7 - The Evolution of Life on Earth

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**STEPS IN THE ORIGIN OF LIFE**

- SIMPLE ORGANIC MOLECULES (MONOMERS) WERE PRODUCED VIA CHEMICAL REACTIONS AND/OR DELIVERED VIA COMETARY IMPACTS.

- SIMPLE ORGANIC MOLECULES COMBINED TO MAKE LONG POLYMERS

- SOME OF THE LONG POLYMERS MUST HAVE BEEN SELF-REPLICATING (LIKE DNA).

- POLYMERS WERE ENCLOSED INSIDE A “CELL” THAT WAS SEPARATED FROM ITS ENVIRONMENT BY A MEMBRANE.
MUTATIONS

CHANGES IN THE SEQUENCE OF BASES IN DNA DUE TO MISTAKES IN DNA REPLICATION. THESE INCLUDE:

– A MISTAKE IN WHICH THE WRONG BASE IS INSERTED INTO A GROWING DNA STRAND.
  • FOR EXAMPLE, IF THERE IS A C IN THE TEMPLATE STRAND, A G SHOULD BE ATTACHED TO IT, BUT AN A MAY BE ATTACHED INSTEAD.
  • THE C AND A WON'T STICK TOGETHER AS WELL AS THE C AND G WOULD.

– A SINGLE BASE THAT IS ADDED OR DELETED
– A SEQUENCE OF SEVERAL BASES THAT IS DUPLICATED OR DELETED
– NOTE: IF BASES ARE ADDED OR DELETED, THIS CAUSES THE STRAND WITH MORE BASES TO LOOP OR BULGE OUTWARD FROM THE OTHER STRAND.
MUTATIONS

MUTATIONS OCCUR BECAUSE OF:

– RANDOM MISTAKES
  • LESS OFTEN THAN ONCE PER BILLION BASES

– EXPOSURE TO:
  • HIGH ENERGY PHOTONS (ULTRAVIOLET, X-RAYS, OR GAMMA RAYS)
  • OTHER HIGH ENERGY PARTICLES
  • CERTAIN CHEMICALS (“MUTAGENS”)
MUTATIONS

WHAT IS THE EFFECT OF A MUTATION?

REMEMBER THAT THE DNA IS PART OF A GENE THAT CODES FOR A PARTICULAR PROTEIN. THEREFORE, WHAT IS THE EFFECT ON THE PROTEIN?

- SOMETIMES THERE IS NO EFFECT AT ALL ON THE PROTEIN BECAUSE OF THE REDUNDANCY IN THE GENETIC CODE. (RECALL THAT SEVERAL CODONS OFTEN CODE FOR THE SAME AMINO ACID.)

- SOMETIMES A SINGLE AMINO ACID IS REPLACED BY A DIFFERENT AMINO ACID.

- SOMETIMES A WHOLE STRING OF AMINO ACIDS ARE REPLACED BY DIFFERENT ONES.

- ADDITIONALLY, SOMETIMES THERE IS A CHANGE IN THE WAY THE PROTEIN IS FOLDED. (THIS IS CAUSED BY A CHANGE IN THE AMINO ACID SEQUENCE.)

- PRODUCTION OF THE PROTEIN MAY BE STOPPED ALTOGETHER.
MUTATIONS

- SOME MUTATIONS HAVE IMPORTANT EFFECTS, AND OTHERS DO NOT. OF THOSE THAT DO HAVE IMPORTANT EFFECTS:

- MOST RESULT IN CHANGES ARE HARMFUL TO THE ORGANISM BECAUSE A PROTEIN DOESN'T FUNCTION PROPERLY. AS A RESULT, THE ORGANISM MAY DIE, OR BECOME SICKER, WEAKER, SLOWER, DUMBER, OR LESS ATTRACTIVE TO THE OPPOSITE SEX.

- HOWEVER, OCCASIONALLY A MUTATION IS BENEFICIAL TO THE ORGANISM, BECAUSE THE ALTERED PROTEIN DOES A BETTER JOB OR CAN TAKE ON SOME NEW ROLE. THIS CAN MAKE THE ORGANISM HEALTHIER, STRONGER, FASTER, SMARTER, OR MORE ATTRACTIVE TO THE OPPOSITE SEX.
DO MUTATIONS GET PASSED ON TO AN ORGANISM'S OFFSPRING?

FOR MUTATIONS THAT HAPPEN IN MOST CELLS OF A MULTICELLULAR ORGANISM, THE ORGANISM ITSELF MAY BE AFFECTED (CANCER, FOR EXAMPLE), BUT THE CHANGE IS NOT PASSED ON TO THE ORGANISM’S OFFSPRING.

IF A MUTATION HAPPENS IN AN EGG OR SPERM CELL OF A MULTICELLULAR ORGANISM, OR IN A SINGLE-CELLED ORGANISM, THEN IT IS PASSED ON TO THE ORGANISM’S SUBSEQUENT OFFSPRING.
THE RESULT OF MUTATIONS THAT HAVE BEEN PASSED ALONG TO OFFSPRING, AND THEN ARE OPERATED ON BY NATURAL SELECTION

NATURAL SELECTION:

– IF THE MUTATION IS HARMFUL, THE ORGANISM HAS REDUCED REPRODUCTIVE SUCCESS. IT MAY DIE BEFORE REPRODUCING AT ALL, OR HAVE FEWER OFFSPRING, OR HAVE OFFSPRING THAT DIE, ETC. AS A RESULT, THE MUTATION TENDS TO BE “SELECTED AGAINST” OR WEEDED OUT OF THE POPULATION.

– IF THE MUTATION IS BENEFICIAL, THE ORGANISM HAS GREATER REPRODUCTIVE SUCCESS. IT HAS A LARGER NUMBER OF OFFSPRING, OR OFFSPRING THAT ARE HEALTHIER OR MORE LIKELY TO SURVIVE AND REPRODUCE THEMSELVES. AS A RESULT, THE MUTATION IS “SELECTED FOR” OR PREFERENTIALLY RETAINED IN THE POPULATION.
EVOLUTION

- As a result of natural selection, organisms often become stronger, faster, or more intelligent with time.
- Organisms with appropriate mutations can often move into new environments that their ancestors could not live in.
- When enough organisms with similar mutations accumulate within a group, they can branch off to eventually form a new species (especially if they have moved into a new environment).
- Remember that some mutations are neither beneficial nor harmful. These lead to variation among individuals within a species, in terms of characteristics like eye color, hair color, and skin color.
EVIDENCE FOR EVOLUTION

OBservations “AftEr the fact” of the effects of evolution:

– CloseLy related species occupying different environments – appears that they had a common ancestor
  • Example: finches in galapagos islands observed by darwin

– Similarities in DNA sequences between related species – the closer the evolutionary relationship, the more similar the DNA sequences
  • Example: humans share 98% of our DNA sequences with chimpanzees

– Many more, too numerous to list
EVIDENCE FOR EVOLUTION

OBSERVATIONS OF EVOLUTION OPERATING IN “REAL TIME”:

- COLD VIRUSES
  - Once you recover from a cold, you are then immune to future infections by that same virus.
  - Sometimes, you may get a cold, pass it on to friends or relatives, and then get it back from one of them.
  - This couldn't happen unless the cold virus had mutated or evolved.

- DEVELOPMENT OF ANTIBIOTIC RESISTANCE IN BACTERIA
  - When bacteria are exposed to an antibiotic, most are killed. Those bacteria with a mutation giving them resistance preferentially survive and reproduce. Eventually most of the bacteria are resistant to the antibiotic. (Overuse of antibiotics has made this problem more serious.)
EVIDENCE FOR EVOLUTION

OBSERVATIONS OF EVOLUTION OPERATING IN “REAL TIME”:

– CHANGE IN COLORATION OF MOTHS IN EUROPE DURING THE INDUSTRIAL REVOLUTION

• MOTHS WERE ORIGINALLY LIGHT-COLORED IN ORDER TO BLEND IN WITH LIGHT-COLORED TREE TRUNKS ON WHICH THEY RESTED. POLLUTION FROM BURNING COAL MADE TREE TRUNKS DARKER IN COLOR, AND PREDATORS COULD MORE EASILY SEE AND EAT LIGHT-COLORED MOTHS. MOTHS WITH A MUTATION FOR DARKER COLOR PREFERENTIALLY SURVIVED AND REPRODUCED, UNTIL MOST MOTHS WERE DARK-COLORED.

– NOTE: “REAL TIME” OBSERVATIONS OF EVOLUTION IN ACTION ARE VERY DIFFICULT TO MAKE FOR “HIGHER” ORGANISMS THAT REPRODUCE SLOWLY. THEY ARE MORE APPARENT IN ORGANISMS THAT REPRODUCE QUICKLY.
DIVERSITY OF LIFE ON EARTH

- The result of evolution is an enormous diversity of species.

- How are living organisms classified?

- The classification scheme should tell us something about how various species evolved.
CLASSIFICATION OF LIFE

LIVING THINGS ARE CLASSIFIED BY:

(IN ORDER FROM MOST GENERAL TO MOST SPECIFIC)
- CELL TYPE
- DOMAIN
- KINGDOM
- PHYLUM
- CLASS
- ORDER
- GENUS
- SPECIES

LET’S LOOK AT CELL TYPES, DOMAINS, AND KINGDOMS, THE MOST BASIC OR MOST GENERAL CATEGORIES.
**TWO CELL TYPES**

- **PROKARYOTIC CELLS**
  - MANY (BUT NOT ALL) SINGLE-CELLED ORGANISMS ARE OF THIS CELL TYPE
  - CELL HAS NO NUCLEUS OR ORGANELLES
  - DNA FORMS A SINGLE STRAND OR LOOP
  - CELLS ARE USUALLY SMALLER

- **EUKARYOTIC CELLS**
  - SOME SINGLE-CELLED ORGANISMS AND ALL MULTICELLULAR ORGANISMS (INCLUDING ALL ANIMALS AND PLANTS) ARE OF THIS CELL TYPE
  - CELL HAS A NUCLEUS AND ORGANELLES
  - DNA IN CHROMOSOMES IN THE NUCLEUS
  - CELLS ARE USUALLY LARGER
Single piece of DNA
Ribosome
Cell membrane
ORGANELLES

- STRUCTURES WITHIN A EUKARYOTIC CELL THAT ARE SEPARATED FROM THE REST OF THE CELL BY MEMBRANES. THESE INCLUDE:
  - MITOCHONDRIA
    - CARRY OUT CHEMICAL REACTIONS THAT RELEASE ENERGY
    - PROVIDE A SOURCE OF ENERGY FOR THE CELL
    - FOUND IN ALL EUKARYOTIC CELLS
  - CHLOROPLASTS
    - FOUND IN CELLS OF PLANTS (BUT NOT ANIMALS)
    - CARRY OUT PHOTOSYNTHESIS
    - \( \text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{O}_2 + \text{FOOD} \)
MITOCHONDRIA AND CHLOROPLASTS

- CONTAIN DNA THAT IS SEPARATE FROM THE DNA IN THE NUCLEUS.
  - MITOCHONDRIAL DNA AND CHLOROPLAST DNA
  - THIS DNA CONTAIN FUNCTIONAL GENES
  - THIS DNA REPLICATES ITSELF WHEN THE CELL DIVIDES

- THE SEQUENCE OF BASES IN MITOCHONDRIAL DNA RESEMBLES THOSE IN CERTAIN BACTERIA.

- THIS PROVIDES A CLUE TO THE EVOLUTIONARY ORIGIN OF ORGANELLES.
MITOCHONDRIA AND CHLOROPLASTS

PROKARYOTIC CELLS ARE SIMPLER THAN EUKARYOTIC CELLS. THEREFORE, THE FIRST CELLS WERE UNDOUBTEDLY PROKARYOTIC.

HOW DID THE FIRST EUKARYOTIC CELLS EVOLVE? AN IMPORTANT STEP WAS THE ORIGIN OF MITOCHONDRIA AND CHLOROPLASTS.

THEORY: ONE PROKARYOTIC CELL WAS ABSORBED BY ANOTHER (THIS IS HOW THEY EAT) OR INVADED THE OTHER (PERHAPS TO INFECT IT WITH A DISEASE). PORTIONS OF THE CELL THAT WAS ABSORBED REMAINED IN THE “HOST” CELL AS MITOCHONDRIA OR CHLOROPLASTS. THE ENERGY PROVIDED BY THE ORGANELLE GAVE THE HOST CELL A SELECTIVE ADVANTAGE.
THREE DOMAINS OF LIFE

BACTERIA

PROKARYOTIC CELLS

SINGLE-CELLED

SOME CARRY OUT PHOTOSYNTHESIS

ARCHAEA

PROKARYOTIC CELLS

SINGLE-CELLED

INCLUDES MANY EXTREMOPHILES

EUKARYA

CELLS ARE EUKARYOTIC

INCLUDES BOTH SINGLE-CELLED AND MULTICELLULAR ORGANISMS

INCLUDES ALL “HIGHER” ORGANISMS

NOTE: DNA EVIDENCE SUGGESTS THAT ORGANELLES IN EUKARYOTIC CELLS PROBABLY RESULTED FROM BACTERIA THAT WERE ABSORBED BY ARCHAEA
CLASSIFICATION OF LIFE

- TWO CELL TYPES
  - PROKARYOTIC CELLS (SIMPLER)
  - EUKARYOTIC CELLS (MORE COMPLEX)

- THREE DOMAINS
  - BACTERIA (PROKARYOTIC CELLS)
  - ARCHAEA (PROKARYOTIC CELLS)
  - EUKARYA (EUKARYOTIC CELLS)

- FIVE KINGDOMS WITHIN DOMAIN EUKARYA
  - PROTISTA (SINGLE-CELLED EUKARYOTES)
  - MONERA (SINGLE-CELLED EUKARYOTES)
  - FUNGI (MULTICELLULAR EUKARYOTES)
  - PLANTS (MULTICELLULAR EUKARYOTES)
  - ANIMALS (MULTICELLULAR EUKARYOTES)

- FURTHER SUBDIVIDED INTO PHYLA, CLASSES, SPECIES, ETC.
**Archaea**

- **Euryarchaeota**
  - Methanothermobacterium
  - Methanococcus
t  - Thermoproteus
  - Pyrodictium
- **Crenarchaeota**
  - Green nonsulfur bacteria
- **Bacteria**
  - Gram-positives
  - Purple bacteria
  - Cyanobacteria
  - Flavobacteria
- **Eucarya**
  - Animals
  - Slime molds
  - Fungi
  - Plants
  - Ciliates
  - Flagellates
  - Trichomonads
  - Microsporidia

- **Dates**
  - 2100 MA
  - 2800 MA
  - 544 MA
  - 1200-1000 MA
  - 2700 MA
CAMBRIAN EXPLOSION

AN ENORMOUS AND SUDDEN INCREASE IN THE DIVERSITY OF LIFE ON EARTH

- ALL BASIC “BODY PLANS” AMONG ANIMALS, SUCH AS CHORDATES (INCLUDES VERTEBRATES) AND ARTHROPODS (INCLUDES INSECTS AND CRUSTACEANS) DEVELOPED THEN
- LASTED FROM ABOUT 545 TO 500 MILLION YEARS AGO

WHY?

- MAYBE OXYGEN LEVELS IN THE ATMOSPHERE REACHED A CRITICAL LEVEL NEEDED TO PROVIDE ENOUGH ENERGY FOR MORE COMPLEX ORGANISMS
- “SNOWBALL EARTH” PERIOD ENDED, AND WARMING OF EARTH OPENED UP NEW ECOLOGICAL NICHES
- MAYBE GENETIC COMPLEXITY OF ORGANISMS REACHED A CRITICAL LEVEL, ALLOWING MANY NEW MUTATIONS AND RESULTING VARIATION
- MAYBE ALL OF THE ABOVE
CHRONOLOGY OF LIFE ON EARTH

- 4.0-4.6 BYA  CHEMICAL EVOLUTION, NO LIFE YET
- 3.8-4.2?  FIRST PROKARYOTIC CELLS
- 3.6  BACTERIA / ARCHAEA SPLIT
- 2.1  FIRST EUKARYOTIC CELLS
- 2.0-2.4  OXYGEN LEVEL IN ATMOSPHERE STARTS TO RISE GRADUALLY
- 1.0  FIRST MULTICELLULAR ORGANISMS
545 MYA  "SNOWBALL EARTH" ENDS, OXYGEN LEVEL BECOMES CLOSE TO CURRENT LEVEL, CAMBRIAN EXPLOSION

475  FIRST PLANTS ON DRY LAND

400  FIRST AMPHIBIANS

300  FIRST REPTILES

250  FIRST MAMMALS

65  EXTINCTION OF LARGE DINOSAURS

2-6  AUSTRALOPITHECUS (HUMAN ANCESTOR)

100 TYA  HOMO SAPIENS, MODERN HUMANS
COMPRESS 4.6 BILLION YEAR HISTORY OF EARTH INTO ONE YEAR:

- JANUARY 1 – EARTH IS FORMED
- EARLY TO MID-FEBRUARY – LIFE BEGINS
- MID- TO LATE MARCH – BACTERIA-ARCHAEA SPLIT
- EARLY JULY – FIRST EUKARYOTIC CELLS
- MID-OCTOBER – FIRST MULTICELLULAR ORGANISMS
- MID-NOVEMBER – CAMBRIAN EXPLOSION
- DEC 13-26 – LARGE DINOSAURS
- DEC 31 EVENING – FIRST HOMINIDS (HUMAN-LIKE CREATURES)
THE “DIRECTION” OF EVOLUTION

- MUTATIONS PRODUCE A WIDE DIVERSITY OF LIFE FORMS, UPON WHICH NATURAL SELECTION ACTS.

- THERE IS NO SCIENTIFIC REASON TO BELIEVE THAT EVOLUTION IS “DELIBERATELY” DIRECTED TOWARDS THE DEVELOPMENT OF COMPLEXITY OR INTELLIGENCE.

- RATHER, COMPLEXITY AND INTELLIGENCE AROSE THROUGH A SEQUENCE OF RANDOM MUTATIONS, EACH OF WHICH GAVE THE RESULTING ORGANISMS A SELECTIVE ADVANTAGE.

- THE MORE COMPLEX AN ORGANISM IS, THE MORE VARIATIONS CAN BE PRODUCED BY MUTATIONS.
SOME QUESTIONS...

- Once life got started, was the development of multicellular life inevitable?

- Once multicellular life got started, was the development of intelligent life (of approximately human intelligence) inevitable?

- Once intelligent life developed, was the development of life that uses technology inevitable?
PRO AND CON ARGUMENTS

- **PRO**: GIVEN ENOUGH TIME, MUTATIONS LEADING TO THESE PROPERTIES SHOULD INEVITABLY HAVE OCCURRED AT SOME POINT. ONCE THESE PROPERTIES DEVELOP, THEY WOULD PERSIST BECAUSE THEY GIVE ORGANISMS POSSESSING THEM ENORMOUS SELECTIVE ADVANTAGES. (MULTICELLULAR LIFE FORMS IN GENERAL, AND HUMANS IN PARTICULAR, ARE VERY SUCCESSFUL.)

- **CON**: THE APPEARANCE OF THESE QUALITIES MAY HAVE DEPENDED ON A SEQUENCE OF EVENTS (EXAMPLE: CLIMATE CHANGES) THAT WERE UNIQUE (OR NEARLY UNIQUE) TO EARTH.
PROBLEM: WE HAVE ONLY ONE LIFE-BEARING PLANET (EARTH) AS AN EXAMPLE. IS IT TYPICAL?

ANOTHER APPROACH: HOW LONG A TIME DID IT TAKE LIFE ON EARTH TO EVOLVE TO DEVELOP THESE PROPERTIES?

IF IT HAPPENED QUICKLY, IT SEEMS THAT IT MAY HAVE “MORE INEVITABLE” THAN IF IT TOOK A LONG TIME.
COMPARED TO THE 4.6 BILLION YEAR AGE OF THE EARTH...

- IT TOOK A VERY LONG TIME (3 BILLION YEARS) AFTER THE ORIGIN OF LIFE FOR MULTICELLULAR LIFE TO APPEAR. (THEREFORE MAYBE THIS WASN'T INEVITABLE.)

- ONCE MULTICELLULAR LIFE DEVELOPED, IT TOOK A FAIRLY LONG TIME (CLOSE TO A BILLION YEARS) FOR INTELLIGENCE TO ARISE. (THEREFORE MAYBE THIS WASN'T INEVITABLE.)

- ONCE INTELLIGENT LIFE DEVELOPED, LIFE THAT USES TECHNOLOGY DEVELOPED QUITE QUICKLY (WITHIN A FEW HUNDRED THOUSAND YEARS). THEREFORE MAYBE THE DEVELOPMENT OF TECHNOLOGY WAS ALMOST INEVITABLE, ONCE INTELLIGENCE AROSE.
CONCLUSIONS FROM THE TREE OF LIFE AND EVOLUTION

- Life on Earth has been predominantly single-celled, for 3 out of the last 4 billion years.
- Prokaryotes are the most successful lifefroms on Earth. (There are more of them than anything else.)
- Humans have occupied Earth for only 0.0025% of life’s history.
- Evolution moves in the direction of increasing diversity, but maybe not necessarily increasing complexity or intelligence.
- The “purpose” of evolution has not been to develop intelligence. The evolution of intelligent beings may not have been inevitable.