

Concepts of Biology: BIOL 111

Study guide for Exam 2

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Lectures 7–14

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Outline

1 Questions and answers

1.1 Exam 1

Results of Exam 1: statistic summary

Summary:

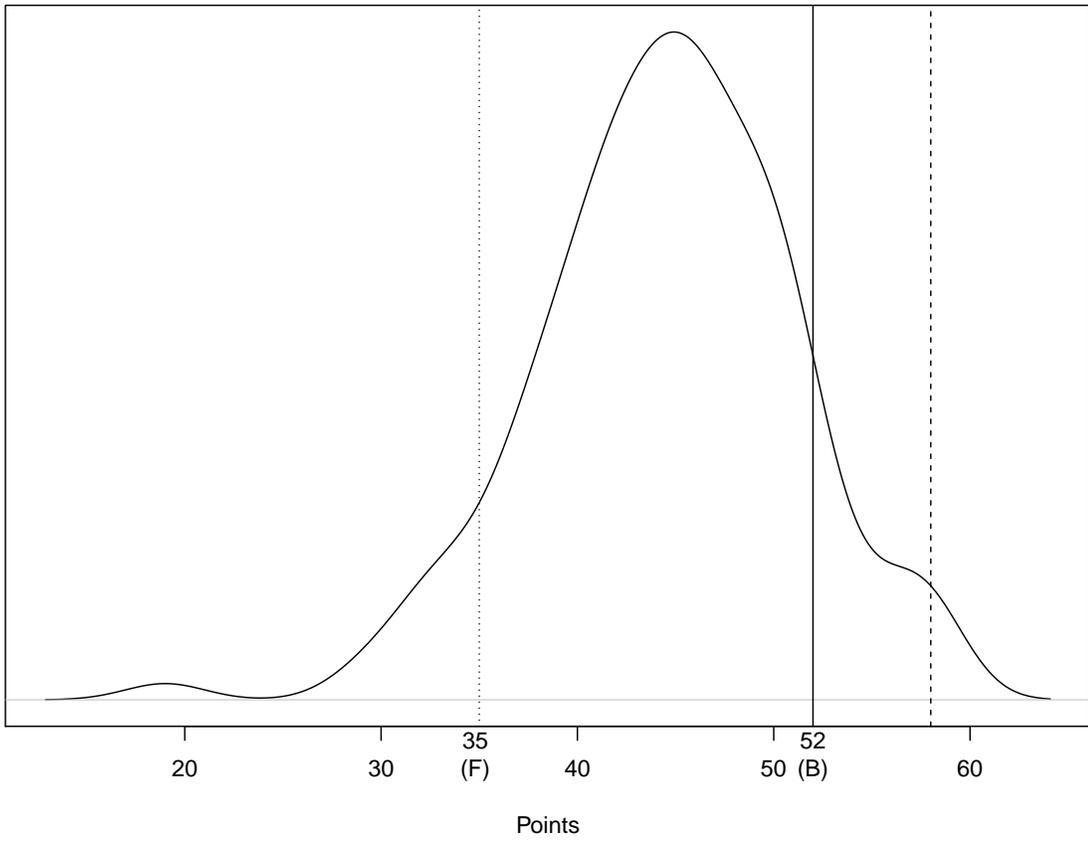
Min.	1st Qu.	Median	Mean	3rd Qu.	Max.	NA's
19.00	41.00	45.00	44.51	49.00	58.00	13

Grades:

F	D	C	B	max
35	41	46	52	58

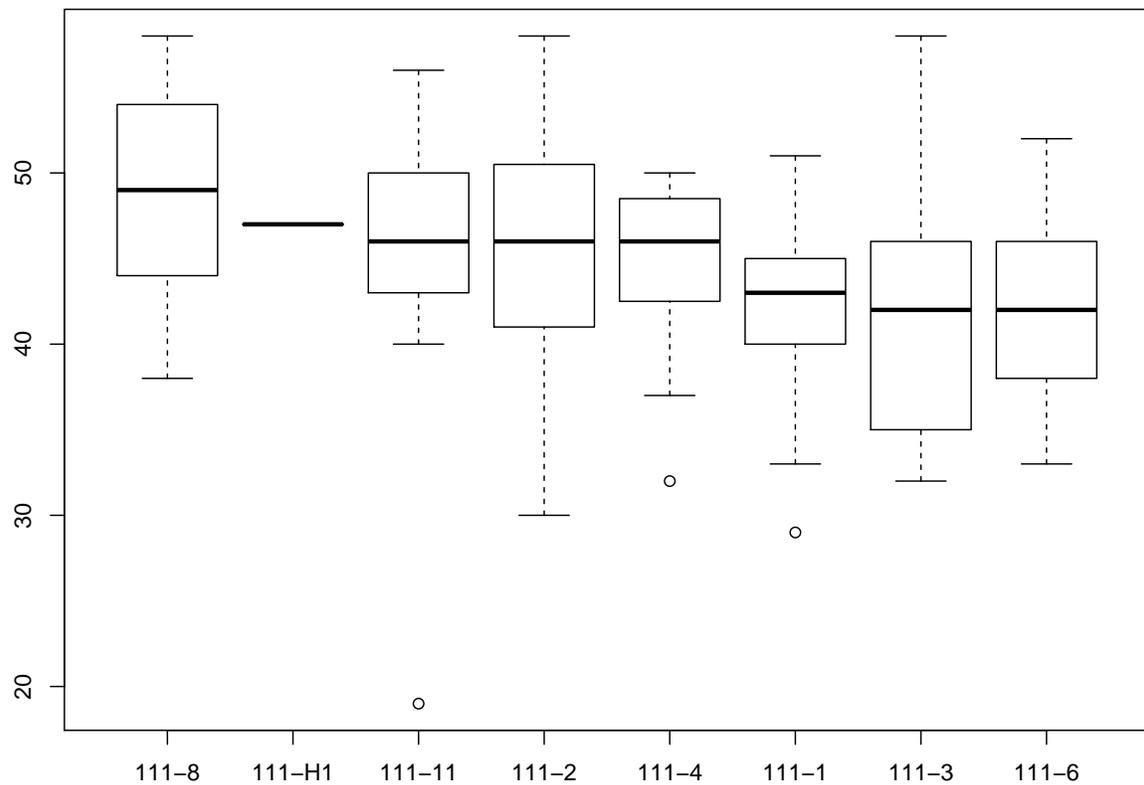
Results of Exam 1: the curve

Density estimation for Exam 1 (Biol 111)



Results of Exam 1: sections

Competition between Biol 111 sections (Exam 1)



Results of Exam 1: some questions

32. Radioactivity was discovered:
- A. In XVII century
 - B. **In XIX century**
 - C. In XXI century
56. What is the difference between reversal and vestigial organs?
- A. **Reversal organs are mutations, vestigial organs are normal**
 - B. Vestigial organs are mutations, reversal organs are normal
 - C. Reversal organs are are results of the convergent evolution, vestigial organs are not
57. Homological structures:
- A. **Are descendants of the same ancestral structure**
 - B. Are results of parallel evolution
 - C. Are mutations
58. What are silenced genes (pseudogenes)?
- A. Non-functional genes which are similar to genes working in other organisms
 - B. Malicious genes which may kill its own cell
 - C. **“Fossil” viruses**

2 Where we are?

Evolution is the fact and research program

- Given the amount of evidence presented, evolution is a fact
- Evolution is also an extremely useful, working research program, both in biology and medicine

3 Origin of life

3.1 Molecules of life

Organic chemistry: chemistry of carbon

- Carbon skeleton
- And H, O, N, P, S

Four types of biomolecules

- Lipids: hydrophobic
- Carbohydrates (sugars): multiple $-OH$ groups
- Amino acids: N + C + O and hydrogen
- Nucleotides: cycle with nitrogen (heterocycle), sugar and phosphoric acid

Organic polymers

- Polymeric carbohydrates: polysaccharides (like cellulose and starch)
- Polymeric amino acids: proteins
- Polymeric nucleotides: nucleic acids (DNA and RNA)

The very basic features of life

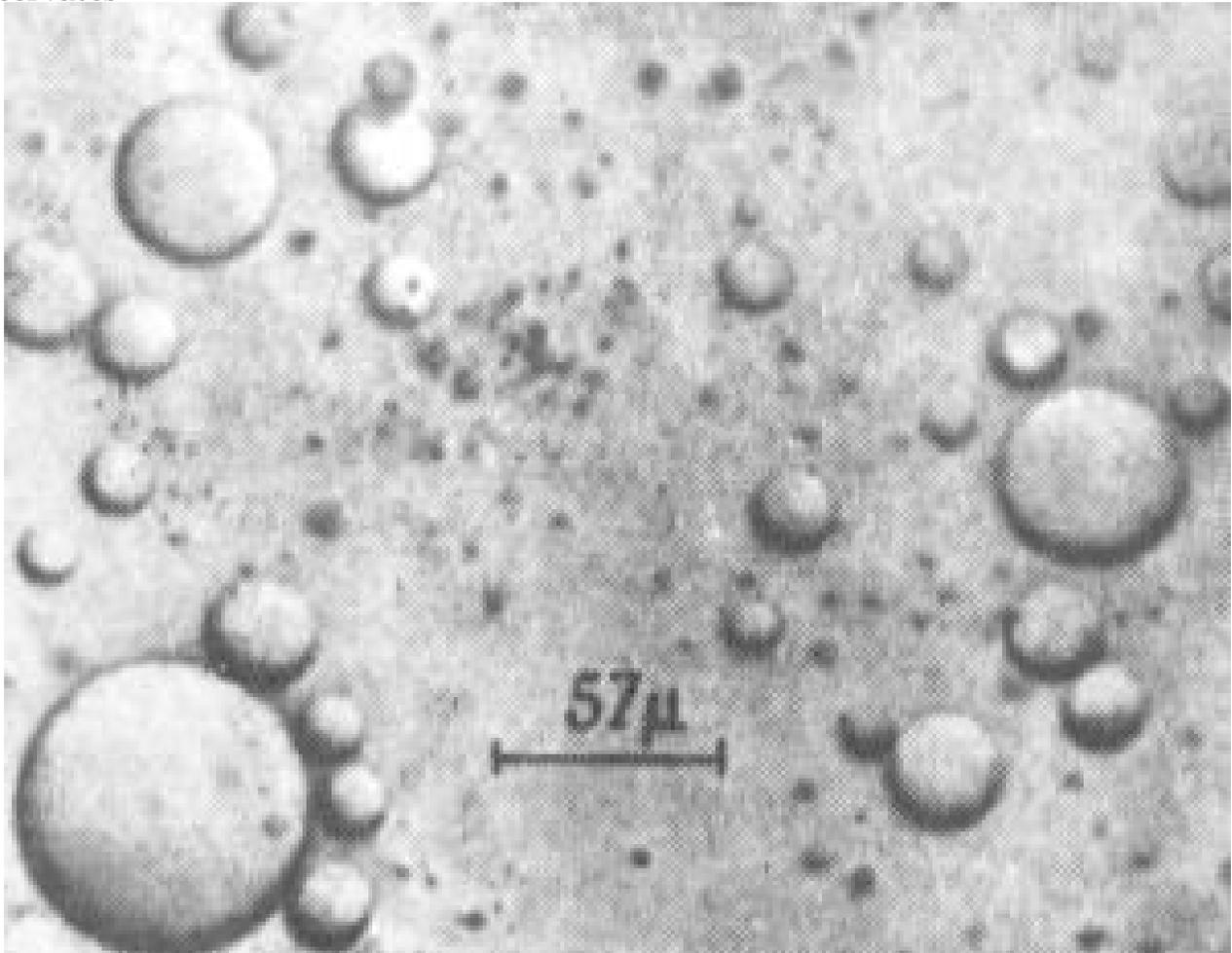
- Semi-permeable (proteins + lipids) membrane
- DNA \rightarrow RNA \rightarrow proteins sequence

3.2 Primordial living structures

Coacervates

- Lipid globules capable to chemical exchange with environment
- Discovered by 1930s, used as an important proof of **abiogenesis** (Oparin's theory)

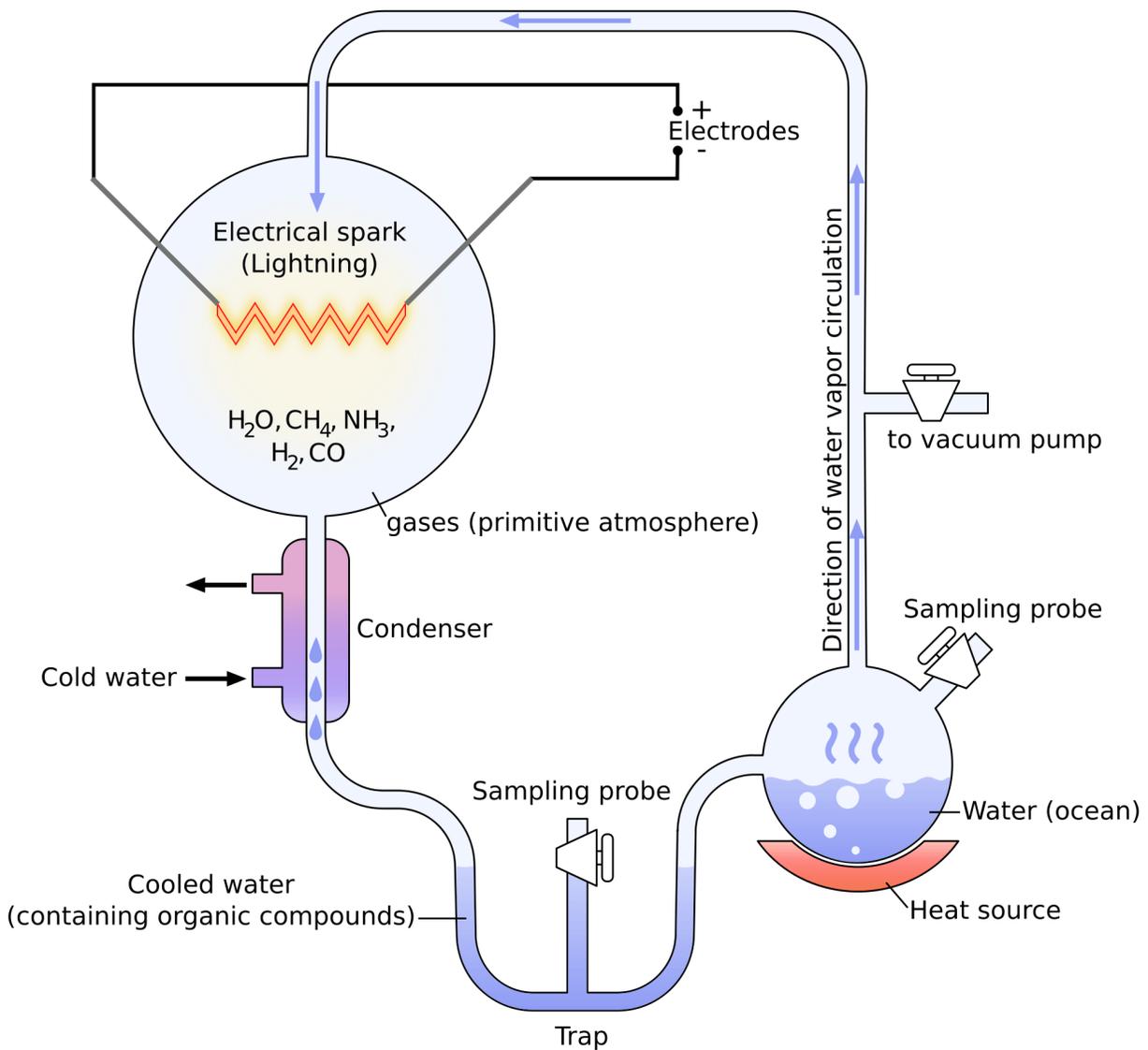
Coacervates



Abiogenesis of proteins

- In 1952, Miller-Urey experiment showed that formation of simple organic molecules is possible when Earth ancient atmosphere and temperature were imitated in lab
- In 1958, Fox and Harada found that “proteinoids” (short peptides) may be synthesized in similar conditions

Miller-Urey experiment



First steps, according to abiogenesis

- Primordial soup
- RNA world
- Proteins
- Cells: last universal common ancestor (LUCA)

Summary

- Four types of biomolecules form biological polymers
- Abiogenesis is the most feasible theory of life origin

For Further Reading

References

[1] Organic chemistry. http://en.wikipedia.org/wiki/Organic_chemistry

[2] Origin of Life. <http://en.wikipedia.org/wiki/Abiogenesis>

Outline

4 Where we are?

Four types of biomolecules form biological polymers

- Lipids
- Sugars and polysaccharides
- Amino acids and proteins
- Nucleotides and nucleic acids

Abiogenesis is the most feasible theory of life origin

- Primordial soup
- RNA world
- Proteins
- Cells: last universal common ancestor (LUCA)

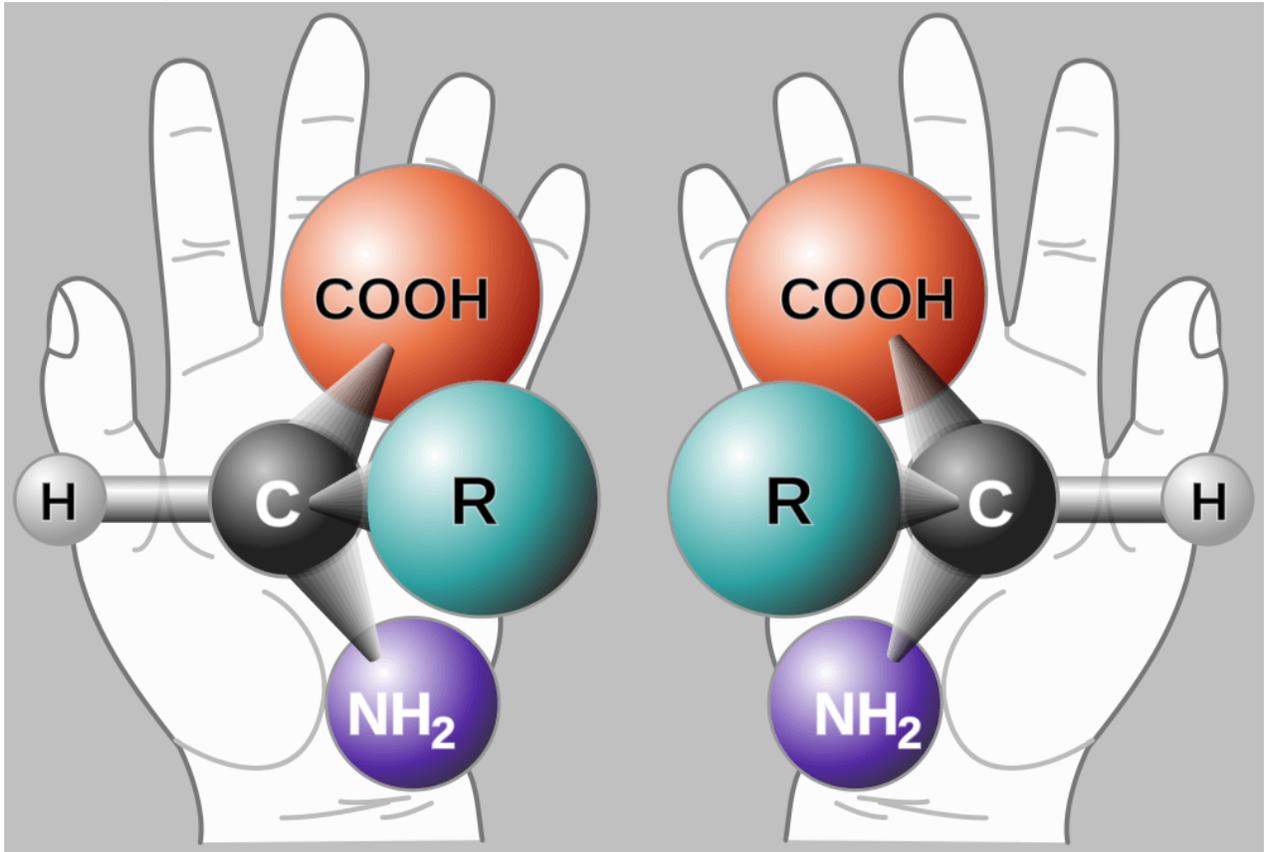
5 Origin of life

5.1 Alternatives and amendments to abiogenesis

Problems of abiogenesis: chiral purity of life

- Most of amino acids are chiral: they have “left” and “right” forms
- *All proteins from living organisms contain only “left” amino acids*
- Sugars (carbohydrates) could also be “left” and “right”
- *Nucleic acids contain only “right” sugars*

“Left” and “right” amino acids



Panspermia theory

- Life is a fundamental feature of Universe
- It always exists and constantly spreading

Self-organization

- Lovelock's (1982) Gaia hypothesis: Earth is a living being
- Life is a way of stabilizing geological cycles on Earth
- Self-organization was based on the principles of Prigogine's **non-equilibrium thermodynamics**
- Life first, organisms second

6 First life

6.1 Hadean and Archean eons

First evidences of life

- Earth age is usually estimated as 4600 Mya (million years ago), Hadean eon was the first epoch
- First minerals are ≈ 4000 Mya, they mark Archean eon

Oldest evidences of life and photosynthesis

- The oldest organic carbon is ≈ 3800 Mya (Greenland, Mesoarchean)
- Organic carbon: carbon with $^{13}\text{C}/^{14}\text{C}$ ratio like in living plants
- Oldest remnants of chlorophyll: 3100 Mya (Mesoarchean)

Photosynthesis

- $\text{CO}_2 + \text{H}_2\text{O} \xrightarrow{\text{light, chlorophyll}} \text{carbohydrates} + \text{O}_2$
- Two stages:
 - A. Light-dependent: production of energy (ATP) and photolysis of water
 - B. Light-independent: assimilation of CO_2 into carbohydrates
- Then carbohydrates are partly converting into lipids; with addition of N—into amino acids; with addition of N and P—into nucleotides

ATP

- Universal energy source in the cell, “universal currency”
- $\text{ATP} \rightarrow \text{ADP} + \text{P} + \text{energy}$

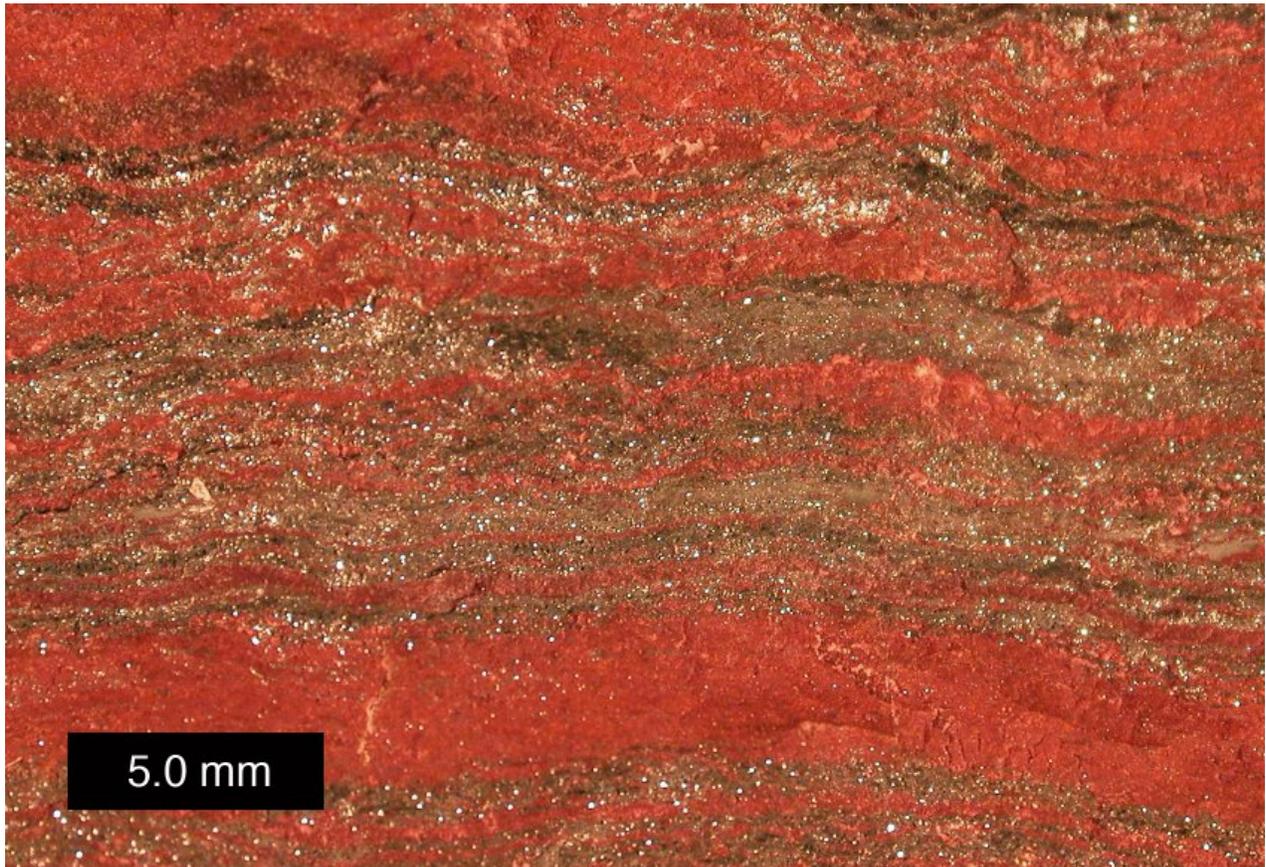
Oxygen and iron

- Initially, Earth atmosphere contained no oxygen
- Photosynthetic oxygen oxidized free iron into quartzite-like rocks contained hematite and other iron minerals
- New iron was always replenished from ocean water
- However, ≈ 2000 Mya, when Proterozoic eon started, almost all iron went deeper into mantle and core

Wheeler Peak, NV



Hematite



From oxygen oases to oxygen revolution

- In Archean, photosynthesis could only produce local “oxygen oases”
- But when no free iron was available anymore, atmosphere started to accumulate oxygen
- When oxygen reached 1% (Pasteur point), aerobic life started
- This was the oxygen revolution which allowed cells to obtain energy via respiration

Fermentation *versus* respiration

- carbohydrates \rightarrow CO₂ + ethanol + 2 ATP
- carbohydrates + O₂ \rightarrow CO₂ + H₂O + 38 (!!!) ATP

6.2 First cells

Who was first?

- Stromatolites: microbial mats from (mostly) cyanobacteria (photosynthetic bacteria)
- *Metallogenium* and others: proteobacteria (e.g., aerobic metal-oxidizing bacteria)

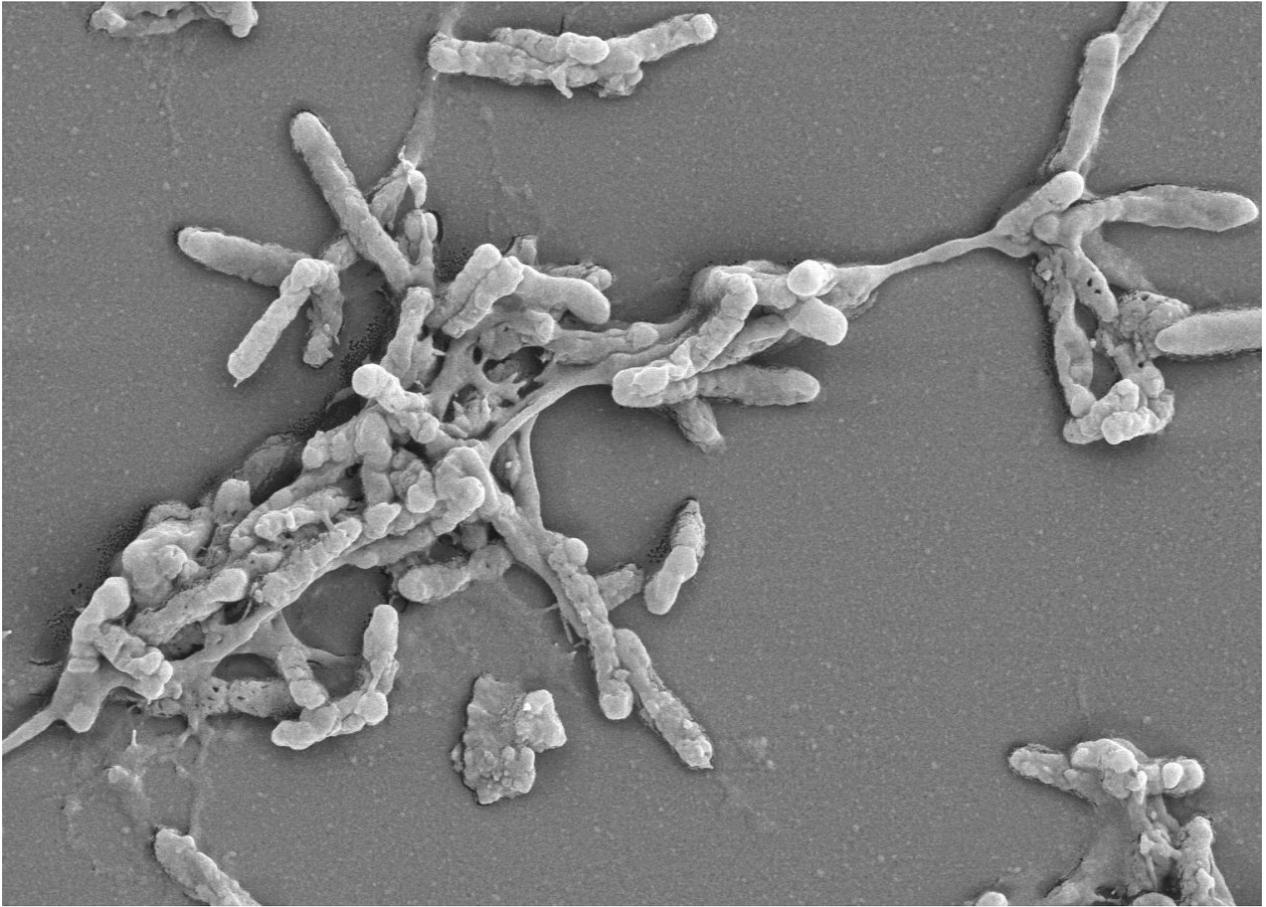
Fossil stromatolite



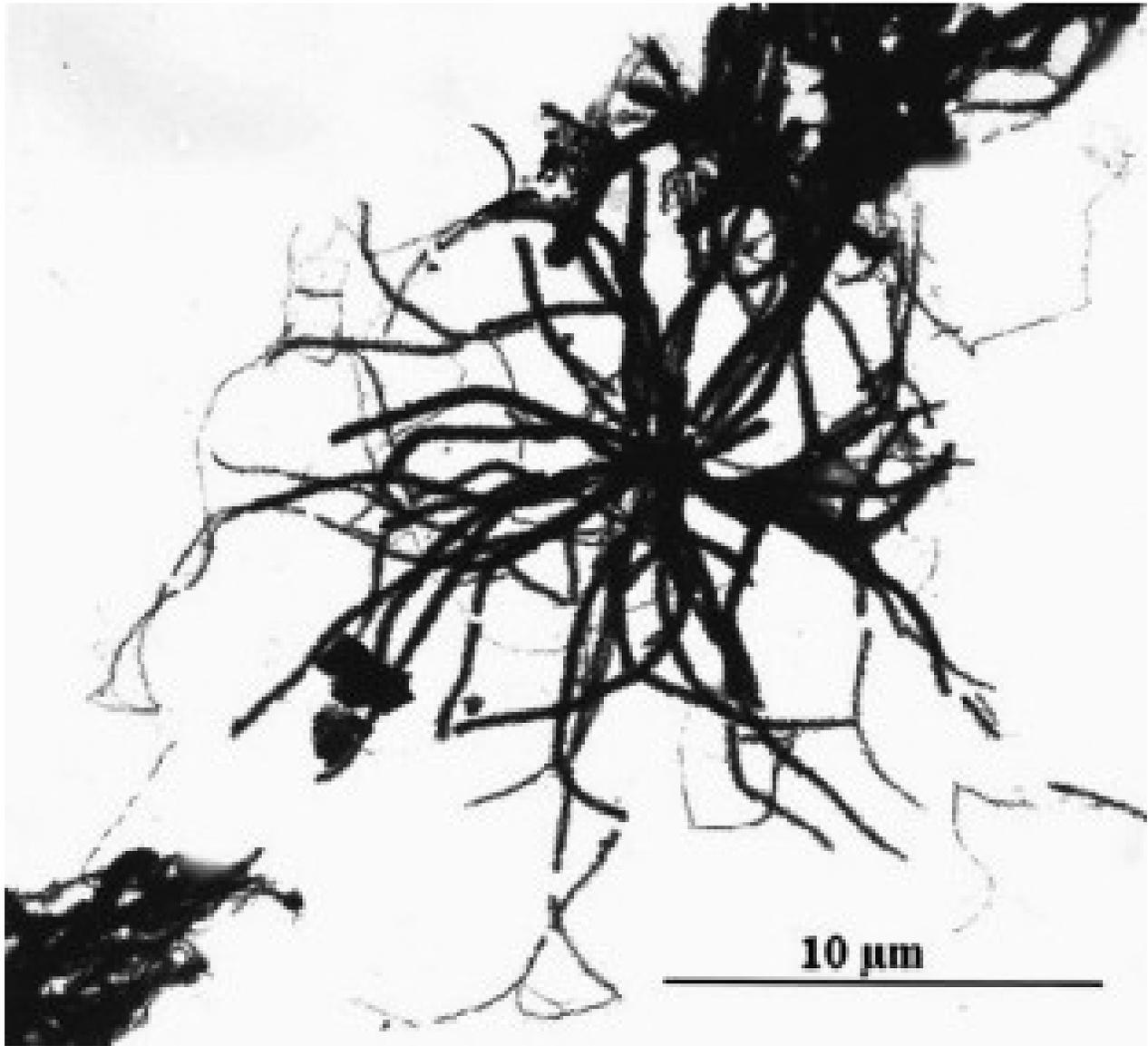
Present-day stromatolite (Shark Bay, Australia)



Present-day iron-oxidizing bacteria



Fossil *Metallogenium*



Summary

- Bacteria were first
- Photosynthesis changed the atmosphere
- Aerobic life respire to obtain more ATP

For Further Reading

References

- [1] Photosynthesis. <http://en.wikipedia.org/wiki/Photosynthesis> (introduction)
- [2] Cellular respiration. http://en.wikipedia.org/wiki/Cellular_respiration (introduction)

Outline

7 Where we are?

First life

- In Mesoarchaeon, cyanobacteria (fossilized as stromatolites) were first
- Photosynthesis changed the atmosphere
- Aerobic life respire to obtain more ATP

Who was first?

- Stromatolites: microbial mats from (mostly) cyanobacteria (photosynthetic bacteria)
- *Metallogenium* and others: proteobacteria (e.g., aerobic metal-oxidizing bacteria)

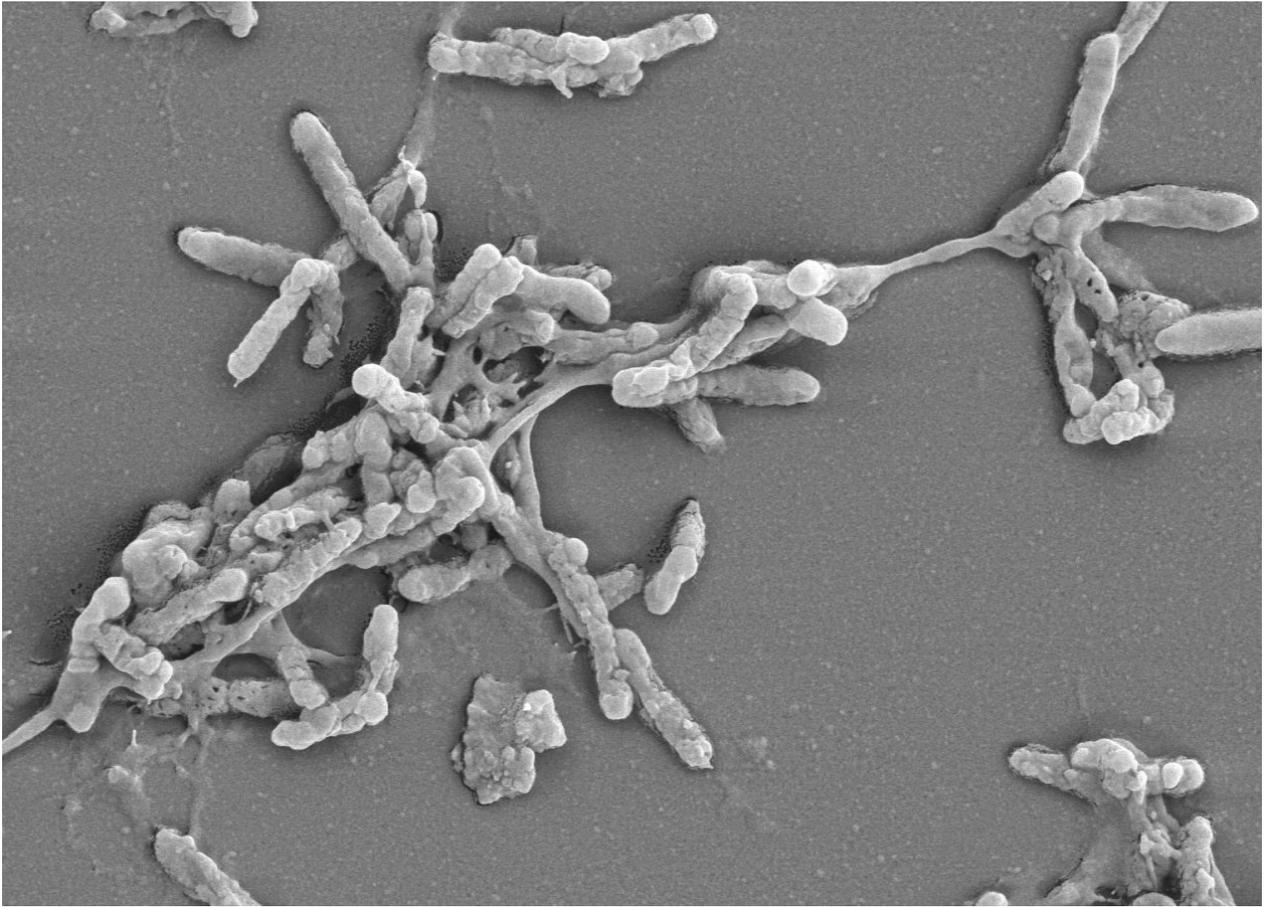
Fossil stromatolite



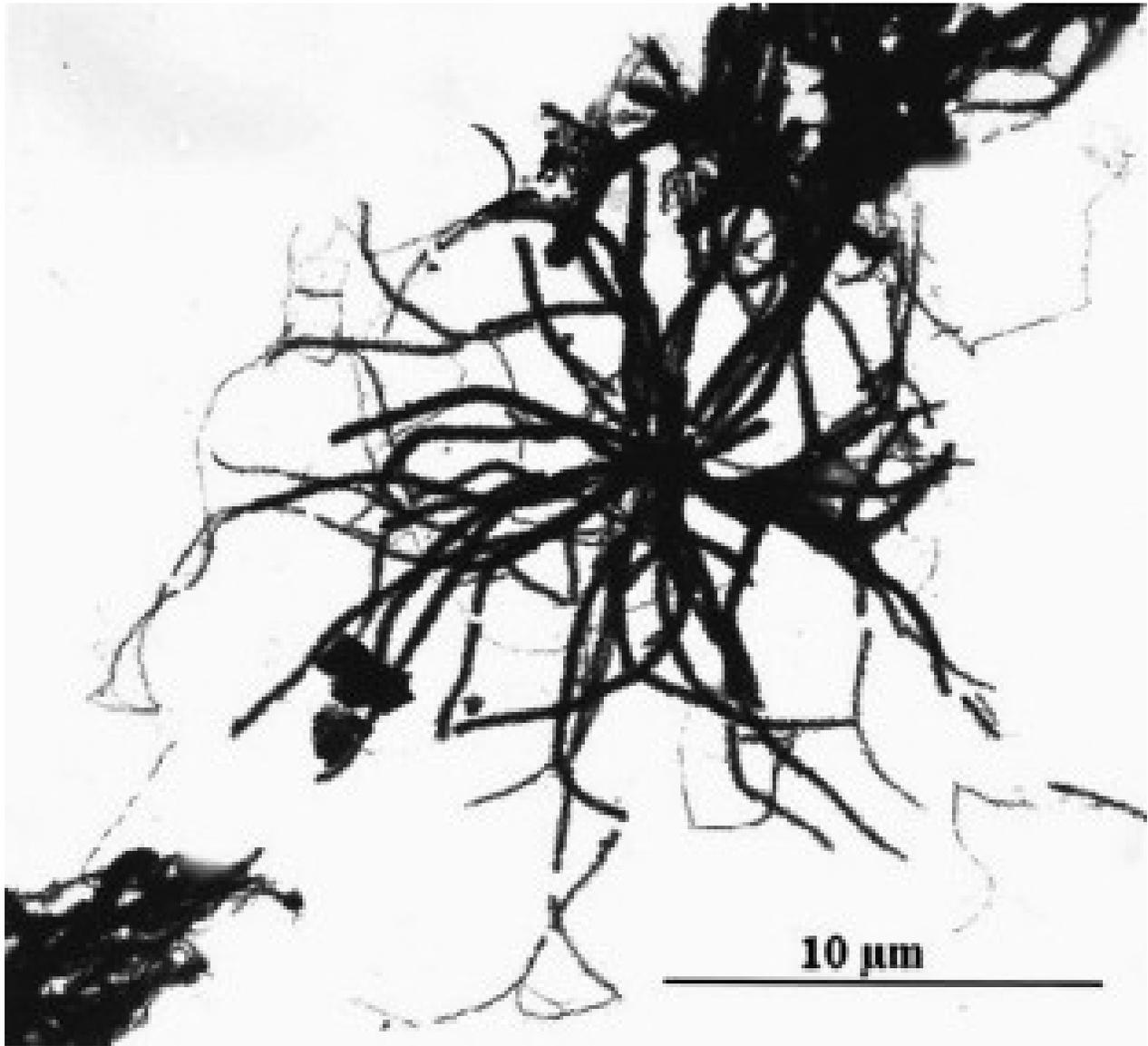
Present-day stromatolite (Shark Bay, Australia)



Present-day iron-oxidizing bacteria



Fossil *Metallogenium*



8 Cell

8.1 Prokaryotic cell

Prokaryotic cell

Main components of prokaryotic cell

- Cell wall
- Membrane
- Cytoplasm
- DNA
- Ribosomes

- Membrane folds and pockets
- Vesicles
- Flagella

8.2 How to be a prokaryote

How to make energy

- Cell respiration and other destructive processes make ATP for all cell
- Photosynthesis and other synthetic processes make ATP and spend it

How to make proteins

- DNA and RNA contain four types of nucleotides
- The sequence of nucleotides is a cypher
- Each three nucleotides will encode amino acid (“genetic code”)
- Ribosomes translate triplets into amino acids and make proteins

How to take food

- Digestive proteins are transported outside membrane
- They destroy polymers into monomers
- Monomers then are pumping through membrane into the cell
- If cell is photosynthetic, it produce monomers itself

How to make body

- Monomers could be spend:
 - in destructive reactions to obtain ATP, **or**
 - in synthetic reactions to make new polymers. These reactions are using ATP

How to multiply

- DNA is a double helix which may copy itself
- Two copies of DNA untangled and separated, then cytoplasm and membrane divide
- Of course, these processes spend lots of ATP

Summary

- Bacteria were first
- Photosynthesis changed the atmosphere
- Aerobic life respire to obtain more ATP
- Prokaryotic cells are simplest cells
- They produce energy, obtain monomers, synthesize polymers, e.g. proteins from DNA and RNA, and sometimes also make monomers themselves (with photosynthesis), divide and even perform a sexual process (recombine DNA between cells)

For Further Reading

References

[1] Genetic code. http://en.wikipedia.org/wiki/Genetic_code

[2] Protein biosynthesis. http://en.wikipedia.org/wiki/Protein_biosynthesis

Outline

9 Where we are?

10 Where we are?

10.1 How to be a cell

Main duties

- Making energy
- Making proteins
- Digesting food
- Constructing body
- Multiplying
- Making sex

How to make proteins I

- Proteins are chemical machines of cell
- Each machine is described in gene
- The only way to make them is DNA → RNA → proteins
- DNA is a folded double spiral; it has two chains
- Every chain consists of four “letters”—nucleotides (A, T, G, C)
- Two chains are complimentary, and only A–T and G–C pairs are possible

How to make proteins II

- DNA may duplicate, then new DNAs will build complimentary chains and become exact copies
- DNA may also “produce” RNA: one of chains serves as matrix for new RNA
- RNA also has four letters (A, U, G, C)
- When RNA is building on DNA, RNA’s “U” will be complimentary with DNA’s “A”; all other rules are the same

How to make proteins III

- New RNA is a matrix RNA (mRNA)
- It will come into ribosome, and ribosome will translate every three letters (triplet) into amino acid
- mRNA moves within ribosome, and new amino acids are joining into growing protein
- Translation rules are known as “genetic code”
- There are 64 possible triplets and only 20 amino acids—genetic code is redundant

Translation rules: “genetic code”

		Second letter				
		U	C	A	G	
First letter	U	UUU } Phe UUC } UUA } Leu UUG }	UCU } UCC } Ser UCA } UCG }	UAU } Tyr UAC } UAA Stop UAG Stop	UGU } Cys UGC } UGA Stop UGG Trp	U C A G
	C	CUU } CUC } Leu CUA } CUG }	CCU } CCC } Pro CCA } CCG }	CAU } His CAC } CAA } Gln CAG }	CGU } CGC } Arg CGA } CGG }	U C A G
	A	AUU } AUC } Ile AUA } AUG Met	ACU } ACC } Thr ACA } ACG }	AAU } Asn AAC } AAA } Lys AAG }	AGU } Ser AGC } AGA } Arg AGG }	U C A G
	G	GUU } GUC } Val GUA } GUG }	GCU } GCC } Ala GCA } GCG }	GAU } Asp GAC } GAA } Glu GAG }	GGU } GGC } Gly GGA } GGG }	U C A G
						Third letter

How to make sex

- If DNA will stay unchanged, cells cannot evolve
- To make evolution possible, there are processes which modify DNA:
 - Mutations
 - Recombinations
- Sexual process allows DNA recombination
- Prokaryotic cells simply connect and exchange pieces of DNA (“bacterial conjugation”)

11 Origin of eukaryotes

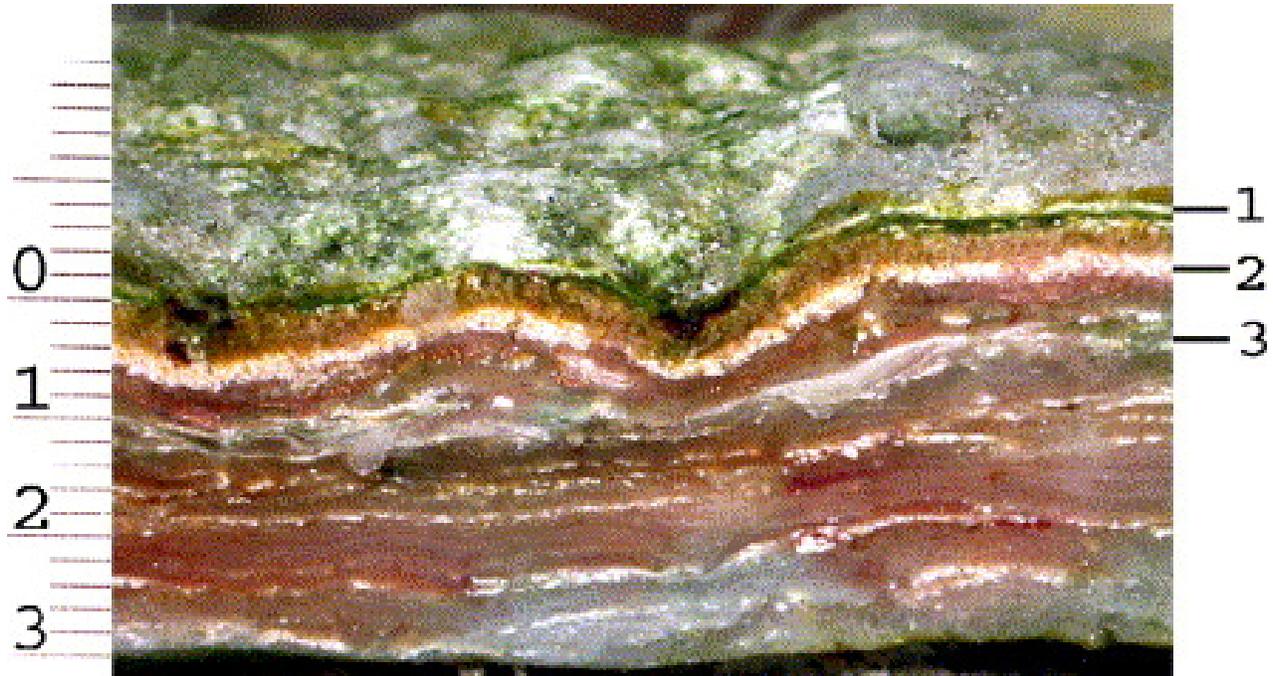
11.1 Microbial mats

Microbial mats complexity

- Mats were not only cyanobacteria (aerobic photosynthetic autotrophs), but also

- anaerobic photosynthetic bacteria and
- heterotrophic and chemotrophic bacteria
- All these bacteria form the first **ecosystem**

Layers in microbial mat



11.2 First eukaryotes: first predators

Bdellovibrio

- Bacteria are small and rigid, there is only one example of bacteria which can “eat” others
- However, this *Bdellovibrio* will only eat in the space between membrane and cell wall

Bdellovibrio invading the prey



Antibiotics

- The other problem was chemicals which bacteria are using to win a competition: antibiotics
- Most of antibiotics change the process of protein synthesis or cell wall construction

Proterozoic challenge

- Archean ecosystems were based on “clone wars” using antibiotics, horizontal transfer of genes and splitting jobs. However, they were incomplete: no predators.
- To predate, one need to *make large cell and invent the phagocytosis* (cellular “swallowing”)
- To escape from antibiotics, one need a different chemical machines for protein biosynthesis

However,

- Large and complicated cell needs more DNA—but how to divide it equally?
- Horizontal transfer will hinder evolution towards something unusual—but how to stop it?
- Large and complicated cells need much more ATP—how to make it?

Summary

- Sexual process is the requirement for evolution
- Microbial mats were first ecosystems
- To predate, bacteria must develop the enhanced cell

For Further Reading

References

[1] Bacterial conjugation. http://en.wikipedia.org/wiki/Bacterial_conjugation

Outline

12 Where we are?

12.1 Basics of ecology

Ways of life

- How to obtain energy?
 - A. From sun light: **phototrophy**
 - B. From chemical reactions with inorganic matter (“rocks”): **lithotrophy**
 - C. From breaking organic molecules into inorganic (typically, carbon dioxide and water): **organotrophy**
- How to obtain building blocks?
 - A. From assimilation of carbon dioxide: **autotrophy**
 - B. From other living beings: **heterotrophy**

Six life styles

	Phototrophs	Lithotrophs	Organotrophs
Autotrophs
Heterotrophs

12.2 Ecological interactions

Two-species model

- Species I and species II may influence each other differently
- For example, species I may facilitate the increase the number of species II individuals (+ interaction)
- At the same time, species II could be neutral to species I (0 interaction)

Six basic ecological interactions

	+	0	-
+	mutualism	commensalism ¹	exploitation ²
0	...	neutralism	amensalism
-	interference ³

¹ Includes phoresy (transportation), inquilinism (housing) and “sponging”

² Includes predation, parasitism and phytophagy

³ Includes competition, allelopathy and aggression

12.3 Proterozoic challenge

Proterozoic challenge

- Archean ecosystems were based on “clone wars” using antibiotics, horizontal transfer of genes and splitting jobs. However, they were incomplete: no predators.
- To predate, one need to *make large cell and invent the phagocytosis* (cellular “swallowing”)
- To escape from antibiotics, one need a different chemical machines for protein biosynthesis

However,

- Large and complicated cell needs more DNA—but how to divide it equally?
- Horizontal transfer will hinder evolution towards something unusual—but how to stop it?
- Large and complicated cells need much more ATP—how to make it?

Two problems

- How to escape from antibiotics?
- How to predate?

Eukaryotic cell as a response to Proterozoic challenge

- New pathways of protein synthesis
- Cytoplasm motility (flagella, phagocytosis) based on cytoskeleton → no cell wall
- Nucleus for interphase and chromosomes for mitosis (too many DNA)
- Mitochondria for ATP (cell needs much more ATP)

Summary

- All life styles were exist before eukaryotic origin
- The only interaction absent in prokaryotic communities was predation
- Eukaryotic cell is a “second-level”, enhanced cell

For Further Reading

References

- [1] Ecological interactions. http://en.wikipedia.org/wiki/Biological_interaction
- [2] Symbiogenesis. http://en.wikipedia.org/wiki/Endosymbiotic_theory
- [3] Eukaryote. <http://en.wikipedia.org/wiki/Eukaryote>

Outline

13 Where we are?

13.1 Proterozoic challenge

ATP, carbohydrates, photosynthesis and respiration

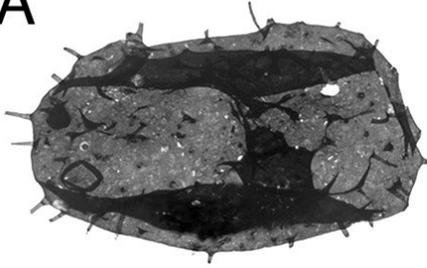
- If organism is capable to convert sun energy into ATP, it is a phototroph
- If organism is using carbon dioxide to build its own organic (ATP is required here!), it is an autotroph
- Most of plants are photoautotrophs, because photosynthesis (combination of the above two processes) is prevalent in their life
- Animals are heterotrophs, they do respiration which is opposite to autotrophy: it breaks organic into inorganic and create ATP

Eukaryotic cell as a response to Proterozoic challenge

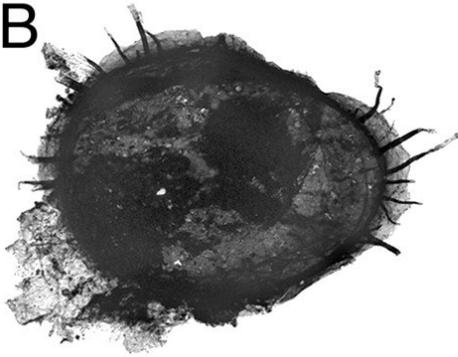
- Predators
- New pathways of protein synthesis
- Cytoskeleton allows for cytoplasm motility
- Nucleus for DNA security and distribution
- Mitochondria make ATP

Acritarchs in Proterozoic (1,900 Mya)

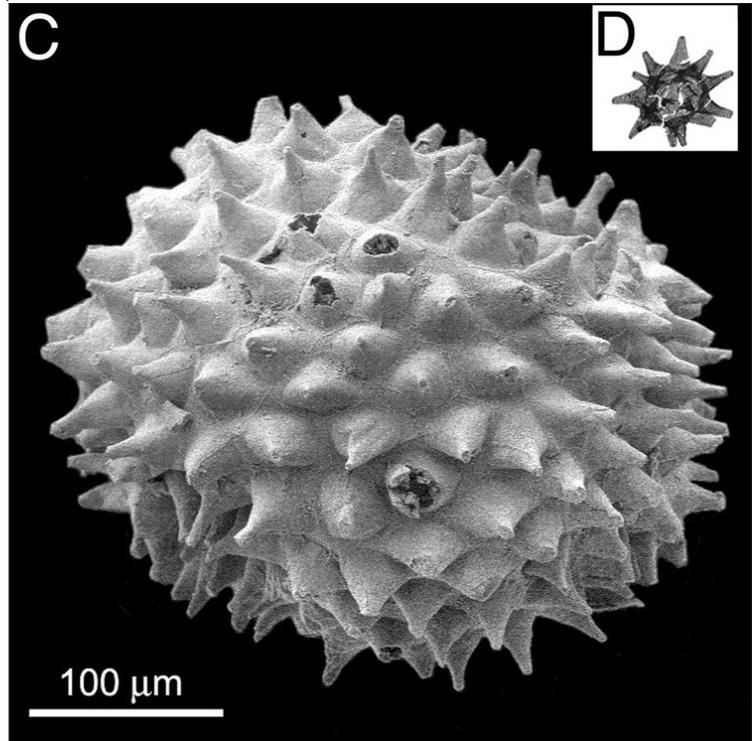
A



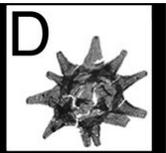
B



C



D



14 Eukaryotic cell

14.1 Organelles and their functions

Eukaryotic cell

Membrane and cytoplasm

- Cytoplasm is constantly flowing
- Membranes are used for construction of multiple internal organelles

Cytoskeleton

- Microtubules and microfilaments
- Flagella
- Phagocytosis
- Motility
- No cell wall (but note that plants and fungi developed cell wall again)

Nucleus

- Regulatory DNA
- Cell division
- Pores

Mitochondria

- Respiration machines
- Mitochondrial DNA

Internal membrane system

- ER
- AG
- Vesicles: vacuoles, lysosomes, peroxisomes etc.

Ribosomes

- Bigger
- Associated with ER

Eukaryotic cell: pluses and minuses

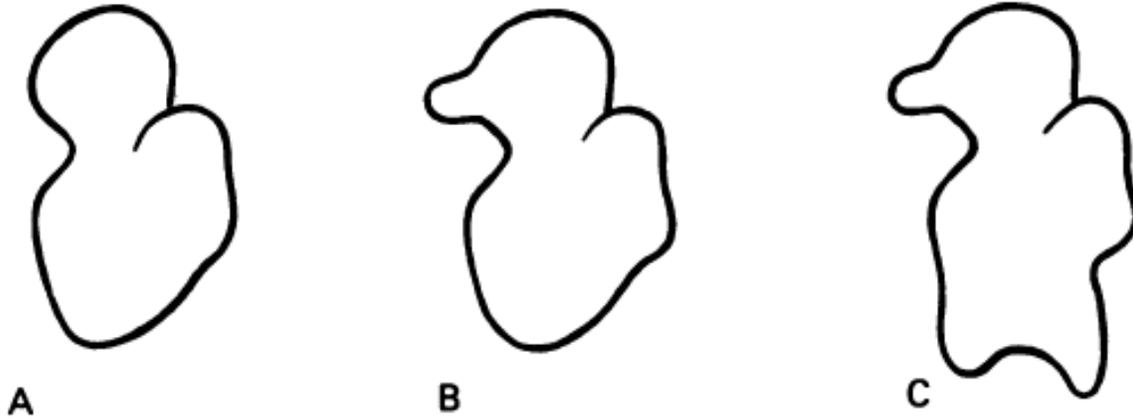
- Flexible, but bigger and no cell wall
- Nucleus, but so many DNA poses a problem
- Mitochondria are very effective, but less controlled

14.2 Evolutionary steps towards the eukaryote

Antibiotic resistance and actin

- Archebacteria were probably first prokaryotes who changed their biosynthetic pathways in order to become resistant to majority of antibiotics
- They also invented actin, the main protein of cytoskeleton

Ribosomes of core bacteria (A), archebacteria (B) and eukaryotes (C)



Taking mitochondria: symbiogenesis

- Mitochondria were separate organisms
- Eukaryotic cell is a “second-level” cell, cell from cells

14.3 Cell division

Cell cycle

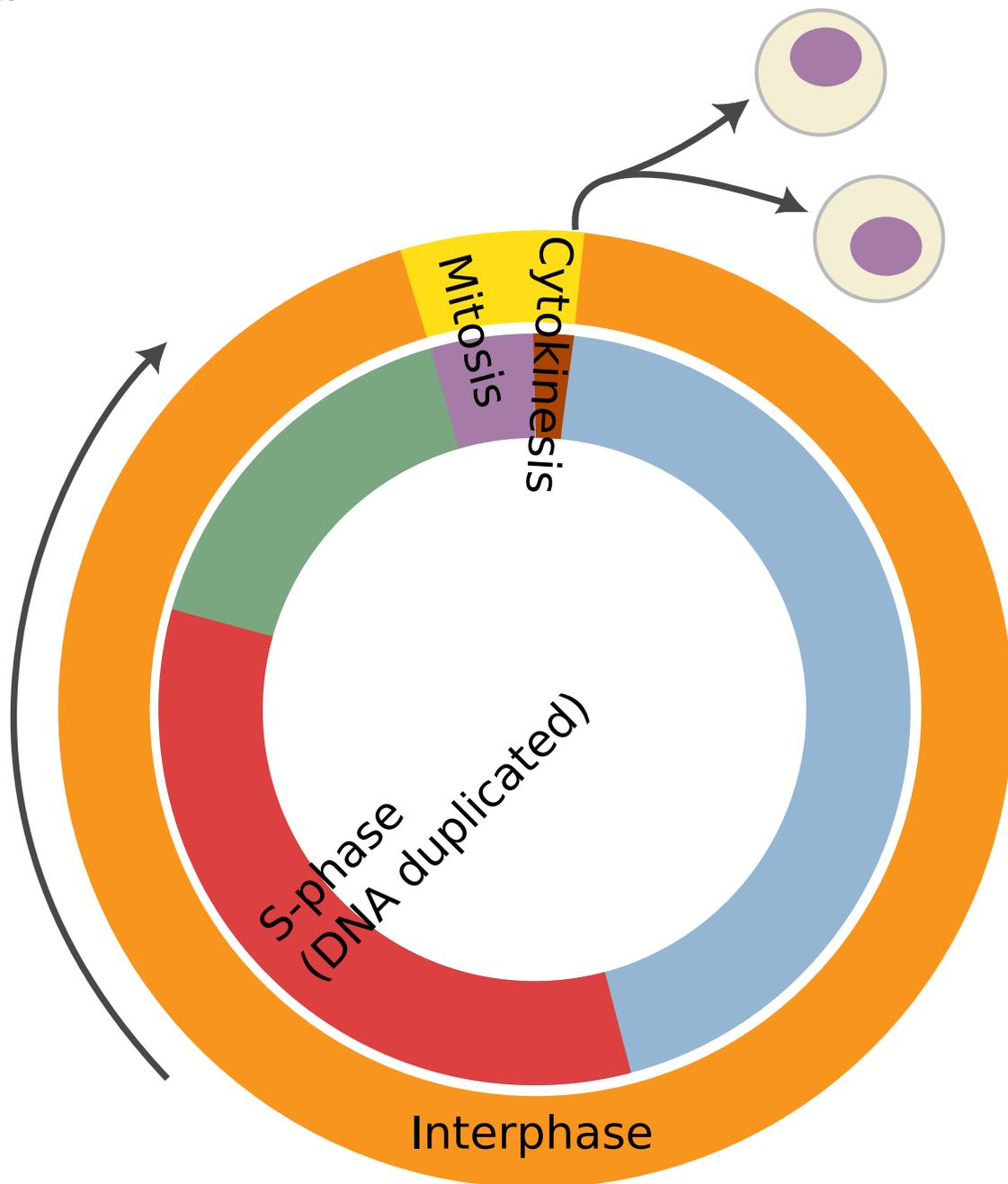
- To multiple, cell should first store energy for DNA duplication
- Then—duplicate its DNA (S-period)
- And only then to divide DNA (mitosis) and the rest of cell (cytokinesis)

This is the **cell cycle**

Mitosis

- Mitosis is an equal division of nucleus where daughter cells will receive the same DNA information as mother cell
- **The goal of mitosis** is the equal distribution of pre-duplicated DNA
- Time between two cell divisions is called **interphase** so cell cycle = interphase + mitosis + cytokinesis

Cell cycle



Summary

- Eukaryotic cell is a “second-level”, enhanced cell
- Symbiogenesis is one of evolutionary steps towards eukaryote
- Mitosis is an equal division of nucleus

For Further Reading

References

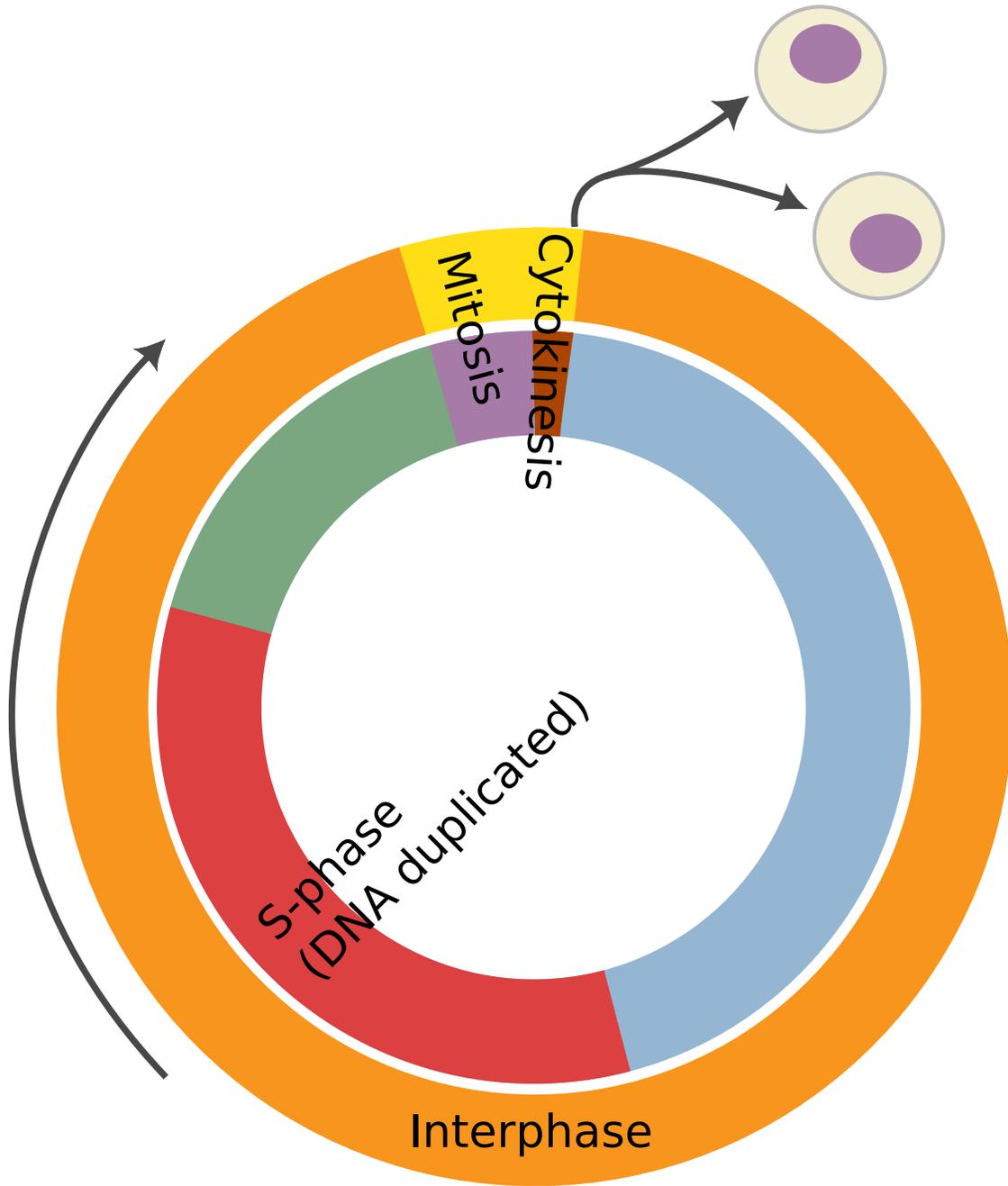
- [1] Symbiogenesis. http://en.wikipedia.org/wiki/Endosymbiotic_theory

Outline

15 Where we are?

15.1 Cell division

Cell cycle

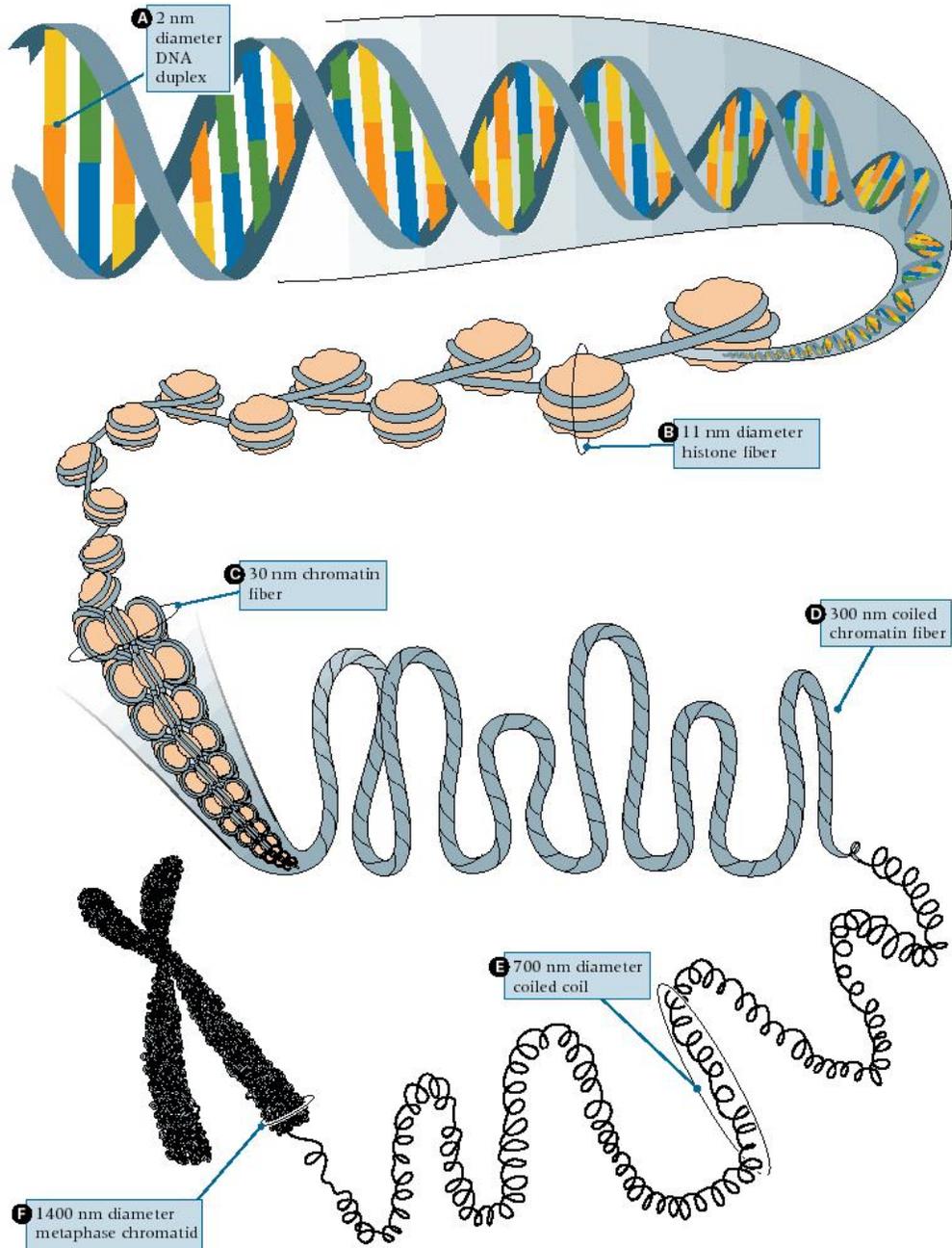


15.2 Mitosis

Stages of mitosis

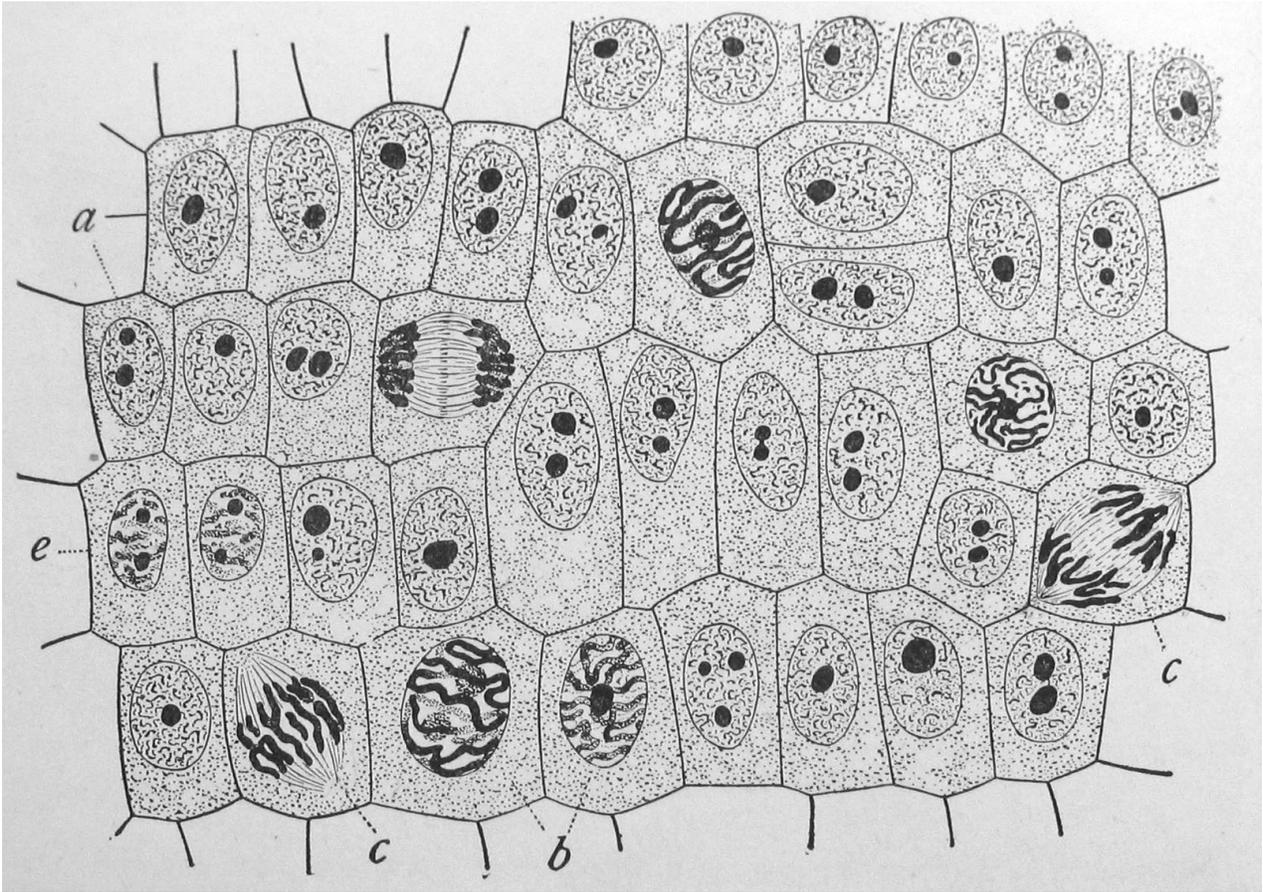
- Prophase
- Metaphase
- Anaphase
- Telophase

Super-coiling of DNA into chromosome

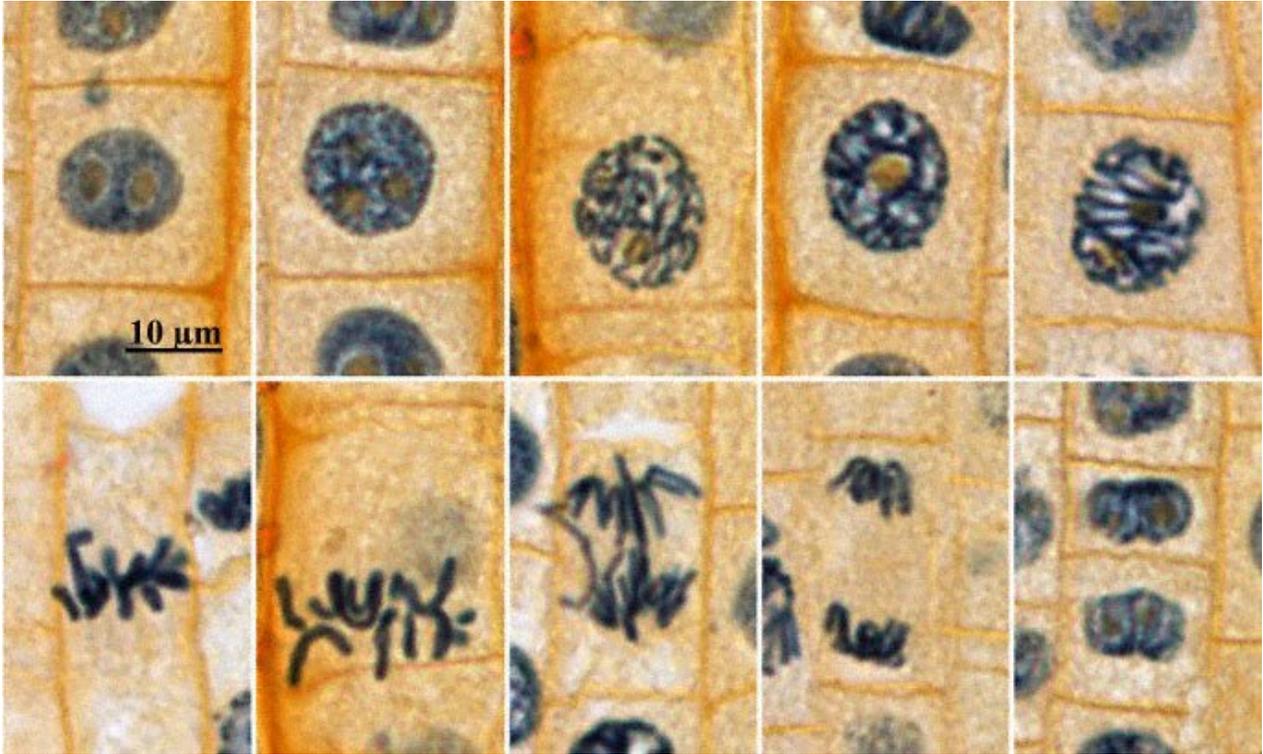


Stages of mitosis

Which stage? (drawing)



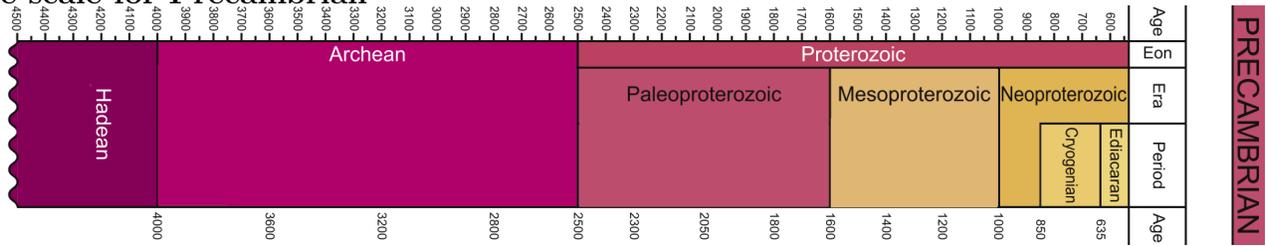
Which stage? (photo)



16 Life in late Precambrian

16.1 Cryogenian period and Snowball Earth

Time scale for Precambrian

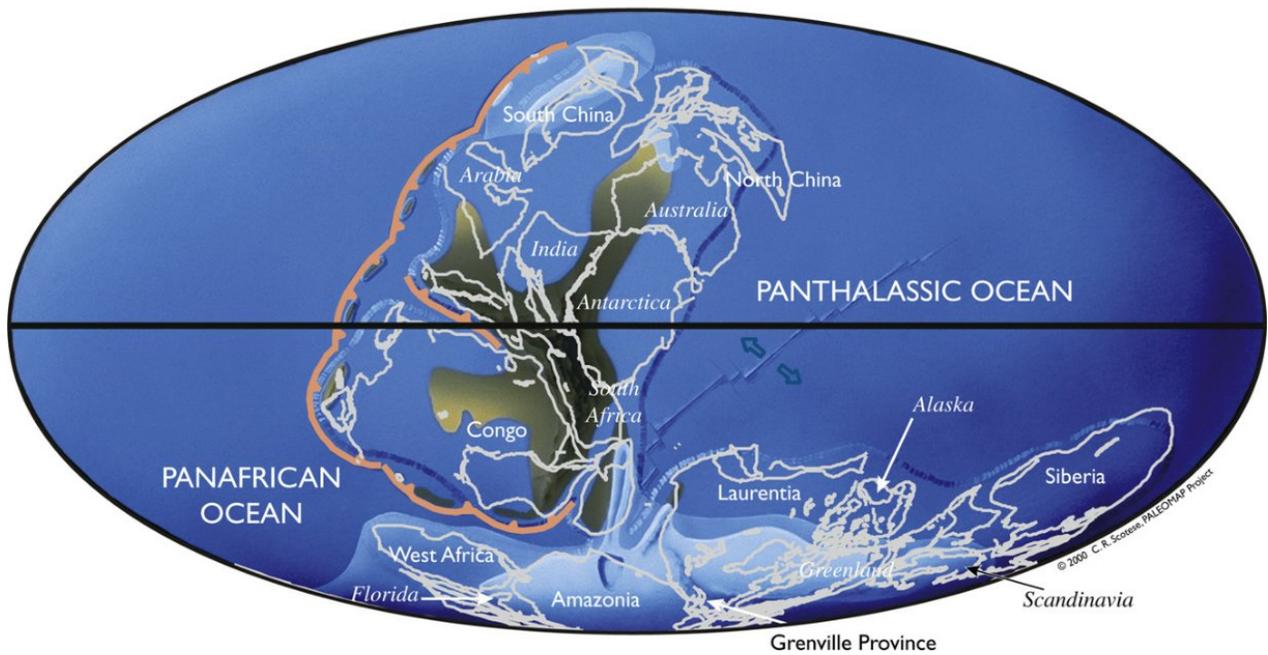


Rodinia—the first super-continent

- Tectonic plates formed (and will form) one continent several times
- 650 Mya this continent—Rodinia was formed right over the South Pole

Cryogenian continents which formed Rodinia

650 Ma Cryogenian



Rodinia: view from South Pole



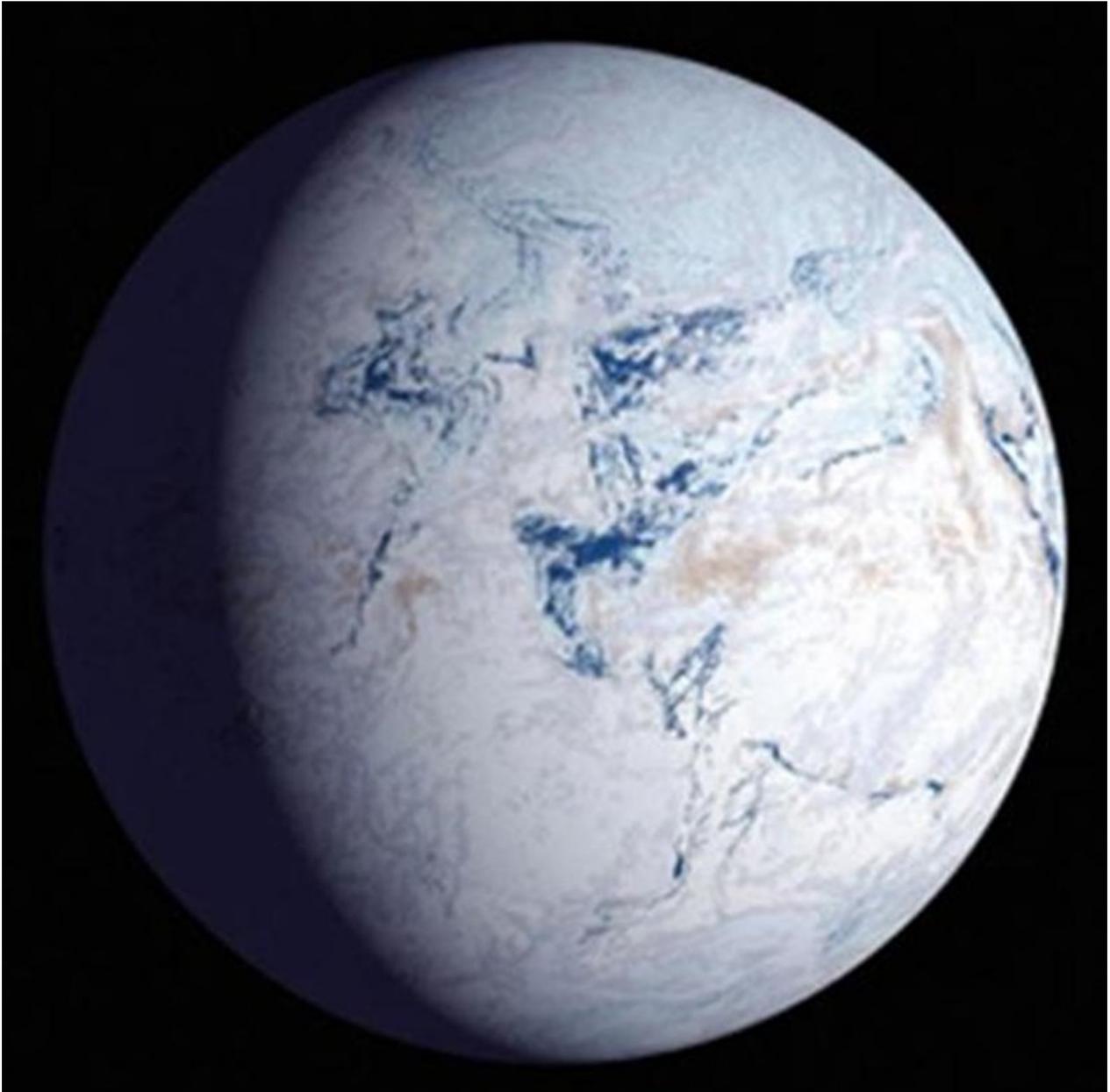
Marionan glaciation: Snowball Earth

- First global glaciation was started because ice started to concentrate over the pole and increase Earth albedo (this is the positive feedback)
- And because the configuration of continents blocked the equatorial warm current
- And because concentration of oxygen was high but greenhouse gases (like CO₂)—small
- As a result, from time to time Earth was completely covered with ice sheet 1 km tall!

Star Wars Hoth—ice planet



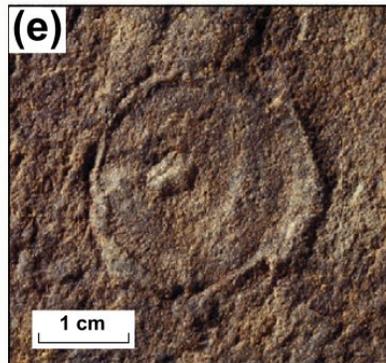
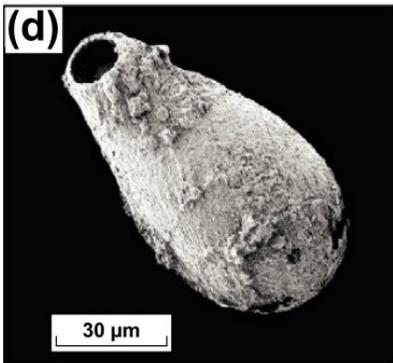
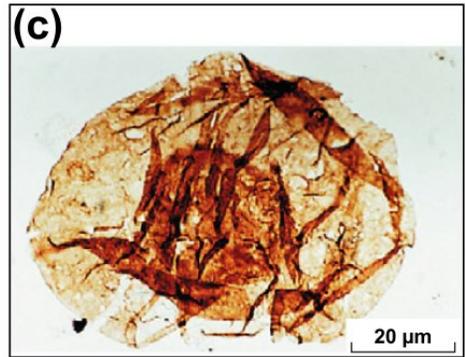
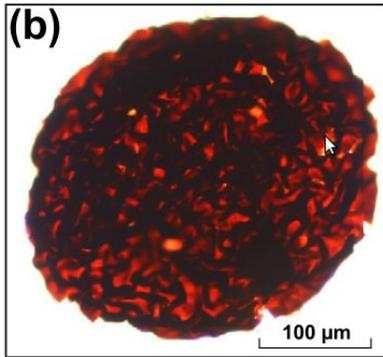
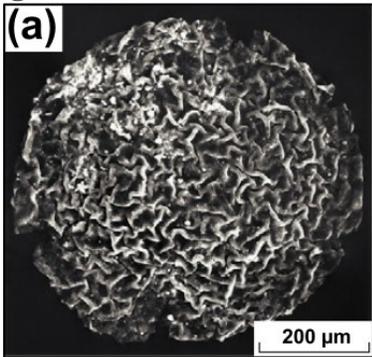
Snowball Earth



The evidence of Marinoan glaciation: diamictite layers everywhere on Earth



Cryogenian fossils



Summary

- Mitosis is an equal division of nucleus
- In Cryogenian, Marinoan glaciation covered the whole Earth

For Further Reading

References

[1] Mitosis. <http://en.wikipedia.org/wiki/Mitosis>

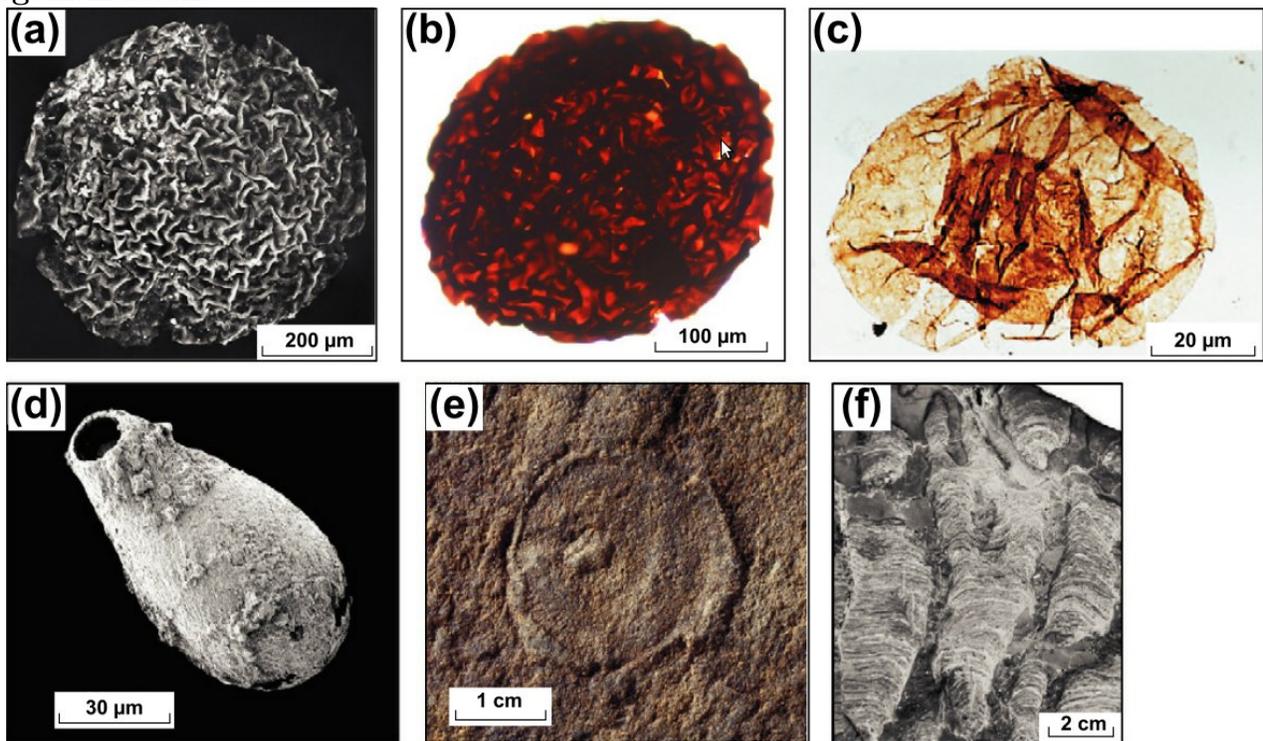
Outline

17 Where we are?

Marionan glaciation: Snowball Earth

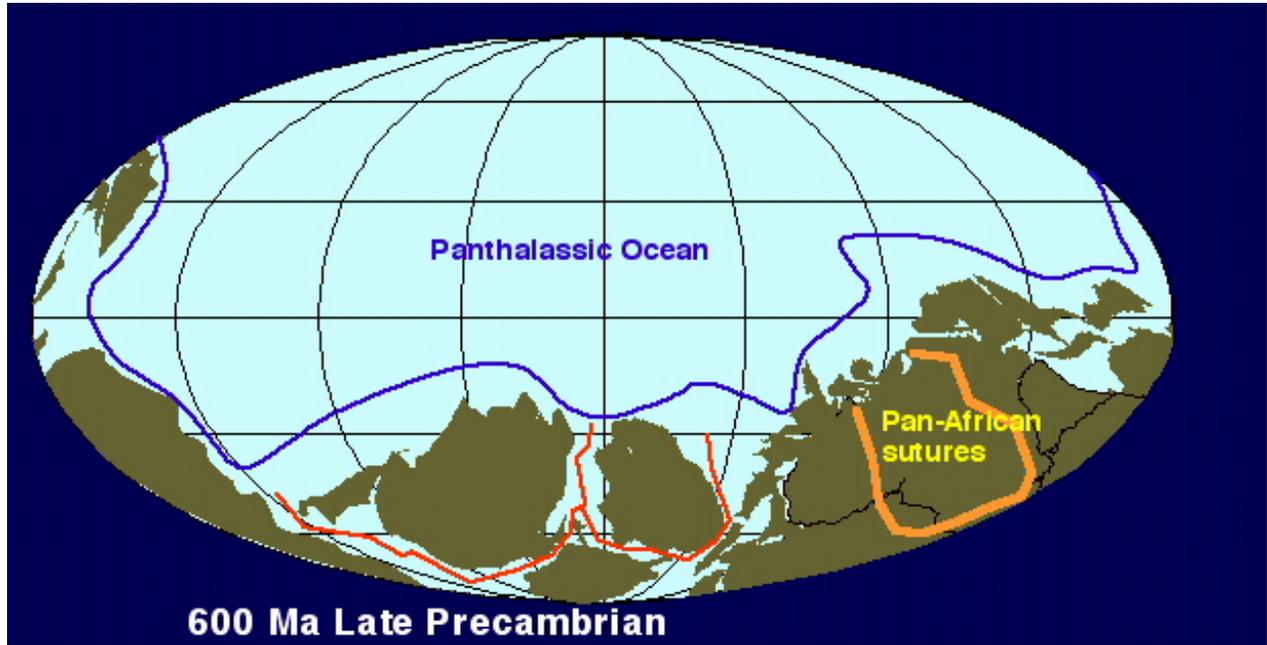
- First global glaciation was started because ice started to concentrate over the pole and increase Earth albedo (this is the positive feedback)
- And because the configuration of continents blocked the equatorial warm current
- And because concentration of oxygen was high but greenhouse gases (like CO₂)—small
- As a result, from time to time Earth was completely covered with ice sheet 1 km tall!

Cryogenian fossils



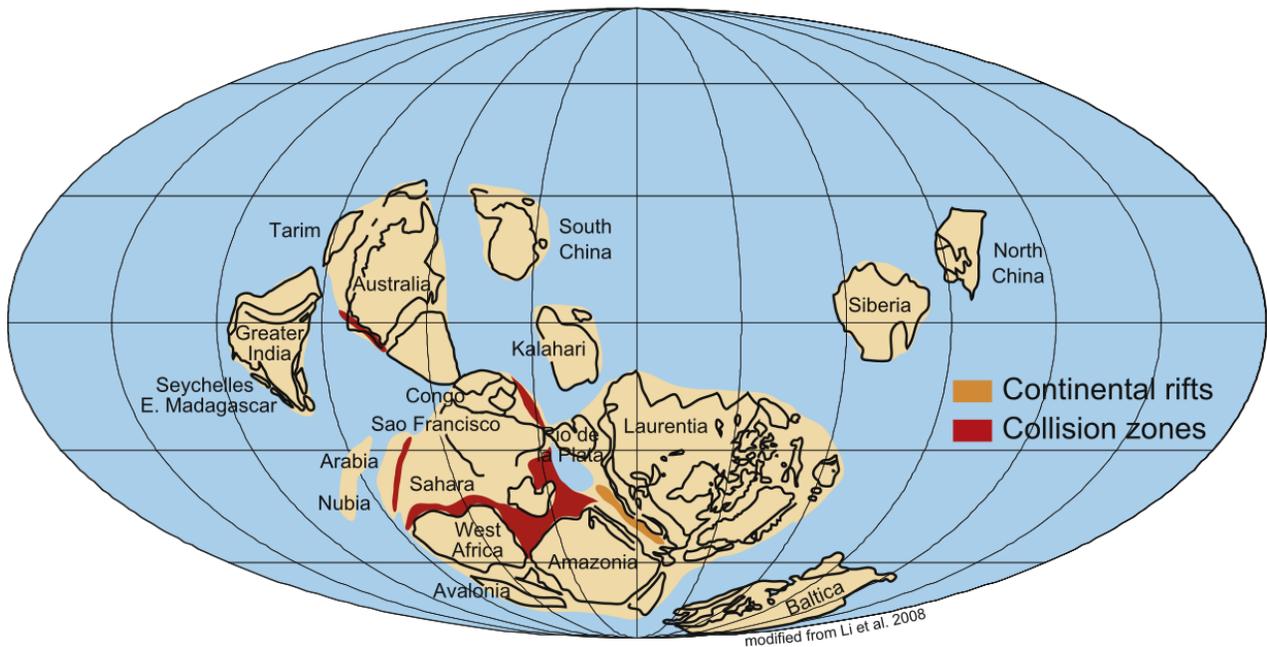
17.1 Ediacarian period and multicellularity

Rodinia breaks



Ediacarian continents

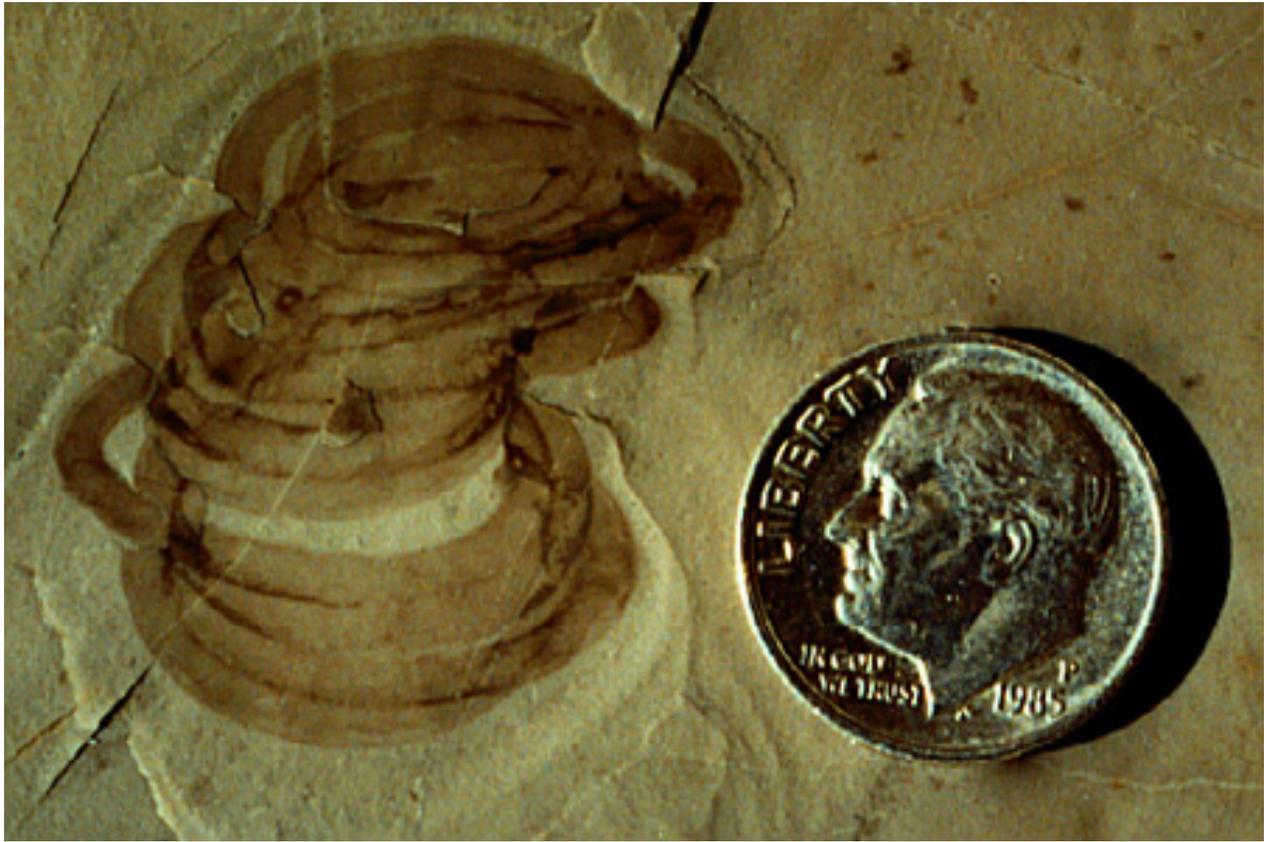
600 Ma Ediacaran



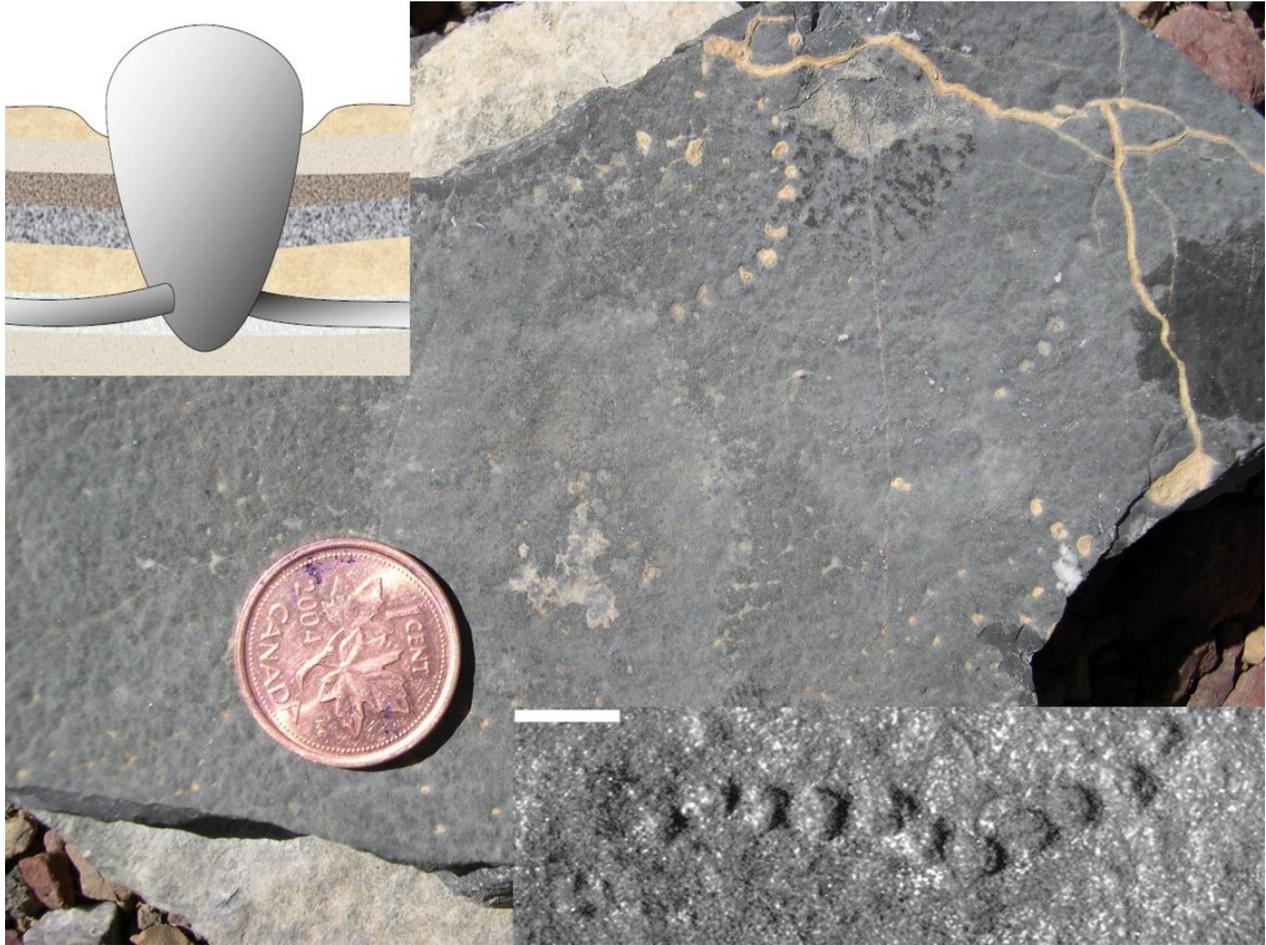
First multicellular life

- Apart from enigmatic *Grypania* and *Horodyskia*, multicellular eukaryotes were not known before Ediacarian
- From the beginning of Ediacarian, multicellular Lantian algae were known, and then—fabulous “Ediacara garden”, the fauna of animals without skeleton

Grypania—the first alga?



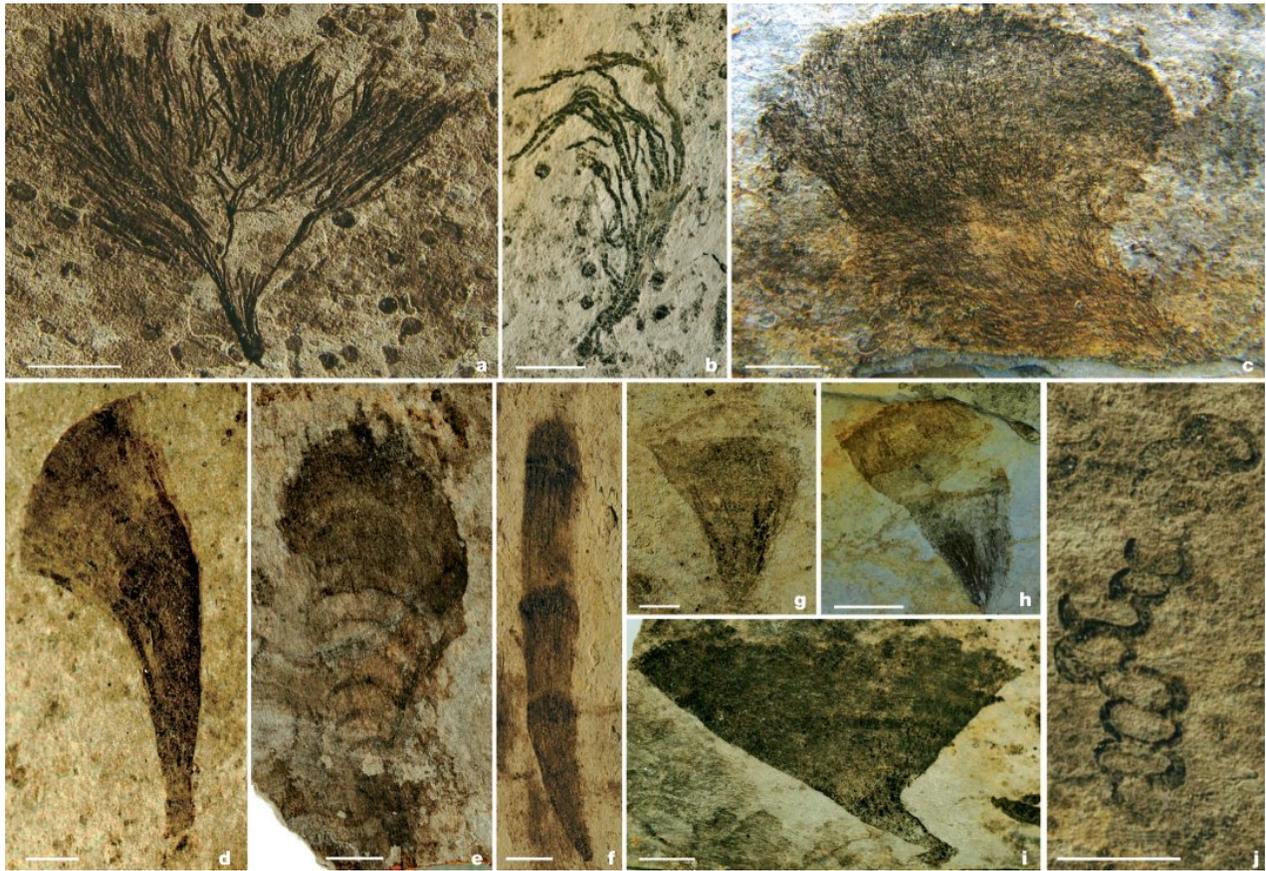
Horodyskia and its interpretations



Multicellularity and origin of death

- Multicellular assemblages were probably originated from incompletely divided cells
- Initially, those assemblages were only benefit from their size
- Then, they started to use a division of labor: differentiated into somatic and generative cells
- Wheres generative cells are specialized for multiplication and will continue to “live” in next generations, somatic bodies ought to die
- Unicellular living organisms are still potentially immortal

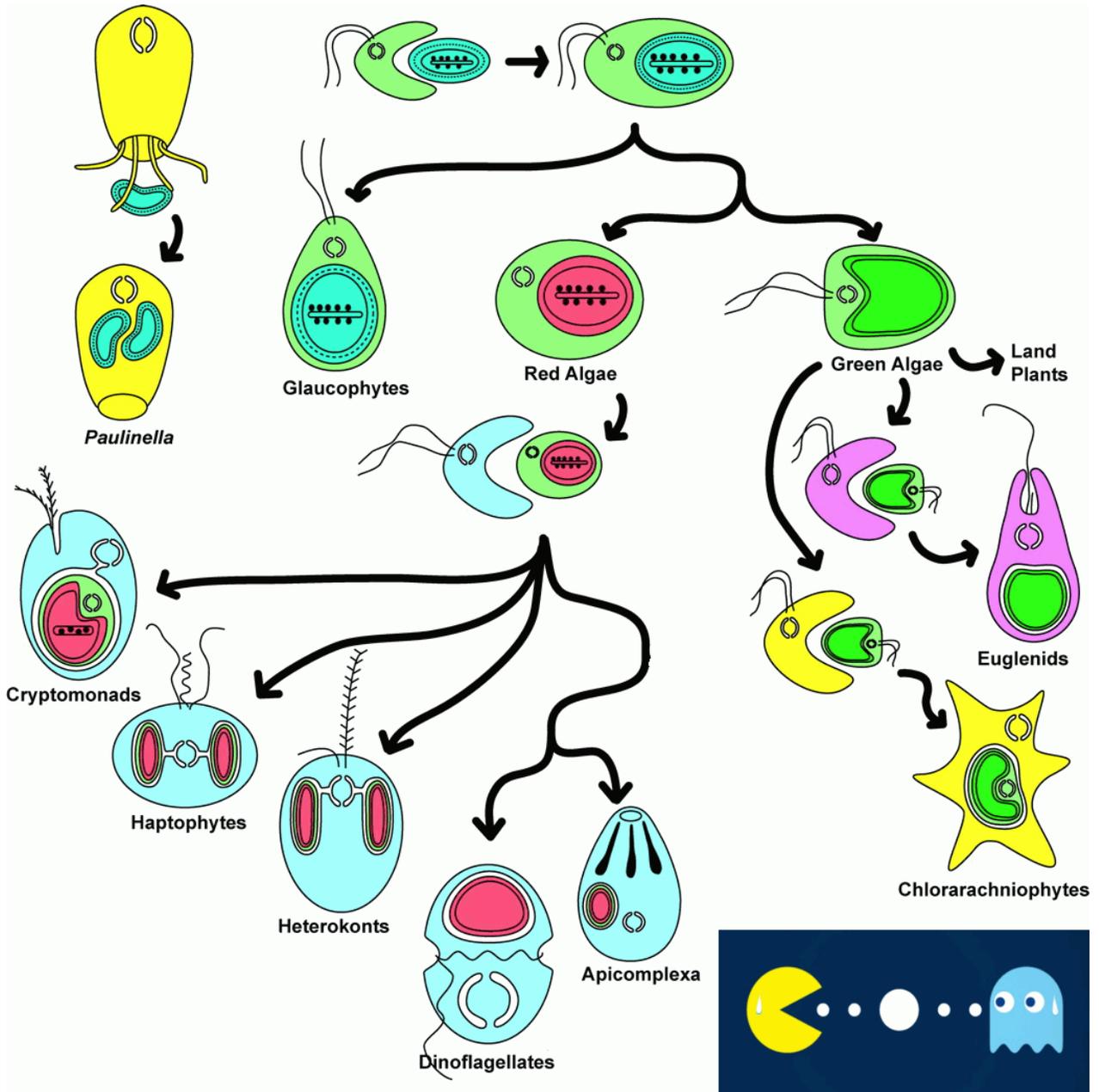
Lantian (China) macroscopic algae



What are algae?

- Eukaryotes which are capable for photosynthesis with chloroplasts
- All chloroplasts were symbiotic (cyanobacteria in the past), and some even secondary symbiotic (other alga in the past)

“Pacman game” of algae origin

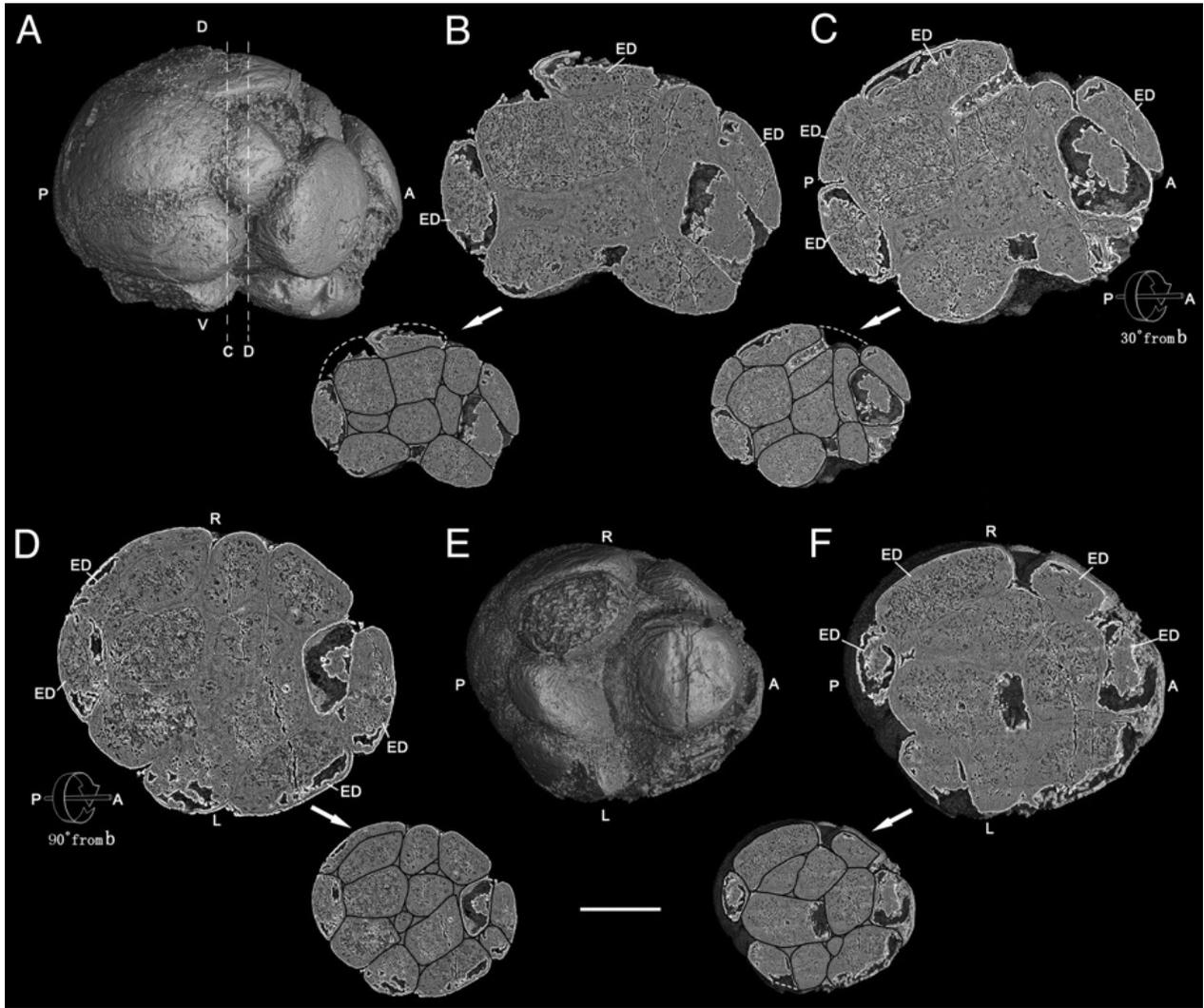


Life without animals

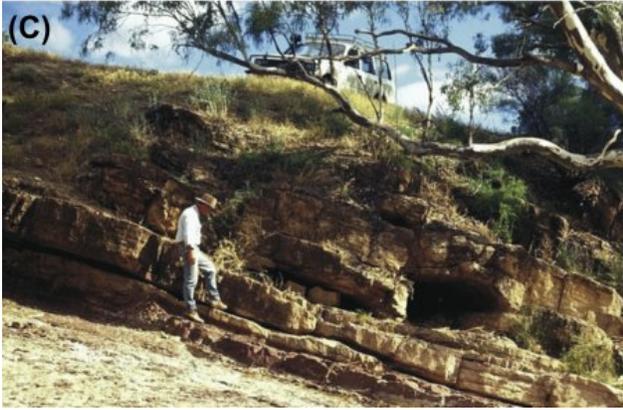


17.2 First animals

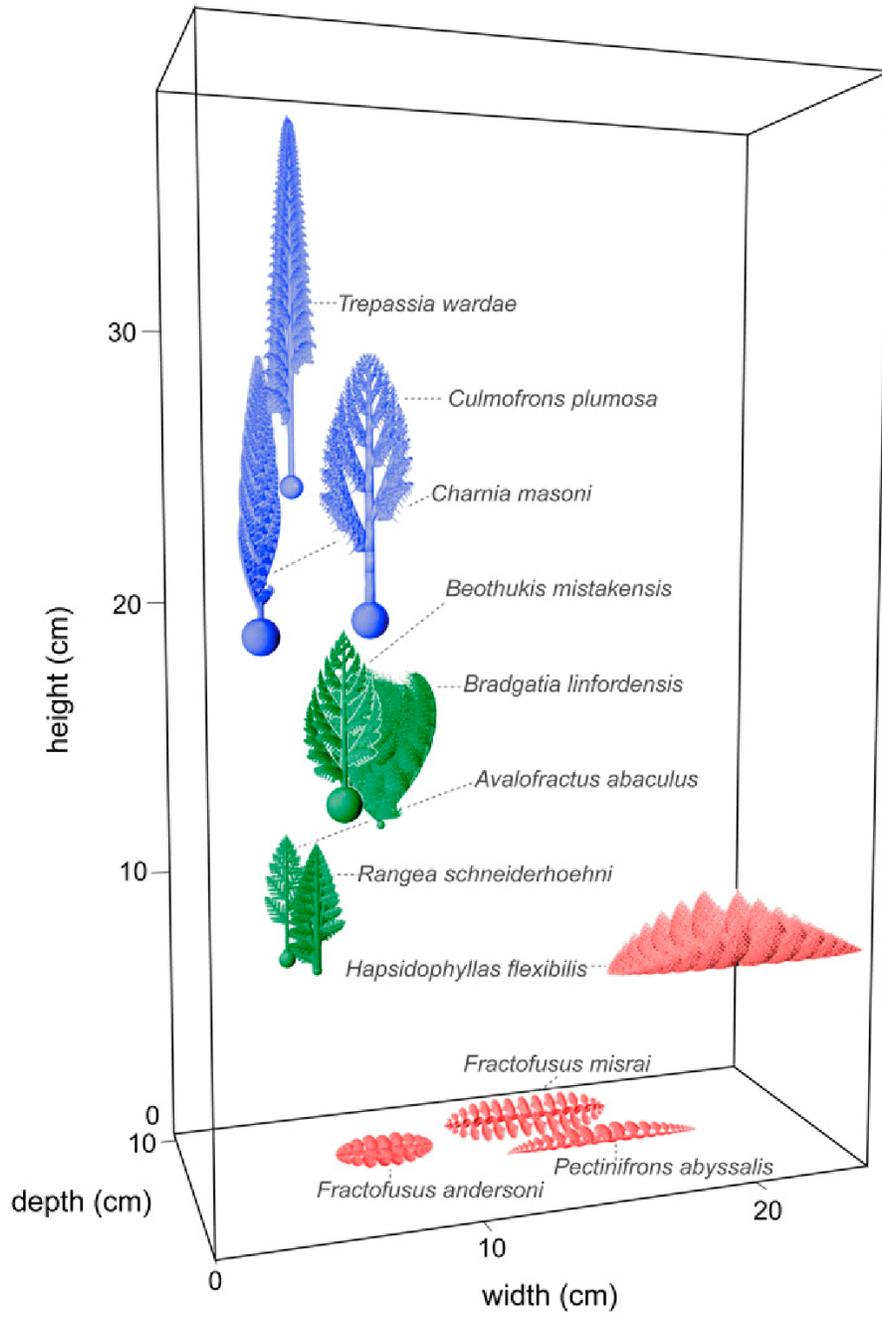
Doushantuo (China) “embryos”—first animals?



Finding Ediacara biota



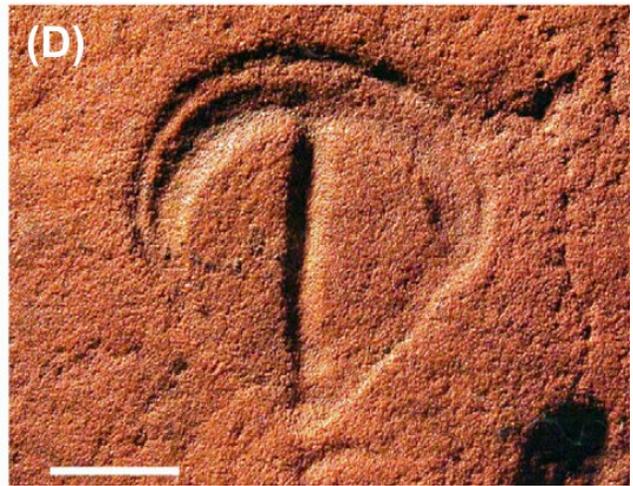
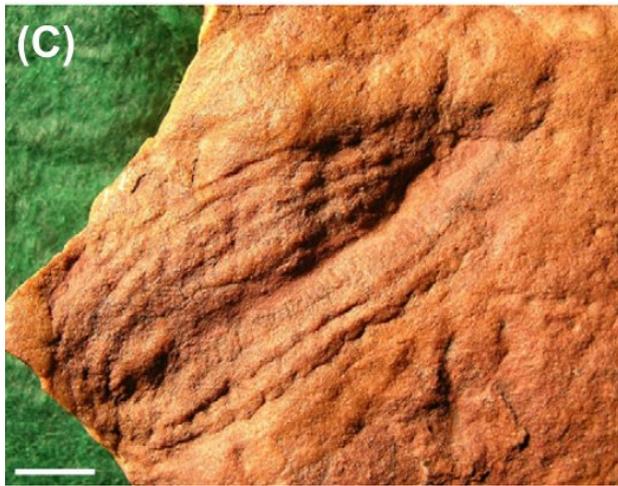
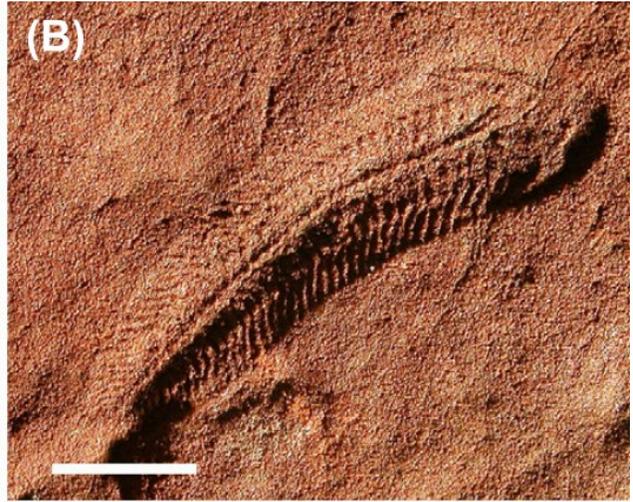
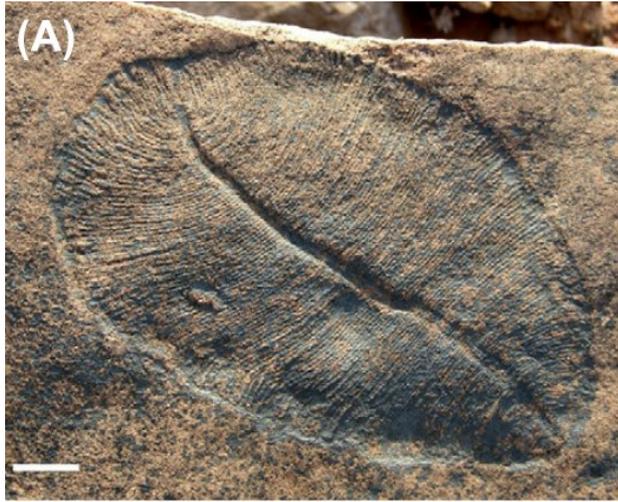
Mistaken Point (Canada) fauna: rangeomorphs



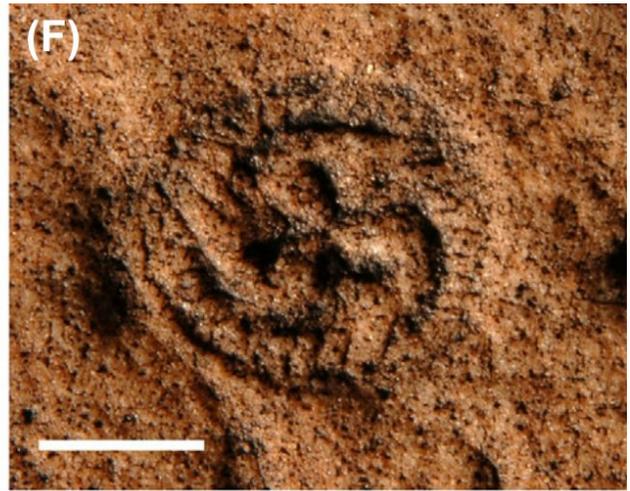
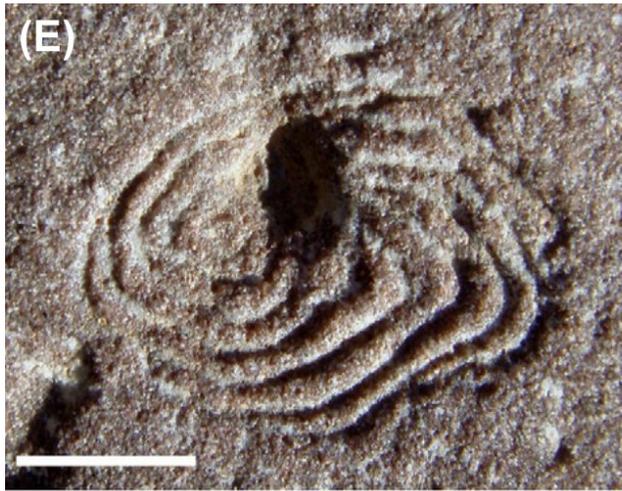
Extant sea pen (Pennatulacea soft corals)



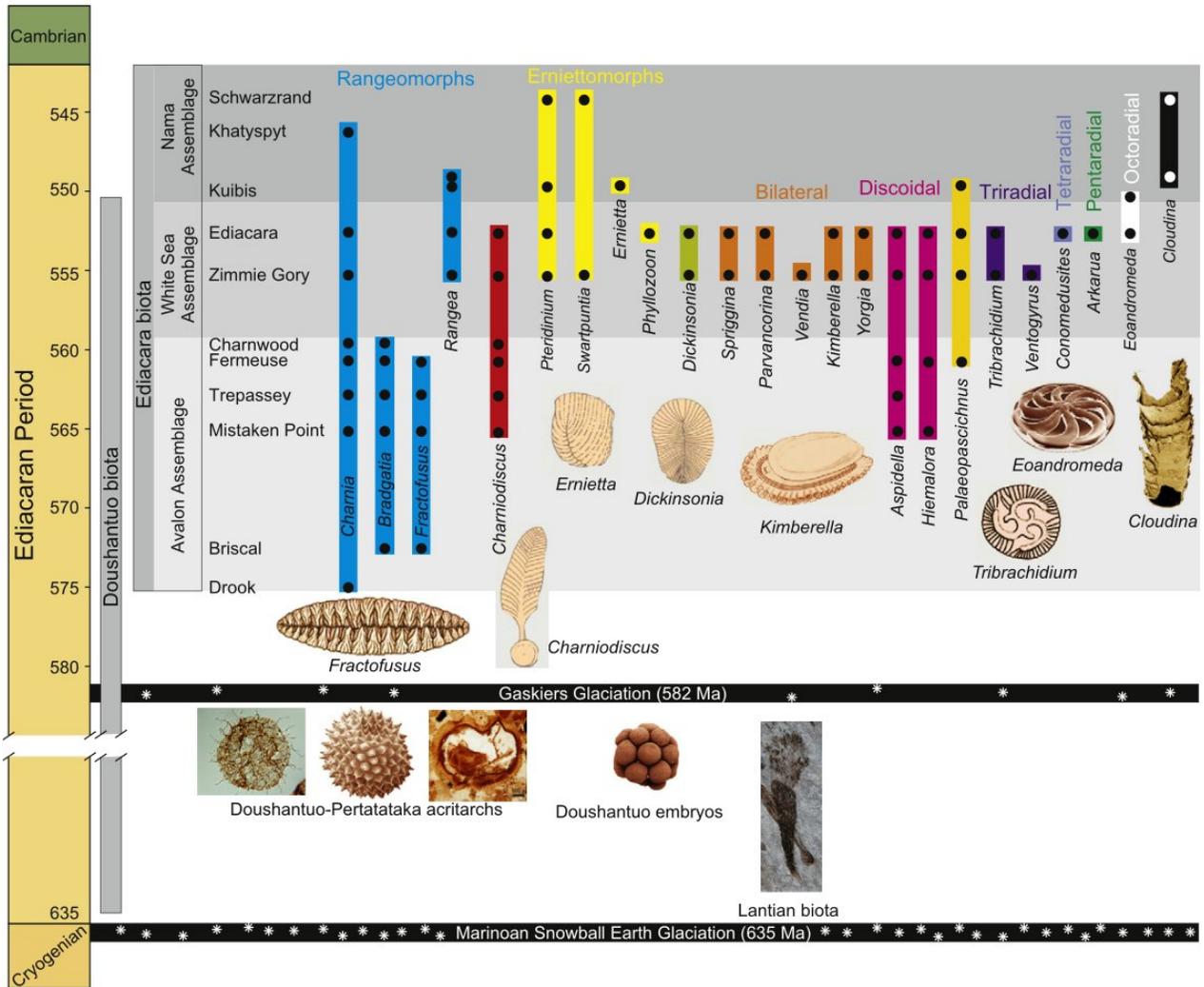
Ediacara Garden: *Dickinsonia*, *Spriggina* etc.



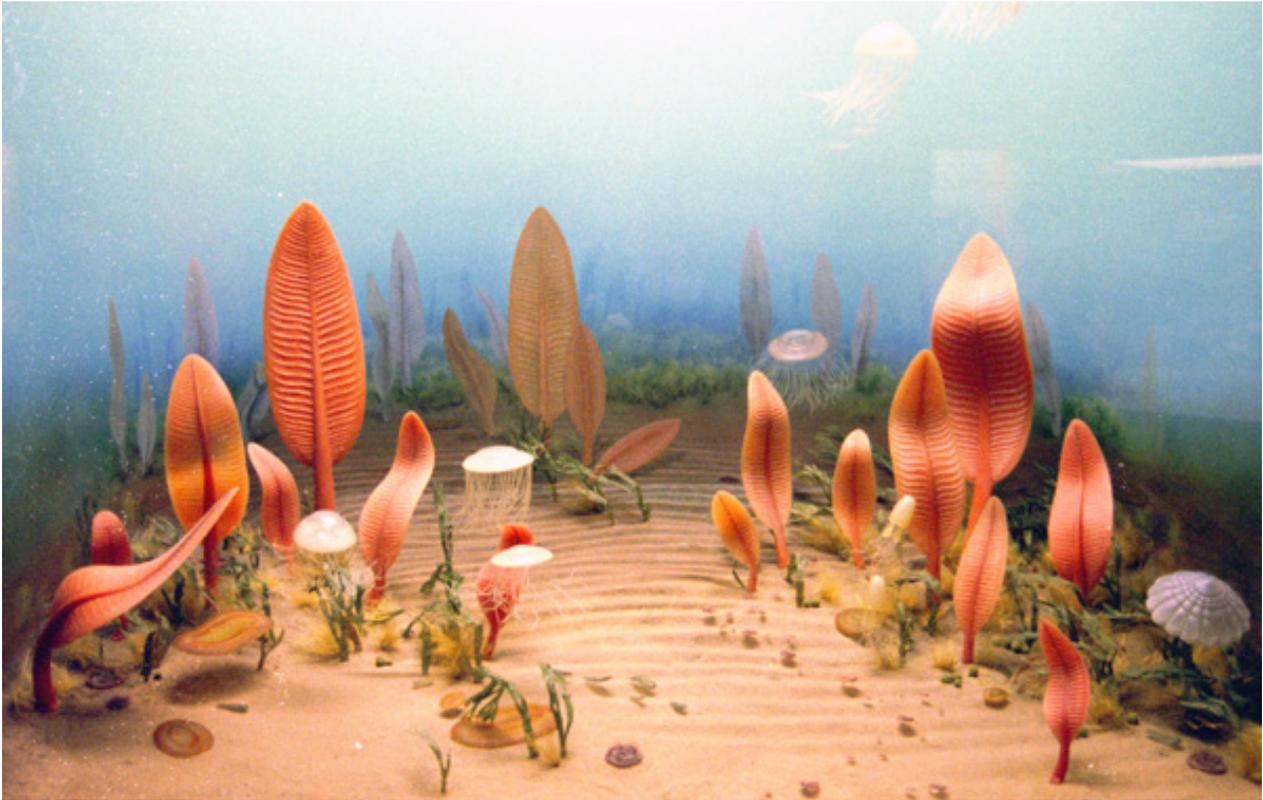
Ediacara Garden: *Eoandromeda*, *Charniodiscus* etc.



Life in Ediacarian



Ediacara “garden”—no predators of macroscopic size, nobody had skeleton



Origin of tissues—the most important event in late Precambrian

- Tissues are assemblages of similar cells doing the similar job
- Tissues are one level more over the eukaryotic cells
- Multicellular animals also have multiple tissues whereas multicellular algae and cyanobacteria are still on pre-tissues level of complexity
- Multi-tissued body is a great achievement, except for cancer...

Questions before Exam 2?

Summary

- In Cryogenian, Marinoan glaciation covered the whole Earth
- In Ediacarian, multicellular and then multi-tissued eukaryotes appeared

For Further Reading

References

[1] Mitosis. <http://en.wikipedia.org/wiki/Mitosis>

[2] Ediacara biota. http://en.wikipedia.org/wiki/Ediacara_biota

Example questions for the exam

1. Proterozoic eon:

- A. Left no traces
- B. There are Proterozoic minerals only
- C. There are both Proterozoic minerals and Proterozoic fossils

2. What is NOT relevant to photosynthesis:

- A. Production of CO₂
- B. ATP synthesis
- C. Both of above

3. Cell membrane:

- A. Defends the cell mechanically
- B. Is a barrier for water
- C. Both of above

4. Chloroplasts:

- A. Were independent bacteria in the past
- B. Have no DNA
- C. Both of above

Answers

1C, 2A, 3B, 4A