteine, cystine, and methionine) contain sulfur; only cysteine contains the sulfhydryl radical. Cystine, which contains the disulfide radical, is an oxidation product of cysteine although it is also found intact in other compounds such as keratin, a protein present in hair (Fruton and Simmonds, 1961, pp. 57-58). Methionine contains its sulfur connected to a methyl group (CH_3). Thus because proteins containing the sulfhydryl group are important constituents of reproductive units and because the sulfhydryl group is capable of being ionized by secondary radiation, the radiation effects on this group may play an important role in some mutations.

The radicals formed after irradiation *in vacuo* are stable at room temperature in their crystalline state; in this form they can be preserved for years. However, when air saturated with water vapor is brought in contact with the radicals they immediately disappear. This disappearance also takes place if the radicals are dissolved in water. DNA and RNA irradiated radicals formed *in vacuo* are not affected by exposure to air that is not saturated with water vapor (Smith, D. E., 1962, p. 584). Therefore, in living cells which contain water, the life of these radicals is probably shorter, lasting not more than a few minutes (Gordy, 1955, and Fairbanks, 1957 *in* Errera, 1959, p. 700). Thus, while recombinations are possible, new combinations and cross-linkages may be formed (Errera, 1959, p. 701); such new combinations and cross-linkages could lead to mutations if they occur in areas vital to the reproductive process. The critical period for mutations to occur is during the few minutes when the newly formed organic radicals are either recombining or forming new units. New combinations of organic radicals in somatic cells (mutations) would not be transmitted to offspring but may, however, play an important role in the development of malignant growths (*idem*, p. 724).

Oxygen also has an effect on the reaction of material to irradiation. The presence of oxygen increases the severity of radiation damage; conversely, in the absence of oxygen only about one-third of the apparent radiation-induced chromosomal breaks appear, as compared to the breaks in the presence of oxygen. This is the so-called oxygen effect (Alexander, 1959, pp. 63, 166-168). This effect is observed in the response of animals to radiation in the active and hibernating states. Animals in hibernation can survive doses of radiation amounting to many thousands of roentgen before they are killed; when they are warmed they will react as though they had been irradiated in the nonhibernating state.

One roentgen produces 2.1 x 10^9 ion pairs in one cubic centimeter of air at 0° C, 760 millimeters of mercury; one roentgen causes approximately two ionizations per cubic micron of tissue; one milliroentgen = 1/1000 of a roentgen; r=roentgen and mr=milliroentgen.

Some hibernating bats are especially resistant to radiation, for they may receive 15,000 roentgen before they are killed which is 20 to 50 times the lethal dosage of other mammals. For other bats in the nonhibernating state when metabolic activity is raised and the bats are eating, the lethal dose is 700 roentgen (*idem*, p. 73).

This oxygen effect may possibly be interpreted to mean that animals with a high metabolism rate (therefore, a high oxygen utilization) would be more readily affected by radiation, both genetically and somatically, than would animals with a low metabolism rate. It might also indicate that during warmer periods, the increased metabolism of cold-blooded animals would make them more radiation-sensitive than the warm-blooded animals with a more constant metabolism. Such a susceptibility might, in part, explain eventual extinction of such poikilothermic animals as the dinosaurs at the end of the Mesozoic Era while the homoisothermic birds and mammals made the transition and subsequently became more diversified.

In the case of high-energy radiation, the cellular response to radiation is reduced "by a factor of 3 to 5" when the oxygen is decreased (Errera, 1959, p. 725). A reduction of oxygen does not affect the response of cells to densely ionizing particles such as alpha particles or neutrons (Bacq and Alexander, 1955 *in* Errera, 1959, p. 725).

Small mammals such as mice may be cooled to a few degrees above the freezing point, irradiated, and warmed to normal temperature a few hours later, increasing their radiation resistance two or three times by this means. This resistance is due to the fact that the cells contain very little oxygen while the animal is in the cooled state (Alexander, 1959, pp. 73-74).

Because of the high water content of most living cells the effect of radiation on water is important. Water is the principal constituent of all organisms; wood contains about 50 percent, vertebrates about 66 percent, and marine invertebrates as much as 99 percent (Mason, 1960, p. 218). In mammals the water content may constitute as much as 85 percent of the animal's weight and much of this water would receive the initial radiation and be ionized (Alexander, 1959, p. 181).

Pure water undergoes almost no decomposition when irradiated with gamma rays or beta particles. With an increase in dissolved materials the decomposition of water increases. Heavier particles decompose water to hydrogen peroxide which subsequently decomposes to form hydrogen and oxygen. When water is ionized by radiation, an electron is ejected from the water molecule leaving a charged water ion (H_2O^+); these ions are formed along the track of the particle (*idem*, p. 185). These ions react with uncharged water molecules to form the following products:

$$H_2O^+ + H_2O \rightarrow H_3O^+ + OH$$

The ejected electron will react in the following manner at a distance from the particle track:

$$e^- + H_2O \rightarrow OH^- + H$$
$$e^- + H_2O \rightarrow H_2O^-$$

The free hydroxyl (OH) and hydrogen (H) radicals which are produced by the ionized water molecule and

the free electron will unite to form a water molecule:

$$H+OH \rightarrow H_2O$$

They may also react:

$$H+H \rightarrow H_2 \uparrow \text{ (hydrogen gas)}$$
$$OH+OH \rightarrow H_2O_2 \text{ (hydrogen peroxide)}$$

These radicals can react with one another to form water:

$$H_2+OH \rightarrow H_2O+H$$
$$H_2O_2+H \rightarrow H_2O+OH$$

An impurity in the water which is capable of being either oxidized or reduced will impede the reverse process by which the water is reformed. Organic materials present will be oxidized by the hydroxyl radicals and carbon dioxide will be produced; the hydrogen will not have a chance to recombine with the hydroxyl to form water (Stephenson, 1954, pp. 226-227; Alexander, 1959, p. 184).

Organisms present in sea water would probably stand a better chance of having mutations, since ionization of the water would subsequently ionize the animals living in it and utilizing it in their circulation. Not only ionized material but hydrogen peroxide would be present to react with organic materials. However, because of the motion of water the chances for recombination of the radicals are greater in water (Smith, D. E., 1962, pp. 595-596).

It would appear that such reactions would primarily affect organisms living near the surface or frequently moving to the surface of the ocean from deeper regions. Deep marine organisms have frequently remained almost static morphologically throughout long geologic ages, while marine organisms showing the most change have either lived near the surface or had easy access to surface waters.

Isotopes present in water would be available for utilization in organisms. Schindewolf (1958, p. 277) cites evidence of beryllium-10 (Be^{10}) in sediments 5000 meters deep. The depth of this one atmospherically produced isotope demonstrates the availability of isotopes for incorporation in organic structures of deeper benthonic organisms. The presence of radioactive isotopes in organic structures will subject the organism to internal radiation and cause disruption of bonds. If isotopes are incorporated into genetic material and subsequently disrupt DNA, a mutation will have taken place. Beryllium-10 is presently produced in the atmosphere at a rate of two atoms per minute above each square centimeter of the earth's surface (Frisch, 1958, p. 4:30); an increase of isotope production would increase the availability of these isotopes for incorporation into organic structures.

MUTATIONAL EFFECTS

In order for radiation to alter structures in an organism and for the pattern in these altered structures to be transmitted to offspring, certain factors must exist.

1. The radiation must not be a lethal dose; the organism must survive in order to produce offspring.
2. The irradiated organism must be young enough to subsequently produce offspring; mutational effects on organisms which will not later bear offspring will not enter the mainstream of evolution.
3. The radiation must affect the reproductive cells (sperm and ovum), the organs which produce these cells, or the fertilized zygote if these mutations are to be transmitted, since these units function to transmit all characteristics to offspring. If they are altered and organisms later develop, the mutation will be faithfully reproduced (Errera, 1959, p. 724).
4. The mutation cannot develop a creature too incompatable with its environment or else it will not survive and the mutation or mutations which produced it will be eliminated.

The nucleus of the cell is especially sensitive to radiation and evidence suggests that the initial radiation injury occurs in cells undergoing active division (Alexander, 1959, p. 216). If the chromosome is severely damaged the cell will die and no mutation can occur; if a gene is damaged a mutant usually occurs. Gene mutations and chromosomal breakage are thought to be the result of fracture of the nucleic acid molecules in some manner (*idem*, pp. 117, 206, 216-218).

Chromosomal breaks are theorized to be of two types: first the rupture of weak ionic bonds which could recombine without external energy; second, the rupture of covalent bonds which are stronger and would require external energy to recombine (Errera, 1959, p. 710). The chromosomal breaks may recombine either as they were prior to irradiation, or in an abnormal manner; however, they may not combine at all. Any changes from the normal preirradiation order would alter the sequence of genes on the chromosome and produce mutations (*idem*).

Lea (1962) determined that 700 eV are necessary to break a chromosome (about 16,130 kcal/mole); that is, an ionizing particle must deposit 700 eV of energy when it crosses a chromosome. This amount of energy is thought to amount to twenty ionizations (Alexander, 1959, p. 61). At very low intensities the general function of cells is not destroyed but damage to the reproductive cells or the organs which produce them can result in reproductive cells that transmit any mutations that occur (*idem*, p. 121).

Errera (1959, p. 719) stated that 100 roentgen of radiation reaching a mammalian cell nucleus can produce damage in one to five genes per cell for each direct hit on cellular DNA; additional radicals formed could cause damage to other genes. The same dosage can damage one to five DNA molecules of mammals (Butler, 1956 *in* Errera, 1959, p. 707). Irradiation of 25 roentgen or less can cause alterations in the chromosomes of embryonic nerve cells (Gaulden *et al.*, 1954 *in* Errera, 1959, p. 710) as well as in plant tissues (Catchside, 1948, and Kaufman, 1954 *in* Errera, p. 710). Theoretically, radiation of less than one roentgen (almost 100 ergs/gram) would be enough to alter permanently a part of the DNA of at least one cell (Errera, 1959, p. 707); however, in order to penetrate and cause changes to deeper cells, such as those of larger animals, higher energies (shorter wavelengths) would be required.

In addition to DNA damage, radiation can alter the chromosome and change larger units than nucleic acids by causing chromosomes to adhere to one another so

that at cell division there is an unequal distribution of chromosomes. Since the process of cell division is disturbed the survival of the cell is at stake (*idem*, p. 711).

The enzymes necessary for production of DNA are quite sensitive to radiation; their activity may be stopped entirely by radiation doses which do not interfere with other cellular enzymes (Alexander, 1959, p. 64). These enzymes are most critical in cell division. If a DNA-synthesizing enzyme is inhibited by radiation, and other enzymes are unharmed during the process of cell division, the DNA will not divide and two chromosomes will not form. Usually this will halt further cell division but cells have been observed which continue to grow but not divide; since all matter of the cell functions except DNA production, these cells become large but are prevented from dividing (*idem*, p. 217).

SUMMARY

Mutations can develop at any stage along the line of an organism's growth from the development of the gamete through morphogenesis. If the mutations affect the gametes they will become hereditary; if they affect the developing embryo they normally will not become hereditary. Mutations of the gametes or reproductive cells must affect the nuclear material of the cells involved in order to alter the genetic code. Radiations apparently are able to penetrate the cell and cause alterations in the DNA sequence by either primary rupture of bonds, by secondary effects of ionization, or other alterations of the cell. The cell is most vulnerable to such alterations during mitosis and meiosis when the chromosomes condense. This is especially true during prophase when the chromatids are close together; an ionizing particle which ionizes one side of the strand has a good chance of also ionizing the other side because of their close proximity (Lea, 1962, p. 203). Other factors apparently cause such hereditary-producing alterations but at present radiation appears to be the most likely environmental source.

If the developing embryo is retarded or interfered with in any stage of its development the resulting organism may develop into a mutant; however, such a mutation is not necessarily hereditary.

A hereditary mutation which is a dominant will either be lethal or will manifest itself in the affected individual. Its continuation will be controlled by the environment. A hereditary mutation which is not lethal and which is recessive may be passed on to generations of offspring before it is manifested in a population. When it does appear its subsequent continuation will be determined by the environment; those characters that are most adaptable to the environment will be favored over all others since the individuals possessing them will be those most likely to survive and reproduce.

The deletion or substitution of a single nitrogen base in a particular cell-type can make major changes in the response of an individual to its environment (*e.g.* sickle-cell anemia).

Variations in organisms can develop suddenly from combinations of long-repressed recessive genes. Variations may also be produced by a slow but continuous process of environmentally selected mutations and genetic combinations.

Radiation is an important mutation-producing agent. There is no radiation level below which mutations do not occur; mutation rate is directly proportional to radiation dosage (Merrell, 1962, p. 354). A constant natural background radiation level exists which varies slightly from place to place and possibly has varied to a greater extent throughout geologic time.

NATURAL BACKGROUND RADIATION

RADIOACTIVITY

Natural radiation, exclusive of cosmic radiation and atmospherically formed radioactive elements, comes from radioactive elements within the earth. Of the more than 700 known radioactive isotopes approximately 50 occur in natural sources; of these, 40 or more radioactive elements of higher atomic number belong to one of three radioactive families known as the uranium, thorium, and actinium series (Gilreath, 1958, pp. 349-350; Frisch, 1958, p. 4:4). Of the main radioactive isotopes present on earth the more important are those of uranium-238, uranium-235, thorium-232, rubidium-87, and potassium-40; these decay respectively to lead-206, lead-207, lead-208, strontium-87, and calcium-40 and argon-40 (Kuiper, 1961, p. 14; Gilreath, 1958, p. 349). Table 3 is a list of some radioactive isotopes (both atmospherically-produced and terrestrial), the type of decay, and decay energies.

Areas of granite outcrop have higher background radiation than do areas containing sedimentary rocks. Radioactive components of most granites can produce seven microcalories of heat per gram per year (Hurley, 1962, p. 76). Sweden and Scotland, which have large areas of granite outcrops, have as much as 100 milliroentgen per year (p. 23) more background radiation than London which has about 0.1 roentgen per year or about 4 roentgen per generation (Alexander, 1959, pp. 126, 129). Tibet and Peru have as much as 300 milliroentgen per year more background radiation than England; however, the human population in these areas does not show more genetic anomalies than people

Table 3. Some naturally occurring radioactive isotopes.[1]

Isotope	Type of decay[2]	Half life[3]	Energy of radiation in MeV[4]	
			particles	gamma rays
H^3	β^-	12.262 y	0.01795	
Be^{10}	β^-	2.5×10^6 y	0.555	
C^{14}	β^-	5568 y	0.155	
P^{32}	β^-	14.30 d	1.712	
K^{40}	β^-,E.C.	1.3×10^9 y	1.32	1.46 (with E.C.)
Rb^{87}	β^-	6.2×10^{10} y	0.273	
Rn^{222}	α	3.825 d	5.486	0.510
Ra^{226}	α	1622 y	4.777 (94.3%) 4.589 (5.7%)	complex emission
Th^{232}	α	1.39×10^{10} y	3.98 (25%) 4.00 (75%)	0.055
U^{235}	α	7.13×10^8 y	4.58 (10%) 4.47 (±3%)	complex emission
U^{238}	α	4.51×10^9 y	4.18 (ground state)	complex emission

1Data from Frisch (1958).
2Type of decay:
α=alpha particle emission
β^-=negative beta particle emission
E.C.=electron capture
3Half life
d=days
y=years
4Million electron volts

elsewhere in the world. Alexander (*idem,* p. 126) suggested that since these are very primitive areas natural selection removes individuals with defective characteristics.

Snow absorbs gamma radiation which is emitted from the ground and thus reduces this surface radiation in the winter (Sievert, 1959, p. 74).

Uranium and thorium occur in acid rocks, primarily in granites and syenites (Gopal-Ayengar, 1959, p. 115). Uranium is chemically weathered from rocks and usually becomes diffused and absorbed as secondary uranium on carbonaceous material, phosphates, and clays. Thorium, on the other hand, is physically weathered and consequently occurs as detrital grains of primary thorium minerals (*idem,* pp. 115-116; Bell, 1955, pp. 99-100).

Thorium may accumulate in beach sands within crystals of monazite (the chief source of thorium oxide) along with such heavy minerals as rutile, zircon, magnetite, and ilmenite (Gopal-Ayengar, 1959, p. 117; Hurlbut, 1957, p. 300). Sands in the provinces of Minas Gerais and Bahia, Brazil provide commercial quantities of monazite (Hurlbut, *idem*) as do sands at Travancore-Cochin State, India. Sands in the 12 miles from Neendakara to Kayankulam, India contain one percent monazite with a thorium content from 10.5 percent to as much as 33 percent in restricted areas (Gopal-Ayengar, 1959, p. 117). The Brazilian concentration of thorium is about 5.6 percent.

In the Travancore-Cochin area external radiation exposure is due to beta and gamma radiation from uranium and thorium of the monazite and from radon and thoron (Rn^{220}) in the atmosphere. Alpha radiation is not considered an external hazard because of the short distances these particles travel (*idem*).

Radioactive elements and their products are taken into systems through water, food, and air and become permanent parts of these systems, where they emit internal radiation. Dust particles, to which are attached radioactive decay products, can be carried into respiratory systems where they act on the epithelium (*idem,* p. 118).

When radium, a product of uranium ores (Sneed *et al.,* 1955, p. 537), is taken into the system by organisms, it is stored principally in calcium areas, normally in the bones (Van Allen, 1952, p. 260; Alexander, 1959, p. 149). Such local doses of radiation being emitted from the bones, even in small quantities, will destroy the bone and induce cancer. No satisfactory way has been found to remove this material from the bone once it has been deposited (Alexander, *idem*).

Miners in the pitchblende mines of Schneeberg and Joachimsthal (Jáchymow), Austria have been subject to a disease called *"Bergkrankheit."* It has been recognized as a cancer caused by inhalation of the radioactive gas radon, first decay product of radium, which emits alpha particles. The mortality rate from lung cancer among these miners was 50 times that of the normal population (*idem,* pp. 148-149).

Radioactive elements formed by cosmic radiation include hydrogen-3, beryllium-7, beryllium-10, and carbon-14. Cosmic ray neutrons of high energy react with atmospheric nitrogen to form carbon-14. Lower energy neutrons of few MeV (p. 21) produce carbon-12.

$$_7N^{14} + {}_0n^1 \rightarrow {}_6C^{12} + {}_1H^3$$

Neutrons with thermal energies produce carbon-14.

$$_7N^{14} + {}_0n^1 \rightarrow {}_6C^{14} + {}_1H^1$$

The carbon-14 subsequently joins atmospheric oxygen to form carbon dioxide ($C^{14}O_2$). This compound is utilized by plants and animals and becomes a part of their systems where it accounts for about one percent of the background radiation (Arnold and Martell, 1959, p. 87). The effect of these particles emitted from carbon-14 incorporated in a DNA molecule could, theoretically, disrupt the molecular structure.

Studies of the incorporation of the radioactive isotope phosphorus-32 into organic structures in amoeba have demonstrated in the 31st generation the conversion of phosphorus-32 to sulfur-32 with the release of an electron. The remaining bonds of the phosphorus-32 atom will either rupture or a bond change will occur. In each case new small acid chains (*Nukleinsäure-Ketten*) will be produced in the chromosome (Schindewolf, 1954, p. 462).

The radioactive isotope of potassium-40 composes about 0.1 percent of all naturally occurring potassium. There are about 140 grams of potassium in the human body of which about 14 milligrams are potassium-40 (Frisch, 1958, p. 2:5). This isotope makes up about 3×10^{-4} percent of all mammalian bodies (Alexander, 1959, pp. 9-10). Potassium-40 emits beta particles and gamma rays at a rate which yields 27×10^{-6} calories per gram of total potassium per year (Hurley, 1962, p. 75) or about 4,000 disintegrations per second within the body (Frisch, 1958, p. 2:5).

The normal background radiation to which organisms are exposed may not cause abundant abnormal genetic changes. It may still, however, be responsible for tumors, cancers, and other nongenetic abnormalities when received in large enough doses, especially when it is ingested and subjects the body to constant doses of localized radiation.

The incorporation of radioactive isotopes into the gene structure, especially the DNA chain, would interfere with the function of the affected structure both by radiation and by rupture if the isotope should revert to another element. The percentage of organically incorporated radioactive isotopes would depend upon their availability; therefore, factors which increase radioactive isotopes, especially those of carbon, oxygen, hydrogen, nitrogen, and phosphorous, would assure their increased availability for organic combinations.

COSMIC RAYS

Cosmic radiation reaches the earth primarily from beyond the solar system. This radiation has a high energy density and consists of about 79 percent protons, 20 percent alpha particles, and 1 percent heavy nuclei (such as iron), and the radiation is comparable to that present in the neighborhood of stars (Wilson, 1961, pp. 273, 285). Electrons and gamma rays are negligible (Van Allen, 1952, p. 250). Most cosmic rays achieve energies of more than 500 million electron volts when they reach the earth's atmosphere; some have energies of more than a billion billion electron volts. Particles of very high velocities can penetrate the magnetic field of the earth and enter the atmosphere; secondary radiation from such high velocity particles reaches the earth's surface at all latitudes (Anderson, 1960, p. 64). Secondary radiation includes "neutrons, electrons, positrons, gamma rays, neutrinos, X-rays, slow protons, slow alpha particles, heavy recoil nuclei, μ-mesons (positive and negative), π-mesons (positive, negative, and neutral), and perhaps other types of mesons, in addition to surviving elements of the original primary radiation" (Van Allen, 1952, pp. 255-256). The energy from cosmic radiation which reaches the earth is about 10 watts per square mile, most of which is dissipated in the atmosphere with only a small part reaching ground level (Wilson, 1961, p. 280).

Cosmic radiation has a penetrating capacity greater than had been previously suspected. Radiation was detected at a depth of 15.2 meters below the surface of Muir Lake; the atmosphere above Muir Lake is equivalent to 7 meters of water. Thus the detected radiation had penetrated the equivalent of 22.2 meters of water or the equivalent of nearly two meters of lead (Stranathan, 1948, p. 470). Cosmic rays have been detected at a depth of 610 meters in salt mines (Winchester, 1961, p. 229).

The water-penetrating capacity of mu-mesons extends to depths of 1000 meters and under rock cover to the equivalent of 3000 meters of water if the vertical intensity is exceptionally intense (Schindewolf, 1958, p. 276). Such energy could affect not only organisms, if direct hits were attained, but also would produce isotopes, some of which could ultimately be incorporated into organic molecules subsequently leading to abnormal conditions and possibly mutations.

The average dose for cosmic rays in milliroentgen per year at various altitudes at the equator is given by Alexander (1959, p. 123) as follows:

Sea level	33 mr/y
10,000 feet	80 mr/y
20,000 feet	300 mr/y

The maximum cosmic ray variation between various points on the earth's surface is about two roentgen per 30 years; this does not include mountains with an elevation of over 4000 meters. Major variations in the amount of cosmic radiation reaching the earth are rare; therefore, for specific altitudes and geomagnetic latitudes the cosmic ray dose may be considered constant. "As to long-term variations, it seems highly unlikely that any major variations in cosmic radiation have taken place during the past 2000 years" (Sievert, 1959, p. 68).

Nevertheless, since excessive increases in radiation would not be expected to leave a record older than about 50,000 years (based on carbon-14 data), nothing definite can be established about periods of increased radiation before then. The results of such increases could appear in the fossil record as world-wide periods of increased organic change.

SOLAR PARTICLES

Solar particles are nearly always protons with minute numbers of alpha particles present. These particles are accelerated by solar flares (Anderson, 1960, pp. 70-71). During periods of sunspot activity the amount of solar particles which enter the earth's atmosphere is increased and these particles are caught in the earth's magnetic field. The velocity of these particles, with few exceptions, is much less when they encounter the upper atmosphere than the velocity of cosmic rays (*idem*, p. 64). "The number of [solar] particles decreases rapidly with the increase of energy" (*idem*, p. 70).

Protons with an energy less than 100 million electron volts cannot penetrate the upper one percent of the earth's atmosphere (*idem*, p. 67). Solar flares can eject particles with energies lower than 500 million electron volts.

SOURCES OF INCREASED RADIATION: THEORIES

Radioactive rocks, cosmic rays and solar emissions constitute the principal sources of natural background radiation which may be high enough to produce a constant low level of mutations in organisms. However, variations in the amount of such radiation could undoubtedly have a direct effect on the biosphere while not significantly affecting the lithosphere.

Radioactive minerals have emitted radiations with a slow but steady decline in intensity since their creation. The only increase in activity at the earth's surface would be achieved when radioactive materials are brought to the surface during periods of orogeny and volcanic activity, and by the addition of atmospherically-produced radioactive isotopes.

Radiation variations from extraterrestrial sources might vary for several reasons. At the present time most high energy cosmic and solar particles are shielded from the earth by the earth's magnetic field. Within this magnetic field is an area of trapped charged particles which produce a radiation band—the Van Allen belt (Rossi and Jastrow, 1961, pp. 63-87). The Van Allen belt is an external reflection of the earth's magnetic field. This vast belt approaches the earth at the polar regions and extends out from the earth in other regions; charged particles are caught in it and spiral back and forth from pole to pole. There is a "drizzling-out" of particles at the poles which increases during periods of high cosmic or solar activity (Sullivan, 1961, p. 132). There is little doubt that this belt is a reflection of the earth's dipolar magnetic field.

Paleomagnetic studies indicate "that the geomagnetic field has suffered extensive changes in earlier epochs" and may even have reversed itself (Vestine, 1961, p. 92). Although reversals of the magnetic field probably occurred during the Precambrian, there is no evidence that the magnetic field reversed between the Cambrian and the latter part of the Devonian Period. Thereafter, however, reversals probably occurred as often as every half million years; these changes may take about 10,000 to 20,000 years (*idem*, p. 93). Some lower Silurian rocks possess a magnetization almost opposite that of younger rocks (Gutenberg, 1951, p. 204).

Results of paleomagnetic studies on Permian, and to some extent Carboniferous rocks, show a definite variation from earlier periods. It has been speculated that the Permian field was not dipolar. All magnetic field directions for both European and North American Permian magnetism have the same polarity—although rocks of the Triassic Period, as well as some Carboniferous rocks, show reversals (Cox and Doell, 1960, p. 748). Since the Eocene Epoch (early Tertiary Period), the earth's average magnetic field has been "that of a dipole parallel to the present axis of rotation" (*idem*, p. 739).

The position of the magnetic poles has apparently changed through time and the poles are still migrating. The declination (angle between the magnetic north pole and geographic north pole) has "changed appreciably over the last century or so and is presumably changing still" (Lee, 1963, p. 240). Between 1815 and 1963 the

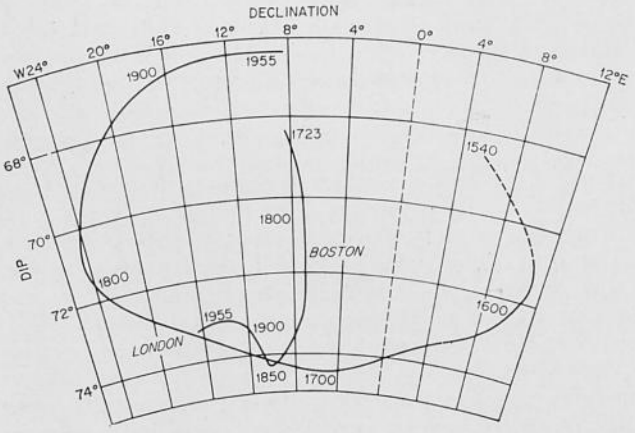


Fig. 25. Secular change in magnetic declination and inclination. *After* Bauer, 1902; Howe and Knapp, 1938; Deel and Howe, 1948; and U. S. Navy Hydrographic Office Charts *in* Howell's INTRODUCTION TO GEOPHYSICS, 1959 [p. 335]. McGraw-Hill. Used with permission.

declination at London changed 13° (*idem*). Since 1540 the direction of magnetic force has transcribed an oval which is apparently about three-quarters complete (fig. 25) and which suggests a cyclic variation of about 500 years (Howell, 1959, p. 335). Between 1922 and 1945 the north magnetic pole moved several hundred miles northwestward (*idem*). "The south magnetic pole appears to be drifting at a rather greater speed" according to calculations made between 1912 and 1945 (Vestine, 1961, p. 90).

In early Cambrian time (fig. 26) the north magnetic pole was apparently located in the Pacific Ocean. Since the Cambrian Period the pole has migrated through eastern Asia to the present position (Runcorn, 1962, p. 280; Lee, 1963, pp. 265-267).

Rocks 30 million years old or younger are magnetically oriented within several tens of degrees of the direction of the present field. Older rocks normally display magnetism which is not related to the present field direction (Doell and Cox, 1961, p. 273).

Reversals of the magnetic fields of stars have been observed; some demonstrate strong magnetic fields which oscillate in polarity (Pawsey and Bracewell, 1955, p. 214). The sun reverses its polar field (general field) every 11 years with the north magnetic pole becoming the south magnetic pole and vice versa (Sullivan, 1961, p. 174). In 1957 the sun's south pole shifted but it was not until the following year that its north pole shifted; thus, for a while the sun had two north or positive poles (*idem*, p. 187; Babcock, H. W., 1960, p. 59; Babcock, H. D., 1959, pp. 364-365). Such observations indicate that magnetic changes are definitely possible.

Supporting evidence from the reconstruction of climatic zones of the past (figs. 26, 27) indicates that poles and equatorial planes have changed position. The location of various sediments and fauna supports the concept of changing poles through time (Bain, 1963a, b).

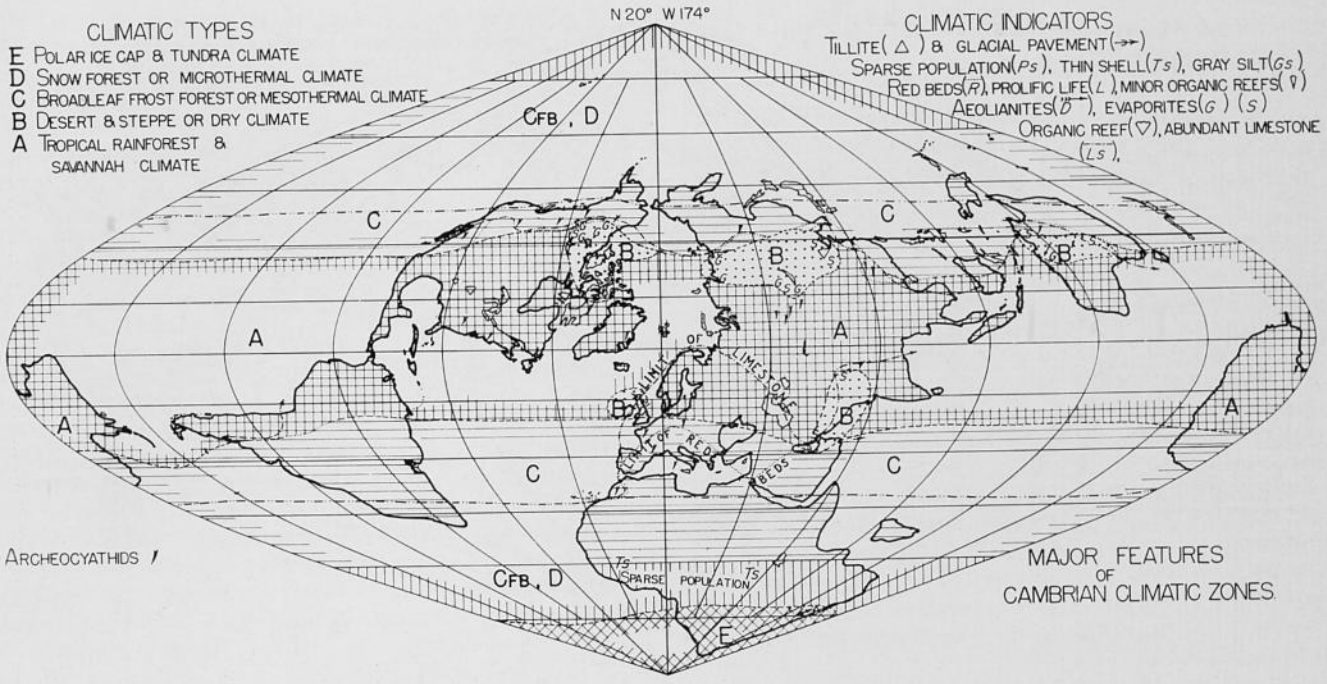


Fig. 26. Climatic zones of the Cambrian Period. *From* George Bain (1963) [with contributions by P. H. Heckel]. Climatic zones throughout the ages *in* POLAR WANDERING AND CONTINENTAL DRIFT, p. 117, Society of Economic Paleontologists and Mineralogists. Used with permission.

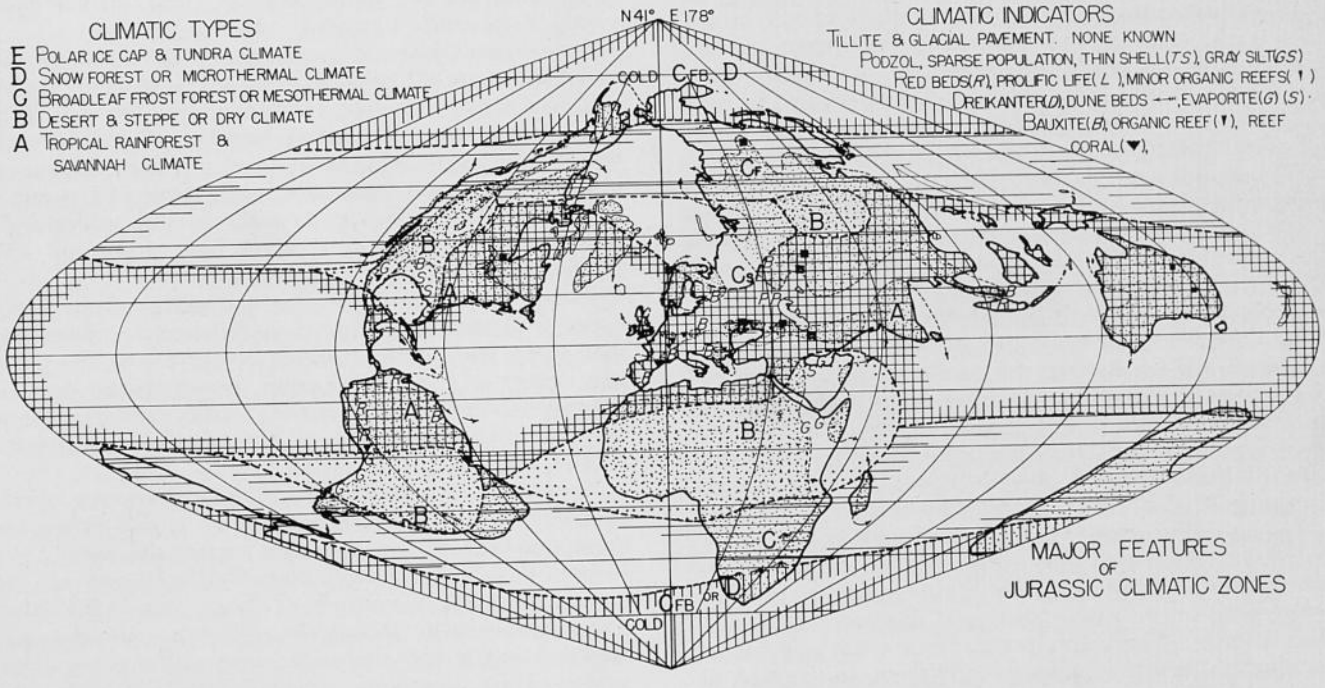


Fig. 27. Climatic zones of the Jurassic Period. *From* George Bain (1963) Climatic zones throughout the ages *in* POLAR WANDERING AND CONTINENTAL DRIFT, p. 108, Society of Economic Paleontologists and Mineralogists. Used with permission.

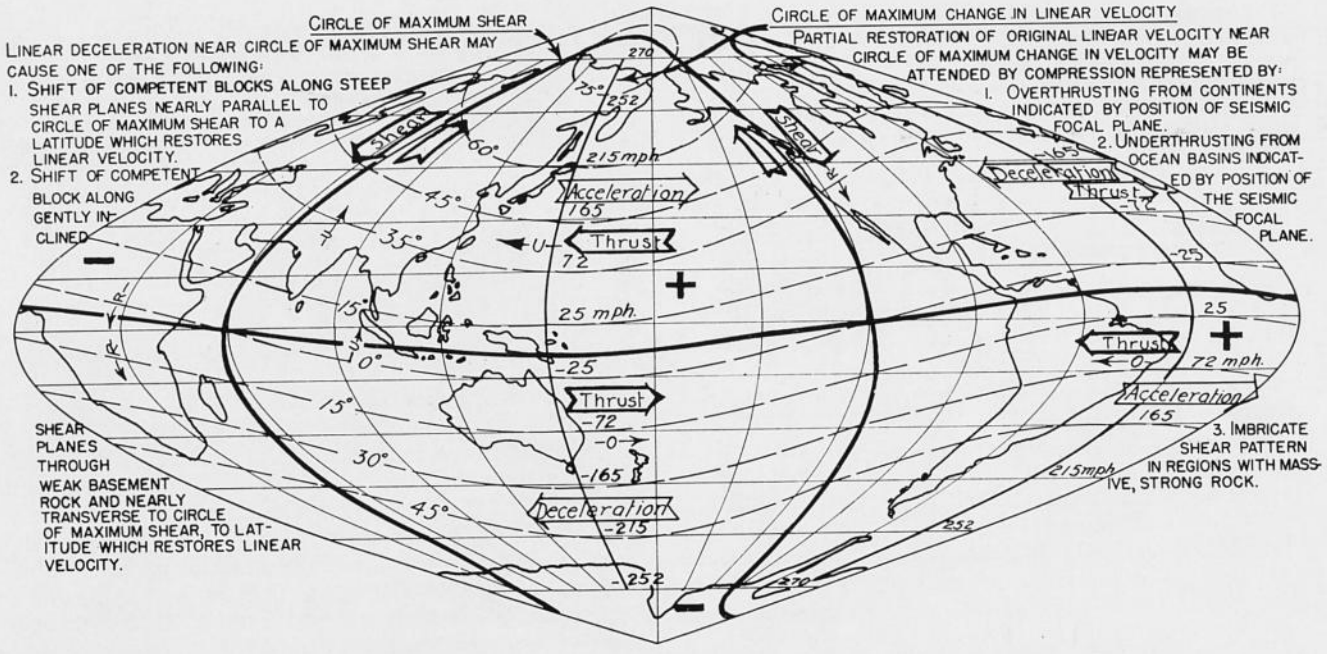


Fig. 28. Acceleration-deceleration features attending a pole shift, late Cenozoic Era. *From* George Bain (1963) Climatic zones throughout the ages *in* POLAR WANDERING AND CONTINENTAL DRIFT, p. 127, Society of Economic Paleontologists and Mineralogists. Used with permission.

If the magnetic field is controlled by dynamo action of the core and mantle, changes in the fluid motions in the earth's liquid conducting core (Vestine, 1960, p. 4), variations in rotation, heat differences, and size (if the core is growing or shrinking) could be reflected in the earth's magnetic field. This would, in turn, be reflected in the area surrounding the earth where particles are trapped. If there were periods during the past when the magnetic field was not dipolar, when it was weak, or when it was absent, much more cosmic radiation would reach the surface of the earth. Such an increase would cause many radiation deaths, as well as many mutations among the survivors and their offspring. Many of these mutations would become part of the species gene pools and provide variations for future change by later environmental adaptations.

Bain (1963b) has postulated the related tectonic features which might accompany a polar shift. Figure 28 demonstrates the locations of these postulated structural forces which may have been developed by polar migration during the Neogene Period (late Cenozoic Era). Among the resulting forces would be the shearing of the San Andreas and Baikal rifts, the northward movement of India to subsequently raise the Himalayas, the underthrusting of Armenia by the Russian Platform to raise the Caucasus, and the underthrusting of the Yukon Plateau by the Bay of Alaska to develop subsequently the Alaska Range (Bain, 1963b, p. 126). Such movements, if they do occur, would continually destroy or modify old environments and create new ones with consequent destruction of some populations. Therefore, populations would be forced to adapt to newly developing conditions, to migrate, or to become extinct.

Such tectonic changes in the crust could also bring radioactive materials to the surface causing increased radiation from this source.

Another possible source of increased radiation has been suggested by astronomers who believe it possible that every 200 to 300 million years the solar system may enter a supernova gas cloud which would bombard the earth with many times the normal cosmic ray dose (Shklovsky, 1960, p. 340; Sullivan, 1961, p. 211). Jordan (1955 *in* Schindewolf, 1958, p. 277) stated that supernovae bursts within 300 light years of the earth would cause such an increase.

Both cosmic rays and cosmic radio waves may develop in intense electrical fields possibly in relation to changing magnetic fields (Pawsey and Bracewell, 1955, p. 230). The sources of only a small number of cosmic radio waves have been identified. An intense source in Taurus is the remains of a supernova; the source in Cygnus is the result of two galaxies in collision 300 million light years from earth (*idem*, p. 234; Ryle, 1956, pp. 204-210).

Estimations based on the frequency with which supernovae appear in our galaxy indicate the probability that every few hundred million years the solar system may enter a region of cosmic density from tens to hundreds of times the present density and remain in such a region for tens of thousands of years (Shklovsky, 1960, p. 340).

Krasovsky and Shklovsky (1957 *in* Shklovsky, 1960) postulated the series of events which would follow the explosion of a star (supernova) near the sun. "For several days there would blaze forth in our sky an object of stellar magnitude −15 or even −20. After some hundreds or thousands of years a shock wave would pass through the solar system—the gaseous envelope of the supernova. We may readily satisfy ourselves that during this event our solar system would experience no palpable physical or dynamical changes. Far more important is the fact that in the course of a few thousand years the solar system would have found

itself in a region where the density of cosmic rays was tens, possibly even hundreds, of times as great as it is now. This could have most serious genetic consequences for a wide variety of species. For some species, these consequences might well be catastrophic; but for others the irradiation might be of little effect, or even favorable" (*idem*).

Studies of carbon-14 (produced by cosmic ray neutrons from nitrogen-14) indicate that there has been no significant increase of cosmic radiation in the last 30,000 years (Rankama, 1954, p. 225). Others extend this date back to 50,000 or more years and find no evidence of an increase of cosmic ray activity evident during this period. Because of the half life of carbon-14 (5,568 years) dates of more than 50,000 years based on carbon-14 are not valid. If a significant increase in cosmic radiation should interfere with the external features of the earth's magnetic field, it is possible that the orientation of magnetic minerals formed at that time might lack polar orientation. Therefore, poorly oriented or apparently random paleomagnetic data for a particular geologic age may be the result of unusually high cosmic radiation which may have temporarily distorted the normal geomagnetic field. It is generally concluded, however, that no physical or dynamic changes would occur except to some vulnerable organisms.

A third possible source of increased radiation is the sun. During the International Geophysical Year (IGY) in 1956, a cosmic ray burst 50 times normal was recorded in conjunction with a solar flare. It appeared that the particles were coming from a region near the sun, but not from within it; however, the particles were accelerated by the sun. If such a burst were recorded in the short time that solar and cosmic radiation studies have been carried out, then it seems also possible that even greater cosmic bursts could have encompassed the earth at various periods during its geologic history (Sullivan, 1961, pp. 203-205).

The sun also emits short electromagnetic radiation of 20 A or less during unusual solar activity; this radiation is capable of ionizing oxygen and nitrogen at the K-limit (Nicolet, 1952, p. 206). The solar spectrum from 1 A to 500 A has been studied very little (Tousey, 1961, p. 15). If radiation of this wavelength does penetrate as far as the earth's surface, its potential ability to affect organic material is great ($eV=12{,}400/\lambda$); the shorter the wavelength the greater is the energy available to interfere with chemical bonds.

SUMMARY

The purpose of this study was to review recent scientific discoveries which seek to explain biochemical aspects of reproduction and organic mutation, to consider generally these studies with respect to paleontology, and to examine factors present in the natural environment which may influence the reproductive mechanism to cause mutations. Mutation is a basic factor in the evolutionary process. Recent advances in biology, chemistry, and physics, which are contributing to a better understanding of life, need to be integrated with the vast paleontologic record if a total synthesis of the history of life is to be approached.

All scientists are aware that geologic time divisions such as periods and eras are in general characterized by the plant and animal record which appears in the rocks deposited during these intervals of time. The integration of this evidence from the time-dimension or geologic past is often omitted from modern studies of evolution by biologists, chemists, and physicists—the rich legacy of paleontology should not be ignored.

Although the first major development of the biologic world—the origin of life—is not preserved in the rock record, the first appearance of abundant fossils in late Precambrian and early Cambrian is well documented by fossil assemblages. There was undoubtedly a long developmental period before the appearance of organisms which possessed skeletal materials capable of preservation. Abundant paleontological data are available concerning the details of the evolution of life through the geologic past, but for the purpose of this review these data are not pertinent. Rather, the broad changes of major taxonomic divisions within the framework of geologic time illustrate for the general reader the evolutionary events which produced the myriad invertebrates, and the impressive vertebrate development—fishes, amphibians, reptiles, mammals and birds—as well as the very significant changes within the plant kingdom.

Environments, which continually change through time, force organisms which inhabit them to adapt or fail in their quest for survival. To adapt to a changing ecologic and chemical-physical environment, a species must utilize the characteristics possessed in its gene pool. If the characteristics necessary for survival are absent the group may become extinct; if they are present in a few individuals, this group will be favored reproductively enabling the favored characteristics to be perpetuated. Thus environments effectively direct evolution within the framework of hereditary and ecologic principles.

The basic unit of all life (except bacteria and virus) is the cell. In both plants and animals essentially the same type of cellular components occur. At the subcellular level there is an even closer relationship between all living things, since many of the same molecules and biochemical reactions occur in all living material. Among the most fundamental of these universally common molecules and reactions are those responsible for reproduction. Nucleic acid molecules of chromosomes control protein production and cellular reproduction for all organisms. The deoxyribonucleic acid molecule (DNA), with its code of four nitrogen bases, is ultimately responsible for maintenance and continuity of every species.

Changes or mutations can occur if the order of nitrogen bases along the DNA chain is altered. If these mutations occur in somatic (nonreproductive) cells the change will be restricted to the individual; if the mutations occur in reproductive cells (eggs, sperm)

or the organs which produce them, the change may be faithfully transferred to any subsequent offspring developing from these units.

After a mutation occurs its subsequent success will depend upon whether or not it enables the individual to adapt better to its environment. Most mutations are harmful and are eventually eliminated by the environment. Relatively few mutations are advantageous and, therefore, transmitted through the population.

Factors which can change nucleic acids include the incorporation of altered nitrogen bases into the DNA chain, abnormal cross-linkages between DNA chains, and rupture of bonds by the addition of energy. One mutating agent capable of penetrating cells and disrupting chromosomal structure is radiation. Normal levels of natural radiation, excluding man-made radiation, are neither sufficiently dense nor powerful enough to produce any but very sporadic and low orders of mutation. Nevertheless, mutations result in direct proportion to the radiation dose so that even very low amounts of background radiation are probably responsible for some mutations. Radiation includes both electromagnetic and charged subatomic particles.

Short electromagnetic radiation is screened from the surface of the earth by gases of the atmosphere; charged particles are deflected from the earth's surface by its magnetic field. Many of the radioactive isotopes which could be incorporated into organic structures are atmospherically produced and therefore would vary in abundance in accordance with their production rate.

Changes in the atmospheric composition should affect the transmission of electromagnetic radiation to the earth's surface. Since an oxygenic atmosphere has probably existed at least since the latter part of the Precambrian, increased energy from this source has probably been relatively unimportant. However, prior to the development of an oxygenic atmosphere, short electromagnetic radiation probably was a major contributor to the source of energy available at the earth's surface.

An increase in charged particles may occur for two reasons: changes in the earth's magnetic field and/or an increase in the number of charged particles reaching the earth if the solar system passed through a region of high particle density.

Increasing evidence points to an earth's magnetic field which has changed through time and may possibly have even reversed. Variations in the magnetic field would be reflected in the external field where charged cosmic particles are trapped and deflected. Thus if the field were weakened or modified, the particles now being deflected could reach the earth's surface and provide energy for mutations and other organic changes.

Areas of high particle density are produced by supernovae explosions. Estimations based on the frequency with which supernovae appear in our galaxy indicate the probability that every few hundred million years the solar system may enter a region of cosmic ray density from tens to hundreds of times the present density and remain in such a region for tens of thousands of years. Such energy bursts would undoubtedly stimulate biochemical reactions including mutations.

Evidence based on carbon-14 studies indicates that no radiation increases have occurred in the last 50,000 years. However, because of its half life, carbon-14 can not be used to measure atmospheric radiation beyond the 50,000 year limit.

An adequate modern interpretation of the history of life must take into account not only classic paleontologic, paleoecologic, and stratigraphic evidence, but also vital information and ideas from other scientific fields. The fundamental biochemical structures and processes, which provide species with the mechanisms for life and continuity of the gene pool, have undoubtedly been affected throughout time by factors in the organism's environment. Not only does the changing environment of the organism direct selection of available genetic characteristics which enable a species to adapt to specific local conditions, but other, perhaps world-wide, factors such as radiation continually modify or mutate the basic biochemical material to provide a changing supply of genetic characteristics within the population. Thus, species are provided a means whereby they attempt to adjust to a dynamic world. In addition, the effects of magnetic, electrical and radiation fields on the evolution of organisms through indirect biochemical and ecologic direction are largely unknown.

The unique and important role of geology in integrating, interpreting and stimulating studies within the many areas where geologic processes, time, and earth history are involved is a major challenge in the future of the science.

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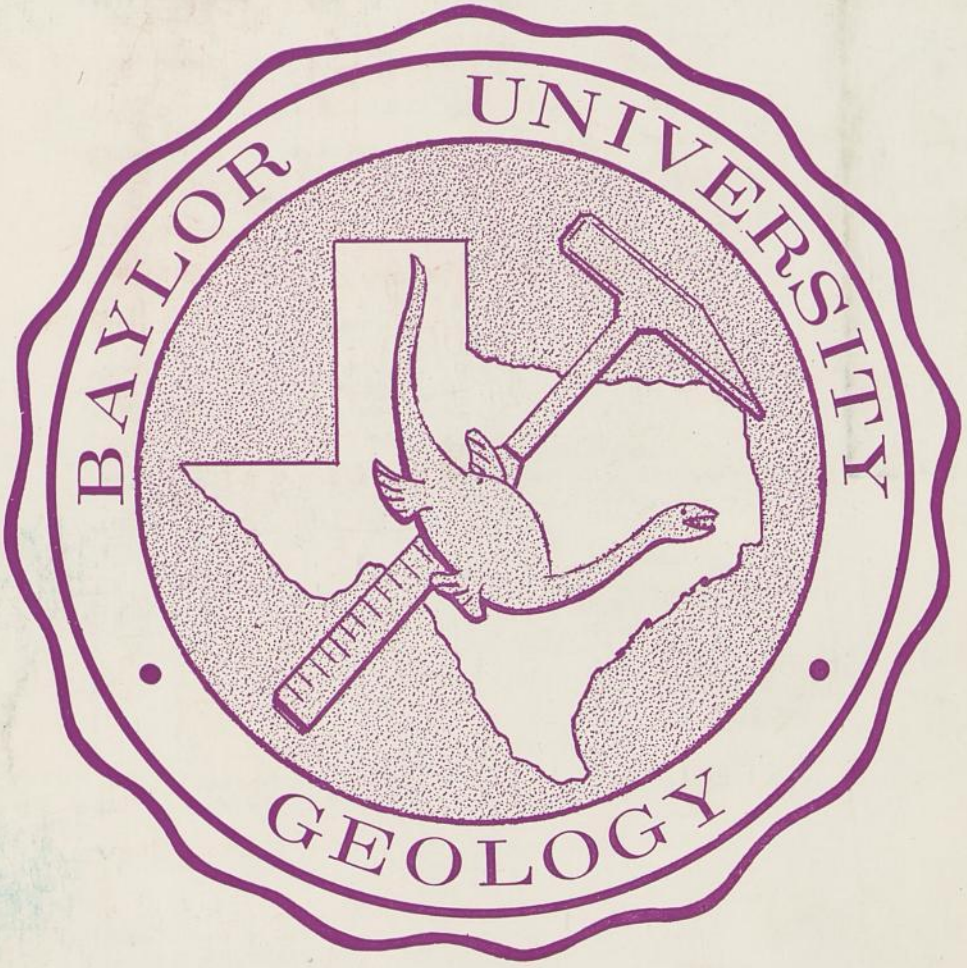
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