BIOLOGY AND GEOLOGY

10th grade (4º ESO)

Name and surname _____ Group: ___

BIOLOGY

UNIT 1. GENETICS

The study of how hereditary characters are transferred from one individual to another. Let's review some basic concepts which are fundamental to understand the unit better.

1.1. NUCLEIC ACIDS

Nucleic acids are macromolecules composed of monomers called **nucleotides.** (Composed of C, H, O, N and P) There are two types of nucleic acids: **ribonucleic acid (RNA)** and **deoxyribonucleic acid (DNA)**. All living organisms contain both types of nucleic acids. Viruses (which as you should remember are not considered to be living organisms) only contain one type of nucleic acid.

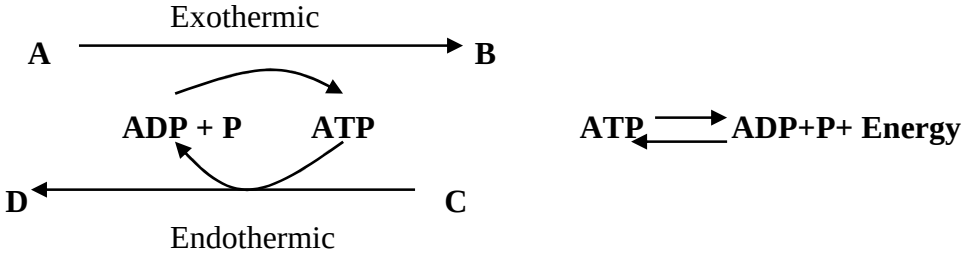
Nucleotides:

A nucleotide is composed of three parts:

1. A **phosphate group** (P)
2. A pentose (a five-carbon monosaccharide), which can be: **ribose (R)** or **deoxyribose (D).** Nucleotides which contain a ribose are called **ribonucleotides**, and those which contain a deoxyribose are called **deoxyribonucleotides.**
3. A nitrogenous base: **adenine (A), guanine (G), cytosine (C), thymine (T) and uracil (U).** The first three bases are common to both types of nucleotides. In ribonucleotides, the fourth base is always uracil (never thymine); while in deoxyrybonucleotides the fourth base is always thymine (never uracil).

The bond between the sugar molecule and the nitrogenous base is called a **nucleoside.**

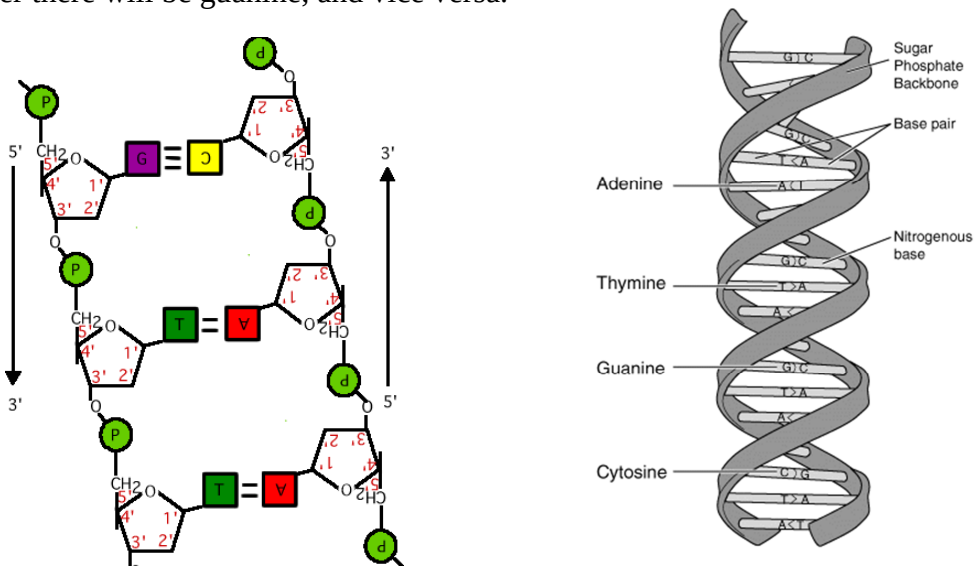
Within cells there are other types of nucleotides which do not make up nucleic acids. Among these types of nucleotides ATP (adenosine-triphosphate) stands out. Adenosine-triphosphate is the energy carrier molecule in living organisms. This is because the chemical bond between the second and the third phosphate contains a great amount of energy (it therefore needs lots of energy to be formed, but when it breaks releases lots of energy; when ATP is hydrolyzed to ADP + P energy is released. This energy can be used to carry out any kind of biological work, such as motion, transport across membranes, etc.) When, in a chemical reaction, energy is released (exothermic), organisms use it to make ATP from ADP and P. On the other hand, when organisms need to carry out a chemical reaction where an energy supply is needed (endothermic), ATP will break into ADP + P releasing all the energy stored in the bond.



Two nucleotides joined together gives rise to a dinucleotide. Many nucleotides joined together form a **polynucleotide**. Nucleic acids are polynucleotides. RNA is a polynucleotide made of ribonucleotides, whilst DNA is a polynucleotide made of deoxyribonucleotides.

DNA

Deoxyribonucleic acid is found in the nucleus of eukaryotic cells, and in the cytoplasm of prokaryotic cells (we will see this later on). It consists of two polynucleotide chains or strands, as they are called, that spiral around an imaginary axis to form a double helix (a spiral staircase shape). The two strands of the double helix are **complementary** to each other. Only certain bases are compatible with each other: Adenine will only fit next to Thymine and Cytosine will only fit next to Guanine. Therefore, if in one of the strands there is an adenine, in the other strand there will be a thymine, and vice versa. In the same way, when in one strand there is cytosine, in the other there will be guanine, and vice versa.



(Scheme taken from → http://www.ageds.iastate.edu/meat/images/dna2.gif)

Additionally, the two strands are **anti parallel** to each other; one is inverted with respect to the other. One of them goes from 5' to 3' while the other from 3' to 5'. This double helix structure described by Watson and Crick is very stable due to the hydrogen bonds between the nitrogenous bases: 2 hydrogen bonds between A and T, and 3 hydrogen bonds between G and C.

Function: DNA is the most important molecule in living organisms since it contains the genetic material of the organism, which will also be transferred to its descendants. DNA is the main component of chromosomes which are long coils of double-stranded DNA, which contain the genes. A gene is a portion of DNA- of chromosome- responsible for a particular hereditary character (the unit of hereditary information); or, as we will see later on, responsible for protein synthesis. Each gene determines the synthesis of a particular protein.

RNA

Ribonucleic acid is a single-stranded polynucleotide molecule. There are three types of RNA in living organisms: ribosomal RNA (rRNA), transfer RNA (tRNA) and messenger RNA (mRNA).

Function: the function of RNA is to aid in protein synthesis, and therefore in the expression of the genetic information encoded in DNA.

1.2 THE GENETIC INFORMATION

As we have already said, the genetic information is found in the DNA. But, how? This information is encoded in a particular **sequence** or order of its nucleotides. You could compare it to the order of the letters in a sentence. Every living organism is characterized and defined by a determined order of such nucleotides.

The information encoded in DNA is organized in small units called **genes**. A gene is a portion of DNA that carries the information for a particular character of an individual (e.g. eye color). Genes are located one after another along the filaments of DNA. Each DNA filament is a **chromosome.** In the nucleus of each and every cell of an organism there are a determined number of chromosomes. Each species of organisms has its own number of chromosomes, which will be the same in all of its cells, with the exception of sex cells or gametes. (Gametes contain half the number of chromosomes than the rest of the cells). For example, we humans have 46 chromosomes inside each of our cells (23 pairs). A chimpanzee has 48 chromosomes (24 pairs) inside each of its cells etc. Therefore, all genes a species contains are found in the chromosomes (the entire set of genes of an organism is its **genome**). In humans, each cell contains about sixty thousand genes (60 000), which are located throughout the 23 pairs of chromosomes. The genetic information of those genes is exactly the same in each cell of the individual. However, not all cells in our body are the same nor do they carry out the same functions. That is because not all of these genes are used by any one cell at any one time. Just a few genes will be 'switched on' in any one cell at any one time and the rest of the genes remain 'switched off'. For example, a nerve cell will express a set of genes that will not be expressed in a muscle cell and vice versa.

How is the genetic information expressed?

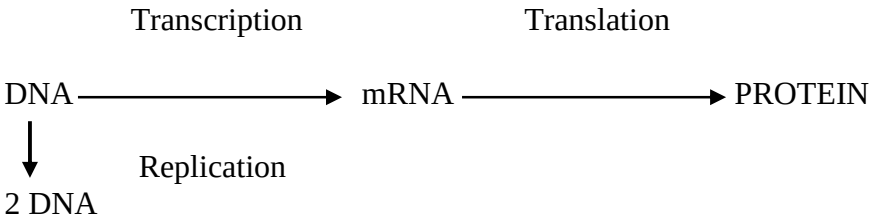
We have said that each gene – portion of DNA- contains the information of a particular character, such as eye color. Now, how can a piece of DNA, with its particular nucleotide sequence, have information to determine that a person will have, for example green eyes? The answer lays in proteins; which are the molecules that carry out cellular functions. What genes really have are chemical instructions for protein synthesis. Each gene determines the synthesis of a particular protein. As we will see later on, the synthesized protein will be responsible for the expression of that particular character, such as the green-colored eyes (refer to protein synthesis).

As we have seen, in order for the genetic information contained in genes (in DNA) to be expressed, such information must be passed down to proteins. Proteins are synthesized in the ribosomes, which are in the cytoplasm of the cell, so the information must somehow get to them. This process, known as protein synthesis, is carried out with the aid of other molecules (mRNA, rRNA and tRNA), and it has two steps (phases):

1st **Transcription**: the information contained in the DNA –in the gene- is transferred to a molecule of mRNA (transcription takes place in the nucleus of the cell). The mRNA leaves the nucleus taking the information to the cytoplasm of the cell.

2nd **Translation**: Once in the cytoplasm the mRNA joins with the organelles known as ribosomes, which will translate the information into a protein. There will be a different protein for each gene and each protein will be responsible for a particular character of the individual- green colored eyes-.

This is the first property of DNA,- transcription and translation- and it is the process by which the genetic code is expressed.



Additionally, DNA presents another property only present in living organisms; it can make copies of itself: **replication.** It is thanks to this property that a cell can divide and make two daughter cells that are identical to each other and identical to the mother cell.

Some times, when DNA replicates **mutations** or alterations of the information take place. These mutations are responsible for the introduction of new characters in organisms, which with time, will lead to the evolution of the species.

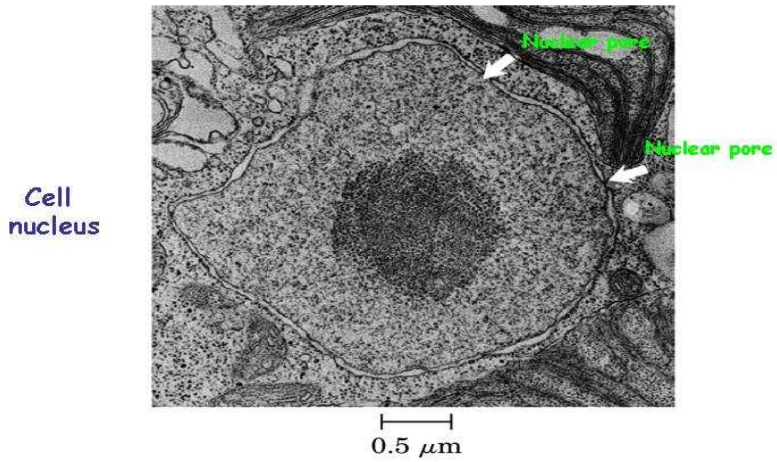
1.3 THE NUCLEUS AND THE CHROMOSOMES

Prokaryotic cells do not have a true nucleus, therefore, the genetic material is found floating in the cytoplasm of the cell. Additionally, the DNA of prokaryotes doesn't condense into chromosomes. Therefore, the following information refers only to eukaryotic cells.

Structure: The genetic material (the DNA) is found in the nucleus. It is composed of: *A **nuclear envelope** which encloses the nucleus, separating its contents from the cytoplasm. It is a double membrane perforated by pores that regulate the entrance and exit of certain large macromolecules and particles (nucleus-cytoplasm). *A liquid known as the **nucleoplasm.** ***The **nucleolus**, roughly spherical and which function is the synthesis of ribosomes. *The **chromatin**, long thin fiber of DNA associated to proteins. (Only when the nucleus prepares to divide does the DNA condense into chromosomes).

Some cells can have more than one nucleus (muscle cells) and sometimes a nucleus can have more than one nucleolus.

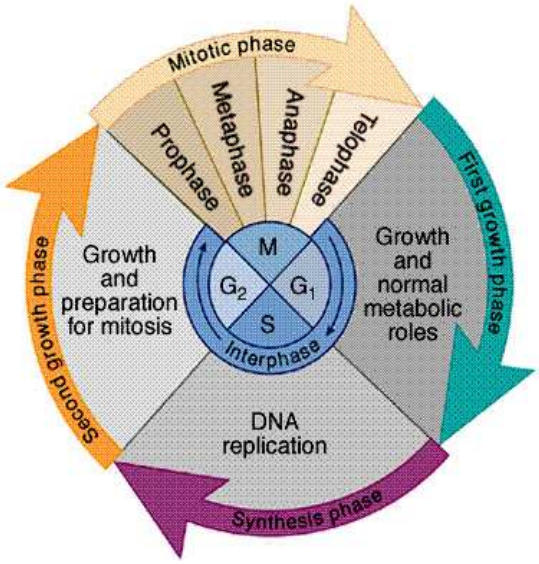
Function: The nucleus controls all cellular processes, as it contains the DNA with the genetic information of the cell. The nucleus controls protein synthesis in the cytoplasm by sending molecular messengers in the form of RNA. The mRNA is synthesized in the nucleus according to the instructions provided by the DNA (transcription). The mRNA leaves the nucleus via the nuclear pores and once in the cytoplasm it attaches to ribosomes, and the genetic message is translated into proteins. Proteins will carry out the different cellular functions (enzymes that catalyze me-tabolic reactions, transport of substances, etc.).



(Scheme taken from → http://www.science.org.au/sats2004/images/kobe7.jpg)

Chromosomes and the cell cycle

The cell cycle is the period that goes from the moment the cell has just been formed (from the division of the mother cell into two), to the point where the same cell divides in two daughter cells. The period when the cell is not dividing is called **interphase**. Therefore, the cell cycle consists of two successive **mitotic divisions** alternated with a much longer **interphase** or growth period. Interphase consists of three periods of growth, the first period is called G1, followed by the S phase, during which the chromosomes replicate; and the last part of the interphase is called the G2 phase. This is followed by cellular division (mitosis divides the nucleus and its chromosomes, and cytokinesis divides the cytoplasm, producing two daughter cells).



(Scheme taken from→ http://bhs.smuhsd.org/bhsnew/academicprog/science/vaughn/Student%20Projects/Paul%20&%20Marcus/cycle.jpg)

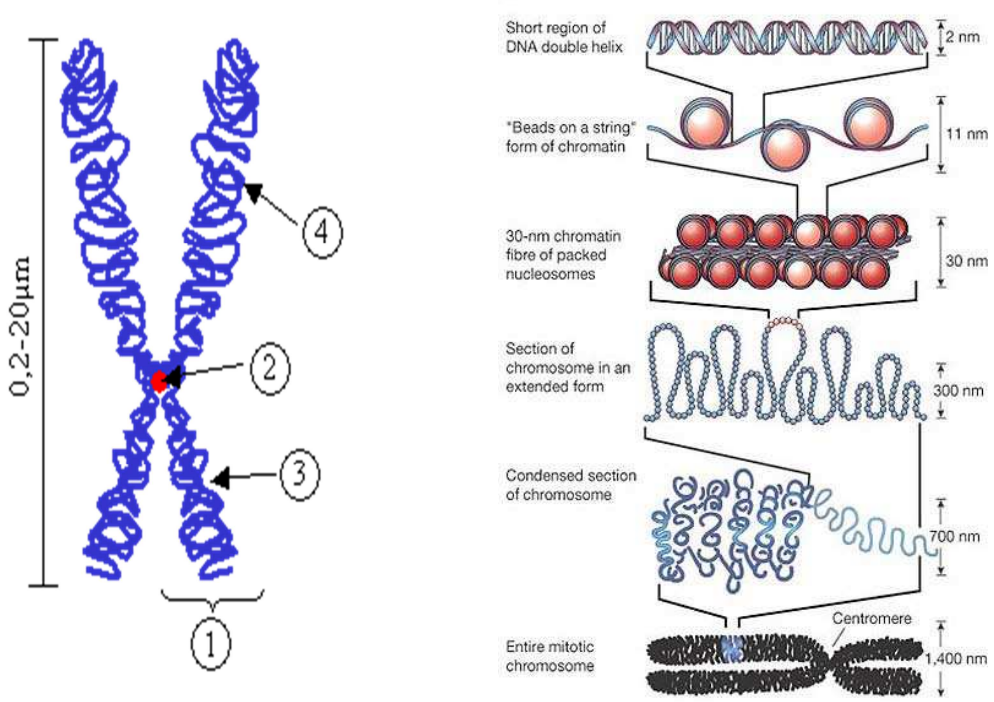


Figure 1: Chromosome. (1) Chromatid. One of the two identical parts of the chromosome after S phase. (2) Centromere. The point where the two chromatids touch, and where the microtubules attach. (3) Short arm. (4) Long arm.

(Schemes taken from → http://www.biocrawler.com/encyclopedia/Chromosome and http://home.planet.nl/~gkorthof/images/chromosome_structure.jpg)

During the interphase the long filaments of DNA-protein complex called **chromatin** are spread through the nucleus. The proteins associated with the DNA are called **histones.** During all three phases of the interphase the chromatin is transcribing itself (therefore synthesizing RNA, mRNA, t and r). It is an active period. However, when the cell is getting ready to divide, the chromatin condenses into compactly folded and coiled **chromosomes**. These chromosomes now do not transcribe. The cell copies its entire genome by duplicating its chromosomes during the S phase, after replication each chromosome consists of two **sister chromatids** (each a collection of the same genes present in single copy prior to replication). The sister chromatids are held together by a structure called the **centromere**. The end parts of a chromosome are called the **telomeres**.

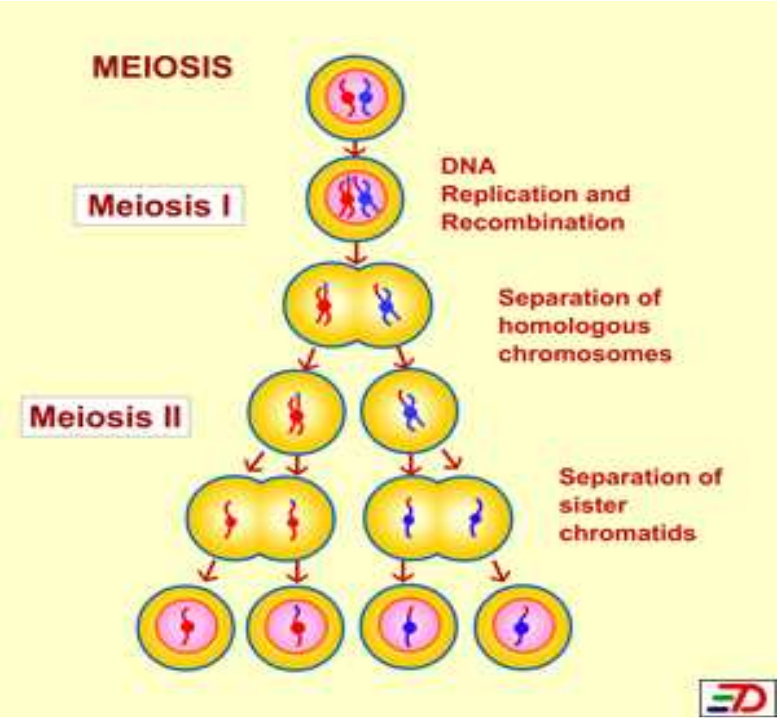
Once cellular division has come to an end, each daughter cell has one sister chromatid from every chromosome (see mitosis later on) so both daughter cells carry identical information. As the interphase starts in each of the new daughter cells, chromosomes start to uncoil going back to the thin fiber chromatin. The chromatin is so thin it can not be seen very well. It starts again to transcribe, then during the S phase it replicates to be ready for the next mitotic division.

The majority of the cells of an organism are **diploid (2n)**; they have two sets of chromosomes. Chromosomes go in pairs (**homologous**), of the same size and shape, and have the same information for the same characters but they are not identical. In a particular place of a chromosome (the same place for both of the pair) we will find the information for hair colour, but in one chromosome we could have the allele for black hair and on the homologous chromosome the allele for blond hair. Each homologous chromosome comes from one of the parents. To summarize, we can say that a diploid cell has **2n chromosomes**, where n indicates the number of one set of chromosomes. This number is characteristic of each species.

Let's use humans as an example. In all normal body cells (somatic cells) we have 2n chromosomes as these cells are diploid (2n is 46, therefore, n is 23). However, the number of chromosomes in a **gamete** – sperm and ovum- is the **haploid number n.** Cells that are haploid only have one set of chromosomes. When fertilization takes place during sexual reproduction, two haploid gametes fuse together to restore the diploid number in the zygote (46 in humans).

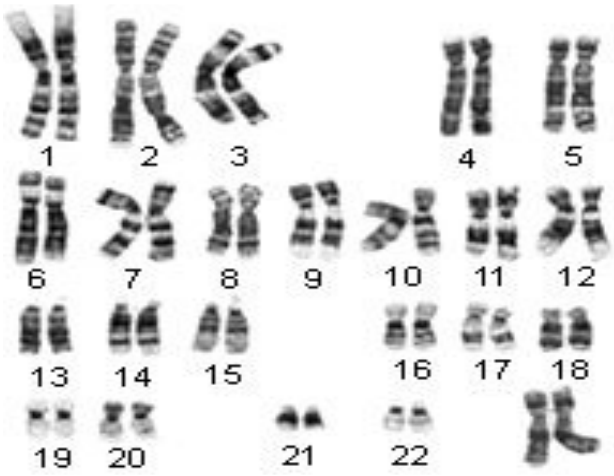
When normal body cells – somatic cells- divide, they do it through a process known as **mitosis**. First of all, cells will replicate their DNA, their chromosomes. Therefore, they will have 4n chromosomes (92 in humans) and then 23 homologous pairs will go to each new daughter cell. Therefore, daughter cells are identical to each other and to the mother cell (all diploid cells).

However, sex cells, those that make gametes, divide through a process known as **meiosis**. Again they will first replicate their DNA, having 4n chromosomes, but they undergo two divisions. From the first division 2 cells are formed each having 2n chromosomes, which again divide resulting in a total of four haploid cells (n), each different from the other and different from the mother cell. When gametes fuse during fertilization, the characteristic 2n of the species is restored.



(scheme taken from → http://www.moe.gov.sg/edsoftware/ir/files/bio-meiosis/images/introduction/image3a.jpg)

In mammals and other living organisms there is a chromosome pair that determines the sexual characteristic of the individual. These are called **sex chromosomes X and Y.** Females have two X chromosomes and males have an X and a Y chromosome. The rest of the 44 chromosomes (in humans) are called **autosomes (autosomal chromosomes).** The group of chromosomes of a cell is the karyotype. Chromosomes can be classified by their homologous pair, and ordered by size and shape. The order obtained is called an **idiogram**. Using specific staining techniques, **banding** of chromosomes is obtained which allows us to pair the homologous chromosomes, as well as to group them by decreasing size. This also allows us to determine some genetic diseases.



(scheme taken from → http://www.colblindor.com/wp-content/images/karyotype.jpg)

1.4 CELLULAR REPRODUCTION

Cells reproduce by **cellular division**. This process is called **mitosis** in eukaryotes, and **binary fission** in prokaryotes. This process gives rise to two daughter cells that are genetically identical to each other and to the mother cell. (Refer to the **cell cycle**).

For unicellular organisms, the cell cycle represents their life cycle, therefore, when the cell divides a new organism is produced. On the other hand, in multicellular organisms, the division of individual cells allows for growth of the organism, repair of damaged tissues, etc, but in order for the organism to reproduce it needs to make gametes; special cells that are produced through a division process called **meiosis**.

As we have already seen in the cell cycle, in order for the cell to divide it needs to replicate its genetic material (DNA), which happens during the S phase.

Reproduction in prokaryotes

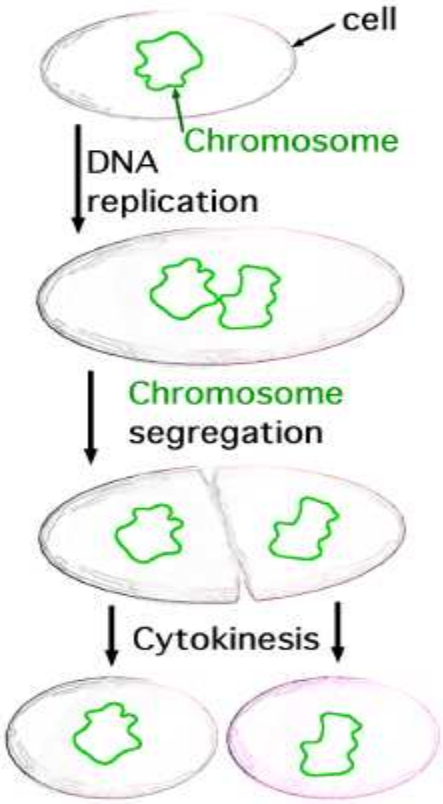
A scheme of reproduction by binary fission:

1. Bacterial chromosome or DNA **replication.**
(Each circular strand of DNA then attaches to the plasma membrane).

2. The cell elongates causing the two **chromosomes** to separate to opposite sides of the cell.

3. The **plasma membrane pinches inward** (invaginates) to divide the cell in two.

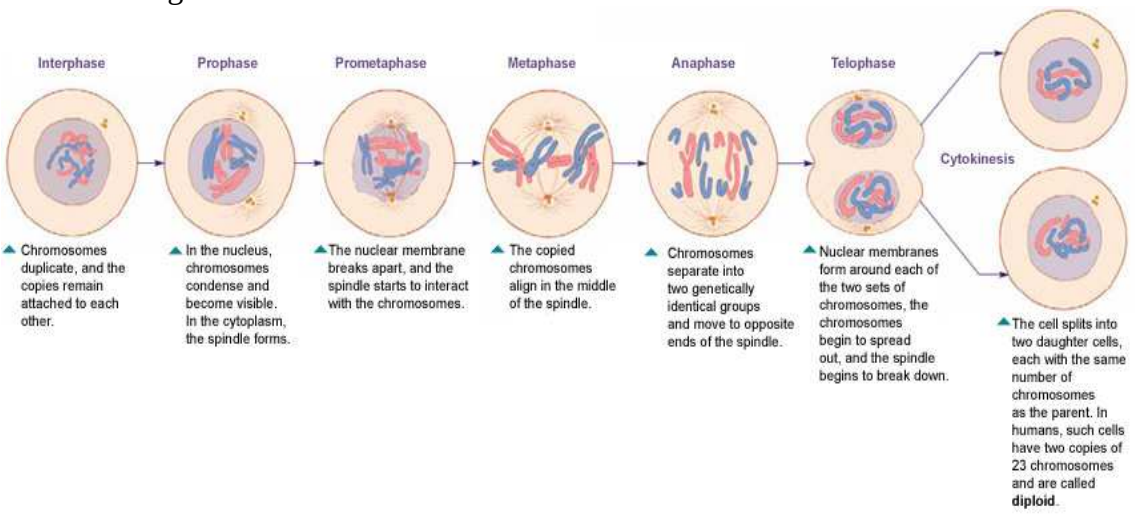
4. Two **daughter cells** are formed that start to grow starting a new cycle.



(scheme taken from → http://www.biocrawler.com/w/images/0/00/Binary_fission.png)

Cellular division in eukaryotic cells: Mitosis

Cellular division in eukaryotic cells consists of two phases: first the nucleus divides (**mitosis**) and then the cytoplasm divides (**cytokinesis**). The following scheme shows the stages of mitotic cell division in an animal cell.



(scheme taken from → http://images.google.es/imgres**)**

Differences with plant cells:

a. There are no centrioles in plant cells.
b. Cytokinesis, in animal cells occurs by a process known as cleavage, where the formation of a cleavage furrow pinches the cell in two. However, cytokinesis in plant cells, which have walls, is very different. A structure called the cell plate made of cellulose will separate both daughter cells. The cell plate will later give rise to the new cell wall.

SUMMARY: mitosis is a cell reproduction process by which multicellular organisms regenerate lost or damaged cells, or simply make new cells. In the case of unicellular organisms it can be considered as asexual reproduction. **It does not generate genetic variability,** as the new daughter cells are identical to each other and to the mother cell. This is how all somatic cells divide (epithelial cells, liver cells, etc. All but sex cells).

Meiosis

Concept: it is a type of cellular division **needed** in organisms with sexual reproduction. In sexual reproduction, there is **fertilization**, which is the fusion of haploid gametes to restore the diploid number in the zygote. The zygote, by successive mitotic divisions gives rise to the multi-cellular organism, which cells are therefore diploid, all containing identical genetic information.

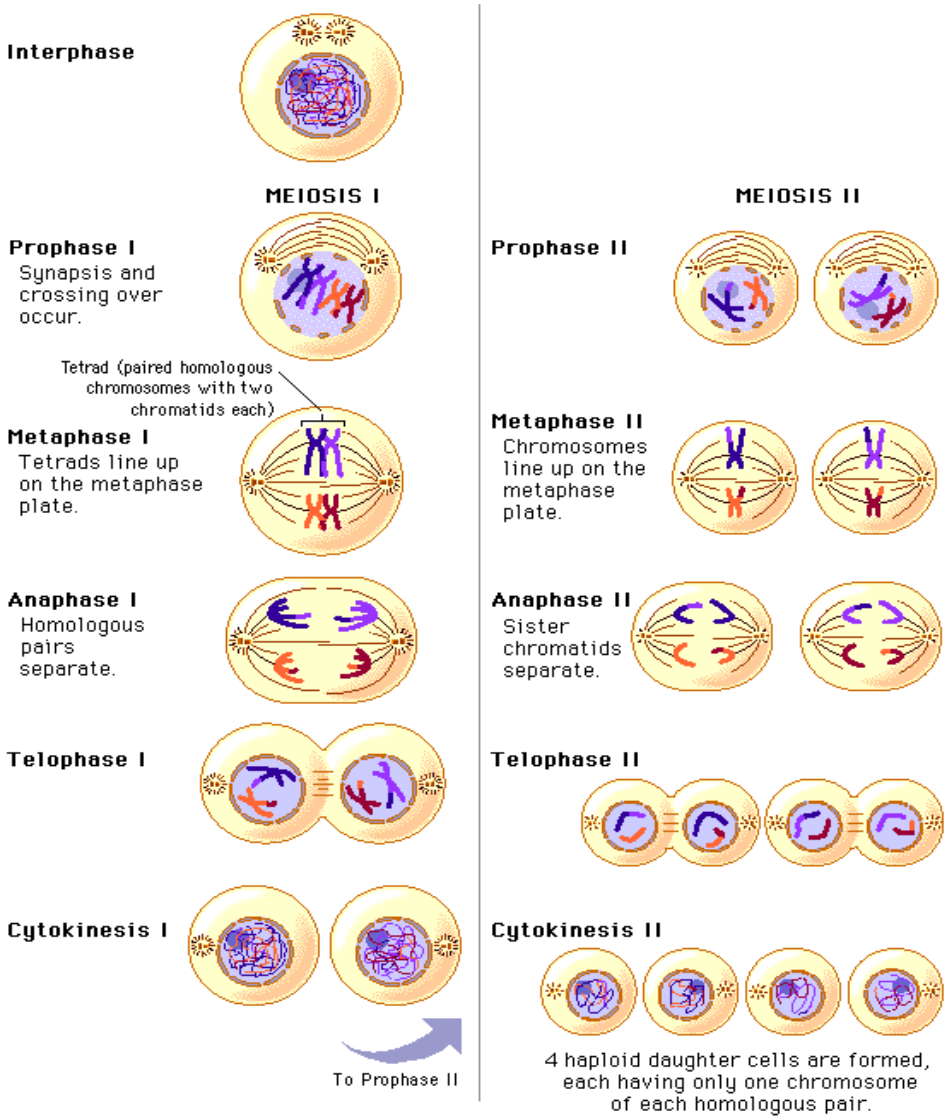
If the gametes were also produced by mitosis, these would be diploid and genetically identical. During fertilization, the fusion of these diploid gametes would produce a tetraploid (4n) zygote, which would give rise to 4n organisms. In the same line, these 4n organisms would produce 4n gametes…. and so on. In each generation the number of chromosomes of the species would be doubled. Therefore a mechanism of cell division is needed where the number of chromosomes is reduced (halved): going from 2n cells to n cells. This process is meiosis.

Besides being necessary, meiosis is very beneficial, as it generates **genetic variability**: the daughter cells are different from each other and also different from the mother cell.

Process: meiosis (like mitosis) is preceded by the replication of chromosomes or DNA. However, this single replication is followed by **two** consecutive cell divisions, called meiosis I and meiosis II. These divisions result in four daughter cells (rather than the two daughter cells of mitosis), each with only half as many chromosomes as the parent.

Meiosis I: consists of prophase I, metaphase I, anaphase I and telophase I.

During **prophase I** homologous chromosomes, each made up of two chromatids, come together as pairs (forming a tetrad, a complex of four chromatids). At numerous places along their length, nonsister chromatids (chromatids belonging to homologous chromosomes, in contrast to sister chromatids belonging to the same chromosome) are **criss-crossed** and **recombined**. As a result of these crossings, mixed chromatids are formed with fragments from the mother and the father chromosomes (this is the first source of variability in meiosis).



(scheme taken from → http://www.phschool.com/science/biology_place/labbench/lab3/images/stages2.gif)

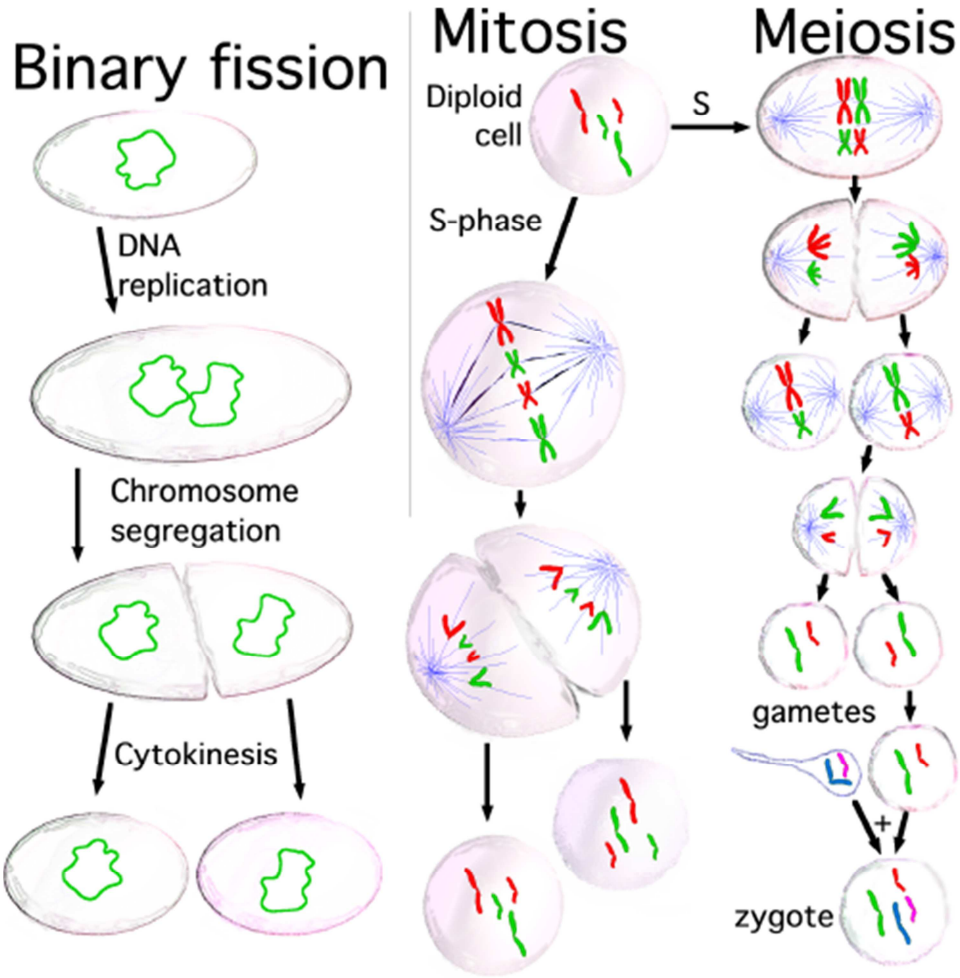
During **metaphase I**, the homologous pairs are randomly arranged on the metaphase plate: sometimes the paternal chromosome is on the right and the maternal on the left and it could also be the other way around. This way many different and diverse combinations can happen (this is the second variability source of meiosis: for example, a new daughter cell could have chromosomes 1, 2', 3, 4, 5' etc, while the other would have 1', 2, 3', 4', 5 etc).

In **anaphase I** and **telophase I** the homologous chromosomes migrate toward the opposite poles of the cells. Segregation of chromosomes (each pole now has a haploid chromosome set, but each chromosome still has two chromatids) and finally cytokinesis, usually occurring simultaneously with telophase I forms two daughter cells each with only one of the homologous chromosomes.

There is no further replication of the genetic material prior to the second division of meiosis II.

During the 2nd meiotic division, the two chromatids of each chromosome separate into the daughter cells in a very similar way as mitosis. At the end of meiosis II there will be four daughter cells, each with the haploid number (n) of chromosomes and genetically different from one another and from the mother cell (genetic variation).

SUMMARY: meiosis is a cellular division necessary for organisms with sexual reproduction. Meiosis reduces the number of chromosomes by half (which will be restored during fertilization) and allows for genetic variation (the daughter cells are genetically different from each other, and also from the mother cell).



GENETICS

CONCEPT: Genetics is the branch of biology which studies not only how hereditary traits (such as physiological, anatomical, behavioral, etc) are transferred, but also, the mechanisms responsible for their transmission. It studies the hereditary information in living beings and how the traits of a living being are transferred to the next generation.

1.5. MENDELIAN GENETICS

http://www.jic.ac.uk/germplas/pisum/zgs4f1.gif

Gregor Mendel, the father of genetics, was an Austrian monk that lived in the XIX century. He worked on the transmission of the characters of pea plants through successive generations. Gregor Mendel discovered the basic principles of heredity by breeding garden peas in carefully planned experiments. Mendel spoke of *heritable factors.* The concepts of gene and chromosome came later. Walter Sutton and Theodore Boveri in 1903 proposed the *chromosome theory of inheritance.* And thanks to the works of Watson and Crick about the nature of DNA, it was proven that the heritable factors (the genes) were in fact DNA fragments.

These are the main concepts that you should know:
GENE: there are different ways to define a gene. If we are talking about classic or Mendelian genetics, we will define a gene as a sequence of nucleotides (usually a DNA fragment, but in viruses composed of RNA it is an RNA fragment) that contains information for a particular character, e.g. the gene that determines eye colour. (Geneticists use the term character for a heritable feature, such as eye colour, that varies among individuals. Each variant for a character, such as brown or blue, is called a trait).

A more complete definition of a gene is:
A sequence of nucleotides to which a specific function can be assigned. Examples of such functions: a) control of the expression of a particular character; b) coding of a specific polypeptide chain (the transcription of itself into mRNA and the following translation into a polypeptide chain in the ribosomal unit); that it transcribes to tRNA; d) transcription to rRNA.

Each gene occupies a specific position on a chromosome called its **locus** (loci – plural).

Genes are passed down from parents to offspring (via the gametes) during sexual reproduction. Each gamete has one set of chromosomes (they are haploid). Fertilization

between a male and a female gamete gives rise to a zygote, with two sets of chromosomes (diploid). The individual from that zygote will also have two sets of chromosomes (also diploid). E.g. Humans have 23 chromosomes in their gametes or sex cells (ovum and sperm). The rest of the cells of our body have 23 pairs (46) of chromosomes.

HOMOLOGOUS CHROMOSOMES are a pair of chromosomes having the same structural features. Each member of the pair of chromosomes has the same number and pattern of genes. The genes found in the same locus on both chromosomes carry information for the same character, but may have different alleles.

ALLELE (OR ALLELOMORPH): An allele is an alternative form that a gene can have due to successive mutations. They are found in the same locus in each homologous and carry information for the same character, e.g. the gene that determines straight hair and that which determines curly hair. A gene can have multiple alleles, but diploid organisms can only have two of those, as we have our chromosomes in pairs.

HOMOZYGOUS (TRUE-BREED): An organism which has a pair of identical alleles for a certain character is said to be homozygous for that character. Normally genes are represented by letters, so a homozygous organism will have the same letters (AA, aa, BB, etc)

HETEROZYGOUS (HYBRID): Organisms having different alleles for a character. E.g. Aa, Bb, etc.

COMPLETE DOMINANCE (DOMINANT HEREDITY): In all hybrid individuals an allele (the dominant allele) for a particular character, is fully expressed, and the other allele or recessive allele has no noticeable effect on the organisms appearance.

CODOMINACE: Neither allele is dominant or recessive. Instead both alleles are separately (equally) manifested in the phenotype. E.g. human blood type group AB.

INCOMPLETE DOMINANCE: It is characterized by an intermediate phenotype. For example the pink flowers of snapdragon hybrids.

GENOTYPE: It is the genetic information of a particular organism as specified by its alleles. The genotype is hereditary, as progenitors pass it down to their offspring, e.g. AaBb, etc.

PHENOTYPE: It is the observable characteristics of an organism produced by the interaction of its genes and the environment which surrounds its development. E.g. Black hair, blue eyes, etc. e.g. how the environment influences the phenotype of an individual: in the Himalayan rabbits, the genotype determines the presence of an enzyme which, at low temperatures, makes a dark pigment that affects certain body parts (nose, legs, tail etc) If the animal moves to a warmer place, the pigmentation in such places disappears.

1.5.1 MENDEL'S LAWS

MENDEL'S FIRST LAW

Experiment

Mendel chose garden pea plants for his experiments (*Pisum sativum).* He observed and followed seven characteristics (which he could easily control as each characteristic only had two possibilities: tall and dwarf plants (stem length), green or yellow seed, round or wrinkle seed shape, etc).

Mendel also made sure that he started his experiments with varieties that were true-breeding (which means that when the plants self-pollinate, all their offspring are of the same variety). In a typical breeding experiment, he would cross-pollinate between two contrasting, true -breeding pea varieties: for example between tall and dwarf plants. This mating or crossing of two varieties is called hybridization. He observed that in the F1 generation (hybrids) all the offspring were tall plants. The character for dwarf plants did not show up. Mendel called the **dominant allele** the feature fully expressed in the hybrids and the **recessive allele** the feature that did not show up in the hybrids. From this experiment he derived (came up with) his first law:

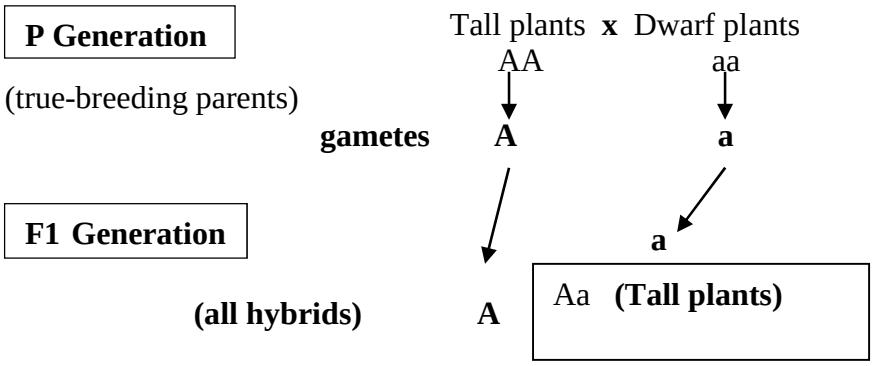
Law of Uniformity of the first filial generation

If two homozygous individuals (P generation) for a single pair of alleles but with different expression, cross themselves, all the descendants from the first generation, (which will be denominated by hybrids F1), will be identical (both, in their genotype and phenotype).

In other words: when the crossover between individuals pertaining to true-breeding of the same species is made, all the hybrids of the first filial generation are alike.

Interpreting the experiment

Let's call A the allele that determines tall plants and a the allele that determines dwarf plants. As this cross is carried out between two contrasting, true-breeding pea varieties, the P generation will be AA and aa. Homologous chromosomes segregate (separate) during gamete formation. All gametes produced by tall plants will carry the allele A, and all gametes produced by dwarf plants will carry the allele a. After fertilization, alleles A and a will join in the zygote and the new plant will carry alleles Aa. Therefore, all of the F1 offspring will be hybrids. Since all plants in F1 were tall plants, that means that allele A (tall plant) was dominant to allele a (dwarf plants), which is the recessive allele.



Expected genotypic proportions: 100% Aa; expected phenotypic proportions: 100% tall plants.

Extending Mendelian Genetics: In this century, geneticists have extended Mendelian principles to patterns of inheritance more complex than Mendel actually described. It was either brilliant or lucky that Mendel chose pea plant characters that turned out to have a relatively simple genetic basis. Each character is determined by one gene, for which there are only two alleles, one completely dominant to the other recessive. However this is not always the case, these conditions are not met by all heritable characters. So we will extend Mendelian genetics to patterns of inheritance that were not reported by Mendel.

It was later demonstrated that although complete dominance is fairly common, there are other possibilities. The range of relationship between alleles includes complete dominance, codominance and different degrees of incomplete dominance. In incomplete dominance, the F1 hybrids have an appearance somewhere in between the phenotypes of the two parental varieties. For example when red snapdragons are crossed with white snapdragons, all the F1 hybrids have pink flowers.

MENDEL'S SECOND LAW

Experiment

Mendel took the plants from the F1 and self-pollinated them producing an F2 generation. He observed that all the traits that were lost in the F1 reappeared in the F2 generation. So in the F2 generation he observed both, tall and dwarf plants (Mendel observed the same pattern of inheritance in the other characters with which he experimented). He therefore derived his second law:

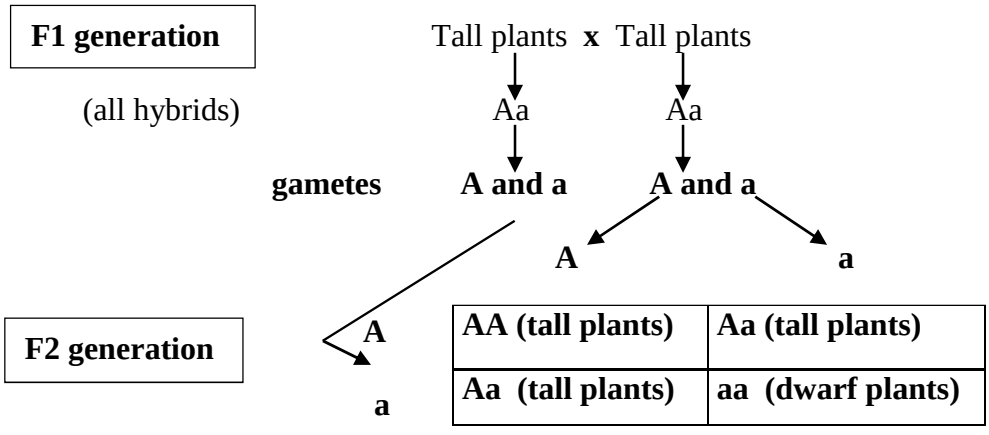
Mendel's law of segregation

When two hybrids are crossed for a particular character, the two genes (alleles) for the character segregate (separate) during gamete production (alleles are independent of each other). Therefore combining randomly in all possible mathematical combinations, giving rise to a non-homogeneous descendency.

Interpreting the experiment (we will refer to the same cross as before)

The tall plants from the F1 hybrids (Aa) will make two different types of gametes with the same probability. Some gametes will carry the allele A for tall plants, and others the allele a for dwarf plants. When the F1 hybrids are allowed to self-pollinate the gametes will combine randomly with all possible phenotypes appearing in the F2 generation: tall and dwarf plants. The mathematical proportions expected will be maintained (there will be more plants with the dominant phenotype).

(Continuing with the same cross as before)



Expected genotypic proportions: ¼ AA; ½ Aa; ¼ aa; expected phenotypic proportions: ¾ tall plants; ¼ dwarf plants.

In the case of incomplete dominance such as with the snapdragon flowers, in the F2 generation we can see pink, red and white flowers, so the law of segregation is also valid for incomplete dominance. The segregation of the red and white alleles in the gametes produced by the pink-flowered plants confirms that the genes for flower color are heritable factors that maintain their identity in the hybrids.

MENDEL'S THIRD LAW

Mendel derived the law of segregation by carrying out monohybrid crosses (breeding experiments using parental varieties that differ in a single character, such as stem length) But what would happen if he mated parental varieties differing in two characters – a dihybrid cross?

Experiment

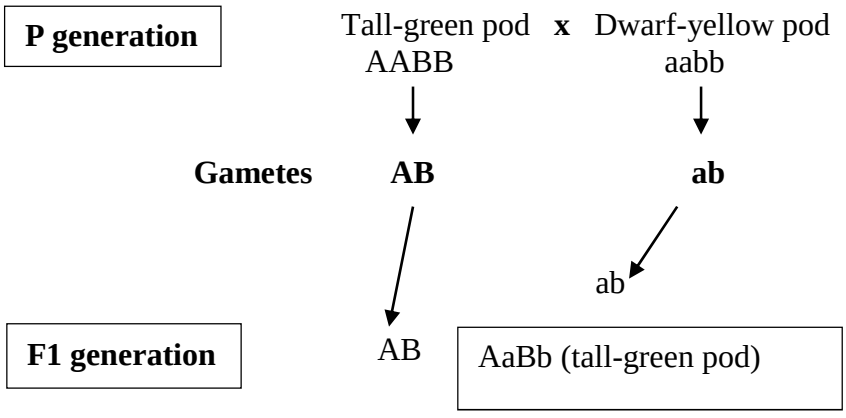
Now Mendel chose a dihybrid cross (stem length, tall or dwarf plants; and pod colour, green or yellow pod). He crossed a true-breeding tall plant with greed pod with a true-breeding dwarf plant with yellow pod. All of the F1 was homogeneous: All of the F1 generation were tall plants with green pod. When he self-pollinated the F1 he obtained the following F2: 9/16 tall plants with green pod; 3/16 tall plants with yellow pod; 3/16 dwarf plants with green pod; and 1/16 dwarf plants with yellow pod. He derived his third law as follows:

<u>Mendel's law of independent assortment</u>

Two pairs of genes (alleles) segregate independently of each other. Each character is independently inherited, and such characters combine randomly in all possible mathematical proportions.

Interpreting the experiment

If we study two characters such as stem length and pod color we can observe the following: The dominant allele A determines tall plants; the recessive a determines dwarf plants. The dominant allele B determines green pods; and the recessive b determines yellow pod. If we cross homozygous tall green-colored pod plants (AABB) with dwarf yellow-colored pod plants (aabb), all of the F1 generation is tall green-colored pod (AaBb). As those hybrids are allowed to self-pollinate (if the two characters segregate independently the gametes produced are: AB, Ab, aB, ab), the phenotypic ratio of the F2 generation is a 9:3:3:1.



AaBb x AaBb

Gametes for both: AA, Ab, aB, ab

	AB	Ab	aB	ab
AB	AABB (tall-green)	AABb (tall-green)	AaBB (tall-gree)	AaBb (tall-green)
Ab	AABb (tall-green)	AAbb (tall-yellow)	AaBb (tall-green)	Aabb (tall-yellow)
aB	AaBB (tall-green)	AaBb (tall-green)	aaBB (short-green)	aaBb (short-green)
ab	AaBb (tall-green)	Aabb (tall-yellow)	aaBb (short-green)	aabb (short-yellow)

1.5.2 EXTENDING MENDELIAN GENETICS

Mendel's laws have been tested over and over again. Additionally, as we have already mentioned Mendelian genetics have been extended as scientists have acquired more knowledge on how heredity works. Let's have a look at some of those:

1. **Lethal genes (recessively inherited disorders):** These could alter mendelian ratios. Lethal genes are generally recessive genes (there could be some lethal dominant genes, however, the majority of those are eliminated as they kill the individual who carries them and therefore are not passed down to any offspring). In disorders classified as recessive, heterozygotes are normal in phenotype, because one copy of the "normal" allele is present. Heterozygotes will be carriers passing them down to offspring, becoming more or less abundant in a population. These lethal genes cause death to homozygotes. Refer to genetic problems.
2. **Multiple alleles:** Diploid individuals can only have two alleles for each character, but most genes exist in more than two allelic forms (Mendel thought that each character only had two allelic forms). The ABO blood group in humans are one example of multiple alleles. Blood group is determined by three alleles A=B>O. There are four phenotypes for this character and six different genotypes. The letters indicate the genotype and in parenthesis the phenotype corresponding to the genotype: AA (blood group A); AO (blood group A); BB (blood group B); BO (blood group B); AB (blood group AB) and OO (blood group O). Refer to genetic problems.
3. **The effect of environment on phenotype**: Phenotype depends on the environment as well as on the genes. As we have already mentioned the product of a genotype is generally not a rigidly defined phenotype, but a range of phenotypic possibilities over which there may be variation due to environmental influences. For example, a seed contains in its genes all the necessary information for it to develop as a plant, grow, blossom and produce fruit. However, environmental factors such as light, water, temperature, etc are needed for those processes to take place. Other environmental factors can be pH, ion concentration, hormones, etc. E.g. Hydrangea flowers of the same genetic variety range in color from blue-violet to pink, depending on the acidity of the soil.

1.5.3 THE CHROMOSOME THEORY OF INHERITANCE

It was not until the year 1900 that biology finally caught up with Mendel. From 1865, the year that Mendel finished his experiments, until 1900 a series of important discoveries, particularly in the field of cytology, took place which favoured the understanding of Mendelian heredity. Around the turn of the century cytology and genetics converged ('came together') as biologists began to see parallels between the behaviour of chromosomes and the behaviour of Mendel's heritable factors. The following are the most important of such discoveries:

- Fertilization of an ovum by a sperm is observed for the first time. It therefore confirmed the role of gametes as carriers of the hereditary material.
- It was discovered that the cell nucleus was involved in the transmission of the hereditary material.
- The first chromosomes were seen, as they, every now and then, showed up in the nucleus.
- Cytologists worked out, step by step, the processes of mitosis (1875) and meiosis (1890s). The material in the nucleus that is strongly stained and gives rise to chromosomes is called **chromatin**.
- It was observed that somatic cells of the same species always have **the same number of chromosomes.** Each species has its own specific number of chromosomes.
- During mitosis the chromosomes contained in the mother cell are equally and uniformly distributed between the two daughter cells.
- Sperms and ova of any species must contain half the number of chromosomes than somatic cells.
- When two gametes fuse together the number of chromosomes of that particular species is restored.
- Chromosomes are DNA filaments. Genes are DNA fragments.
- In 1903, Walter S. Sutton and Theodore Boveri, independently suggested that **genes are located on chromosomes in a lineal manner** (much like the pearls in a necklace), and the **chromosome theory of inheritance** began to take form; According to this theory, Mendelian genes are located on chromosomes, and it is the chromosomes that undergo segregation and independent assortment. It is important to understand the following:

- During meiosis I chromosomes that are very similar pair up (homologous chromosomes); each homologous coming from each parent. There are therefore two genes (alleles) for each character, each one coming from each of the parents.
- During meiosis homologous chromosomes undergo segregation and independent assortment. –therefore giving rise to different gametes.
- Each gamete will only have one of the homologous. During fertilization when two gametes fuse the new pair of alleles will be produced.

1.5.4 LINKED GENES AND RECOMBINATION

The number of genes in a cell is far greater than the number of chromosomes. Therefore, the number of genes an individual has is also much greater than the number of chromosomes of such individual (humans have 23 chromosome pairs and about 50000 genes). In fact, each chromosome has hundreds or thousands of genes. Genes located on the same chromosome tend to be inherited together in genetic crosses, since they are part of a single chromosome that is passed along as an unit. Such genes are said to be **linked genes**.

Thomas Hunt Morgan an embryologist at Columbia University, and his co-workers determined the location of many genes. Morgan worked with a species of fruit fly (*Drosophila melanogaster)* and carried out different experiments which were of great importance in supporting the chromosomal basis of inheritance. Let's have a look at one of Morgan's *Drosophila* experiments to see how linkage affects the inheritance of two different characters. Morgan observed that the majority of the flies had grey bodies and normal wings (wild-type flies; A and B are the corresponding alleles for each trait). However, there were some flies with black bodies and vestigial wings -which are much smaller than normal wings- both of those being recessive (mutant phenotypes for those characters; a and b are the alleles for each trait). He crossed homozygote wild-type (grey body and normal wings) flies with homozygote mutants (black body and vestigial wings). The F1 was all dihybrids; grey bodies and normal wings flies. He allowed the F1 to mate amongst themselves to obtain the F2. According to Mendel's law of independent assortment, the expected Mendelian ratios of the F2 would have been: 9:3:3:1 (9/16 grey bodies and normal wings; 3/16 grey bodies with vestigial wings; 3/16 black bodies with normal wings; 1/16 black bodies with vestigial wings).

P: AABB x aabb → F1 AaBb F2: Expected Mendelian's ratios according to his third law (the law of independent assortment).

Those results were expected as long as the characters body colour and wing size were inherited independently. However, the actual results were very different. Morgan reasoned that body colour and wing size were transmitted together since the genes for these two characters are located on the same chromosome- that is they are linked genes. As a result, the alleles of one gene will not be independent of the alleles of the other gene, both being transmitted to the same gamete during meiosis.

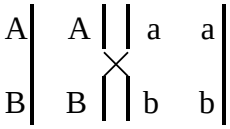
P: $\frac{A}{B}\,|\,|\,\frac{A}{B}$ $\frac{a}{b}\,|\,|\,\frac{a}{b}$

F1: $\frac{A}{B}\,|\,|\,\frac{a}{b}$

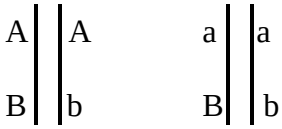
The F1 hybrids, AaBb, can not produce the 4 types of gametes proposed by Mendel: AB, Ab, aB and ab. Those gametes with the chromosome on the left will have alleles A and B, and those gametes with the chromosome on the right will have alleles a and b. We will expect then in the F2 grey bodies with normal wings flies (AABB or AaBb) and / or black bodies with vestigial wings flies (aabb). However, the other two phenotypes (grey-vestigial and black-normal) were also represented, in low numbers, among the offspring of Morgan's cross. How can we explain that? This resulted from the **crossing over** between homologous chromosomes that takes place during prophase I of meiosis. Going back to the above example. (Let's have a look at it):

G1 phase: G2 phase:

Now recombination by crossing over during prophase I of meiotic division:



Result of crossing over:



We can now make those gametes proposed by Mendel (two of those as recombinants), although in different proportions.

1.5.5 SEX CHROMOSOMES AND SEX-LINKED INHERITANCE

Generally, males produce small motile gametes, and females produce large non-motile gametes. Although the anatomical and physiological differences between male and females are numerous, the chromosomal basis of sex is rather simple. Most frequently, in determining the sex of an individual there are two chromosomes involved. These are know as **heterochromosomes** or **sex chromosomes** (we have already seen that chromosomes which do not determine the sex are called autosomes) In humans and many other species, there are two varieties of sex chromosomes, designated the X and the Y chromosomes. Females have two X chromosomes (genotype XX), and males have an X chromosome and a smaller Y chromosome (genotype XY). When meiosis occurs in the gonads (male testes and female ovaries), the two sex chromosomes segregate, and each gamete receives one. Each ovum contains one X chromosome. In contrast, half the sperm cells contain an X chromosome, and half contain a Y chromosome. If a sperm cell bearing an X chromosome happens to fertilize an ovum, the zygote is XX, a female; if a sperm cell containing a Y chromosome fertilizes an ovum, the zygote is XY, a male. Sex is a matter of chance; a 50% probability for each sex.

In addition to the role of sex chromosomes in determining sex, these chromosomes, especially the X chromosome, have genes for many characters unrelated to sex. Therefore, the heredity of such characters is **sex-linked**. In humans the term sex-linked usually refers to X-linked characters. Fathers pass X-linked alleles to all their daughters, but to none of their sons. On the other hand, mothers can pass sex-linked alleles to both sons and daughters. There are very few but yet some characters which are Y-linked. Fathers pass Y-linked alleles to all their sons.

If a sex-linked (X-linked) trait is due to a recessive allele, a female will express the phenotype only if she is a homozygote. Any males receiving the recessive allele from his mother will express the trait. A heterozygote female for a sex-linked disorder will show a normal phenotype but as she is carrying the recessive allele is called a carrier. Some sex-linked (X-linked) disorders are the following:

Colour blindness (daltonism) is a mild disorder due to a recessive allele (d), where the person with the disorder can not distinguish red from green. The dominant allele (D) determines normal vision. The different genotypes and corresponding phenotypes possibilities are: X^DX^D (normal female); X^DX^d (normal female but carrier of the disorder); X^dX^d (colour blind female); X^DY (normal male) and X^dY (colour blind male).
Hemophilia is a sex-linked recessive trait where the dominant (H) allele determines a protein required for blood clotting. The recessive allele (h) determines hemophilia; the most seriously afflicted individuals may bleed to death after relatively minor cuts, etc. X^HX^H (normal female); X^HX^h (normal but carrier female); X^hX^h (hemophiliac female); X^HY (normal male) and X^hY (hemophiliac male).

1.5.6 MUTATIONS

A mutation is any change in the genetic makeup of a cell or organism that can be passed down to offspring.

Mutations can happen spontaneously (for example, errors during DNA replication can lead to base-pair substitutions etc.) or can be induced by what are called mutagens. Some examples of mutagens are X-rays, ultraviolet light, some chemicals or even some viruses. Mutations are generally prejudicial to the organism. However, some times they are beneficial, and in such cases they can be important in the evolution of the species, as the mutation can be transmitted to an entire population.

Types of mutations:

1. Genetic mutations: affect just one nucleotide or a few nucleotides in a single gene (of a particular chromosome). For example sickle-cell anemia.
2. Chromosome structure mutations: Those that affect larger or more important sections of a chromosome, changing the structure of the chromosome. For example the Cri du chat syndrome (cat cry syndrome).
3. Chromosome number mutations: This will alter the number of chromosomes in a cell. For example Down syndrome (or trisonomy 21, as the individual will have 3 chromosomes 21 instead of the normal 2).

UNIT 2. THE NEW GENETIC OR DNA TECHNOLOGY

Since the 70's there have been great advances in the knowledge of nucleotides, as well as some major developments in DNA technology (known as **recombinant DNA technology or genetic engineering**) that allows the manipulation of genetic material. DNA technology has launched an industrial revolution in biotechnology: specific genes can be isolated, large amounts of pure DNA can be obtained, DNA can be spliced at specific locations, genes from one organism can be transferred to other living organisms where it can be replicated and expressed (**transgenic organisms**), the synthesis of artificial genes etc.

The application of DNA technology is of great importance in different fields such as the medical field, in the diagnosis of diseases and a possible cure of such diseases; in the forensic field, identifying dead people or possible criminals; in the pharmaceutical industry, in agriculture etc. The old mysteries of Genetics have now become clearer, but the manipulation of the genetic material opens up new unknowns.

GENETIC ENGINEERING

What is genetic engineering?

It is a group of techniques which allow the manipulation of the genome of a living organism.

Such genetic manipulation basically consists of the following:

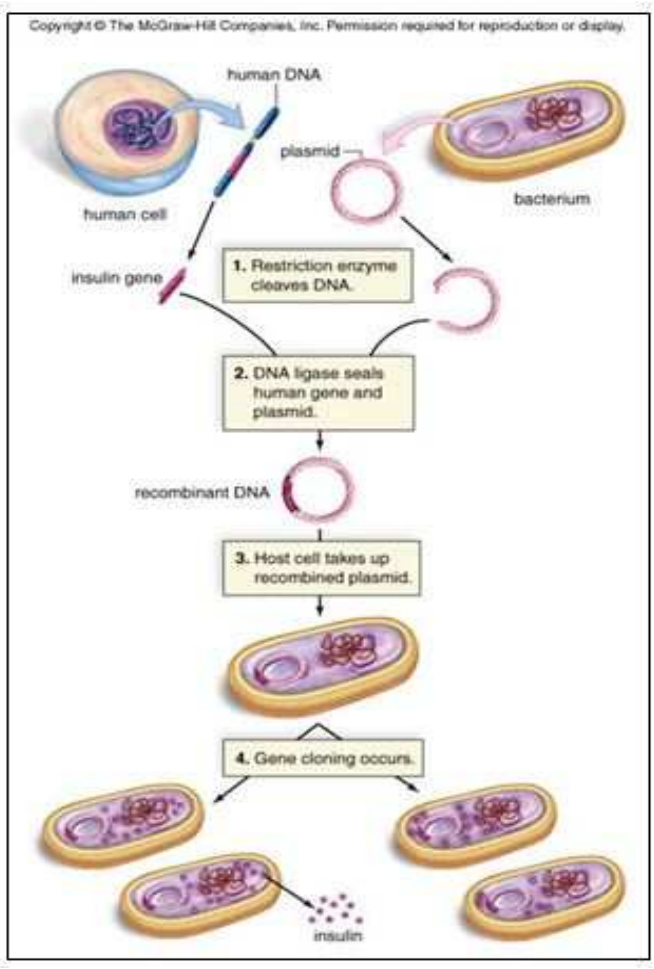
a) Insertion of new genes into a genome (transferring genes).
b) Eliminating existing genes.
c) Modifying the information of a particular gene.

The advances achieved in the field of molecular Genetics, (in reference to the genetic material its replication and transcription), have been the basis for a group of techniques used for manipulating and analyzing DNA used in genetic engineering and known as **recombinant DNA technology.**

The use of genetic engineering in research has allowed the production of valuable products by manipulating the genetic material of microorganisms such as: insulin and the growth hormone, interferons, vaccines, enzymes for industrial use, etc. Additionally, manipulation of the genome of some organisms has allowed the development and production of a number of transgenic organisms (animals and plants) for potential agricultural use.

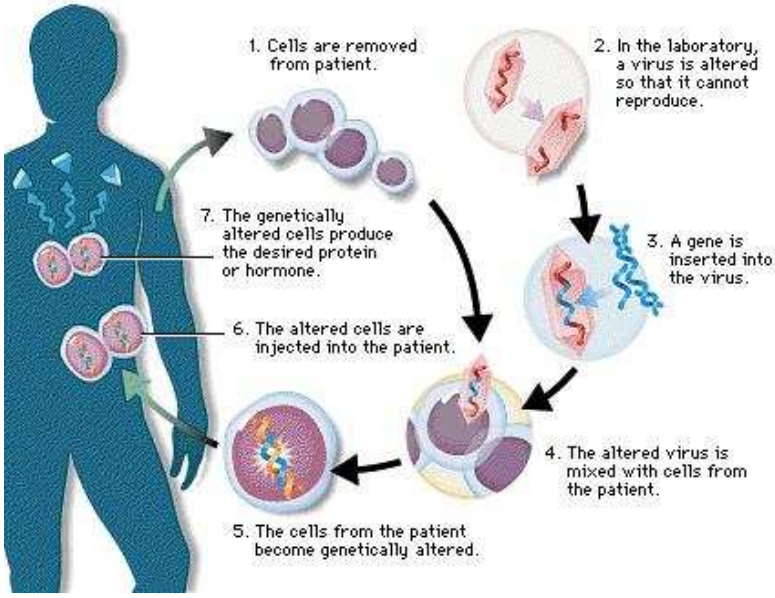
To carry out recombinant DNA technology, the following are needed:

1. **Restriction enzymes,** which are a kind of "genetic scissors" used to cut segments of DNA which contains the gene that we want to transfer. Each type of restriction enzyme cuts at specific sequence of DNA.
2. **DNA ligases**, which are enzymes which join segments of DNA.
3. **Transfer vector**, generally plasmids (small circular molecules of DNA present in many bacteria) and viruses, which act as "vehicles" to transport the DNA to the receptor organism.
4. **Receptor or host cells**, which will receive the gene from another organism. The individuals that have received the new gene are called **transgenic organism.**



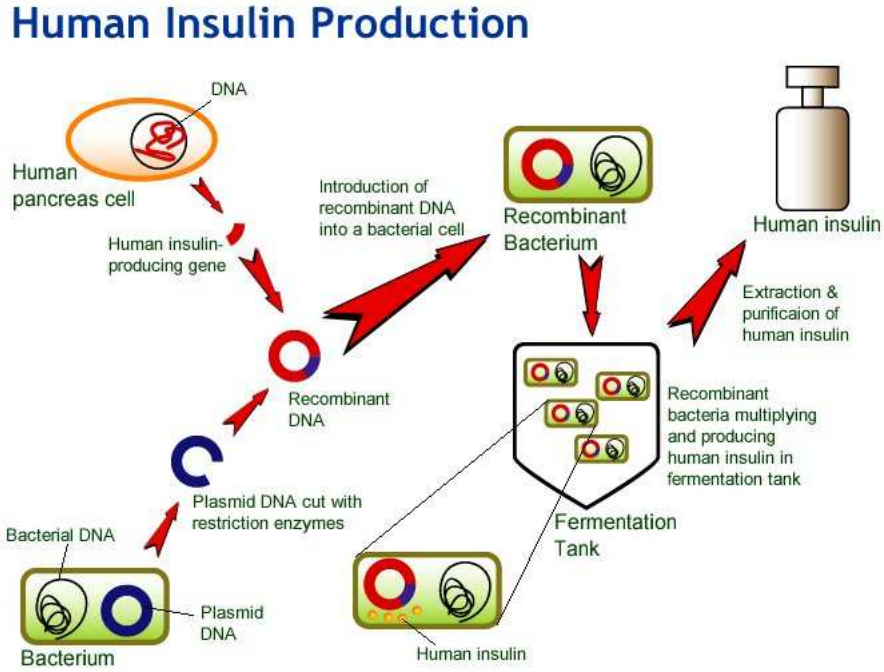
PRACTICAL APPLICATIONS OF GENETIC ENGINEERING

1. Gene therapy. Genetic engineering has the potential to actually correct some genetic disorders in individuals. In the near future, many therapeutic treatments will not be providing the individual with the molecule that he/she is not able to synthesize (insulin, growth hormone etc), but rather supplement the defective gene with a functional, normal gene, so that the individual can again synthesize its own molecule.



2. Making antibiotics. Traditionally specific strains of microorganisms were used for the production of antibiotics. With genetic engineering, the genes responsible for the production of the particular antibiotic are cloned in microorganisms. Modified antibiotics can also be obtained.

3. Producing mammalian proteins. Before genetic engineering a number of proteins of medical interests (insulin, growth hormone, several proteins of the immune system – such as molecules called interferons) were directly obtained from tissues. Nowadays, these are made by recombinant DNA procedures. The genes in charge of a particular protein are cloned in microorganisms for use in treating human patients E.g. Human insulin is produced in bacteria or yeast – *Saccharomyces cerevisiae.*



4. Vaccines. Traditional vaccines for viral diseases are of 2 types: particles of a virulent virus that have been inactivated by a chemical or physical means, and active virus particles of an attenuated (non-pathogenic) viral strain. In both cases some risks are taken as not all the micoorganism is completely inactivated. With genetic engineering, since most **antigens** are proteins, the genes of interest are cloned. (An antigen is a foreign substance that triggers an immune response; some antigens include molecules of viruses, bacteria, fungi, etc). Recombinant DNA techniques can generate large amounts of a specific protein molecule from the protein coat of a particular disease-causing virus, bacterium or other microbe. This avoids the risks mentioned earlier.

5. Production of transgenic organisms (animal and plants). It is possible to produce living organisms which genome has been artificially modified by the insertion of genes. Transgenic animals are produced by injecting foreign DNA into the nuclei of egg cells or early embryos. And transgenic plants are usually obtained by using DNA vectors to move genes from one organism to another in cell cultures.

6. DNA sequencing. The human genome project.

THE HUMAN GENOME PROJECT

The Human Genome Project is perhaps the most ambitious biological research project worldwide to date. This effort to map the entire human genome, is not only very expensive, but it will also take many years to be accomplished. The goal of this project is to locate each and every gene of the 23 pairs of chromosomes that make up the entire human genome, and to study its mechanisms of expression. It has been estimated that human DNA contains about 20 000 – 25 000 genes, though this number is constantly being modified. These genes make up about 5 to 10% of the total content of our DNA: there are lots of duplicated fragments, and other fragments that do not code for proteins. The sequencing of all the nucleotides that make up the human genome has already been accomplished (2003). However, the most difficult task is still under progress: determining all coding genes, localizing each and every gene, studying how they are expressed, etc. In many years, once the project is completely finished, among many others things we will be able to determine: which parents could have children with particular genetic disorders; there will be some significant advances in gene therapy, we will have a better understanding of some diseases such as cancer and their possible treatments, etc…….But it will also raise significant ethical questions.

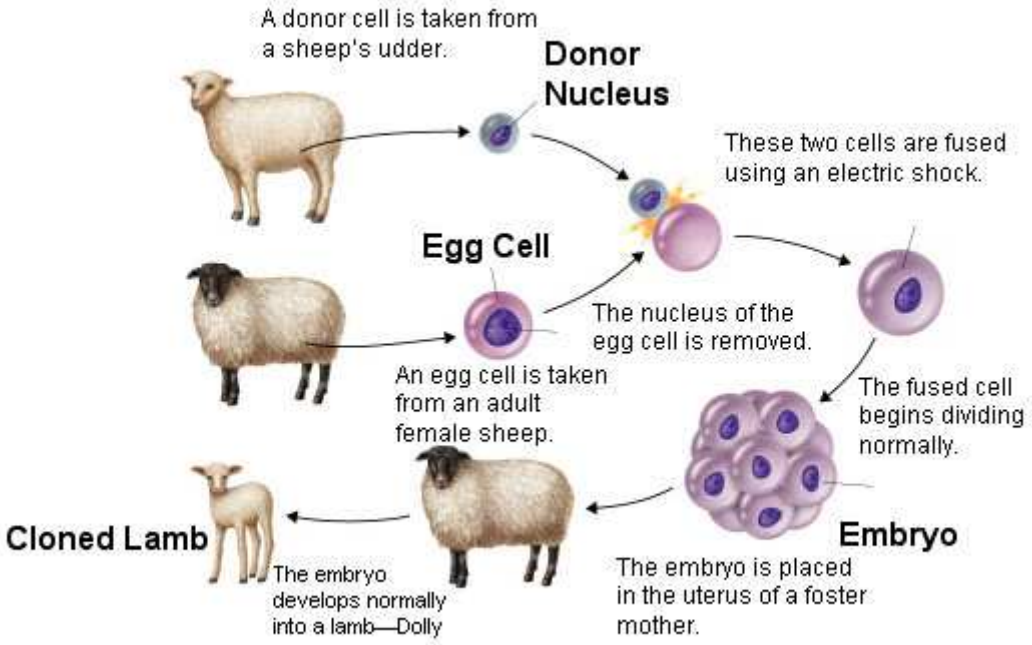
CLONING

A clone is a group of organisms that has been derived asexually from a single progenitor (individual). Unless mutation occurs during the development of the cells in a clone, the resulting descendants are genetically identical among themselves and to the progenitor.

Although many organisms produce clones as a natural form of reproduction, this type of reproduction does not happen among vertebrates (there are some rare exceptions).

Procedure (diagram in the following page): if we extract the nuclei of sheep's ovule, and replace them with diploid nuclei from another sheep's udder, this new cell will develop normally and it will differentiate making a clone. This procedure has been done with other mammals such as mice, etc.

The technical problems that could arise in cloning a human are minimal, and some of the advantages that this could bring about are obvious. However, there are many ethical issues regarding the cloning of humans.



GENETIC ENGINEERING AND BIOETHICS

We have already mentioned the great possibilities that the development of genetic engineering represents. But, the magnitude of such possibilities opens the door to numerous unknowns that should not only be answered by the scientific community, as they concern our entire society. Over the last few decades, a new discipline that brings together Biology and Ethics – **Bioethics,** has been created. One of the main purposes of Bioethics is to determine precise limits on how far the development of genetic engineering should go, as it raises significant ethical questions. We propose some questions for class discussion:

- Do we have the right to direct or lead the future of a species, including our own?
- UNESCO has declared the human genome Patrimony of Humanity, however, biotechnological research is being carried out mainly by private companies. Therefore, the obtained products have property rights. The sequencing of a human gene could be exploited by the company that identifies it. To what extent can we commercialize the genes of our genome?
- Who should have the right to examine someone else's genes?
- How should the information be used? Should a person's genome be a factor in their suitability for a job? Should insurance companies have the right to examine an applicant's genes?
- Could it be dangerous to consume transgenic foods?
- Would it be fair to use the enormous amount of money needed to sequence and study the 90% of the human genome that never transcribes towards other aims such as food production for a rapidly growing and malnourished population in developing countries?
- Stem cell research is another controversial issue. Do we have the right to stop all research with stem cells knowing that millions of diseased people will benefit from the research? What restrictions should be placed on such research?

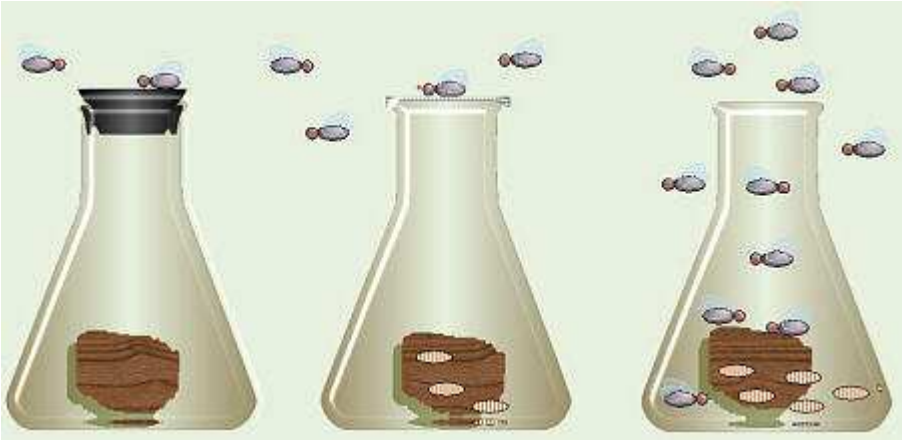
UNIT 3. EVOLUTION

The origin of life: This question has troubled mankind throughout time. The main theories are as follows:
Divine Origin: The belief that life was created by God during a single week. As you would understand this point of view has no interest to scientists as it can not be proven.

3.1 THE THEORY OF SPONTANEOUS GENERATION

The theory of spontaneous generation was believed for centuries, since at least the time of Aristotle (4th Century BC, classical Greek philosopher). People, including scientists, believed that higher living organisms, including man, had a divine origin; however, simple living organisms could come into being by spontaneous generation. This was the idea that non-living objects can give rise to living organisms. It was common "knowledge" that simple organisms like worms, beetles, frogs, salamanders and mice among other, could come from dust, mud, etc., and food left out, quickly swarmed with life. Doctor Van Helmont gave a recipe to obtain mice in 21 days from a few grains of wheat and some dirty shirts or rags.

In the XVII century, F. Redi, an Italian physician proved that 'worms' were really the maggots of insects, and that neither maggots nor insects appeared in meat if female insects had not been able to lay eggs on the meat.



Only flies can make more flies. In the uncovered jars, flies entered and laid eggs on the meat. Maggots hatched from these eggs and grew into more adult flies. Adult flies laid eggs on the gauze on the gauze-covered jars. These eggs or the maggots from them dropped through the gauze onto the meat. In the sealed jars, no flies, maggots, nor eggs could enter, thus none were seen in those jars. Maggots arose only where flies were able to lay eggs.

Other scientists, such as Schwann and Spallanzani, carried out experiments with similar results, however, the idea of spontaneous generation was still under debate. By 1860, the debate had become so heated that the Paris Academy of Sciences offered a prize for any experiments that would help resolve this conflict. The prize was claimed in 1864 by Louis Pasteur, as he published the results of an experiment where he proved that microorganisms did not arise by spontaneous generation in media broth, but that microorganisms would come from other places colonizing the broth. In order to prove this, Pasteur carried out the following experiment:

Pasteur boiled broth in order to sterilize it in flasks with long, S-shaped necks (swan-neck flasks). He did not seal any of the flasks, therefore allowing fresh air to enter the

flasks as they cooled. He did the same in normal flasks, but these were closed with cotton plugs. Air could enter all of the flasks, but the long, swan neck or the cotton plugs filtered out any bacteria present in the air. So the broth did not spoil, it stayed sterile.

He subsequently broke the long necks of some of the swan-neck flasks, but kept the cotton plugs in the other flasks. Broth in flasks with necks opening straight up spoiled (as evidenced by a bad odour, cloudiness in previously clear broth, and microscopic examination of the broth confirmed the presence of bacteria), whilst broth in swan-neck flasks did not, even though fresh air could get it.

Broth in flasks with cotton plugs did not spoil, even though air could get through the cotton. If the neck of a swan-neck flask was broken off short, allowing bacteria to enter, then the broth became contaminated. Pasteur claimed that microorganisms were in the air, in the experimental utensils, and even on the hands of the people running the experiments. With his experiments a new era started in the history of clinical surgery etc. Still today, some of Pasteur's original flasks are on display in France, and are sterile.

3.2 PANSPERMIA THEORY

Panspermia literally means seeds everywhere. It suggests that life could have existed on another planet and moved to Earth by meteorites, comets etc. Currently, this theory can not be proven. Additionally, it simply transports the question somewhere else.

3.3 CHEMICAL EVOLUTION THEORY

This theory states that the first living organisms that appeared on Earth arose from inorganic matter in a time when the chemical environment and conditions of the planet were very different from today's conditions. In this idea, pre-biological changes slowly transformed simple atoms and molecules into the more complex chemicals needed to produce life. On the Earth, about 4000 million years ago there was a reducing atmosphere (lacking in oxygen) and a series of inorganic compounds (carbon monoxide and carbon dioxide, ammonia, water, etc.). Additionally, the numerous electric storms as well as the ultraviolet radiation from the Sun were an important energy source. The first organic molecules arose and were the precursors of living organisms. Over time, simpler organic molecules joined to form more complex structures: macromolecules, aggregates, microspheres (coacervates). These more complex structures eventually gave rise to the first primitive cells. By the process of evolution and after millions of years, the prokaryote and eukaryote cells that we know today were formed from those first primitive cells.

3.4 PRE-EVOLUTIONIST VIEWS

There are two theories about the existence of living organisms on Earth as well as two different views about the dynamics among living organisms. **Creationism** states that life on Earth was created by God, in one or multiple 'creation events'. On the other hand, there is also the belief that a divine action is not necessary to explain the origins of life. Additionally, the doctrine of **fixed species** believes that the different forms of life that had been individually made by the Creator have stayed immutable over the history of life. Opposite to that there is the theory of **evolution,** which states that species derive from other species as a result of successive transformations or evolution.

The Book of Genesis (from the Bible), explains how species were created by God in the immutable and definite form that we know today. Due to the pressures and the great influence of the Church, the prejudice against evolution were firmly embedded in Western thought. Scientific thought adopted creationism and the doctrine of fixed species up until the beginning of the XIX century. Even as Darwinism emerged, biology in Europe and America was dominated by natural theology, a philosophy dedicated to discovering the Creator's plan by studying his works. A major objective of natural theology was to classify species in order to reveal the steps of the scale of life that God had created. In the XVIII century, Carolus Linnaeus (1707-1778), a Swedish physician and botanists (father of taxonomy and binomial nomenclature system of naming organisms) sought and found order in the diversity of life. But placing certain species under taxonomic banners implied no evolutionary kinship to Linnaeus. As a natural theologian, he believed that species were permanent creations, and he developed his classification scheme only to reveal God´s plan. As Linnaeus himself put it, *Deus creavit, Linnaeus disposuit*- "God creates, Linnaeus arranges."

At the beginning of the XIX century, the great French anatomist Georges Cuvier (1769-1832), explained the existence of fossils based on the view of Earth's history known as *catastrophism;* during catastrophic events (such as floods or drought), species, created by God, would die. After such periodic catastrophes two things could happen: God created life anew (the new species being different from the extinct ones, although occasionally having similar characteristics), or the ravaged region would be repopulated by foreign species immigrating from other areas. This would explain the existence of species in the fossil record different to the ones of the time.

Also, during the XVIII century, an important step toward the modern theory of evolution was presented by Georges-Louis Leclerc Compte de Buffon (1707-1788). He studied animals and plants fossils, proposing that species had not been created as they appeared, but rather that species of the time were modified forms of common ancestors. He writes that living creatures evolve according to natural laws. However, his heretical* ideas were later recanted under pressure: "I abandon everything in my book ... contrary to the narrative of Moses."

***Heretic**: A person who holds controversial opinions, especially one who publicly dissents from the officially accepted dogma of the Roman Catholic Church.

EVOLUTION

Evolution refers to the processes, more or less gradual, that have transformed life on Earth from its earliest forms to the vast diversity that characterizes it today. The first primitive living organisms are dated as far back as 3800 million years ago. In fact everything in the Universe evolves, nothing stays still. We can talk about the evolution of a star, the evolution of the lithosphere… and the evolution of living organisms. It seems obvious that living beings have appeared and disappeared throughout geologic time, and that many species, nowadays with different characteristics, have common ancestors. It is known that there are species that existed in past times and are now extinct, and others which did not exist in older geologic times but that exist today. Generally speaking, evolutionary change is based on the interactions between populations of organisms and their environment. As there have been changes in the environment, different characteristics have been needed in order to adapt to such changes. The different evolution theories study evolution, its history (that is to say the

interactions among populations of organisms), and the mechanisms by which life evolves.

3.5 EVOLUTION THEORIES

1. Lamarck's Theory of Evolution (1744- 1829)

What is his theory based on?

1. Evolution was driven by an innate tendency towards higher and greater complexity, towards perfection. (**vital force**).

2. This innate tendency to perfection is influenced by environmental changes, therefore becoming better adapted to their environments. These environmental changes would create '**new needs'** in organisms, needing to use certain organs or characteristics more than others.
3. This use and disuse of certain organs causes those organs that are used more often to cope better with the environment, making them become larger and stronger, while those that are not used deteriorate. In other words: **the function makes the organ**. So, organisms could acquire certain characteristics throughout its lifetime, and lose others.
4. Lamarck believed that the modifications an organism acquires during its lifetime are passed to its offspring (**inheritance of acquired characteristics**).
5. One species can not transform into any other species, but only into a similar one where the species can evolve gradually.

Lamarck established the fact of evolution, but his theory had several flaws:

- There is no evidence to prove that innate tendency (vital impulse) of organisms toward complexity.
- **Acquired characteristics are not inherited**. We all know that physical exercise will make our muscles develop, but such acquired physical characteristics (which are not genetic) are not passed down to offspring. Such acquired characteristics are produced by environmental factors and development, but not by genes. Only those characters which are regulated by genes are hereditary, and only if such genes are found in the reproductive cells. Whatever happens to somatic cells due to their use or disuse will not affect the genes in the gametes, therefore it will not be hereditary. F.L. August Weissmann (1834-1914) carried out the following experiment to refute Lamarck's theory: He cut off the tails of fifteen hundred mice, repeatedly over 20 generations, and reporting that no mouse was ever born in consequence without a tail. According to Lamarck and his theory, the disuse of the tail should have given offspring without a tail or with an undeveloped tail, however that was never the case.

Evolution of the giraffe according to Lamarck: The ancestors of the giraffe (with a short neck and short legs), also ate leaves. As the lower leaves were eaten, it had to stretch its neck to new lengths in pursuit to eat the higher leaves. Due to that 'innate impulse', its neck and legs began to grow. The long neck and legs of the giraffe Lamarck reasoned,

evolved gradually as the cumulative product of a great many generations of ancestors stretching higher and higher, which would be inherited by offspring.

2. Darwin's theory of evolution

Charles Darwin (1809-1882) was born is the West of England (Shrewsbury), in the same year that Lamarck published his theory of Evolution. Darwin was 22 years old when he sailed from England with the *Beagle* in December 1831; a voyage around the world that would last five years. During the expedition Darwin collected thousands of specimens of the exotic and exceedingly diverse faunas and floras of different places. He was also able to observe the various adaptations of plants and animals that inhabited such diverse environments. After returning from his voyage, Darwin spent almost 20 years analyzing and studying all the data obtained during those five years. Another naturalist, Alfred Wallace who was working in the East Indies, sent a manuscript to Darwin in which he developed a theory of natural selection essentially identical to Darwin's.

Together, in 1958 they published together their theory on Evolution (it should be called the Darwin-Wallace theory), which replaced Lamarck's evolutionary theory. Darwin explained his theory in his book *The Origin of Species*, where he presented his theory of natural selection as the mechanism of evolution. Basically, his **theory of natural selection** is based on three observations and two conclusions from such observations:

1st Observation: In the absence of environmental pressures (or normal conditions), all species have such great potential fertility that their population size would increase exponentially if all individuals that were born reproduced successfully.

2nd Observation: However, in normal conditions, most populations are stable in size, except for seasonal fluctuations.

1st CONCLUSION: Therefore, not all gametes produced by an individual end up becoming zygotes; not all zygotes become adults; and not all the adults survive and reproduce. So, production of more individuals than the environment can support leads to a struggle for existence among individuals of a population, with only a fraction of offspring surviving each generation.

3rd Observation: Individuals of a population vary extensively in their characteristics. There are not two individuals exactly alike. (Think of your classmates, you each have your particular characteristics, which define you).

2nd CONCLUSION: Survival in the struggle for existence is not random, but depends in part on the hereditary constitution of the surviving individuals. Those individuals whose inherited characteristics fit them best to their environment are likely to leave more offspring than less fit individuals.

A few comments about this theory:

- According to Darwin, evolution is gradual, slow and continuous: there are no sudden or brusque changes. It is a gradual accumulation of minute changes.

- Environmental factors are what drive natural selection. With time, those individuals with characteristics less fit to their environment would disappear, and those with favourable variations would be perpetuated. (Survival of the fittest).
- Over vast spans of time, and always due to environmental factors, a group of individuals could accumulate a considerable amount of favourable characteristics giving rise to a new species from the original population.
- Still nowadays, many people mistakenly believe that it is Darwinism that explains evolution. There are many objections to the Darwinian view, (many of those objections were presented whilst he was still alive).
- When Darwin had to explain what caused individual variations among organisms of a population he had to borrow Lamarck's acquired characteristics theory (Weissman will not carry out his experiments until 1880). Mendel enunciated the laws of heredity six years after Darwin published his book, however Mendel's work was not recognized or appreciated until 30 years later, which considerably slowed down the understanding of evolutionary mechanisms.
- Another objection: if natural selection only preserves or eliminates what already existed, how can it create new species? As we will see, natural selection does create new species.

Evolution of the giraffe according to Darwin: The variability which appeared in giraffe populations in each generation (some would stretch their neck or legs more than others) gave rise to the appearance of some individuals within the population with longer legs and a longer neck . These characters were transferred to their offspring. At first, this was not of any advantage to the individual, as there were enough low leaves on trees. However, as the lower leaves became scarse, only the individuals with the longer neck and longer legs could reach the higher leaves, which allowed them to survive through generations and have more offspring. With time it became the only type of giraffe that existed.

TODAY'S THEORY OF EVOLUTION (The modern evolutionary synthesis or neo-Darwinism)

A comprehensive theory of evolution that became known as the **modern synthesis or neo-Darwinism** was forged in the earlies 1940s. This theory is not the work of one but many scientists. It is called the synthesis because it integrated discoveries and ideas from many different fields, including population genetics, paleontology, taxonomy, etc)

It brings together Charles Darwin's theory of the evolution of species by natural selection with Gregor Mendel's theory of genetics as the basis for biological inheritance. Major figures in the development of the modern synthesis include Ronald Fisher, Theodosius Dobzhansky, J.B.S. Haldane, Sewall Wright, Julian Huxley, Ernst Mayr, George Gaylord Simpson and G. Ledyard Stebbins.

We can define evolution as **the natural selection (which is seen through differential reproduction), that acts upon genetic variations (which are the outcome of mutations or sexual recombination) which appear among the members of a population**.

Some important aspects of this definition are:

- A population is a localized group of individuals belonging to the same species, where the individuals interbreed amongst themselves, and occasionally, with members of other populations.
- As a result of this closed sexual interaction in a population, a gene flow is created (that is to say that the genes of the different individuals circulate within the population, and could be transmitted to the entire population).
- The genetic variations among individuals could be due to: **mutations** (this variations can take place in individuals with both types of reproduction, asexual and sexual); and **meiotic or sexual recombination** (this takes place during meiosis I, therefore, it can only happen in individuals with sexual reproduction).
- Because of mutations and meiotic recombinations, individuals with new characteristics are constantly born. If those individuals survive and have offspring, their new characteristics will stay within the gene pool or group of genes of the population. In successive generations those genetic variations could be passed down to many (or all) members of the population.
- Whether that would happen or not depends on natural selection (some individuals have more offspring than others). Those organisms best adapted to a given environment will be most likely to survive to reproductive age and have offspring of their own. Organisms that are successful in their environments will be more likely to be successful in reproduction, and therefore the better-adapted organisms will reproduce at a greater rate than the less well-adapted organisms. Therefore, the genes of the ones that reproduce more will predominate in the gene pool of the population. This is known as **differential reproduction.**
- It is important to understand that it is just how well adapted they are, but how well they are able to reproduce, in order to be able to pass down the new characters. (Though they usually go hand and hand). For example, it could be that an individual is very well adapted to its environment, however, it has a mutation that makes it sterile. Would this individual have any impact in the evolution of its population?
- The process of evolution has therefore two stages: first of all genetic variation must occur due to mutations and/or meiotic recombinations; and second, those variations must spread throughout the population by differential reproduction (natural selection) in successive generations.
- Individuals do not evolve, populations do. The genetic characteristics that an individual has usually don't vary throughout its life and once it dies they disappear. However, if the individual reproduces sexually, it could introduce genetic variations to its offspring.

- The process of evolution does not follow a fixed pattern, as genetic variations happen randomly. This does not mean that evolution lacks a driving force: as the individuals that are most successful in reproduction are those that are best adapted, the driving force of evolution is natural selection.
- Therefore, natural selections acts by means of differential reproduction, and not by the struggle for survival.

Evolution of the giraffe according to the modern evolutionary synthesis:

The ancestors of today's giraffes did not have a long neck nor long front legs. By mutation and/or genetic recombination new individuals presenting a long neck and/or long legs appeared in a population. Those new individuals were better adapted to the environment. They ate more, found mating partners more easily and therefore reproduced more often. With time they became the only existing giraffes. Obviously the individuals that presented the short neck and short legs (both negative characteristics), as they were less well adapted to the environment, they did not reproduce as successfully as the well-adapted giraffes. And eventually the less favorable genes disappeared from the population.

UNIT 4. ECOLOGY

4.1 ECOSYSTEMS AND SPECIES

An **ecosystem** is a system formed of the *biocenosis* and *biotope*; the relationships established between the populations of living things form the biocenosis, while the relationships with the physical factors constitute the biotope.

A population is a group of individuals of the same species that have the ability to reproduce amongst themselves.

SPECIES

* *As a reproductive unit*. The species is the taxonomic unit that describes all organisms capable of reproducing by producing fertile offspring.

* *As a unit of evolution.* Due to reproduction, each species is also the unit of evolution. Given that each species is the result of interbreeding between members over the length of their history, member organisms are more closely related to each other than to any other organisms. So they have in common certain structural and functional characteristics and share the species' gene pool.

**As an ecological unit*. Being evolutionary units, all species are also ecological units. Each one is defined by its ecological niche: its place in nature (it lives in a certain environment, it uses certain materials, it eats certain types of food, with certain habits, it reproduces following certain habits, etc.)

4.2 ENVIROMENTAL FACTORS

The environmental factors are all the components of an ecosystem, whose presence or variation influences the organism that from the biocenosis. The environmental factors can be abiotic and biotic.

Abiotic. These factors are the physical and chemical elements of an ecosystem. The most important abiotic factors are:

- Temperature; most living things cannot live at temperature below 0ºC or above 50ºC).
- Light; essential for autotrophic organisms.
- Water; without water life cannot exist.

Biotic. These factors refer to any organism or the behavior of any organism which affects the life of the other organisms within the system. We can distinguish intraspecific and interspecific relationships:

- Intraspecific relationships are relationships between members of the same species. The most important are *competition*, where animals compete for resources such as food, mates, territory, etc., and *associations*, including related individuals (family) or not related (gregarious).
- Interspecific relationships are relationships between members of different species. They are classified according to the effects that individuals of interacting species have on each other, using symbols: – (negative effects), + (positive effect) and 0 (no effects). Some of the most common are Competition (-,-); Predation (+,-); Parasitism (+,-); Commensalism (+,0) and Mutualism (+,+).

4.3 MATTER AND ENERGY IN ECOSYSTEMS

To understand the relationships within an ecosystem, it is useful to visualise the food or trophic structure. To do this, all the organisms of the biocenosis must be grouped according to how they obtain nutrients.

TROPHIC LEVEL

The position an organism occupies in the food chain. Green plants, which obtain their energy directly from sunlight from this energy, make organic material from inorganic material, form the level of **producers**. Producers are autotrophs – they make their food. These then are the base of all food pyramids. The **consumers** are heterotrophic organisms. *Primary consumers* feed on plants (the producers), these are called herbivores. The *secondary consumers* feed on the primary consumers. The tertiary consumers feed on the consumers from the level below, etc. Many animals belong to different trophic levels. The decomposers obtain their energy from the chemical decomposition of dead organisms or from the waste products of plants and animals. They are above all, bacteria and fungi. The role they play is vital, they return the organic material to the environment as inorganic material, so that it can be re-used again by plants.

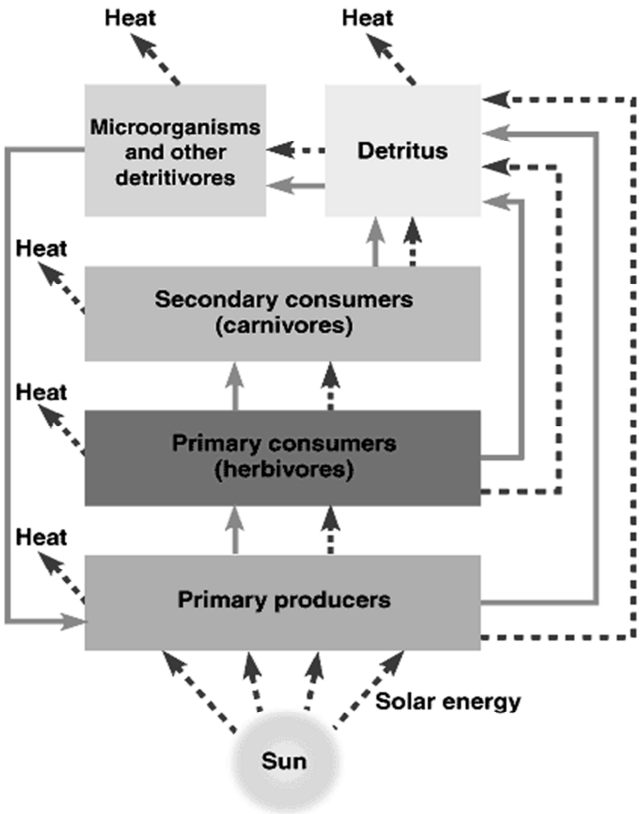
A **trophic chain** is a diagram which has drawings or the names of the different organisms in the different trophic levels of the ecosystem.

The feeding relationship is indicated by arrows. The tip of the arrow indicates the organism which eats, and the end of the arrow the organism which is eaten.

Trophic networks are representations of all the trophic chains in an ecosystem and how they interconnect with each other.

THE FLOW OF ENERGY

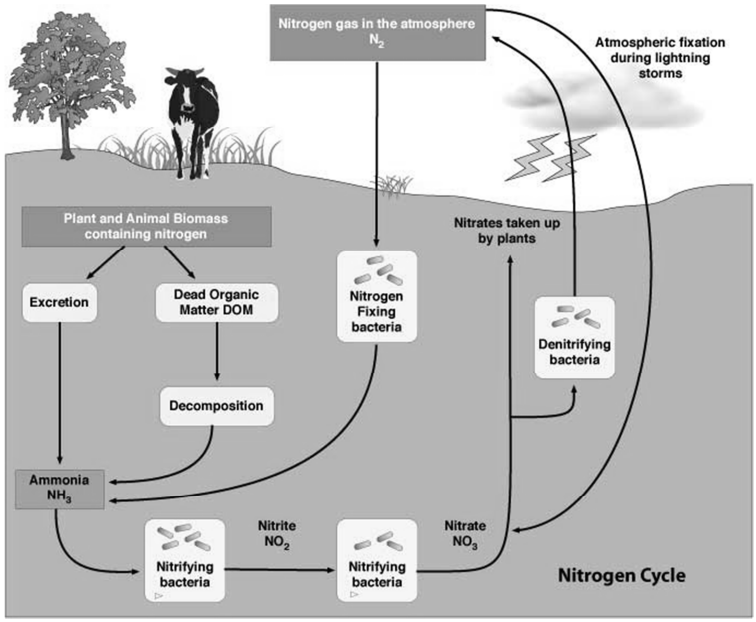
Energy enters the ecosystem via the producers (plants), as energy from the sun. Plants using photosynthesis, convert light energy, into chemical energy, this energy is then stored in the bonds of the products. This energy is then transferred from level to level as food; a good part of the energy is lost from one level to another, mainly in the form of heat (e.g. from respiration), so the chain rarely has more than five levels, since the fifth level rarely contains sufficient energy to support a sixth. Energy is also wasted in the products of excretion.



CIRCULATION OF MATERIAL

We have already seen that the energy is not a cyclical process, due mainly to the waste from respiration and excretion.

Nevertheless, the material is recycled. The chemicals involved are cycled (*biogeochemical cycles*) they pass from living things (in different trophic levels) to their environment (rocks, water, air). E.g. the Carbon cycle, the Nitrogen cycle



4.4 TROPHIC PARAMETERS

BIOMASS

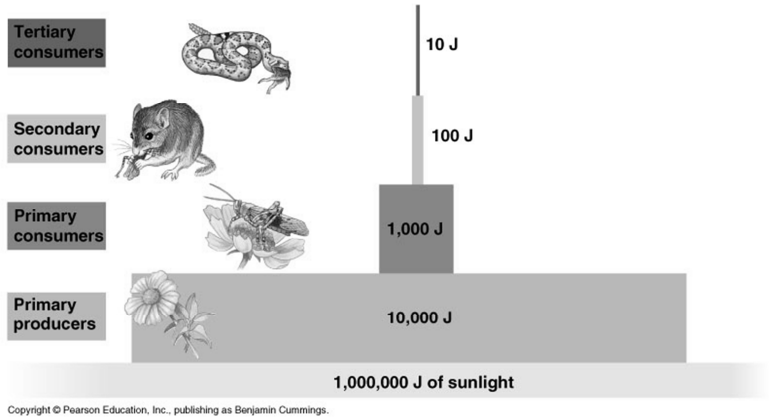
The mass, fresh or dry of living things per unit of area (for terrestrial communities), or unit of volume (in aquatic communities)

PRODUCTIVITY

The capacity at which an organism, population or community assimilates energy. Primary production is the total quantity of the organic material (biomass) synthesized by the producers (green plants) of an ecosystem. Secondary production is the biomass produced by the heterotrophs.

ECOLOGICAL PYRAMIDS

A mode of presentation, using horizontal bars, one on top of the other, such that each of the bars represents the same characteristic in the ecosystem. The length of each bar is proportional to the value represented and each step on the pyramid is one link in the food chain, such that the height of the pyramid is a function of the length of the chain. There are food pyramids, biomass pyramids, energy, population etc.



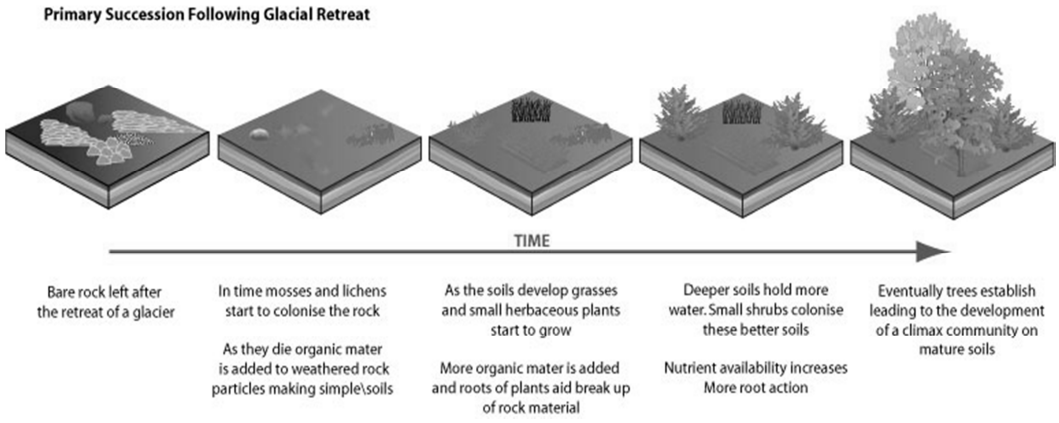
4.4 ECOLOGICAL BALANCE

SUCCESSION

This is an evolutionary process of the biocenosis, in which species replace others in the same biotope, beginning with the pioneer community (initial community) to end up with the climax community. Succession is produced due to changes in the physical environment, due to changes in the climate, or due to other changes caused by the community, or by other organisms close by that cause changes in the environment. The *primary succession* is that which initiates a virgin biotope (one which has never been inhabited by living organisms), e.g. a new volcanic island. The *secondary succession* is that which takes over after the primary succession has been eliminated or outcompeted.

CLIMAX

This denotes the final stage of a geobotanic succession, in equilibrium with the conditions of the environment. This constitutes the optimum biological stability of a community – the culmination from: primary → secondary → tertiary →…..→ climax



GEOLOGY

INTRODUCTION: THE GEOLOGICAL CYCLE

The enormous amount of energy existing in our planet when the Earth was first formed was not lost when the lithosphere, the solid crust of our planet, was formed, but it was contained within the Earth. This means that the Earth is not a dead planet, lacking activity or movement, it is quite the opposite. We can appreciate constant and deep changes in our dynamic planet. Except for a few brusque changes, (volcanoes and earthquakes), they are usually very slow changes, not easily seen by human kind.

The constant changes that take place on the Earth's surface (**lithosphere**) are caused by a series of forces. These forces that continuously change the lithosphere are known as **geological agents**, and can be external (acting from the outside) or internal (acting from the inside). External geological agents are, in general, responsible for the destruction or modelling of the land relief, levelling and flattening the surface of the Earth. The external geological agents are: the atmosphere, water, and living beings. Internal geological agents, generally, build the land relief, elevating or sinking the terrain by means of great pressures, known as *orogenic forces*. The outcome of the deformations provoked by the orogenic forces, are folds and faults and at a larger scale, the appearance of mountain ranges.

External geological agents are driven by the external energy that comes from the Sun (and gravity). Internal geological agents are driven by the internal thermal energy (convection currents) of our Earth (and gravity), due to the decaying (disintegration) of radioactive elements present within the Earth. The changes taking place on the Earth's surface by the combined action of the two types of agents are known as **geological processes**, and they are:

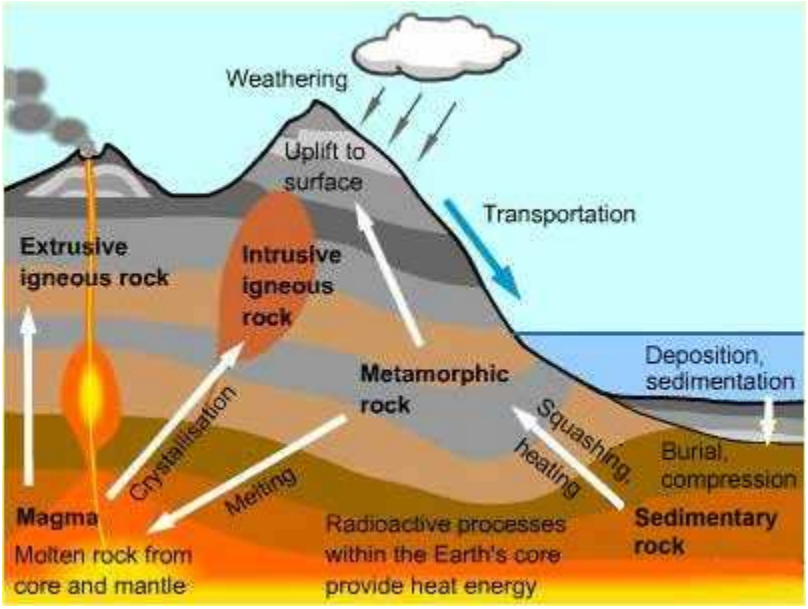
1. **Erosion** or fragmentation of rocks, can be carried out by the atmosphere (weathering), by the wind (corrosion), by rain water, (normal erosion), etc.
2. **Transport** of the materials torn off by erosion, which is usually carried out by water or wind.
3. **Deposition** or sedimentation of the transported materials. It usually takes place in the lower parts of the crust, forming layers or strata.
4. **Diagenesis**: Deposited materials undergo changes (diagenesis) which transform them into new rocks, with different properties to those of the original sediments. Diagenesis is mainly the compaction and cementation of sediments (lithification).
5. **Metamorphisms**: As materials go deeper into the crust the physical conditions change drastically, especially pressure and temperature; these physical changes give rise to new rocks.
6. **Geological Fold**: The materials undergo great pressures (see plate tectonics) which can form new mountain ranges building the land relief.
7. **Epeirogenic movements**: The uplift or depression of the Earth's crust which can affect large areas of land or the ocean floor.
8. **Volcanoes and earthquakes** or seismic movements, also build the land relief (e.g. volcanic islands).

Therefore, slowly but continuously, the land relief is being built by the internal geological agents, and destroyed by the external geological agents. Geological processes follow a cycle. This cycle has three phases:

A. **Glyptogenesis**. The destruction of the land relief by the external agents. Processes 1 and 2.
B. **Lithogenesis**. The formation of new terrain and rocks. Processes 3, 4 and 5.
C. **Orogenesis**. The formation of new land relief. Processes 6, 7 and 8.

Obviously, there is no need for this cycle to finish in order for it to begin again: a land relief recently formed (hardly eroded), can become younger by the action of new orogenic forces.

Rocks and minerals are composed of chemical elements (**geological elements)** and if we analyze the chemical composition of the three types of rocks and minerals that make up the Earth's crust, we notice that their total chemical composition is very much alike. This is because, as we will shortly see, such elements concentrate and spread out differently in the different materials as the geological cycle takes place, but it is always the same elements which form these materials. Let's take a look at the **rock cycle,** which is how these processes take place**.**



Let's think of the elements that make up the different types of magma. Due to erosion an epeirogenic uplifting movement takes place, so that the material gets closer and closer to the Earth's surface. As the magma reaches the surface, it solidifies as the temperature decreases, and becomes a plutonic magmatic rock. If erosion continues, or an earthquake, etc takes place, the rock could reach the surface, and be exposed to the exterior. Once the rock is on the Earth's surface, due to the action of the geological agents, the rock will become fragmented. These fragments or sediments will then be transported and deposited, giving rise to a sedimentary rock. As the new sediments exert more and more pressure over the old ones the materials sink deeper, the chemical environment changes and the temperature and pressure increase. These new conditions make the materials undergo changes known as metamorphisms, becoming metamorphic rocks. If the sinking of material keeps taking place, it can melt becoming magma again. From this magma, new magmatic or igneous rocks can arise, which can again undergo the same processes mentioned above. **This cycle must not be understood strictly as an obligated succession of steps** (one step after another). The rock cycle can be interrupted, and not necessarily all of the steps of the cycle have to take place in a particular and determined place on the crust.

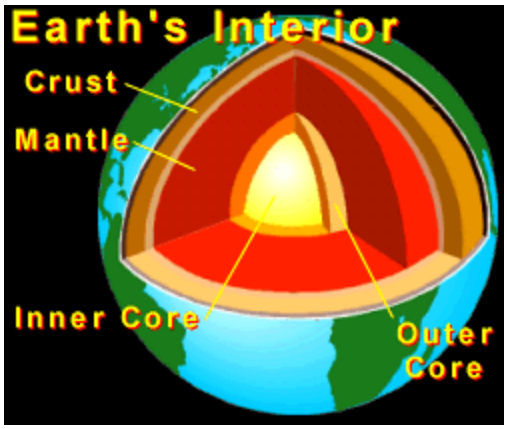
UNIT 5. THE EARTH'S INTERIOR

5.1. THE EARTH: A VERY DYNAMIC PLANET

The Earth is not a perfect sphere, but an ellipsoid with an equatorial radius of 6 379 km and a polar radius of 6 357 km. It is therefore slightly flattened at the poles, and the shape that defines our planet is called a geode. Its surface is known in great detail, but its interior has hardly been explored. Even with the use of the most modern techniques, the deepest hole ever drilled reached 13 km down into the Earth. This is less than half way through the Earth's crust. If no one has ever bored right through the Earth's crust, how do geologists know what the Earth is like inside? Before we answer that question, let's take a look at some of the old hypotheses about the inside of the Earth.

Aristotle believed that the Earth was a completely solid sphere. At the end of the XVII century it was believed to be formed by a solid core surrounded by water (from the deluge: 'the 40 days and 40 nights flood). However, others thought that it was a liquid incandescent sphere surrounded by a thin solid crust.

Nowadays, it is believed that the Earth's interior is made up of three main layers (from the inside to the outside): nucleus or core, mantle and crust.



The crust is divided into plates (lithospheric plates) that move over the mantle below them. As we will see, these plates can collide, drift from each other, etc.

The **core** is in the centre of the planet. We can distinguish the inner solid core, a mixture of nickel and iron, from the outer core which is mainly molten iron. Man's knowledge of the mantle and the core is based on indirect evidence.

As we have already mentioned, the interior of the Earth has a huge amount of energy. The clearest evidence of this internal energy on the Earth's surface are earthquakes and volcanoes. We will study both natural phenomena as we look at the techniques used to study the interior of the Earth.

5.2 INVESTIGATION TECHNIQUES USED TO STUDY THE EARTH'S INTERIOR

Since it is impossible to drill a hole in the crust deep enough to reach the inside of the Earth, different investigation techniques have been used in order to discover what the inside of the Earth is like.

Geologists have to take different pieces of evidence and fit them together. Some of this evidence comes from volcanoes which bring molten rock to the surface from deep down inside the Earth. However, most evidence comes from seismology, the study of earthquakes.

Direct Investigation Techniques

These techniques study materials that come from the inside of the Earth which come up to the surface due to different reasons: lava extruded by volcanoes (which can sometimes carry solid rocks in it), mining (up to a depth of 3 km), drilling of boreholes

(perforations of up to a depth of 13 km), and through the analysis of rocks which where formed deep down inside the Earth, but have been exposed by erosion.

These materials are thoroughly analyzed by different methods such as direct observation, microscopy, chemical analysis, X rays, etc.

Indirect Investigation Techniques

Indirect investigation techniques use information about the inside of the Earth obtained from various sources such as seismic movements, gravimetric studies, etc.

One of these techniques used is the diamond-anvil cell, a research technique which reproduces the expected pressure and temperature conditions of the inside of the Earth. If rocks from the lithosphere are submitted to such conditions we can study the transformations they suffer, and their general behaviour under these conditions. By relating the data collected through the different indirect methods we can formulate hypotheses about the possible layers that make up the interior of the Earth.

Physical characteristics of planet Earth

The following data about the physical characteristics of the Earth can help us formulate the hypotheses mentioned above, and can also help us understand what the inside of our Earth looks like.

Magnetic field: the Earth has a very strong magnetic field which is responsible for the orientation of a magnetized needle. This can only be explained if there is a great quantity of a metallic material in the interior of the Earth.

Thermal flow: it has been observed that in mines and when drilling boreholes, the temperature rises by 3 ºC every 100 m. This rise in temperature is known as the **geothermal gradient.** The geothermal gradient can be defined as the rate of increase in temperature per unit depth in the Earth. Nowadays it is believed that this geothermal gradient exists only up to a certain depth, and below this depth the increase of temperature slightly decreases. The estimated temperature of the core is 6 000 ºC.

Density: the average density of the Earth has been calculated to be 5.5 g/cm^3. However, the density of the rocks from the lithosphere is lower – with an average of 2.9 g/cm^3-, therefore, the rocks from the inside of the Earth must be of higher density.

5.3 SEISMIC METHOD

Besides volcanoes, the other clear manifestations of the internal activity of the Planet are earthquakes or seismic movements. Seismic activity is caused by the interaction between the lithospheric plates. As the plates try to move against or away from each other, potential energy builds up and eventually the tension is released, causing the ground to shake violently: **earthquakes or seismic movements**. The energy released travels through the Earth as a series of shock waves called seismic waves.

The study of earthquakes can be used to study and investigate the interior of the Earth. It is an indirect technique that studies the behaviour of the seismic waves which travel through the Earth in all directions ending up at the surface shaking the ground. Seismic waves are registered in seismic stations by seismographs.

Seismograph: A seismograph is an instrument that records how the ground shakes. It consists of a simple pendulum. When the ground shakes the base and frame of the instrument move with it, but inertia keeps the pendulum bob in place. It will then appear to move relative to the shaking ground. As it moves it records the pendulum displacements, as they change with time, tracing out a record called a seismogram.

Seismogram: The graph that records the movements in which the different types of seismic waves can be observed.
Focus: The point inside the Earth's crust (normally about 100 km deep) where an earthquake originates.
Epicentre: The point on the Earth's surface directly above the focus of an earthquake.

The intensity of an earthquake is measured using the Richter scale (a logarithmic scale of 1 to 10) The formula that the scale uses takes into account the energy released by the earthquake (measured in joules—intensity), as well as the magnitude of the earthquake.

Today we can make simulations of the seismic method through controlled explosions, using this technique to study areas of scarce or no seismic activity. We can also monitor particular areas of interest as well as the magnitude of the shock waves.

Types of seismic waves

P-waves (or primary waves) travel faster and therefore are the first to be detected by seismograms. They are *longitudinal waves* which make rock particles vibrate backwards and forwards in the same direction as the motion of the wave (parallel to the trajectory of the wave). They compress and decompress the materials.
S-waves (shear or secondary waves) travel slower than p-waves but faster than l-waves. They are *transverse waves* which make rock particles vibrate at right angles to the direction of motion (perpendicular to the trajectory of the wave).
L-waves (or long waves) are the slowest-moving waves and travel only through the Earth's crust from the epicenter. They are the ones we feel as they make the ground move, sometimes causing catastrophes. However, they are of no interest when studying the Earth's interior as they only travel through the surface.

The information we have about the inside of the Earth is obtained thanks to the different properties of the p-waves and the s-waves as follows:

- P and S waves increase their velocity as the density of the materials they travel through increases.
- P and S waves increase their velocity as the pressure of the materials they travel through increases.
- Both types of waves slow down as temperature increases.
- S-waves cannot travel through liquids (and therefore cannot pass the outer core), whilst p-waves slow down as they travel through liquids.
- When p-waves and s-waves arrive at a discontinuity they are refracted and depending on the angle of incidence, sometimes they can even be reflected. A **discontinuity is an area where materials of different chemical composition or physical state come into contact.**

Discontinuities

They are zones deep within the Earth where the velocity or the trajectory of the earthquake waves changes radically. We can distinguish the following:

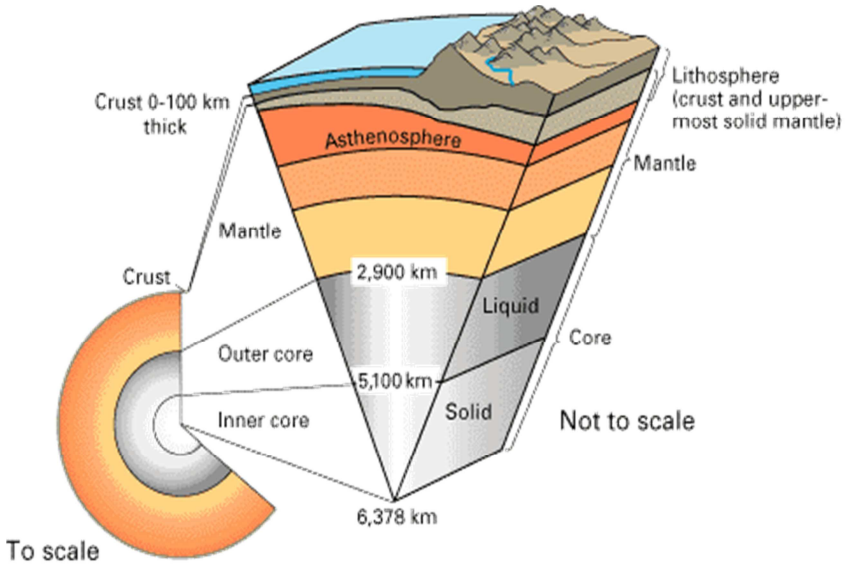
1. **Mohorovicic discontinuity→** usually referred to as the Moho, is the boundary between the Earth's crust and the mantle.
2. **Gutenberg discontinuity →** Located at a depth of about 2 900 km, it separates the mantle and the outer core (the outer core being fluid) Up until this zone, P and S waves increase their velocity, however, as they arrive at the discontinuity p-waves abruptly slow down, and s-waves disappear.

3. **Wiechert-Lehman discontinuity** → It is the boundary between the fluid outer core and the solid inner core. It is located at a depth of about 5 100 km.

5.4 MODELS OF THE EARTH'S INTERIOR

If we put together the information gathered by the direct and indirect methods of investigations we can conclude that the Earth is made up of different and distinct layers. These are concentric layers which increase in density towards the centre of the Earth; each layer contains different materials and has different physical characteristics. The deeper layers are composed of heavier materials; they are hotter, denser and under much greater pressure than the outer layers. We can talk about two different models: one model refers to the different materials that make up each layer, and the other refers to the behaviour of such materials.

Model based on the chemical composition of each layer



- Crust: It is the outermost layer. It is solid and it continues up until the Moho discontinuity, at a depth of about 35 km. Silicates rich in aluminum are very abundant in this layer.
- Mantle: Under the crust (therefore below the Moho discontinuity) and all the way to the core (to the Gutenberg discontinuity at a depth of 2 900 km). Iron and magnesium silicates are abundant in this layer.
- Core: It is the innermost part of the Earth and it is mainly composed of iron. The outer core is in a liquid state and the inner core is solid.

Model based on the physical behaviour of the material within the layers

It is based on the changes on plasticity, rigidity, etc., of the materials.

- Lithosphere: The crust and the rigid upper mantle make up the lithosphere.
- Asthenosphere: It is located below the lithosphere. Its thickness and depth varies (for example its depth is somewhere between about 100 and 250 km deep). In some areas the asthenosphere has not been observed. It is the part of the upper mantle that exhibits plastic properties. P and S waves slow down as they reach the asthenosphere, which can be explained due to the partial melting of the rocks in this layer due to the high temperatures and the particular chemical environment.
- Mesosphere: It is located below the asthenosphere and reaches all the way down to the beginning of the core (Gutenberg discontinuity) It is more rigid than the asthenosphere, however, in some areas, and under certain pressure and temperature conditions, it could also present more fluidity (plasticity).
- Endosphere: It is composed of the outer and inner core:

- Outer core: It starts below the mesosphere going to the Wiechert-Lehman discontinuity, at a depth of 5 100 km. Geologists have concluded that the material in the outer core is molten since p-waves drastically slow down as they reach it and s-waves disappear once they get there.

- Inner core: It is believed that the inner core is solid, since p-waves increase their velocity once they reach it, and because of the very high pressure that exists at such depth.

5.5 THE CRUST

It is the outermost layer of the Earth. It is made up of continental and oceanic crust. The crust is thinner under the oceans, varying from 6 to 11 km thick. Continental crust is about 25 to 75 km thick.

Continental crust

It has a heterogeneous structure with variable thickness. It is made of: igneous rocks (such as granite and basalt), metamorphic (such as slate and gneiss) and in a smaller proportion, sedimentary rocks (such as clay and limestones).

The average density of these rocks is of 2.8 g/cm^3 . The most abundant chemical elements are, in decreasing order of abundance: O, Si, Al, Fe, Ca, Na. These elements make up silicates, quartzs, micas, orthose, etc.

The age of the rocks varies. The oldest ones are dated as old as 3 800 million years old, and generally, the age of rocks increases as we move towards the interior of the continents.

On the surface of continents we can distinguish among others the following features:

- **Cratons**: old devastated large portions of continental plate which can be covered by sediments; e.g.: the Siberian plain is a craton with sediments. Cratons are composed of the oldest rocks and are the most stable areas of a continent. They are eroded over many years showing hardly any land relief; with a thickness of about 30 km. (Cratons have been relatively undisturbed since the Precambrian).
- **Orogens**: are extensive belts of rocks deformed by orogeny, which have been formed by a large/great thickness of folded sediments. They are the youngest parts of the continental crust with a thickness of about 70 km. (E.g. the Rocky mountains).
- **Continental shelf** (or submerged continental platform): it is the continuation of the continental crust underneath the ocean waters. Sometimes it can be above water (emerged), such as in Florida.

Oceanic crust

It forms the ocean floors. It is much thinner than the continental crust. It is composed of basalt and gabbros. The average density of the oceanic crust is 3.3 g/cm^3. The rocks that make up the ocean floors are much younger than those which make up the continental crust.

We can distinguish the following structures on the ocean floor:

- **Abyssal plains**: Areas of little relief which make up most of the ocean floor.
- **Submarine mountains, seamounts, guyots and volcanic islands**: Volcanic relief rising over the abyssal plains. Sometimes they can rise above sea level (like the Hawaiian chain).
- **Mid-ocean ridges**: Submarine mountain ranges, which can be thousands of km long. Sometimes they can rise above sea level forming islands. Most of these

islands are found in the middle of the oceans. The rocks making up the crust below the ocean floor are younger at the axis of the ridge and age as we move away from it.

- **Oceanic trenches**: Deep depressions of the sea floor generally close to the continents. They are the deepest parts of the ocean floor.

Dynamics of the crust. The crust and the lithosphere

The lithosphere is divided into **lithospheric plates** which drift slowly over a less rigid asthenosphere due to the internal energy of the Earth.

5.6. THE MANTLE

The mantle, going from the Moho discontinuity (at about 35 km) down to the Gutenberg discontinuity (at about 2 900 km), makes up 80% of the Earth's volume and 70% of its mass. It is mainly composed of periodites (igneous rocks made of olivine and other silicates containing lots of magnesium and iron).

Structure and composition

*****Upper mantle.- It is subdivided into several layers:

1. The first part, which extends to a depth of 100 km, is rigid (P and S waves travel very fast in this layer). It is the last part of the **lithosphere**.
2. Under this first rigid part P and S waves slow down due to the partial melting of periodites, therefore giving certain fluidity to this layer. It is called the **asthenosphere** and its thickness varies.
3. Finally an increase in velocity of P and S waves is observed until the limit with the lower mantle, therefore indicating the existence of another rigid layer. In this last rigid layer the mesosphere begins, which goes all the way down to the core boundary.

*Lower mantle.- It goes to a depth of 2 900 km. It is a solid layer which continues down until the Gutenberg discontinuity. Seismic waves keep increasing in velocity as they travel through it however, this increase in velocity is still less than is found in the upper mantle.

D layer

In the area between the lower mantle and the core we can find the D layer. Although it is often identified as part of the lower mantle, seismic discontinuities suggest that the D layer might differ chemically from the lower mantle lying above it. It is believed that many of the global processes that influence the angle of the axis of rotation, as well as the magnetic field of the Earth, take place in this layer. (Scientists theorize that it is in this layer that convection currents originate). This layer is believed to be formed as a result of the chemical reactions that take place between the materials of the lower mantle and those of the outer core. These are highly exothermic reactions where rocks from the mantle are partially molten in the liquid iron of the outer core. Depending on where we are along the D layer, its thickness varies from hundreds to thousands of metres.

Dynamics of the mantle

It is believed to be composed of extremely hot materials and that this heat is transferred as **convection currents**. Such currents are the way in which heat energy is transferred through fluids when there is a difference in temperature in the particular fluid. The hotter materials – less dense – rise and the colder materials – with higher

density – sink. Therefore within the fluid mantle there are warm currents rising and cool currents descending.

It is accepted that there are such currents in the asthenosphere, due to its relative fluidity. It is also believed that convection currents can occur in particular areas of our Earth, throughout the mantle, as under certain pressure and temperature conditions solids can behave like very viscous fluids.

5.7 THE CORE. STRUCTURE AND COMPOSITION

It is the innermost part of the Earth. It goes from a depth of 2 900 km to the Earth's centre. It is believed to be mainly composed of iron.

Outer core.- It starts at the Gutenberg (2 900 km) discontinuity extending all the way to the Wiechert-Leman discontinuity. It is a **fluid layer** due to the very high temperature thought to be inside it, more than 4 000 ºC. Besides iron, geologists think it is also composed of oxygen, sulfur and silicon, but in much smaller quantities.

Inner core.- It goes from the Wiechert-Leman discontinuity to the centre of the Earth. Scientists believe that it has a density of 13 g/cm^3 and a temperature above 6 000 ºC, nonetheless scientists believe that the inner core is solid due to the enormous amount of pressure within it (3.5 million atmospheres). It is thought to be composed of almost pure iron.

Dynamics of the core

Scientists theorize that in the liquid outer core there are intense convection currents as a result of differences in temperature, and of the rotation of the Earth. Such convection currents give rise to **electric currents** which produce the **Earth's magnetic field**. The magnetic field changes in intensity and polarity with time. Nowadays, the magnetic north coincides with the Earth's geographic north (though there is a slight displacement between the two). However, millions of years ago the magnetic north was over the geographic south, even longer ago the opposite was true and so on. Recent data seems to indicate that the intensity of the magnetic field is diminishing (decreasing). It is believed by scientists that in a few thousand years the magnetic field will completely disappear with the possibility of re-appearing with time. There is also evidence of the existence of convection currents in the inner core of the Earth.

5.8 EARTH'S DYNAMICS

5.8.1 OLD HYPOTHESES ABOUT GEOLOGICAL PROCESSES

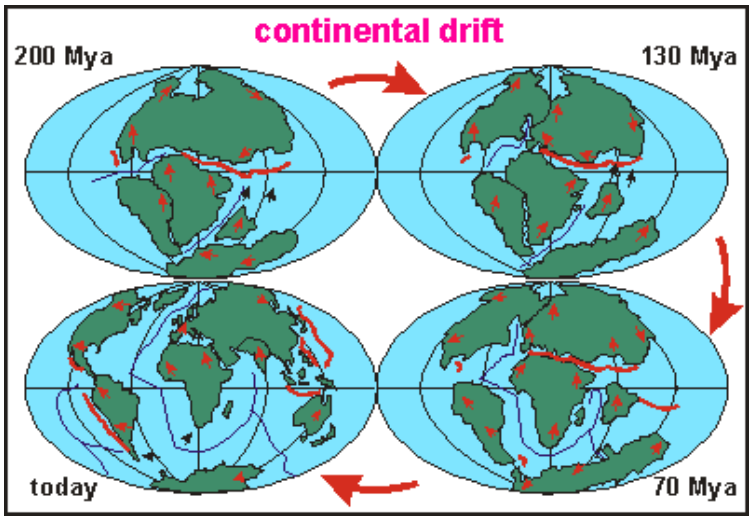
Let's have a look at some of the main theories about geological processes.

Catastrophism: Geological processes such as the formation of mountains, valleys, and volcanic eruptions, were explained from a catastrophic point of view. It was the idea that the changes that take place on the Earth's surface are a result of sudden, short-lived, violent events, such as earthquakes and volcanic activity.

Gradualism: It was the belief that changes occur slowly in the form of gradual steps throughout time. The great changes that take place are the sum of many small changes throughout long periods of time.

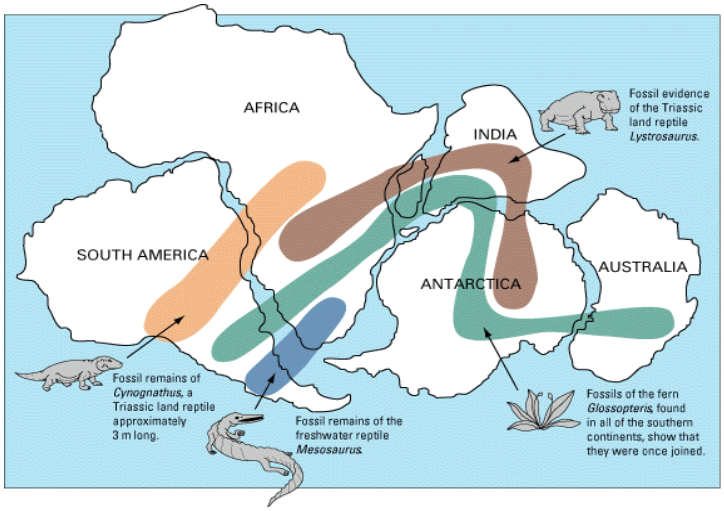
Actualism: The different geological processes that took place in the past are the same that are taking place nowadays. If we study the geological processes that are happening today we can obtain information of similar phenomena that took place in the past.

5.8.2 CONTINENTAL DRIFT



The geophysicist Alfred Wegener proposed that 200 million years ago there was only one giant continent known as Pangaea (the whole Earth). Pangaea broke apart into many continents that started to drift away from each other until reaching their current locations. The pieces of evidence that support his theory are the following:

A. <u>Geographical evidence</u>: The coincidence between the shape of the African and the South American continents is very evident, as they fit together like a puzzle. This is not the case with the North American and European continents, however, if we take into account the line on the continental crust underwater which defines the end of the continent, and not the actual coastline, then there are also similarities.



B. <u>Paleontological evidence</u>: Fossils of plants and animals of the same species of past eras were found in continents which are now widely separated by the ocean, but that in theory were once joined.

C. Geological evidence: There are similar geological structures such as coal fields of similar orientation and age, mountain ranges of similar types of rocks and age, etc., in the continents mentioned above which are today separated by the Atlantic ocean.
D. Paleoclimatic evidence: The existence, for example, of glacial deposits of the same age in places that are nowadays very far from each other. If those continents had always been in their current location they would not have had the same climate in the past.

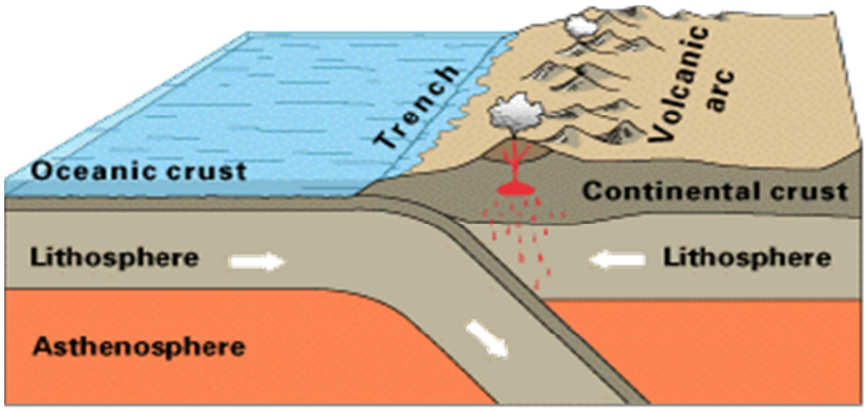
5.8.3 THE THEORY OF PLATE TECTONICS. WHAT IS IT BASED ON AND WHAT ARE THE MAIN CONSEQUENCES?

The theory of plate tectonics explains geological processes such as continental drift, orogenies, volcanoes, earthquakes, etc. The theory of plate tectonics is also known as the theory of global tectonics. It is based on the following:

1. The existence of **mid-ocean ridges**, where ocean floor is being generated.
2. The existence of subduction (or sinking) zones, where the oceanic crust that is generated by the ridges is destroyed.
3. Oceanic ridges and subduction zones divide the Earth's crust into plates – **lithospheric plates** – that move as they are pushed by the new crust generated at the ocean ridges.

The consequences of all that are the following:

A. The motion of the plates compresses the material deposited in the **geosynclines** (marine basins where deposition of sediments takes place), and as a result, gives rise to mountain ranges. This theory clarifies all that had been attempted to be explained previously by many orogenic theories.
B. Continental drift (the movement of the plates) confirms the main points of Wegener's theory.
C. The location of volcanoes and earthquakes in the ocean ridges, in subduction zones and in general, in the boundaries between two plates explains in a logical manner the origin of these geological processes.



Oceanic-continental convergence

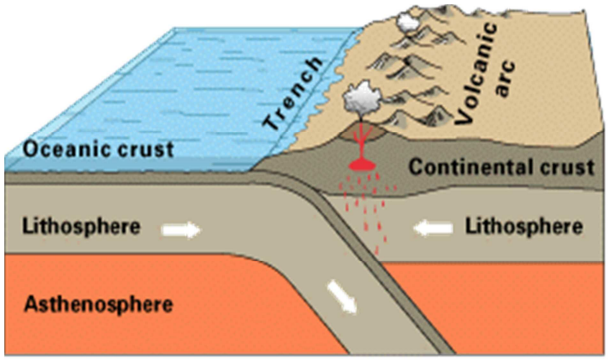
5.8.4. EVIDENCE THAT PROVES THE THEORY OF PLATE TECTONICS

Evidence of the existence of **mid-ocean ridges**:

*Magnetic methods used to study rocks along the ridges tell us that the orientations of the magnetic poles have changed over the history of the Earth (North-South). If we take samples on each side of an ocean ridge we can observe a symmetric distribution of rocks with respect to the magnetic field. The mineral magnetite collected on either side of the ridge and studied shows the same orientation depending on where the magnetic

North was at a particular time. This orientation is always the same in material collected at the same distances on each side of the ridge.
*The age of rocks on each side of the ridge also follows a symmetrical pattern. The rocks are older as we move away from the ridge and vice-versa.
*The geothermal gradient is extremely high right at the ridge (as magma is extruded at the ridges, the temperature considerably rises). The geothermal gradient at the ridge can be up to 30 ºC each 100 m of depth (versus 3 ºC).
*The ocean floors are only 300-400 million years old, as they are being constantly renewed. On the other hand, the material of the continents can be as old as 3 500 million years.

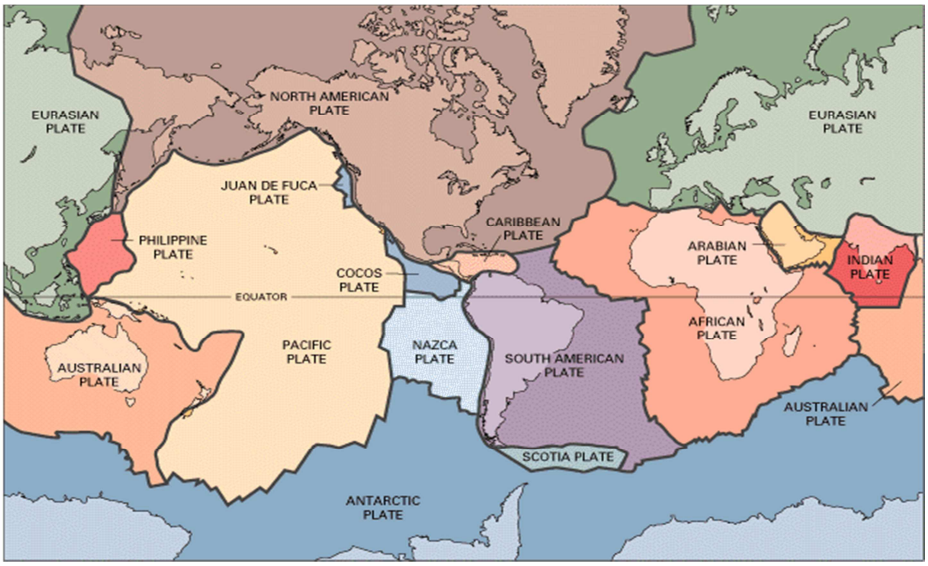
Evidence of the existence of **subduction zones**:
As Benioff was able to prove, the foci of earthquakes are very abundant along the boundaries of continental and oceanic plates. Oceanic plates sink under continental plates. The foci of earthquakes are found deeper and deeper as we go further inland.
*In the areas near oceanic trenches we can observe negative anomalies in gravity. There is less gravity than expected; a big and dense block of rock is being displaced by sea water, with less density. (Remember Fw = mg).
*In the areas near oceanic trenches the velocity of p and s waves does not decrease at depths of 35-100 km, as expected if there was plastic asthenosphere, but on the contrary, it increases up to a depth of 300 km. However on the other side of the trench, the expected behaviour takes place. This is explained by the fact that at these points of subduction the rigid oceanic crust is occupying a space where there would usually be plastic asthenosphere.

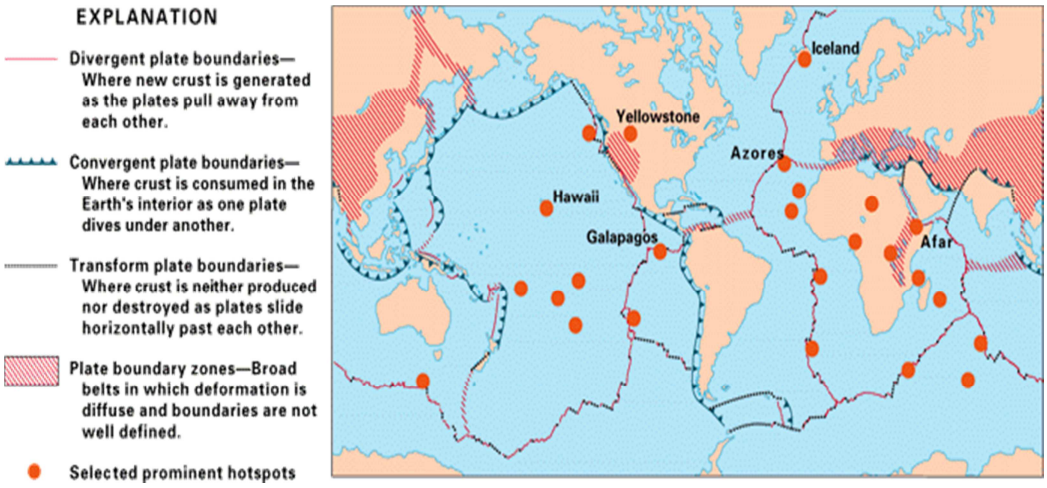


Oceanic-continental convergence

5.8.5 LITHOSPHERIC PLATES AND THEIR LIMITS

The lithosphere is divided into plates. There are two types:
*Oceanic plates, which are made of only oceanic crust, such as the Pacific or Nazca plates.
*Mix plates, made of oceanic and continental crust, such as the North American plate.





Divergent plate boundaries, where new crust is generated: Mid-ocean ridges

As we have already mentioned, mid-ocean ridges are underwater mountain ranges, formed by plate tectonics at divergent boundaries. The mid-ocean ridges of the world are connected and form a single global mid-oceanic ridge system that is part of every ocean, making the mid-oceanic ridge system the longest mountain range in the world. The total length of the system is 80,000 km. The usual altitude of this mountain range is 1 500 m to 3000 m over the abyssal plains. However, sometimes they can rise above sea level forming islands such as the Azores, the St. Helena islands etc.

Transform plate or passive boundaries.

This boundary between plates is very peculiar since crust is neither produced nor destroyed as plates slide horizontally passed each other. A good example of this type of interaction is the San Andres Fault, where the North American and the Pacific plates come into contact, producing lots of earthquakes in the Californian gulf.

Convergent plate boundaries: subduction zones

The oceanic lithosphere generated at the mid-ocean ridges is recycled at the subduction zones. Subduction zones exist at convergent plate boundaries where one plate of oceanic lithosphere converges with another plate and sinks below it to depth of approximately 100 km to once again become part of the mantle. As a result of this, over the surface of the earth an **oceanic trench** opens up, with depths of 11 000 m. There are two types of subduction zones: oceanic lithosphere sinking below continental lithosphere, and oceanic lithosphere sinking below another oceanic lithosphere. Where this happens, the subduction plane is called Benioff's plane. Many foci can be found there as a result of these compressing forces.

5.8.6 WHAT PRODUCES THE MOVEMENTS OF THE PLATES

The interior of the Earth has a great amount of energy. Such energy comes from:

1. The energy left over from the enormous amount of energy existing in the planet when it was first formed.
2. The energy released due to the decaying of radioactive elements found in its interior.

Due to this existing energy, convection currents are produced. As materials warm up they become less dense and rise, as they rise they cool down becoming denser and descend. These convection currents cause the lithospheric plates to move.

Plates are also pushed by the new material being generated at the mid-ocean ridges.

Some scientists also believe that the movements of the lithospheric plates are also a consequence of the subduction zones. As a plate sinks below another, it pushes everything else along. The movement of the lithospheric plates is most likely due to the interaction of several of the processes mentioned.

5.8.7 THE WILSON CYCLE

Wilson postulated a cycle where the fundamental geological processes controlling the evolution of the continents were explained.

A continent rifts, such that the crust stretches, faults and subsides (a-b). Seafloor spreading begins, forming a new ocean basin (c). The ocean widens and is flanked by sedimented passive margins (d). Subduction of oceanic lithosphere begins on one of the passive margins, closing the ocean basin (e) and starting continental mountain building (f). The ocean basin is destroyed by a continental collision, which completes the mountain building process (g). At some later time continental rifting begins again.

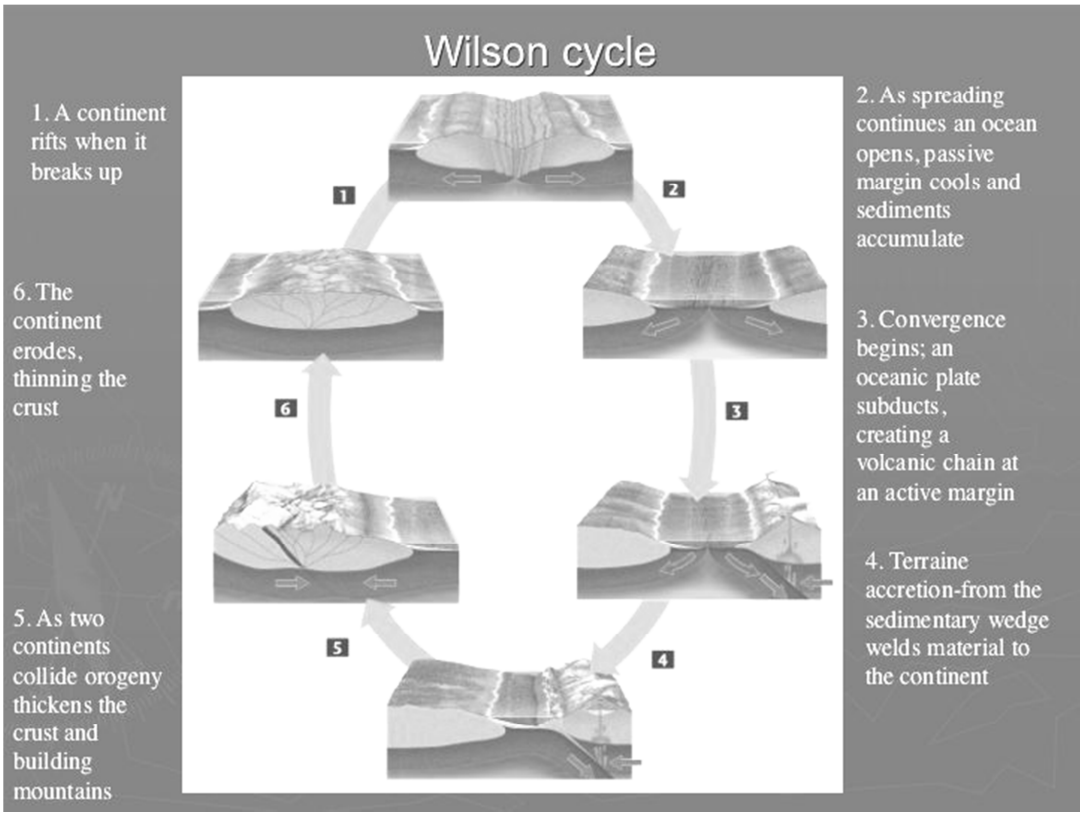
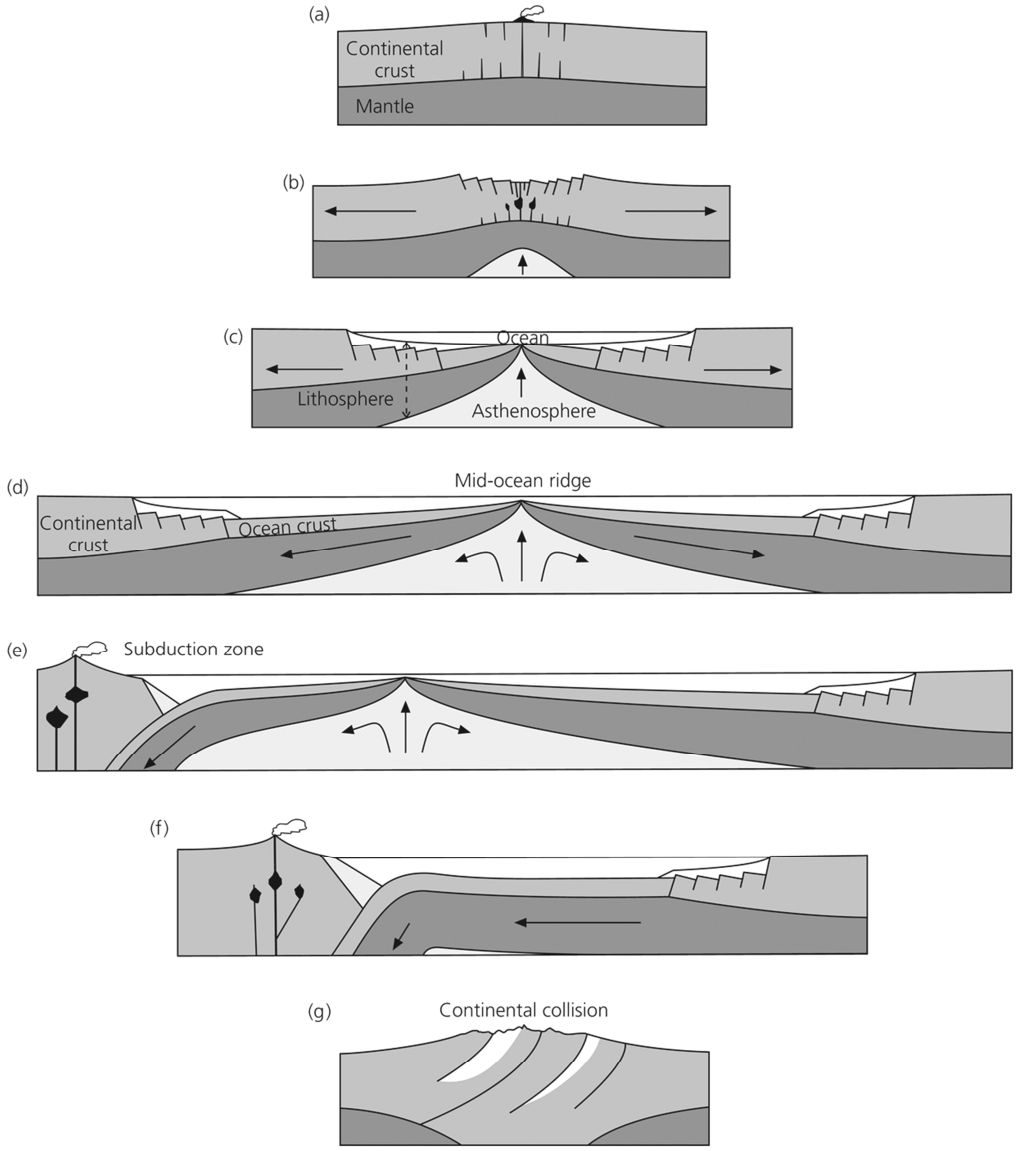


Figure 5.6-1: Schematic diagram of the Wilson cycle.



5.9 MANIFESTATIONS OF THE INTERNAL DYNAMICS OF THE EARTH: DEFORMATIONS AND FRACTURES.

CHANGES IN THE ORIGINAL DISPOSITION OF ROCKS

The interior of the Earth is not static, but quite the opposite. The dynamics of the interior of the Earth can be observed on its surface. The deformations and fractures that take place in the rock strata is a direct result of the internal activity. **Tectonics** is the branch of Geology that studies these deformations and the resulting structures, as well as the internal forces which produce them.

Tectonic forces

Rocks are under **stress** when they are subjected to a force at depth. When the rocks are exposed at the surface after uplift and erosion, the effects of the stress can be studied. Stressed rocks show varying degrees of **strain:** the change in the volume and/or shape of the rock because of that stress. Originally, sediments spread out in horizontal layers. However, the layers of strata are not found placed horizontally very frequently, but 'inclined', folded or fractured as a result of the internal forces that act in specific directions. Three kinds of stress can be applied to rocks: tensional, compressive, and shear.

1.- Compressional stress: two aligned forces that converge (pushing towards each other)
2.- Tensional stress: two aligned forces acting in opposite directions (pulling apart)
3.- Shear stress: parallel forces that run in opposite directions (producing sliding and translation).

Deformations

When subjected to stress, materials can undergo one of three kinds of deformation or strain: elastic, plastic or brittle. Therefore, rocks can present three types of deformations, depending on their composition and on the geological environment in which the deformations were produced. When an **elastic strain** is produced, the material goes back to its original shape once the stress disappears. **Plastic strain** results in a permanent change in the shape of the rock, but the materials do not break, producing **geological folds**. And in **brittle strain** the materials break producing **faults**.

Factors that control deformations

(ductile; rocks bend, fold)

Temperature: If the temperature is high materials will have a ductile behaviour.
Presence of fluids: The presence of fluids allows rocks to be more ductile. For example, clay behaves in a plastic manner in the presence of water but it breaks when it is dried.
Time: If stress is applied over long periods of time, rocks show a ductile behaviour.
Rock composition: Depending on the nature of the materials that make up the rock, some rocks are more ductile while others are more brittle.

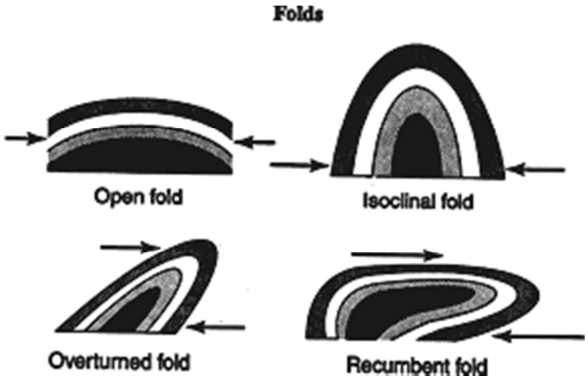
Elastic deformations or strains

Low intensity seismic waves are the most important elastic strains that rocks undergo. Refer back to the notes on the study of the seismic method.

Plastic deformations or strains. Formation of Geological Folds

The term fold is used in Geology when one or a stack of originally flat and planar surfaces, such as sedimentary strata, are bent or curved as a result of plastic deformations.

Folds are continuous deformations of rocks. Folds are frequent in sedimentary rocks and in metamorphic rocks with a low degree of metamorphism. The parts of a fold are the following:



The axis of fold: the central line from which the rock strata dip away in opposing directions. It is the resulting line of the intersection of the axial plane and the surface of the ground.

Hinge: it is the area of maximum curvature of each stratum (therefore, the point of minimum radius of curvature for a fold).

Axial plane: it is the imaginary planar surface defined by connecting all the hinge lines of stacked folding surfaces, which divides the fold in two parts.

Limbs: they are the flanks of the fold; each of the parts in which the axial plane divides the fold.

Nucleus: the innermost part of the fold.

Trend: it is the angle the axis of fold forms with respect to the geographical north (compass orientation of line).

Plunge: it is the angle of hinge line to horizontal plane. It is measured perpendicular to the trend. It varies from 0 degrees (horizontal stratum) to 90 degrees (vertical stratum).

Folds are classified by different criteria such as their geometry or shape, inclination of the axial plane, fold tightness etc.

Fractures in rocks. Formation of faults and joints

Rocks fracture when they undergo stresses beyond the plasticity limit of the materials they are composed of. If the rock has been displaced along a fracture, such as having one side that is moved up or down, the fracture is called a **fault**, and if there is no displacement along the crack, the fracture is called a **joint.**

The parts of a fault are the following:

Fault plane: it is the surface along which the displacement of the fractured blocks takes place.

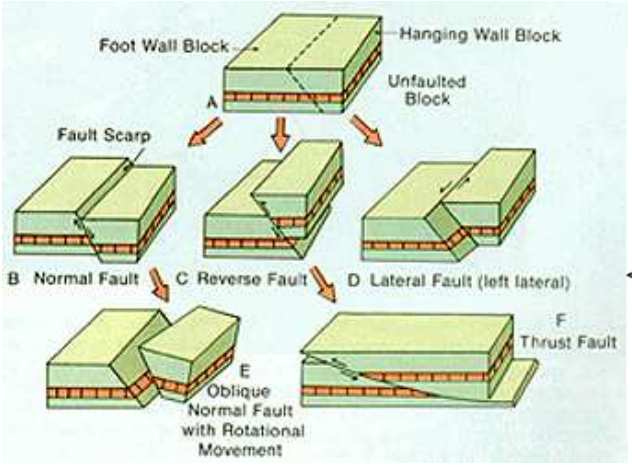
Walls: they are each of the blocks formed by the fracture. There is the hanging wall block and the foot wall block.

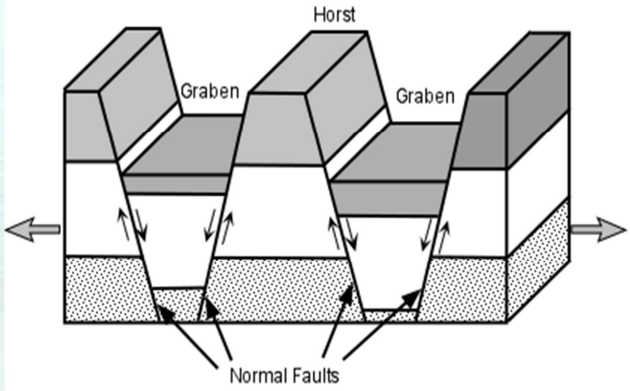
Dip: it is the angle, always less than 90º that the fault plane forms with respect to a horizontal plane.

Types of Faults

1. Dip-slip faults → The movement along dip-slip faults is vertical; one side moves up and the other side moves down. There are two main types: normal faults and reverse faults. Sometimes dip-slip faults are grouped producing topographic mountains and valleys. **The mountains** are called **horsts** and the **valleys** are called **grabens**.

2. Strike-slip faults → The movement along strike-slip faults is horizontal. There are two basic types: left-lateral strike-slip faults, and right-lateral strike-slip faults.


Foot Wall Block
Hanging Wall Block
Unfaulted Block
A
Fault Scarp
B Normal Fault
C Reverse Fault
D Lateral Fault (left lateral)
E
Oblique Normal Fault with Rotational Movement
F
Thrust Fault


Horst
Graben
Graben
Normal Faults

UNIT 6. HISTORY OF THE EARTH

6.1. THE AGE OF THE EARTH. RECONSTRUCTING EARTH HISTORY.

In the XVII century it was believed that the World had been created in six days in the year 4004 BC. This was calculated using the genealogical record of the Old Testament to work back to the biblical account of Creation. This date was accepted by scientists until the XIX century. Nowadays geoscientists have calculated that the Earth is approximately 4 600 million years old. In order to reconstruct the history of the Earth we have to identify the geologic events which have taken place, order them in a time-line and additionally know the age of such events (in million years). If the order of such events in a time-line are known a **relative chronology** is established. If in addition the exact age (in years) of such events can be determined then a **numerical dating** (also known as absolute dating) is established.

Determining Relative Age

It allows to order geologic events by determining which events took place before and after. In other words, to determine what is older and what is younger. It is based on the following principles:

* The **principle of uniformitarianism** "The present is the key to the past" (James Hutton). He claimed that what we see happening today, happened in the same ways in the past. Therefore by looking at today's processes, we hold the key to interpreting the geological past.

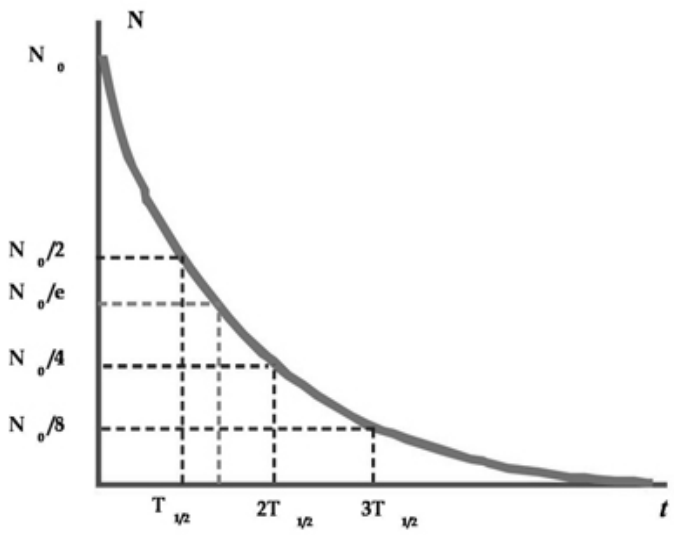
* The **principle of superposition** states that sediments are deposited in horizontal layers on top of earlier, older deposits. Consequently in any horizontal sequence of strata (or rock layer) the youngest stratum will be at the top and the oldest at the bottom.

* The **principle of cross-cutting relationships (also known as the principle of superposition of geologic events)** states that any geological structure that affects another one is younger than the structure being affected (e.g. fractures in rocks that have been displaced. Faults must be younger than the rocks they cut and displace).

*The **principle of faunal succession** states that specific groups of fossils follow (or succeed) one another in the rock record in a definite order. Fossils found in the upper layers are younger than those found in the lower layers. And therefore, rocks containing younger fossils are younger and those containing older fossils are older.

Fossils (from the Latin *fossilus* → "something dug up") are the remains of ancient organisms, or other evidence of their existence, that became preserved in geologic material. Usually only the hard parts (such as shells and bony skeletons) are preserved, and very rarely the soft tissues or even whole organisms are preserved (such as the original bodies of entire insects that have been recovered from hardened tree sap or amber; or mammoths in ice). An **index fossil** is a fossil that determines the specific age of a rock and a specific time of Earth history. They are organisms that lived only during relatively brief, specific periods of Earth history. The most useful index fossils include those species that were geographically wide-spread during their short time on Earth.

Determining Numerical Age



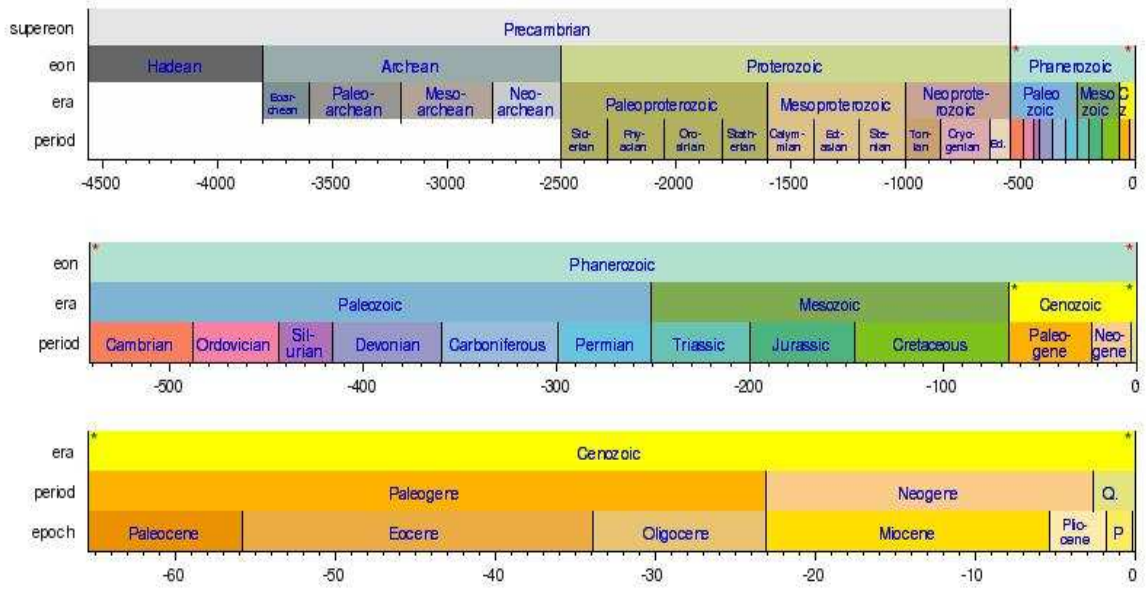
Numerical-dating methods tell us an age in years for a geological material or event. The numerical-dating method which is used most is isotope dating. It relies on the rate of decay of radioactive isotopes within minerals. The nuclei of radioactive isotopes are unstable, and decay from one form ("parent" isotope), to another more stable form ("daughter" isotope) this is a natural process which occurs at a constant rate. Radioactive decay produces an entirely different element from the parent isotope- for example; the decay of uranium isotopes produces lead. As time passes a rock containing a radioactive isotope will contain less and less of its initial radioactive parent isotopes and more of their daughter products. The time it takes for half of the atoms of the radioactive isotope (or parent isotope) to decay is known as the isotope's **half-life**.

For example: radioactive potassium decays to argon with a half-life of 1 310 million years. If we find in a rock only ¼ of the original amount of radioactive potassium which composed it, we can calculate the exact age of the rock, which would be 2 620 million years.

6.2. THE GEOLOGIC TIMESCALE

It organises all of Earth history into blocks of time during which the planet's major events occurred. The divisions of the geologic timescale have been established by studying successions of strata and the fossils found in them. Applying the principles of relative dating mentioned before, allows us to determine a relative chronology of Earth history. The largest unit of time shown on the geologic timescale is the **supereon,** composed of **eons**. Eons are divided into **eras,** which are large time spans defined by their dominant life forms. Eras are subdivided into **periods**, these periods record less dramatic biological changes (such as changes on the earth's surface and the appearance and dis-appearance of species). Dating the rocks of different periods using isotope-dating methods have allowed us to determine the age of each period.

Precambrian: The only recognised supereon as of today, being the longest time span on the history of our Earth. It is a time period when life was mainly limited to organisms such as algae and bacteria. The terrains dated to this time period are much metamorphosed and the fossil record is very scarce (almost non-existent). The Precambrian Supereon is divided into the first three **eons:** Haden, Archean and Proterozoic. Nowadays we are in the **Phanerozoic eon**, the time period when life on Earth started to develop and diversify. (Phaneous → "evident"; zoic → "life"). This Eon is subdivided into **eras**. The Eras of the Phanerozoic are: Paleozoic, Mesozoic and Cenozoic.



6.3. PRECAMBRIAN

It is the longest era of Earth history. It goes from the origin of Earth, about 4 600 million years ago (m.y.a.) to the beginning of the Paleozoic Era, about 600 m.y.a. The Precambrian Supereon is divided into the Archean and Proterozoic Eons.

The Earth originated about 4 600 m.y.a., with the rest of the entire Solar System. Initially it was an incandescent sphere, slowly its surface cooled down forming its primitive outer crust. Nowadays, there are very few rocks from the Archean Eon. The oldest rocks are dated 3 800 million years old. There was only one continental mass (Pangaea I), which started to fragment into plates (plate tectonics).

The primitive atmosphere was composed of gases: carbon dioxide, water vapour and nitrogen. About 3 800 m.y.a. primitive photosynthetic bacteria started to release oxygen to the atmosphere. The oceans were formed as the water vapour present in the atmosphere condensed (as the planet kept cooling down). The climate at this time was very irregular, with alternating hot and cold periods. There is growing evidence of glaciations at the beginning and at the end of the Protorozoic Eon.

Most scientists believe that life originated as follows: Organic molecules arose from inorganic molecules present in the primitive atmosphere (Urey and Miller's experiment), which started to accumulate in seas and lakes. Aggregates of organic compounds formed, which under suitable conditions would give rise to the first living single-celled organisms. These primitive unicellular organisms evolved giving rise to all living beings. The fossil record proves it. The oldest signs of life have been found in Australia, in rocks dated 3 800 million years old. These correspond to mounds of microbial photosynthesizers (cyanobacteria) known as **stromatolites**. The first Protist appeared 1 400 m.y.a.. Fossils of some metazoans (coelenterates, and marine warms) are found at the end of the Precambrian Eon.

6.4. PHANEROZOIC

The Paleozoic Era

Paleozoic means “ancient life”

It goes from 600 to 230 m.y.a. It is divided into: Cambrian, Ordovician, Silurian, Devonian, Carboniferous, and Permian). The continental reconfiguration that started during the Precambrian continued in this Era. During the Paleozoic era, most continents were joined to form a super continent in the southern hemisphere (Gondwana). Over time, it drifted north, colliding with smaller continents and forming an even larger super continent of Pangaea II.

At the beginning of the Paleozoic era the climate was warm, then it started to slowly cool until Gondwana suffered a glaciation. There was another drastic climate change as it began to warm up again, first becoming similar to today’s climate, but then becoming too hot and arid. Once again it cooled down, and in some regions the climate became warm and humid (like the climate of a rain forest), favouring the growth of abundant vegetation, which later turned into coal deposits. This was followed by another glaciations period and finally at the end of the Paleozoic era, it returned to a hot desert climate.

The fossil record shows lots of marine invertebrates, such as **trilobites**, echinoderms, sea sponges, etc. at the beginning of the Paleozoic era. Trilobites are the index fossils of this era. Then the first vertebrates appeared and that’s when animals and plants first colonized the land. This colonization grew as ferns and gymnosperms (first plants containing seeds) appeared. All this vegetation gave rise to great coal deposits. The first flying insects and the first reptiles also appeared during this time. At the end of the Paleozoic era, (the Permian), mainly due to the climate becoming hot and arid, 95% of all living organisms, both marine and land living died out, in the biggest mass extinction known. Trilobites, among many others, disappeared.

The Mesozoic Era

It goes from 230 m.y.a. to 65 m.y.a. and it is divided in three periods: Triassic, Jurassic and Cretaceous.

At the end of the Triassic period, the super continent Pangaea began to break up, which continued as time went on. America broke apart from Africa, India separated from Africa and the Antarctica. Lots of rifts and subduction zones were formed, giving rise to lots of mid-ocean ridges. The climate was warmer than in other previous eras. This is the era of the big reptiles (such as the dinosaurs), which were very diverse and lived in many different habitats. Mammals (first egg-laying mammals and then placental mammals) and birds are the two groups of warm-blooded vertebrates that appeared and came to dominate Cenozoic landscapes. Angiosperms (flowering plants) appeared and evolved through the Cretaceous period. Besides dinosaurs, other index fossils of this lifespan are ammonites.

At the end of the Cretaceous period the **cretacic extinction** took place: three out of four species disappeared (75%). The extinction seemed to be caused by the impact of a large meteorite in the Caribbean Sea (the dust caused by the impact filtered the sunrays to the point that the climate cooled down several degrees).

The Cenozoic Era

It is divided in two periods: the Tertiary Period (from 65 to 1.8 m.y.a.) and Quaternary Period (from 1.8 m.y.a. to present time). The breaking up of the continents which began during the Mesozoic period continued until they reached the position they are in today.

At the beginning of the Cenozoic period the climate was warm. However, there was an important glaciation during the Tertiary Period. The Quaternary Period was marked by periodic fluctuations between colder glacial and warmer interglacial periods. The present warm period may just be another interglacial period.

Era	Period		Epoch (start mya)	
Cenozoic	Quaternary		Holocene	0.01
			Pleistocene	2.6
	Tertiary	Neogene	Pliocene	5.3
			Miocene	23.0
		Paleogene	Oligocene	33.9
			Eocene	55.8
			Paleocene	65.5

The Cretaceous extinction allowed the development of many groups of organisms which occupied the ecological habitats of those that had disappeared. Nummulites, protozoan with a calcium shell, were abundant during this time, being the index fossils of this period. Mammals took over the habitats of the extinct reptiles during the Cretaceous period, expanding rapidly. The first primates appeared in the early Cenozoic and the first hominoids in the late Tertiary Period.

"You see extinction as a problem, Earl, while I view it as a wonderful opportunity for personal growth!"