FUNDAMENTOS DE ASTROBIOLOGIA

AST-416-3

AULA 5

Química pré-biótica, origem e evolução da vida

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A vida na Terra: química prebiótica, origem e evolução da vida

Leitura:

- ☑ Caps. 5 e 6 do livro "Astrobiologia: uma ciência emergente"
- ☑ Cap. 9 do livro "Astrobiology: a multidisciplinary approach".

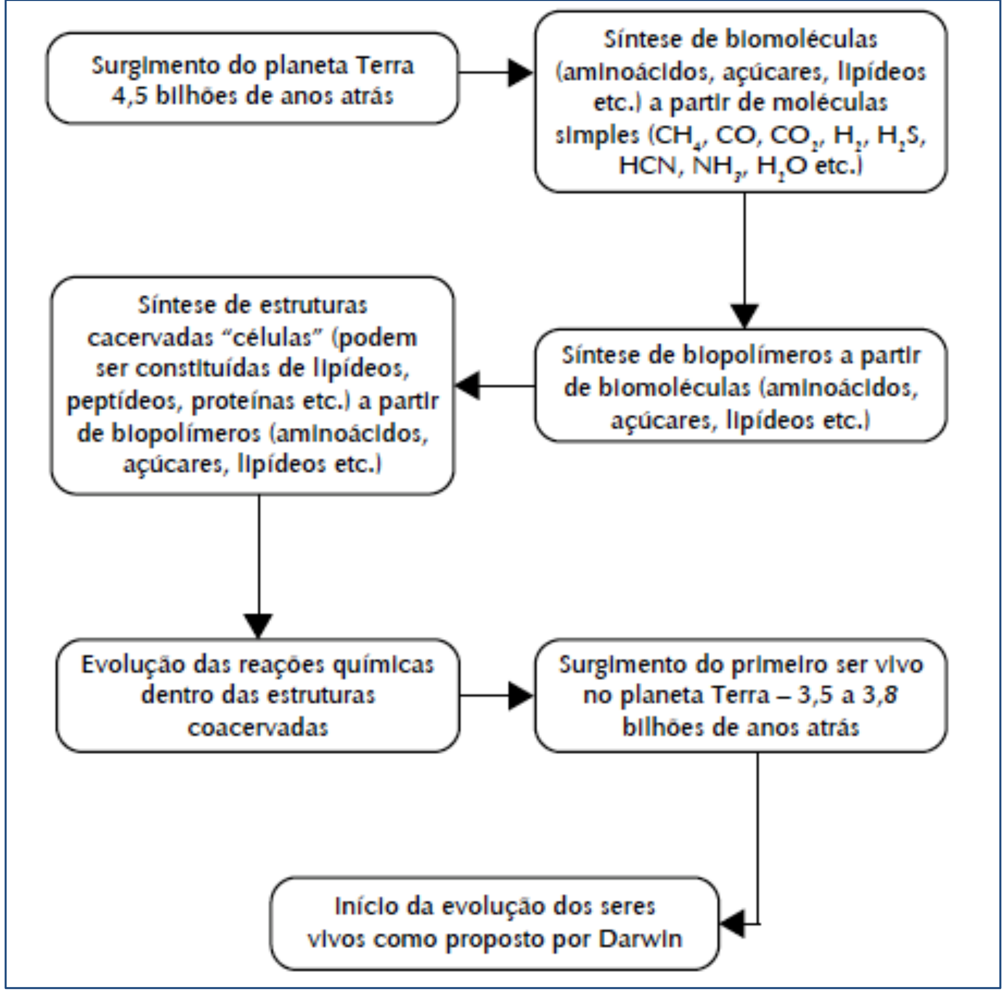
A evolução molecular da vida

- ☑ A Terra possui, desde sua condensação e momentos iniciais, a química necessária para a formação de compostos orgânicos mais complexos (4 ou mais moléculas contendo pelo menos um átomo de C)
- ☑ A Terra ofereceu, nas primeiras centenas de milhões de anos, as condições energéticas, a interface sólido-líquido e o reservatório químico necessários para que reações químicas com baixos canais de reação ocorressem
- ☑ As condições astrofísicas e cosmológicas sugerem que a bioquímica necessária para o aparecimento de sistemas vivos está disponível (embora com pouca abundância, comparada com os dias de hoje) desde cerca de 150 x 10^6 anos após o Big Bang (aulas 2 e 3)

Histórico

☑ Investigações sobre a origem da vida remontam a:

- ✓ Francesco Redi (séc. XVII)
- ✓ John Needham (séc. XVIII)
- ✓ Louis Pasteur, John Tyndall e Charles Darwin (séc. XIX)
- ✓ Alexander Oparin, John Haldane, Harold Urey e Stanley Miller (séc. XX)



Surgimento do planeta Terra 4,5 bilhões de anos atrás

Síntese de biomoléculas (aminoácidos, açúcares, lipídeos etc.) a partir de moléculas simples (CH_4, CO, CO_2, H_2, H_2S, HCN, NH_3, H_2O etc.)

Síntese de biopolímeros a partir de biomoléculas (aminoácidos, açúcares, lipídeos etc.)

Síntese de estruturas cacervadas "células" (podem ser constituídas de lipídeos, peptídeos, proteínas etc.) a partir de biopolímeros (aminoácidos, açúcares, lipídeos etc.)

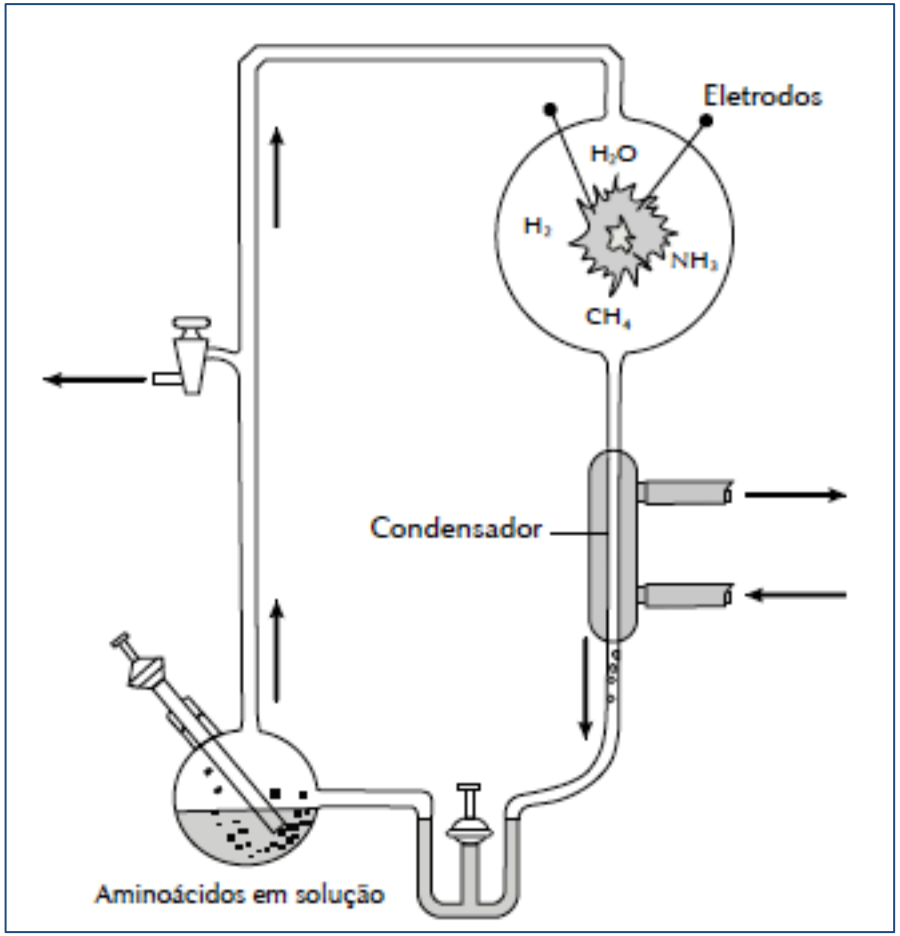
Evolução das reações químicas dentro das estruturas coacervadas

Surgimento do primeiro ser vivo no planeta Terra – 3,5 a 3,8 bilhões de anos atrás

Início da evolução dos seres vivos como proposto por Darwin

Esquema de Oparin-Haldane

Experimento de Urey e Miller



Fonte: Galante et al. (2016)

Sistemas químicos complexos

☑ A noção de que as leis da natureza continham, em sua essência, a capacidade de gerar não somente regularidade e estrutura, mas também um comportamento intrincado e imprevisível evolui pelos séculos seguintes a Kepler e Newton quantificarem a atividade um Universo que funcionava semelhante a um relógio

☑ Equações não lineares dissipativas que descrevem a dinâmica de sistemas complexos podem produzir um comportamento complicado dependendo dos parâmetros escolhidos para descrever o sistema

☑ Sistemas complexos físicos podem exibir uma propriedade de auto-ogranização que pode parecer (mas não é) uma violação à 2a. Lei da Termodinâmica

Algumas questões ligadas à origem molecular da vida

☑ Fontes de energia

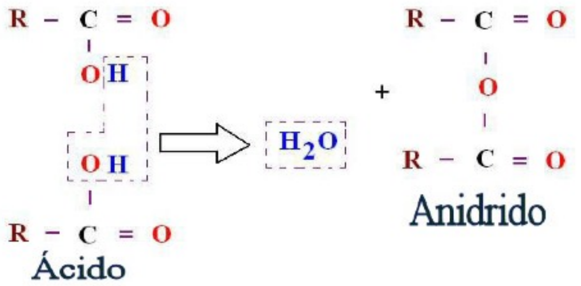
☑ Compartimentalização

☑ Armazenamento e reprodução de informação

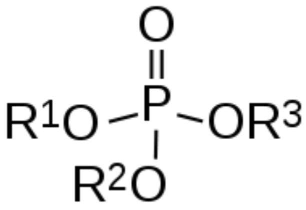
☑ Quiralidade

☑ Surgimento e evolução dos primeiros sistemas vivos

Fonte de energia molecular



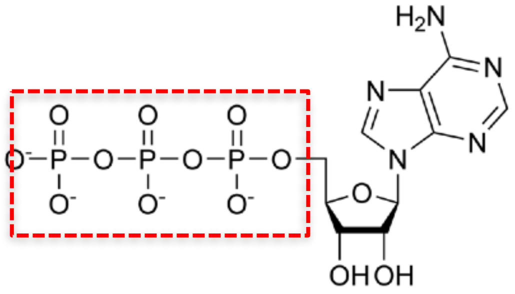
- ☑ Como processar a energia disponível?
- ☑ Qual a natureza química dos compostos "ricos em energia" disponíveis para mobilizar processos relevantes?



  - ✓ Disponibilidade de ésteres de fosfato (e anidridos)
  - ✓ Disponibilidade de ATP
  - ✓ Possibilidade de uso de pirofosfato inorgânico (PPI), ger

    sais, e ésteres do ácido pirofosfórico.

P – O - P



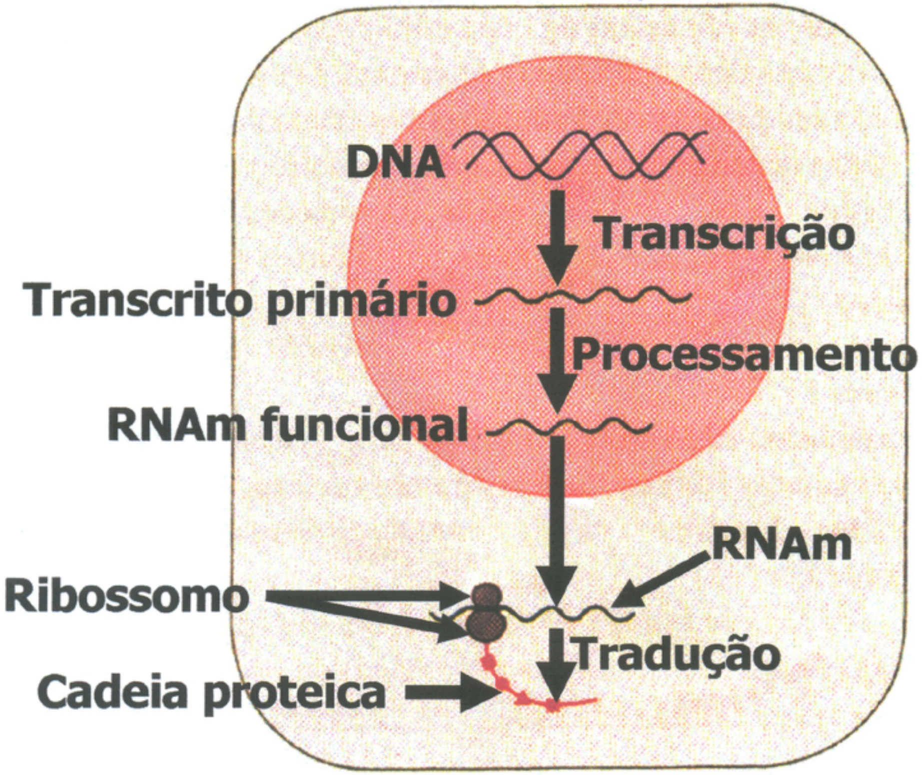
- Aparentemente o P está presente em todos os compostos disponíveis para produção de energia na Terra jovem.
- Moléculas fosforiladas talvez sejam os compostos responsáveis pelos processos de transdução e conservação de energia nas etapas prebióticas e incorporadas por enzimas posteriormente

$P_2O_7^{4-}$

Compartimentalização

- ☑ Membranas são essenciais para a organização autopoiética – confinamento de processos químicos relevantes numa estrutura encapsulada e com isolamento adequado
- ☑ Trocas por difusão e osmose!!!!
  - ✓ Soluções de aminoácidos dessecado
  - ✓ Micelas reversas
  - ✓ Mineirais como fontes de bolhas
- ☑ Essência: manter a autonomia e organização internas, às custas de aumento de entropia externo – **SISTEMA EM ESTADO PERMANENTE DE NÃO-EQUILÍBRIO!!!**

Armazenamento e reprodução de informação



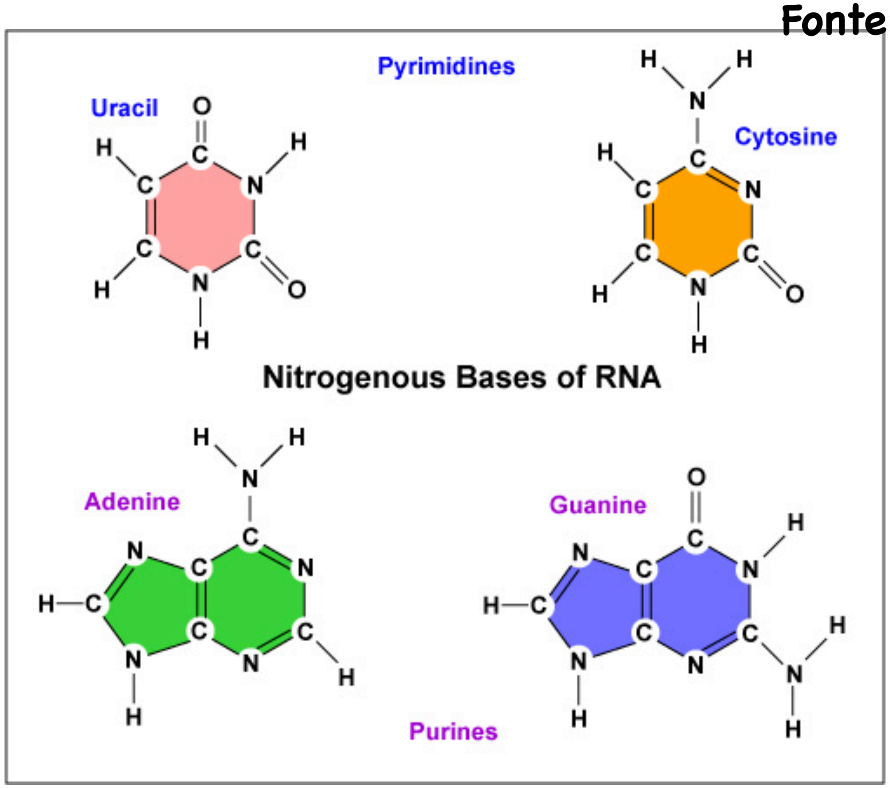
- ☑ Nucleotídeo: açúcar (C_5) + grupo fosfato + base nitrogenada
- ☑ Analogia:
  - ✓ Bases: alfabeto (C, T, G, A, U)
  - ✓ Tripletos de bases: palavras (CUU, UGU, UAU…)
- ☑ Essência: codificação e fluxo entre sistemas
- ☑ DNA e RNA empregam essencialmente o mesmo código, que especifica a sequência de aminoácidos de cada proteína, com instruções contidas em nucleotídeos, que compõem os ácidos nucleicos (DNA e RNA)

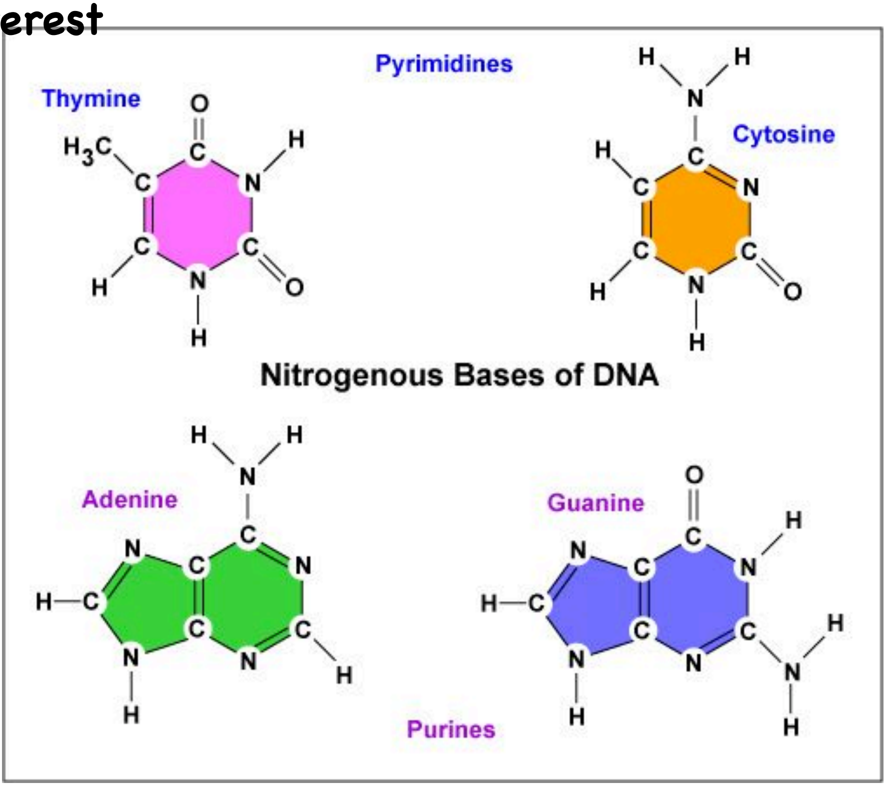
Estrutura bioquímica

☑ DNA	☑ Software
☑ RNA	☑ Software OU hardware OU ambos
☑ Proteína	☑ Hardware
☑ Ribossoma	☑ Fábrica de proteínas
☑ Mitocôndria	☑ Gerador de energia

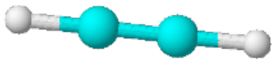
As 5 bases nitrogenadas (nucleobases)

Fonte: Pinterest

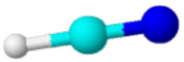




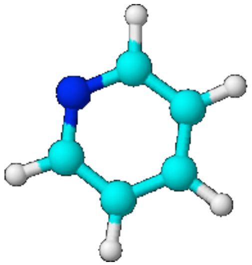
Moléculas precursoras detectadas



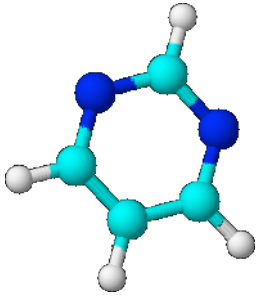
Acetileno



Cianeto de Hidrogênio

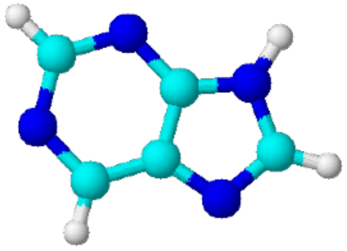


Piridina



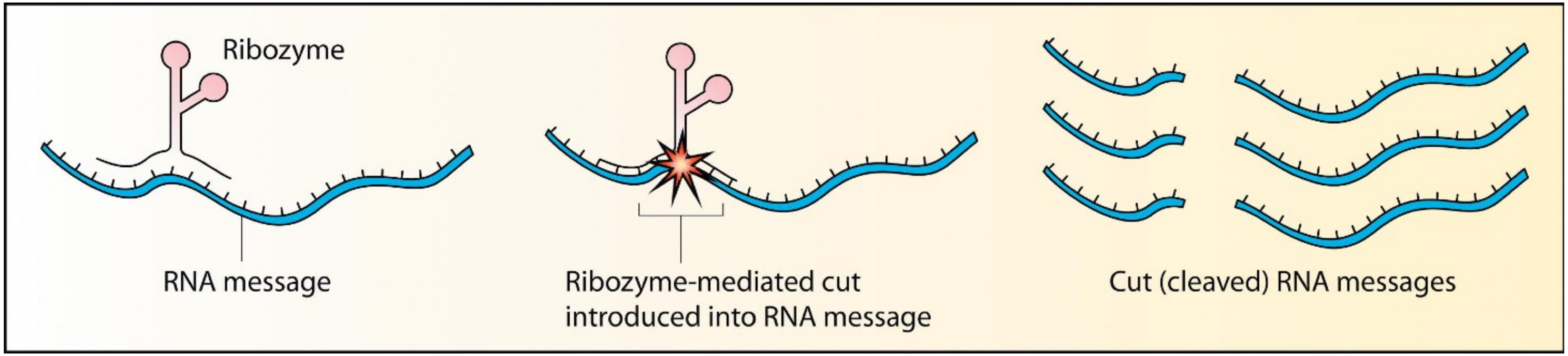
Pirimidina

Purina



Mas o problema permanece…

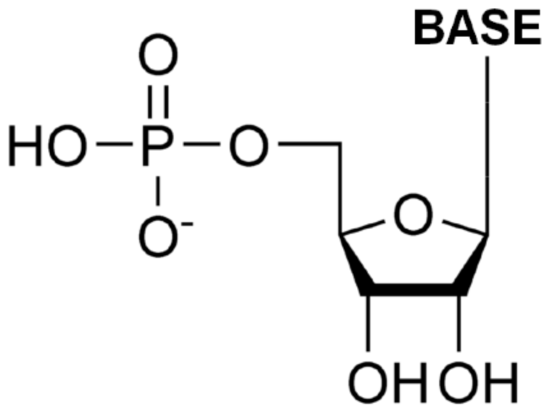
- ☑ Que reações químicas originaram o aparecimento do sistema interdependente de ácidos nucleicos e proteínas ?
- ☑ Possibilidade: um mundo de RNA (ribozimas são boa evidência disso), anterior ao de DNA

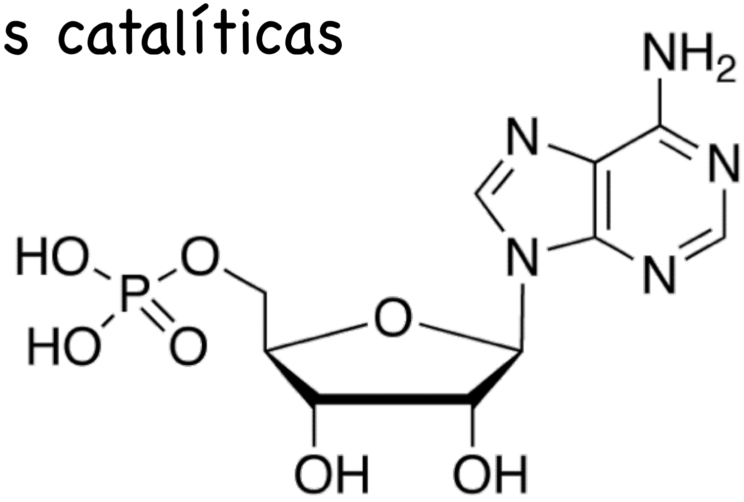


Mas o problema permanece...

- ☑ Outra possibilidade "pré-RNA" (entre diversas existentes na literatura): coevolução de peptídeos e ribonucleotídeos e a criação de uma rede de comunicação entre ambos, formando um sistema misto de armazenamento de informações

- ☑ A escolha de um sistema em favor de outros deve-se, provavelmente, a vantagens seletivas oferecidas pelo aperfeiçoamento da capacidade de armazenamento de informação ou aumento de propriedades catalíticas



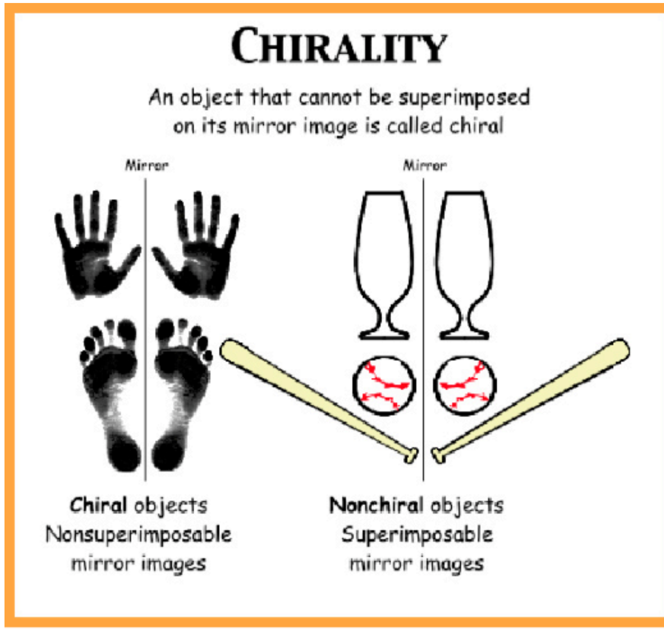


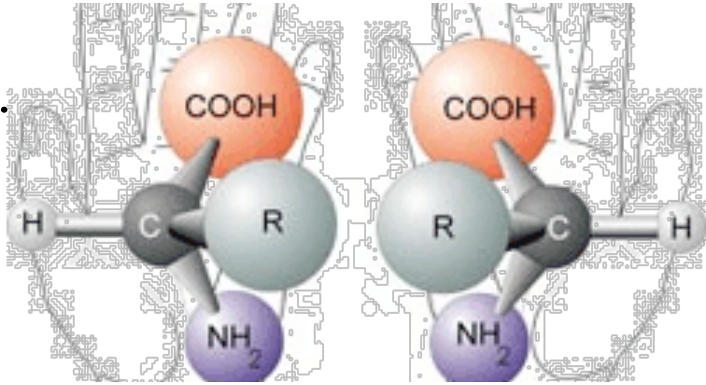
Quiralidade

- ☑ Propriedade óptica de alterar a reflexão da luz polarizada ainda é um mistério
- ☑ Baixa probabilidade de ocorrer ao acaso (2^{-N}), em que N é o número de monômeros da cadeia
- ☑ Estereoseletividade é a propriedade de seleção de moléculas que formam uma cadeia
- ☑ Um polímero homoquiral requer um meio homoquiral essencialmente puro (e qualquer estereoseletividade) ou uma estereoseletividade alta num meio de qualquer polarização quiral

Quiralidade

- ☑ Aminoácidos homoquirais são mais resistentes à hidrólise
- ☑ Origem terrestre ou extraterrestre?
  - ✓ Terrestre: não há evidências da evolução de quiralidade a partir de uma mistura racêmica na história geobiológica da Terra
  - ✓ Mecanismos abióticos terrestres, surgidos de condições aleatórias e evoluindo para o equilíbrio também carecem de evidências.
  - ✓ Campos magnéticos terrestres eram fracos para induzir quiralidade na Terra jovem
- ☑ Extraterrestre: origem na polarização da radiação sincrotron galáctica, produzindo fotólise seletiva na superfície de grãos. Também carece de evidências…

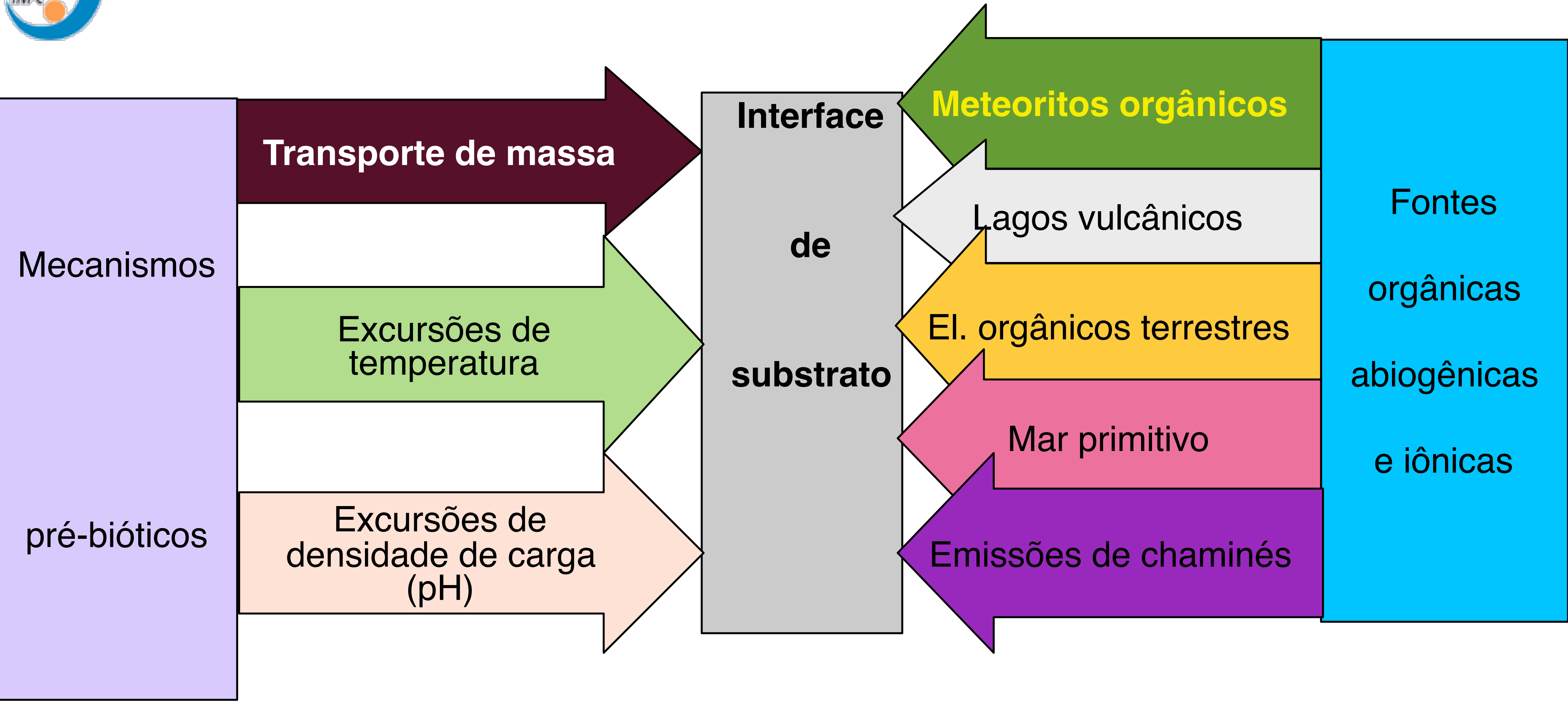




Os primeiros sistemas vivos

- ☑ A evolução dos primeiros sistemas vivos pode ter ocorrido em 2 conjuntos de cenários:
  - ✓ Terrestre:
    1. Interface aquosa (mares, lagunas) e atmosfera primitiva terrestre
    2. Interface aquosa e superfície de minerais
    3. Chaminés hidrotermais (quimicamente muito favorável ao aparecimento de biomoléculas, se comparada com 1)
  - ✓ Extraterrestre: banco de moléculas precursoras
    - ➢ Requer a compatibilidade entre condições terrestre e extraterrestre para surgimento de uma química mais elaborada

Adaptada de F. Souza-Barros, 2006



Mecanismos

pré-bióticos

Transporte de massa

Excursões de temperatura

Excursões de densidade de carga (pH)

Interface

de

substrato

Meteoritos orgânicos

Lagos vulcânicos

El. orgânicos terrestres

Mar primitivo

Emissões de chaminés

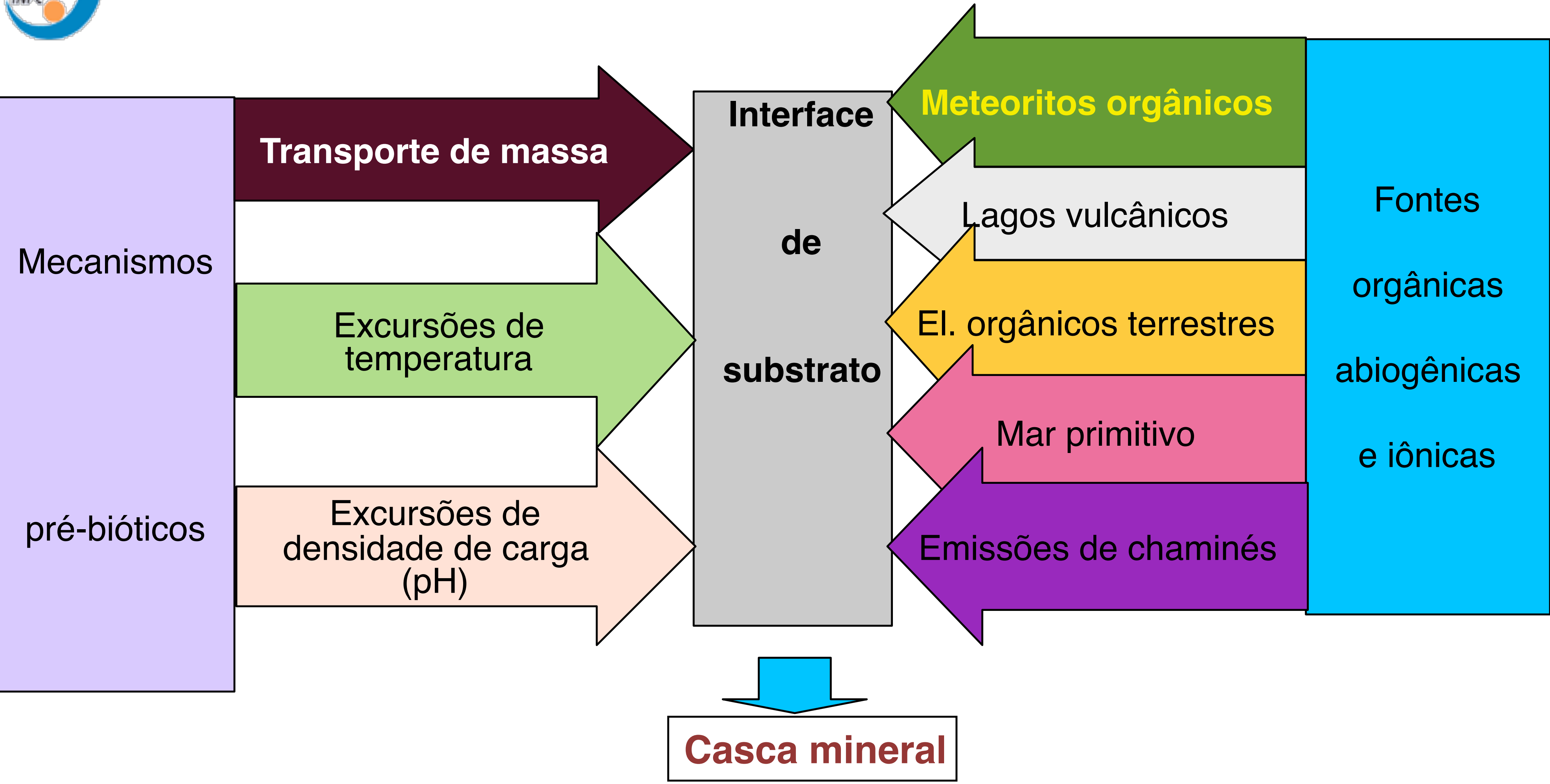
Fontes

orgânicas

abiogênicas

e iônicas

Adaptada de F. Souza-Barros, 2006



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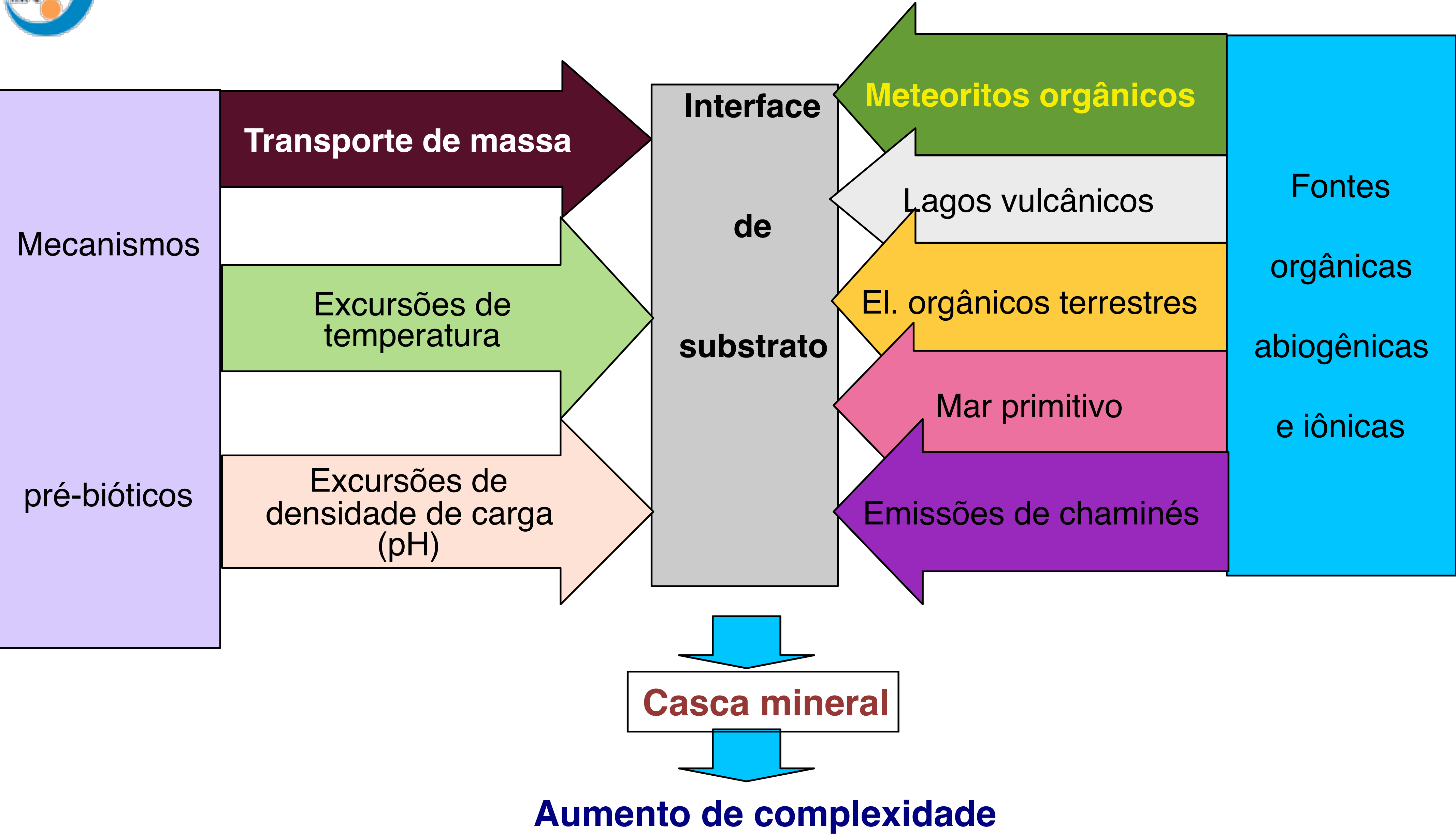

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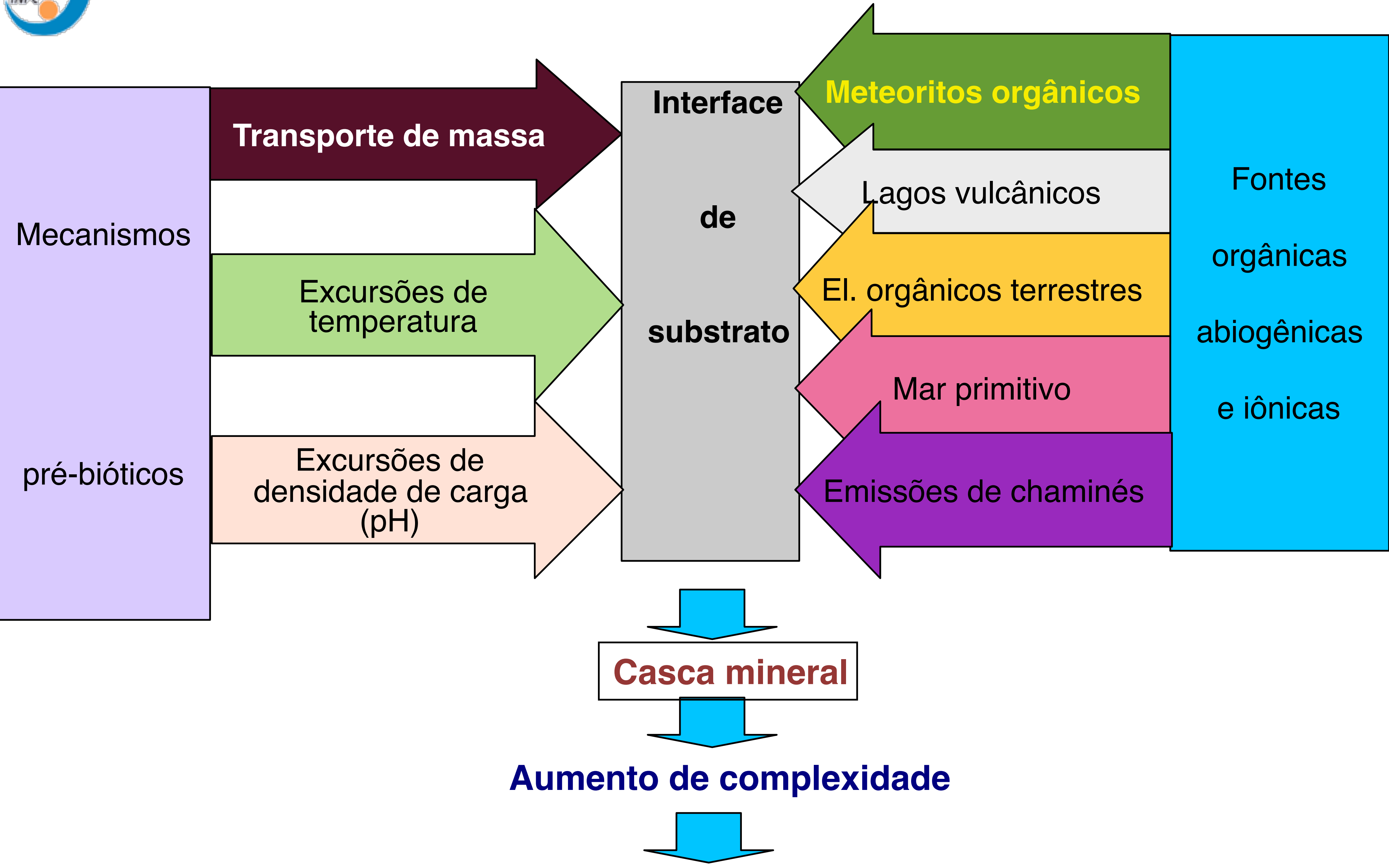
Adaptada de F. Souza-Barros, 2006



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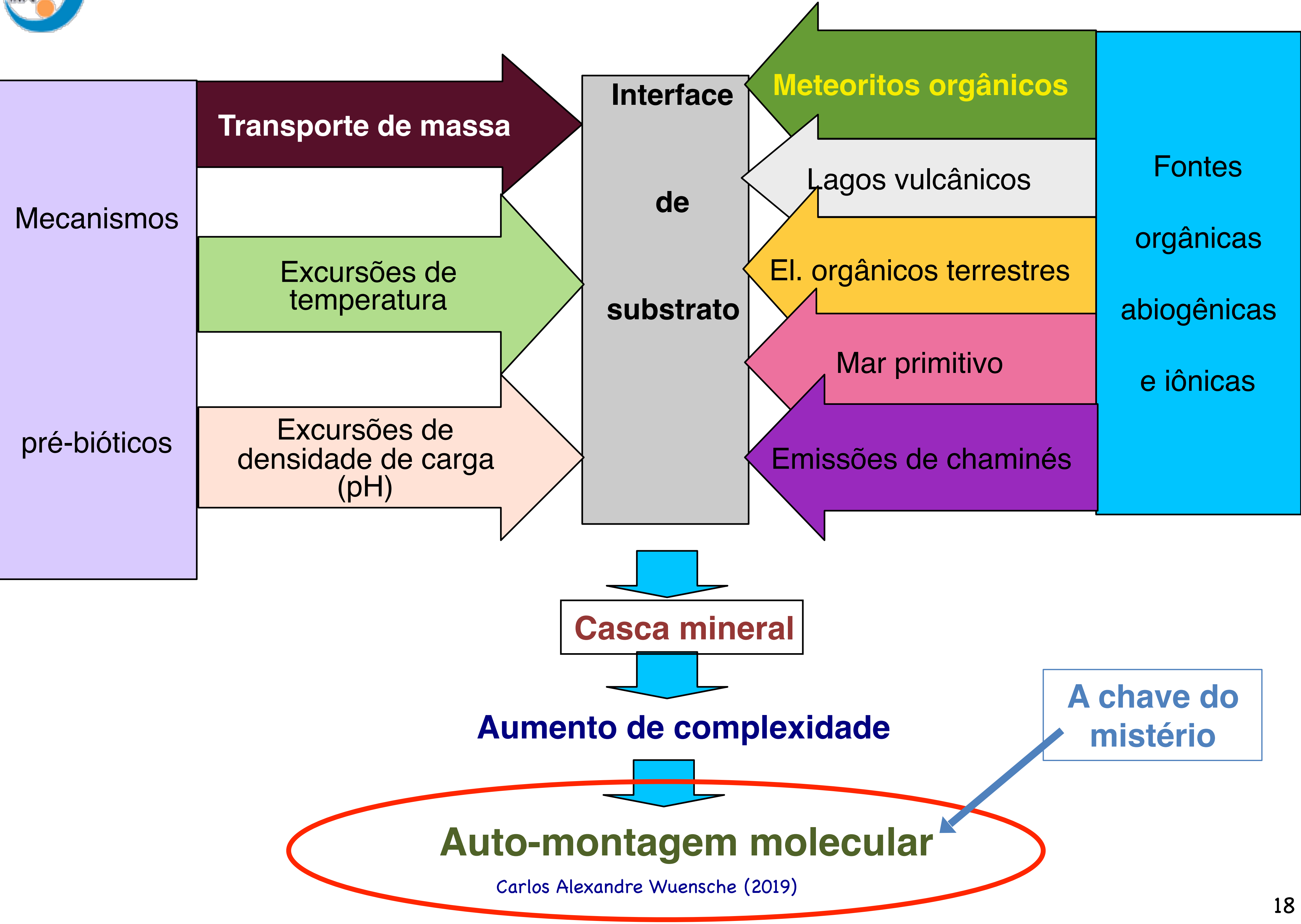
Auto-montagem molecular

Carlos Alexandre Wuensche (2019)

Adaptada de F. Souza-Barros, 2006



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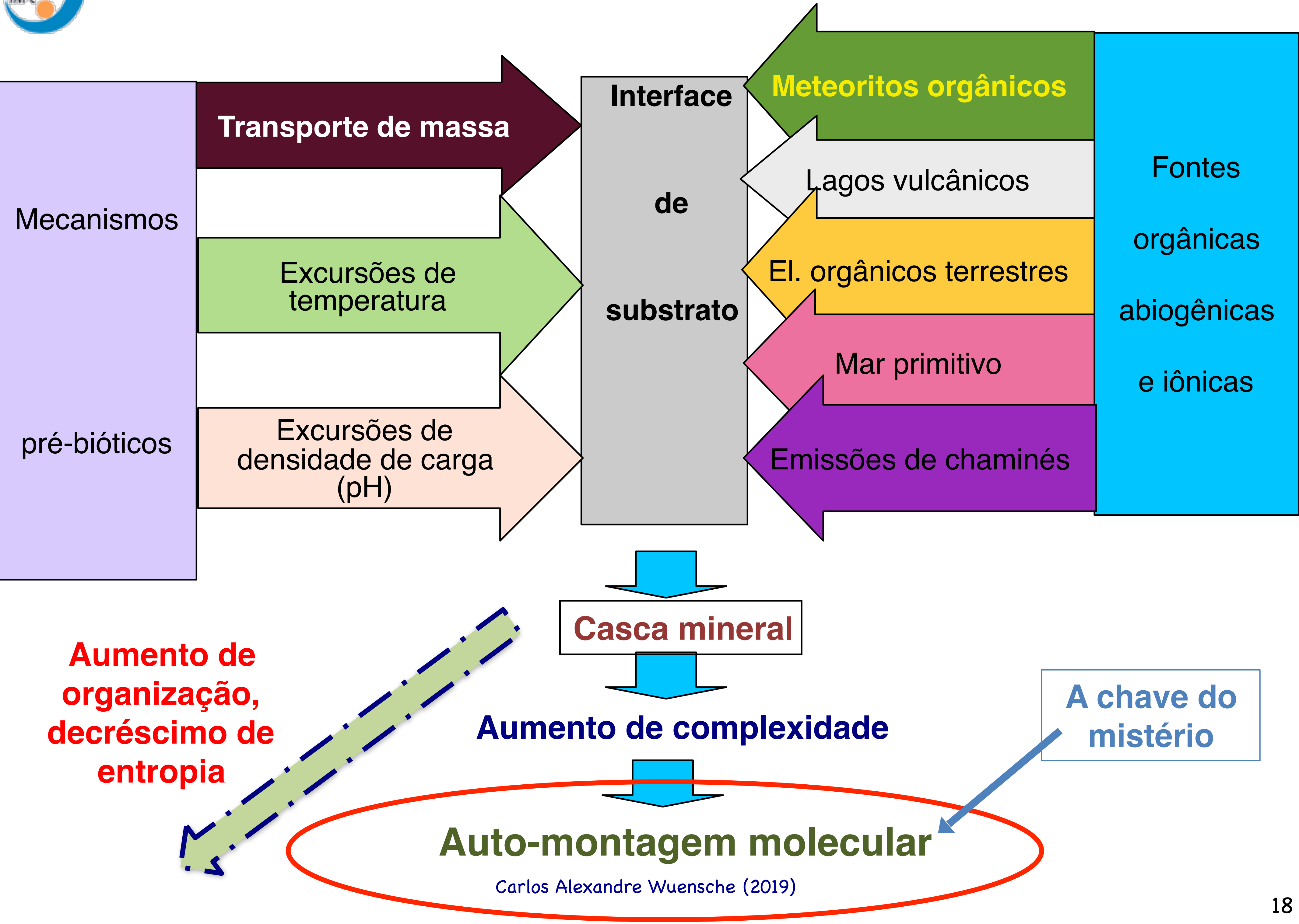
Auto-montagem molecular

A chave do mistério

Carlos Alexandre Wuensche (2019)

Adaptada de F. Souza-Barros, 2006



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Auto-montagem molecular

Aumento de organização, decréscimo de entropia

A chave do mistério

Antes da “transição”

- ☑ Modelo de Dyson: evolução de sistema químicos complexos
    - ✓ Descrição heurística das propriedades de auto-organização e comportamento.
- ☑ Suposições para passar de um sistema não-vivo para um sistema vivo

Pontos do modelo de Dyson

- ☑ Sistemas químicos suficientemente complexos podem sofrer transições para estados mais ordenados
  - ✓ Suposições: catalisadores eficientes (construídos a partir de uma classe de monômeros menores, número suficiente de monômenros e sítios de adsorção)
  - ✓ Probabilidade de construir sistemas que diminuem sua entropia é de 10^{10}, para obter taxas de transição interessantes
  - ✓ Graus de liberdade são definidos pela abundância de monômeros

Pontos do modelo de Dyson

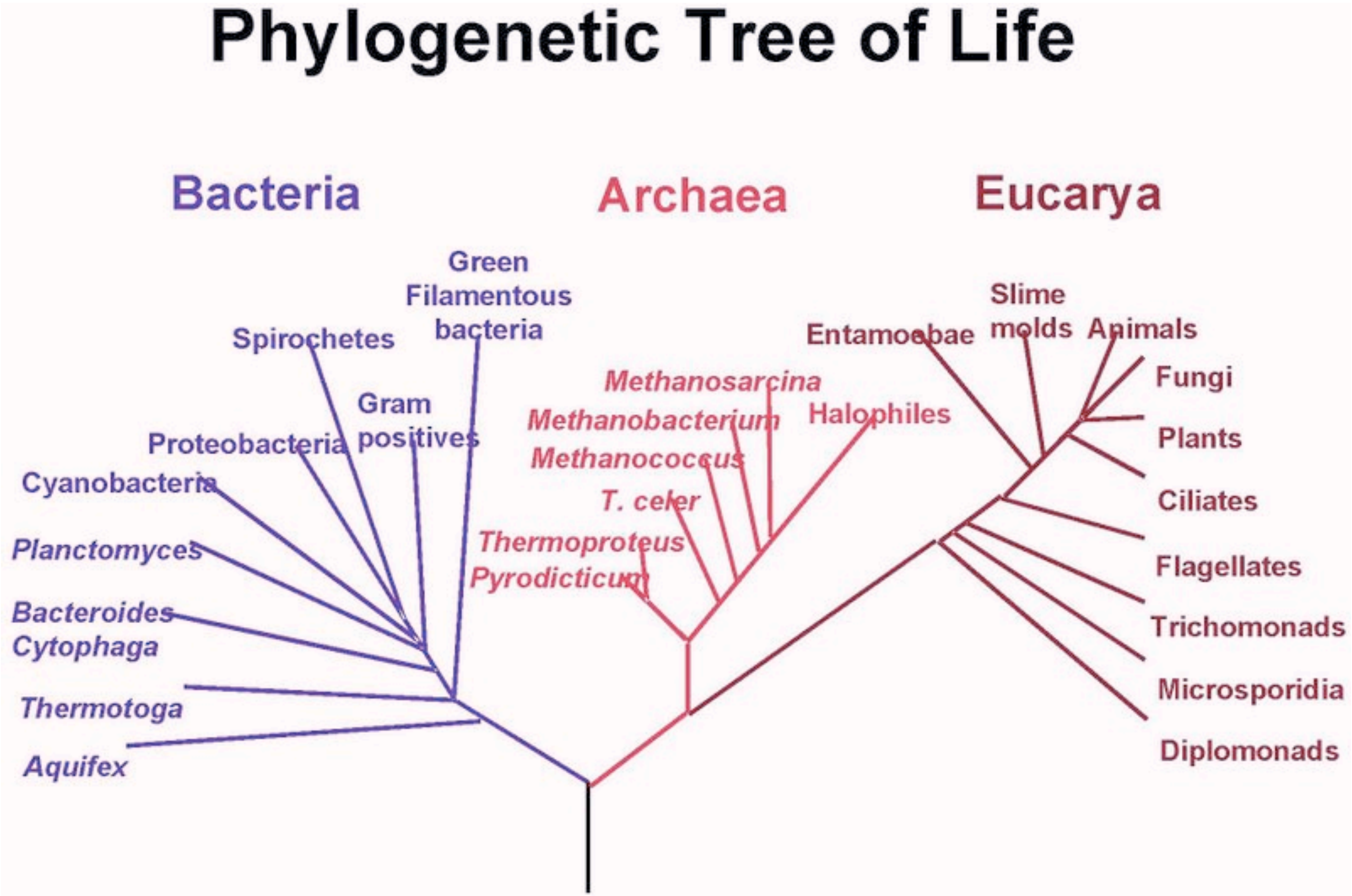
- ☑ A propriedade de catálise e o número de "tijolos" fundamentais exigido para um comportamento de auto-organização é razoável
  - ✓ São necessários 10 monômenos-chave para o início do processo de auto-organização (pouco menos do que é usado hoje)
  - ✓ Se sistemas auto-organizados são os precursores da vida baseada em "templates", surge uma explicação natural, baseada somente no comportamento geral de sistemas dinâmicos, do porque a vida utiliza somente uma pequena fração dos aminoácidos produzidos na natureza

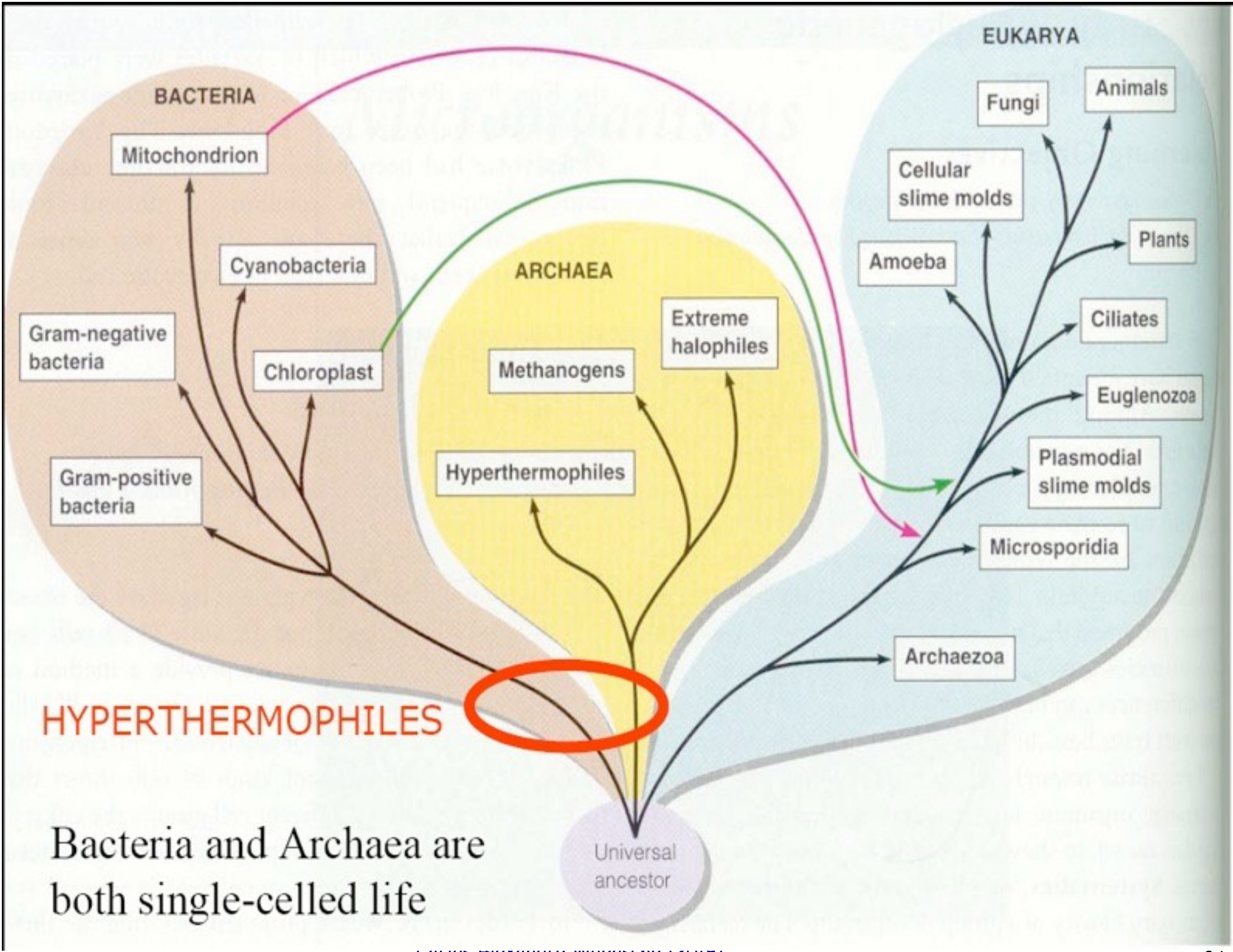
Pontos do modelo de Dyson

- ☑ Existe um corte natural no tamanho e complexidade dos sistemas, além do qual a auto-organização que não é baseada em modelos é interrompida
  - ✓ As estruturas das células mais simples requer, para sua formação, replicação e subsistência, um vasto número de compostos que – embora infinitamente menores do que está disponível naturalmente – são muito numerosos para surgirem através de auto-organização a partir de sistemas menos sofisticados
  - ✓ PORÉM, o grau de complexidade abaixo do qual essa evolução "sem modelo" poderia ocorrer é só 1 – 2 ordens de grandeza inferior ao da célula mais simples

Após a "transição"

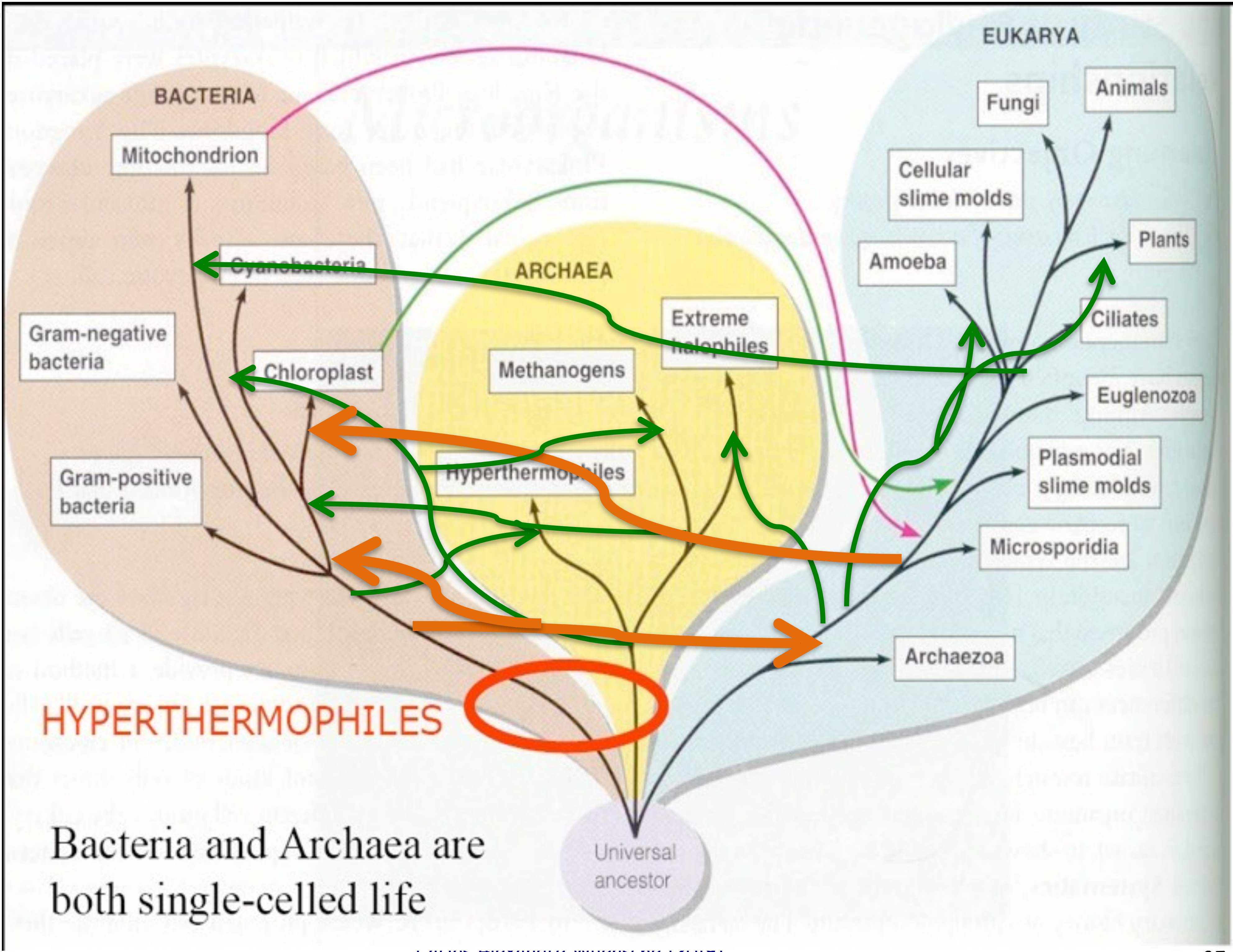
- ☑ Porque 3 domínios, e não 2 ou 5?
- ☑ Construída com base na análise de sequencias do RNA ribossômico.





HYPERTHERMOPHILES

Bacteria and Archaea are both single-celled life



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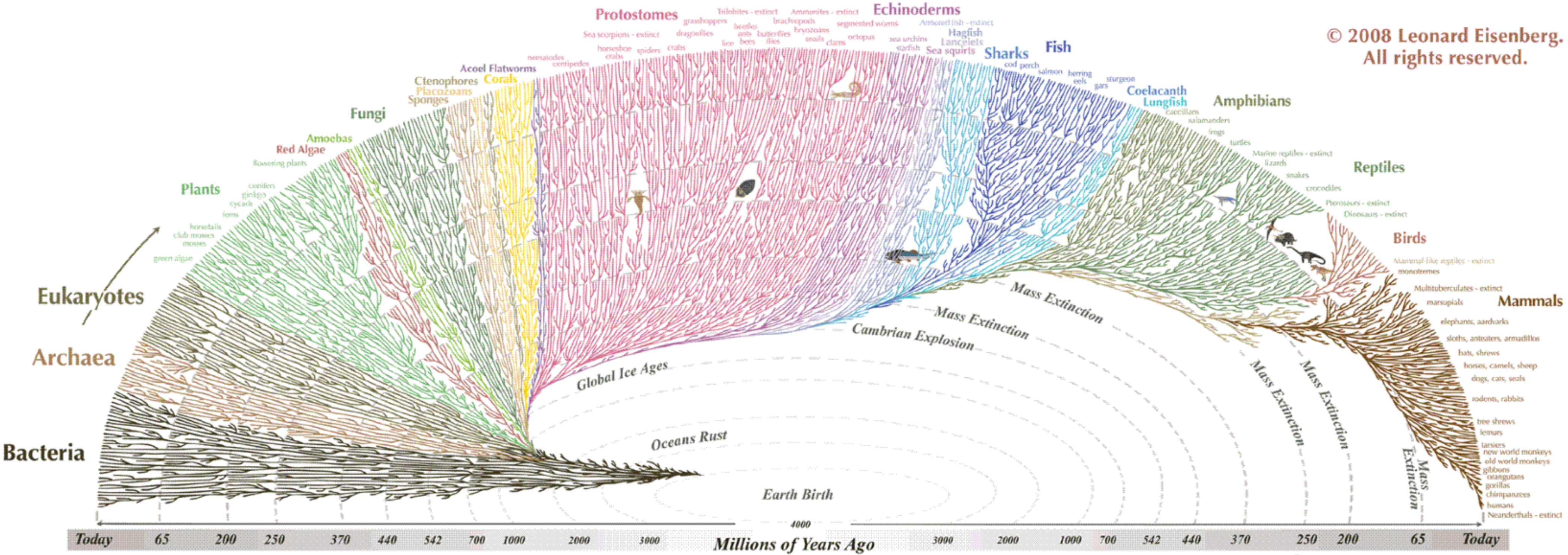
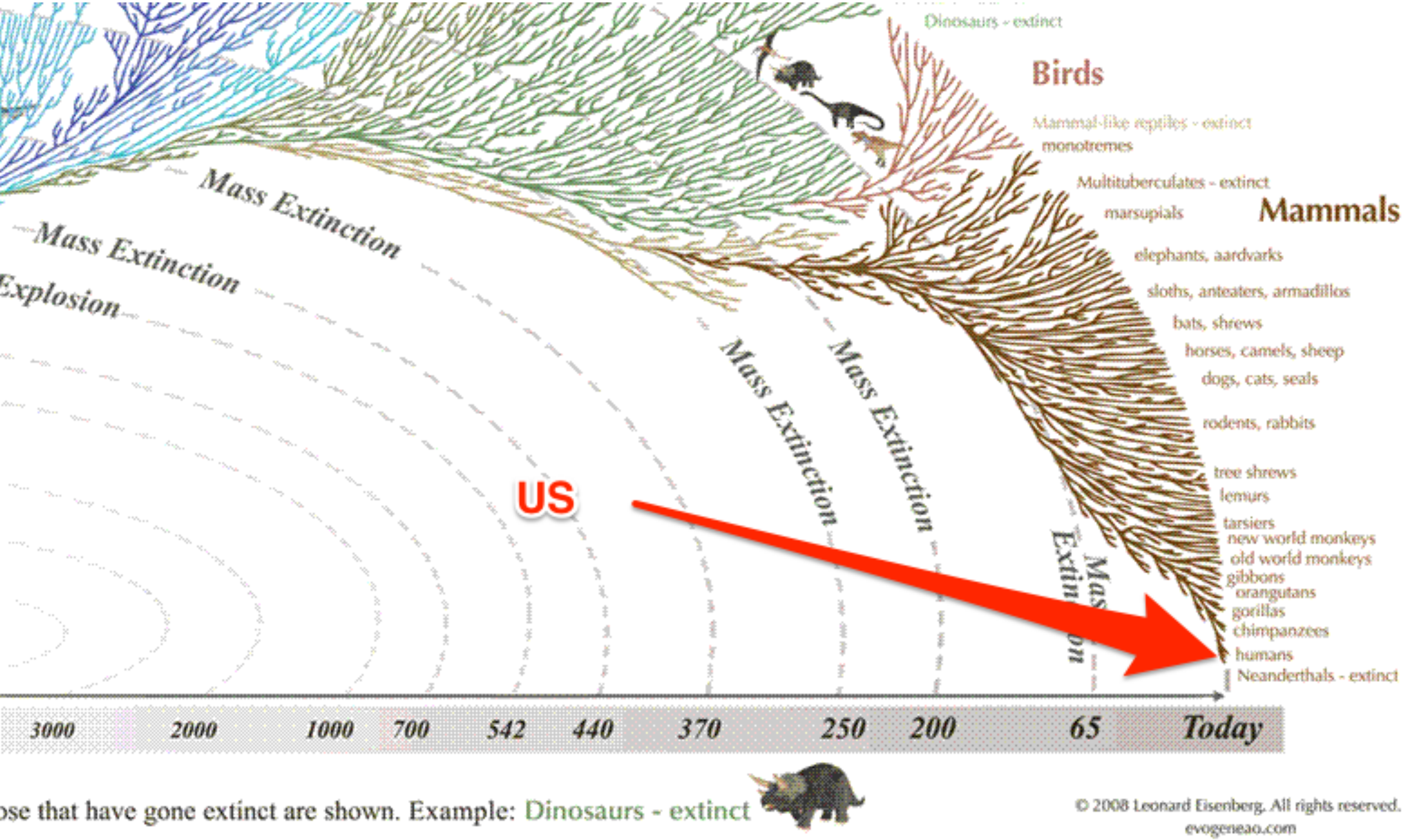


All the major and many of the minor living branches of life are shown on this diagram, but only a few of those that have gone extinct are shown. Example: Dinosaurs - extinct



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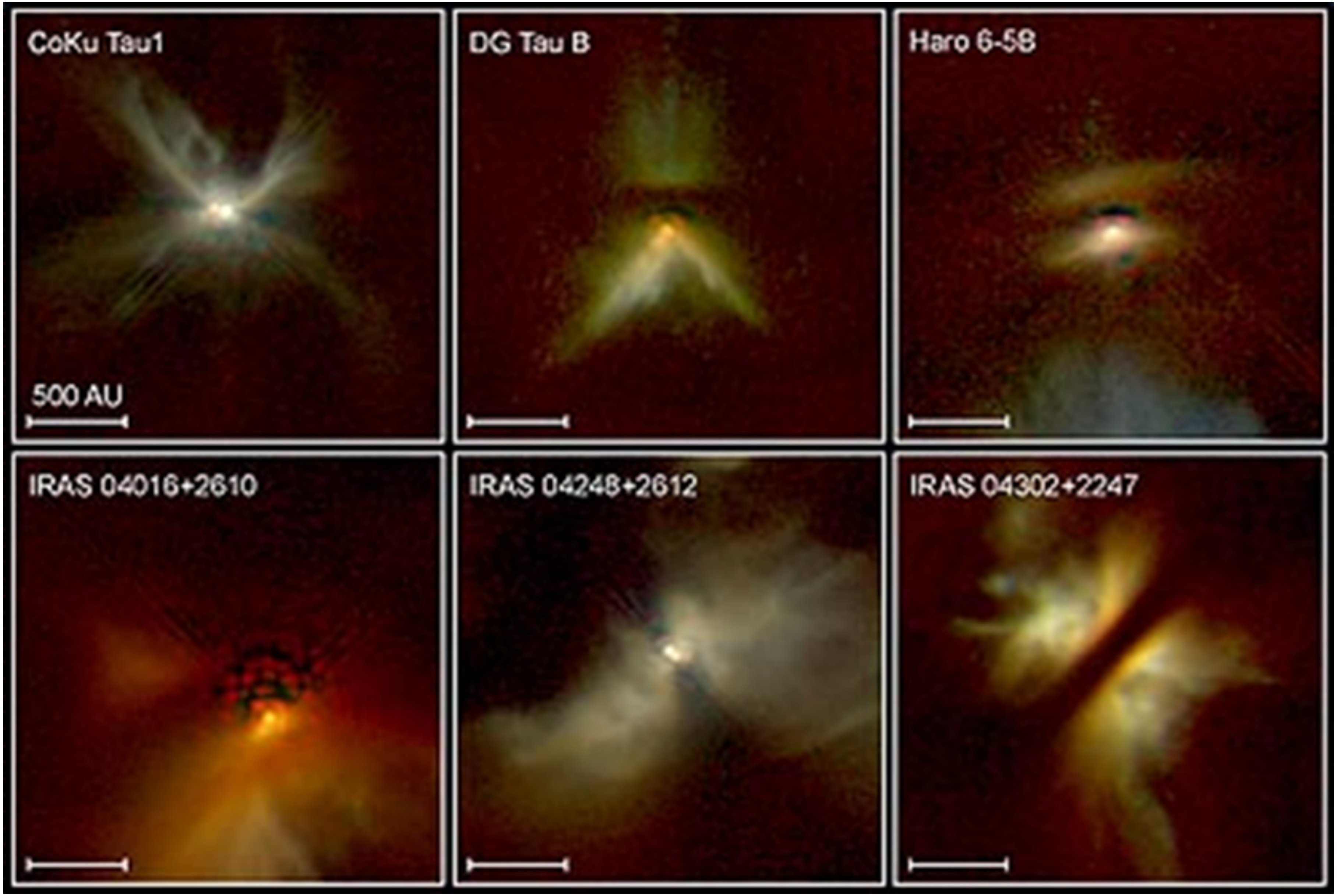
Organizando a “transição”

Formação do Sistema Solar (revisando a aula anterior...)

- ☑ estado inicial:
  - ✓ nuvem de gás e poeira em equilíbrio hidrostático
  - ✓ composição: basicamente hidrogênio
- ☑ estopim da contração
  - ✓ explosão de supernova
  - ✓ outro tipo de perturbação
- ☑ nuvem vira massa central + disco
  - ✓ massa central será o Sol
  - ✓ disco dará origem aos planetas
- ☑ formação dos planetas
  - ✓ formação de anéis
  - ✓ formação de planetesimais por colisão
  - ✓ colisão dos planetesimais - liberação de calor
  - ✓ estruturação: temperatura de condensação
- ☑ Idade do Sistema Solar: 5 bilhões de anos!
- ☑ Álbum de família

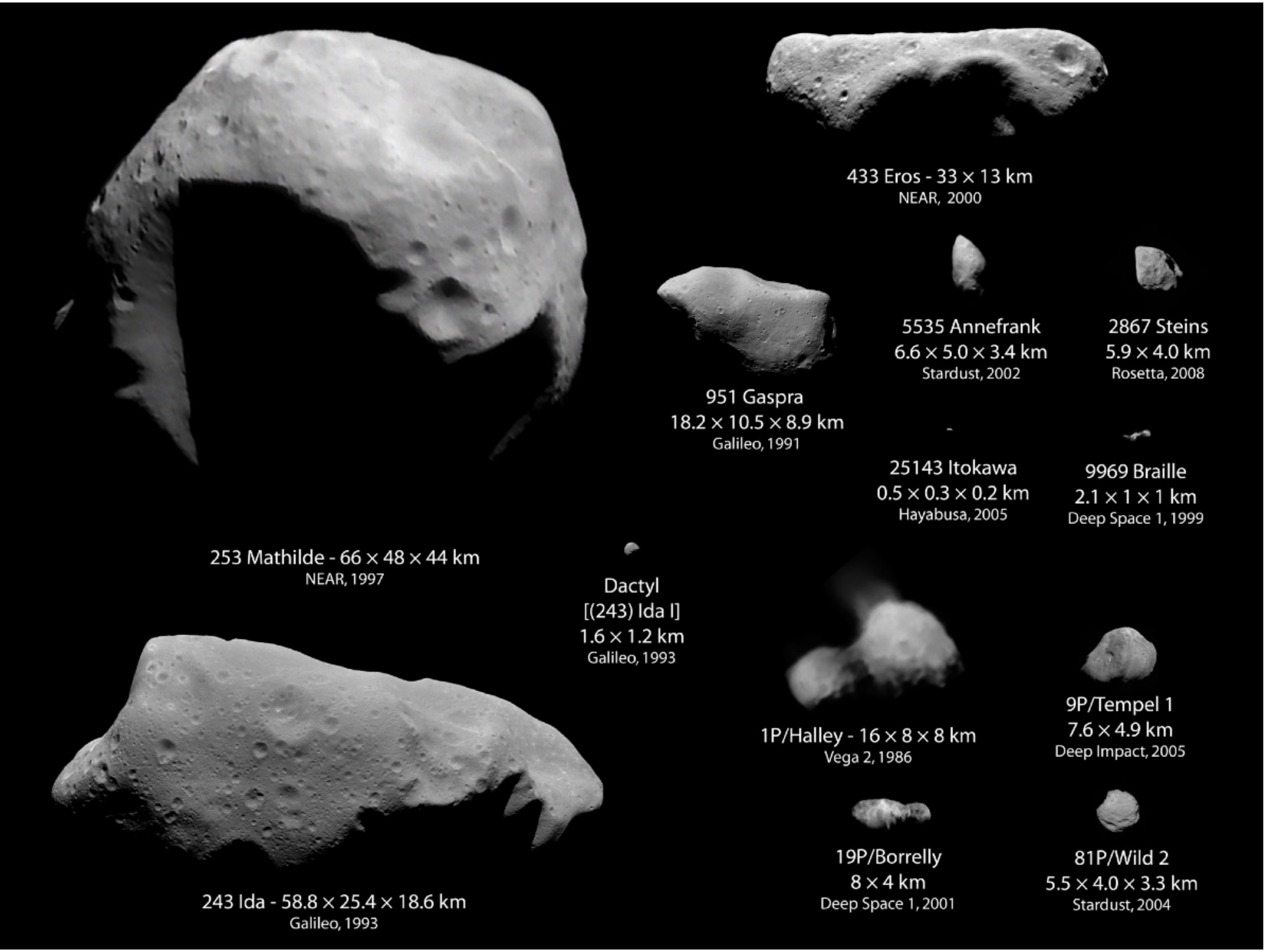
A EVOLUÇÃO DA TERRA E SUA RELAÇÃO COM A EVOLUÇÃO DA VIDA

A Terra é "rara"?



Cometas e asteróides

(killerasteroids.org)



Importantes para formação (deposiçao de orgânicos e H_2O)

e aniquilação (extinção em massa)

da vida na Terra

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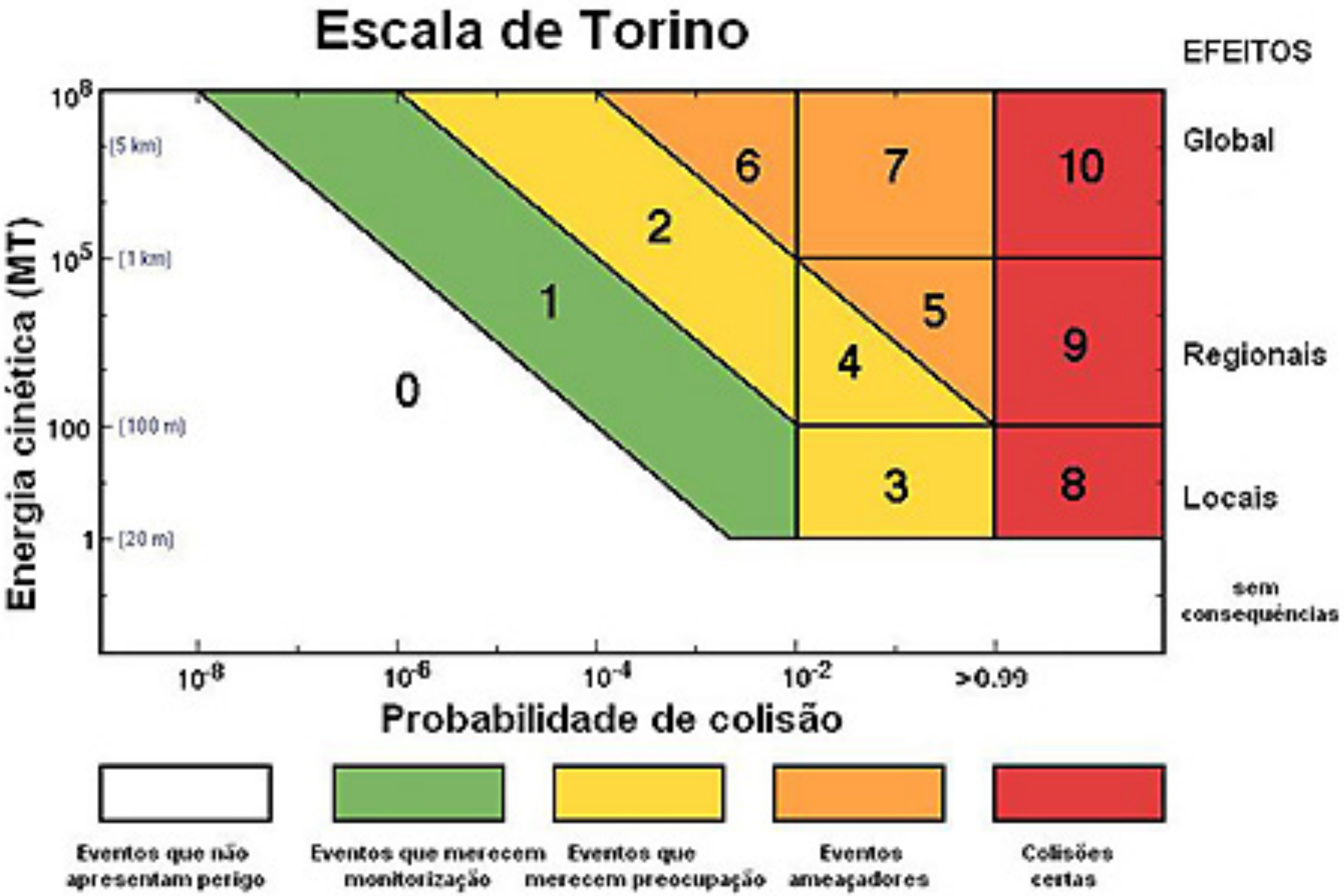
Meteoros, …itos e …óides

- ☑ Meteoróide
  - ✓ corpo sólido que entra na atmosfera
  - ✓ fragmentos de cometas ou asteróides
- ☑ Meteoro
  - ✓ fenômeno: quando um meteoróide entra na atmosfera terrestre
- ☑ Meteorito
  - ✓ meteoróide que atinge a superfície da Terra
  - ✓ Em geral, fragmentos rochosos de asteróides
- ☑ Chuva de meteoros
  - ✓ Ocorre quando a Terra atravessa os rastros de um cometa
  - ✓ Ocorre em determinadas épocas do ano

Escala de Torino



Carlos Alexandre Wuensche (2019)

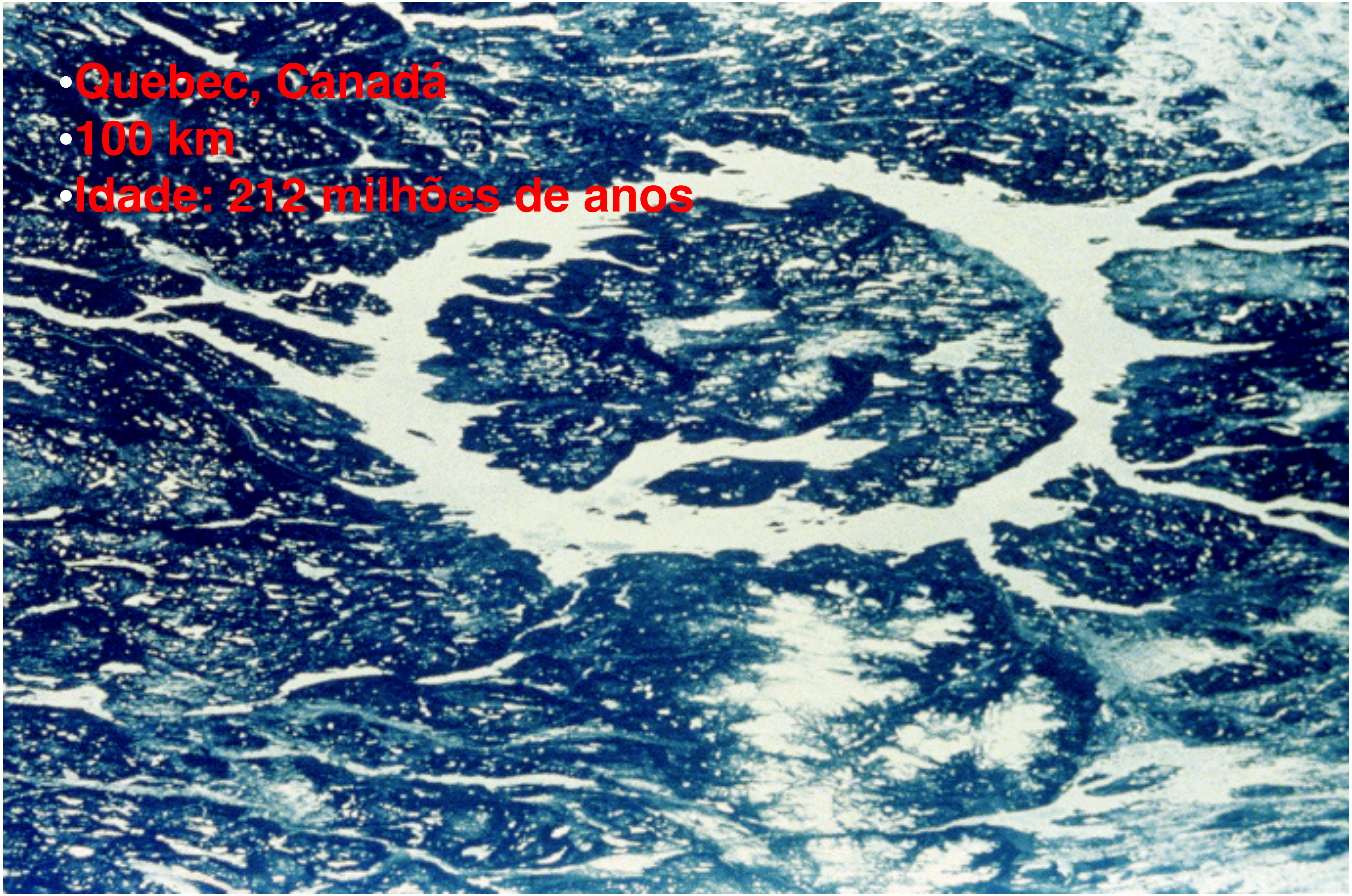
Torino impact hazard scale

Eventos sem maior importância	0	Sem chances de colisão. Também se aplica a qualquer pequeno corpo que, numa eventual colisão, dificilmente atravessaria toda a atmosfera e colidiria com o solo.
Evento merece monitoramento	1	As chances de colisão são improváveis. Aproximadamente as mesmas de um objeto qualquer de mesmo tamanho atingir a Terra dentro das próximas duas décadas.
Evento exige monitoramento cuidadoso	2	Passagem bem próxima, mas a colisão é improvável. Não é muito raro de acontecer.
	3	Passagem próxima com chance de 1% ou maior de uma colisão capaz de causar destruição local.
	4	Passagem próxima com chance de 1% ou maior de uma colisão capaz de causar uma devastação regional.
Eventos ameaçadores	5	Passagem próxima com ameaça de colisão capaz de causar destruição regional.
	6	Passagem próxima com ameaça de colisão capaz de provocar destruição global.
	7	Passagem próxima com grande possibilidade de um impacto de proporções catastróficas.
A colisão é certa	8	Colisão certa capaz de provocar destruição local. Eventos desse tipo ocorrem uma vez a cada 100 ou 1000 anos.
	9	Colisão certa capaz de causar destruição regional. Ocorrem uma vez entre 1000 e 100.000 anos.
	10	Colisão certa capaz de provocar alterações climáticas globais. Ocorrem uma vez a cada 100.000 anos — ou menos.

Cratera do Arizona

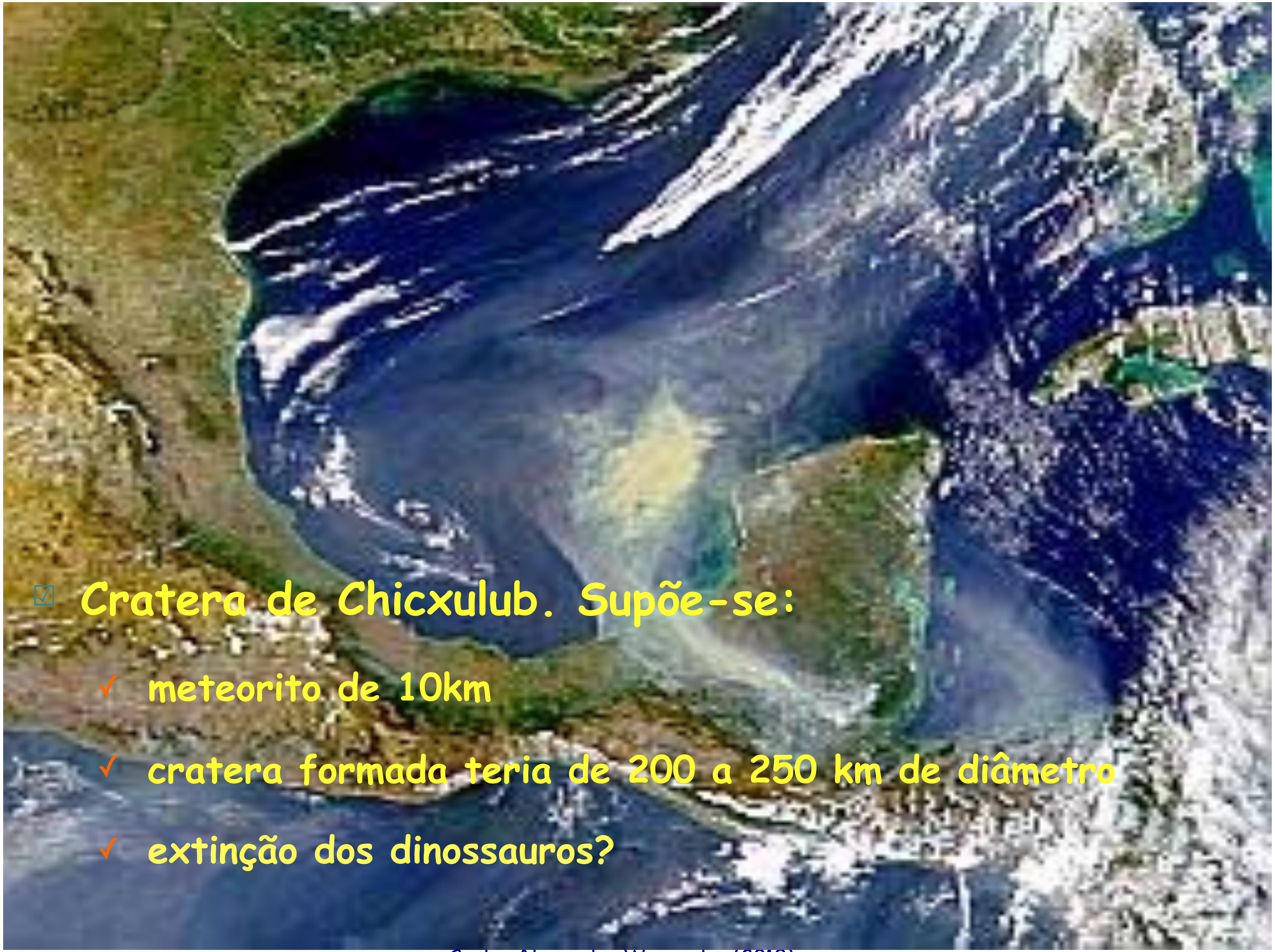
- Arizona, EUA
- 1,2 km de diâmetro
- Idade: 49.000 anos

Manicouagan



- Quebec, Canadá
- 100 km
- Idade: 212 milhões de anos

Colisões com a Terra



- ☑ Cratera de Chicxulub. Supõe-se:
  - ✓ meteorito de 10km
  - ✓ cratera formada teria de 200 a 250 km de diâmetro
  - ✓ extinção dos dinossauros?

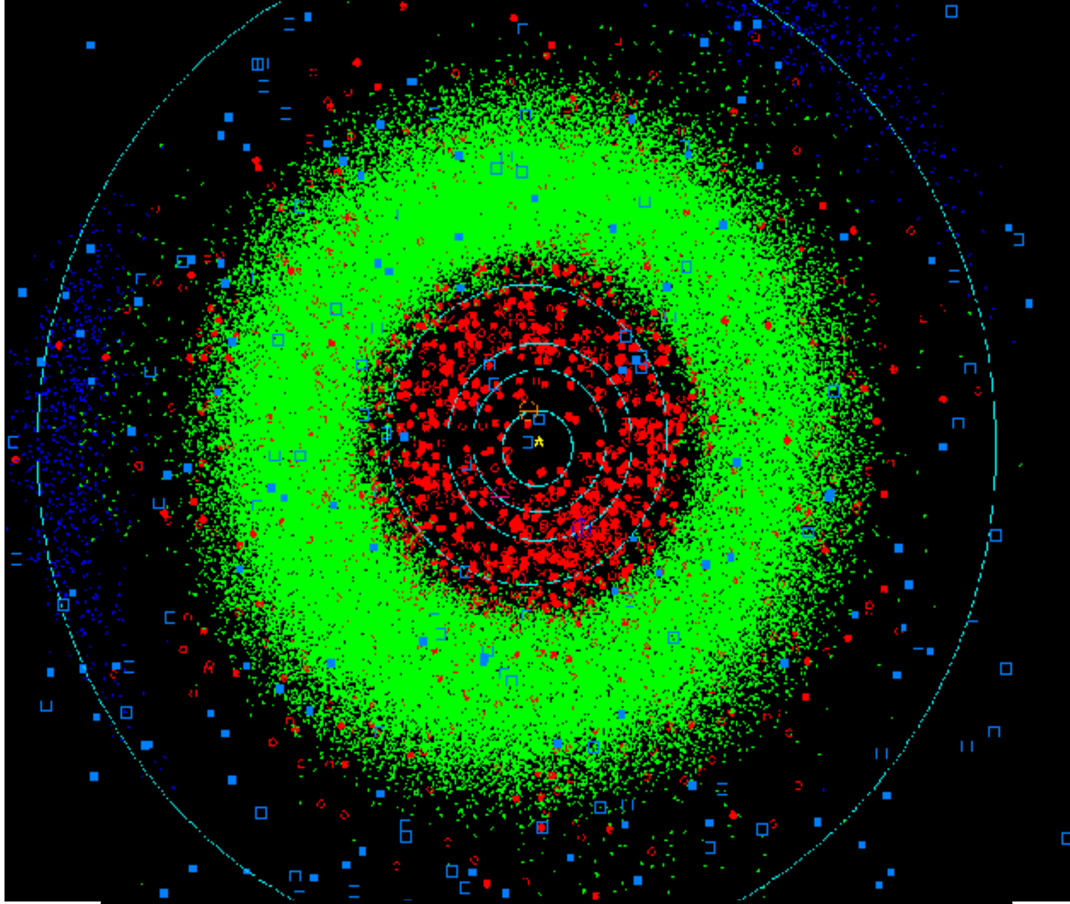
Cometas

- ☑ Essenciais para o entendimento da nuvem que deu origem ao Sistema Solar e sua evolução
- ☑ Sondas para estudar os processos químicos que ocorrem no interior (plano) dos discos astronômicos

- ✓ **Possíveis "fornecedores" do material orgânico necessário para disparar o processo da formação da vida na Terra**
- ✓ **Reservatório de material interestelar virgem?**

Asteróides

- ☑ Principal fonte de meteoritos
- ☑ Maior interesse na classe dos condritos: silicatos, silicatos com C, silicatos com H_2O
- ☑ Provável principal fonte de H_2O na Terra



Verdes asteróides
Vermelhos: asteróides a < 1,3 U.A.
Azuis: Cometas
Linhas: órbitas de Júpiter a Mercúrio

- ✓ Rico em material orgânico (% C > 0,03)
- ✓ Único material extraterrestre passível de ser estudado da Terra
- ✓ Condritos carbonados ⇨ fonte de aminoácidos

http://phys.org/news/2015-05-fresh-evidence-earth-asteroid-debris.htm

Material orgânico encontrado em meteoritos

Conteúdo de carbono: > 3% (por peso); fração solúvel < 30% do total de carbono

COMPONENTES

Ácidos

Aminoácidos

Ácidos carboxílicos

Ácidos hidrocarboxílicos

Ácidos dicarboxílicos

Ácidos hidroxidicarboxílicos

Ácidos sulfônicos

Ácidos fosfônicos

Outros

N-Heterocíclicos

Amidas

Aminas

Álcoois

Compostos carbonílicos

H-carbonetos não voláteis:

Alifáticos

aromáticos (PAH)

polares

H-carbonetos voláteis

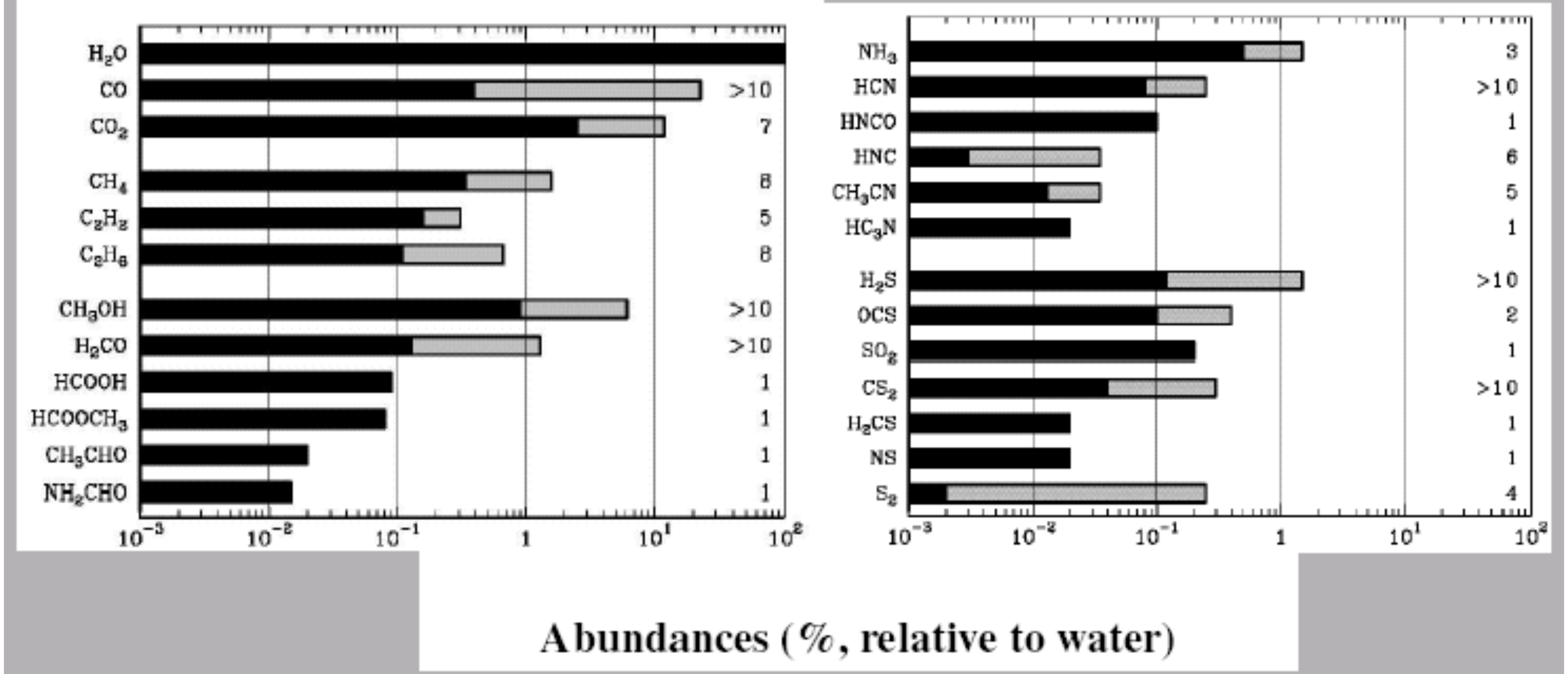
Fulerenos

C_{60}, C_{70}, He em C_{60}

Fulerenos mais complexos

Chemical Composition of Comets

(The grey bar indicates the range measured to date)

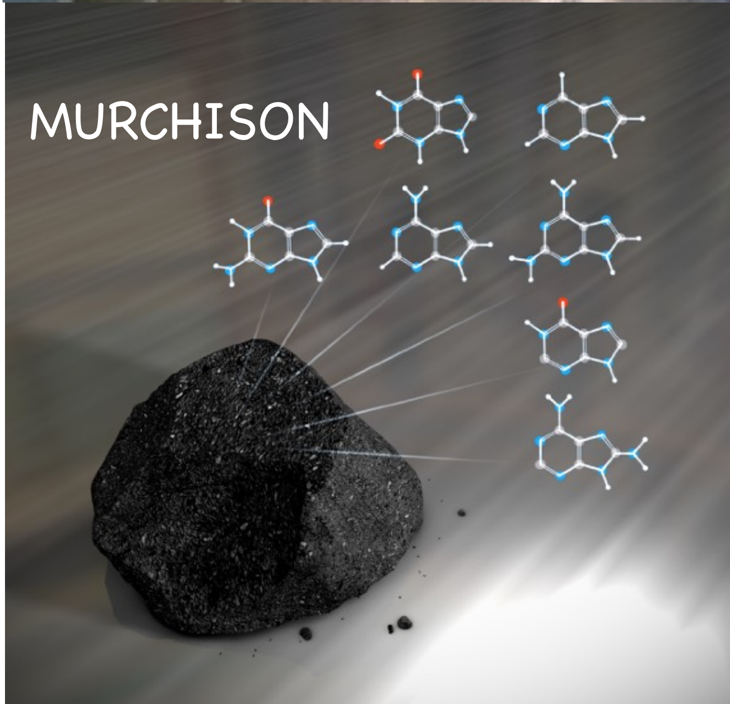


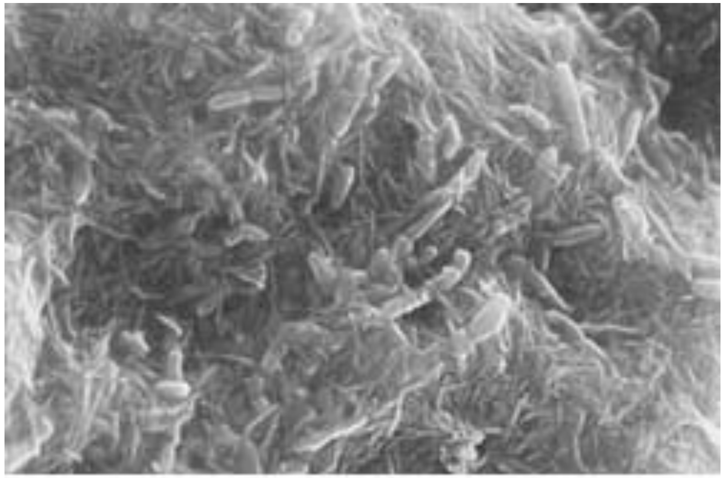
Bockelee-Morvan, Crovisier, Mumma, and Weaver (Comets II, 2003)

Chanrley, EAA lectures (2004)

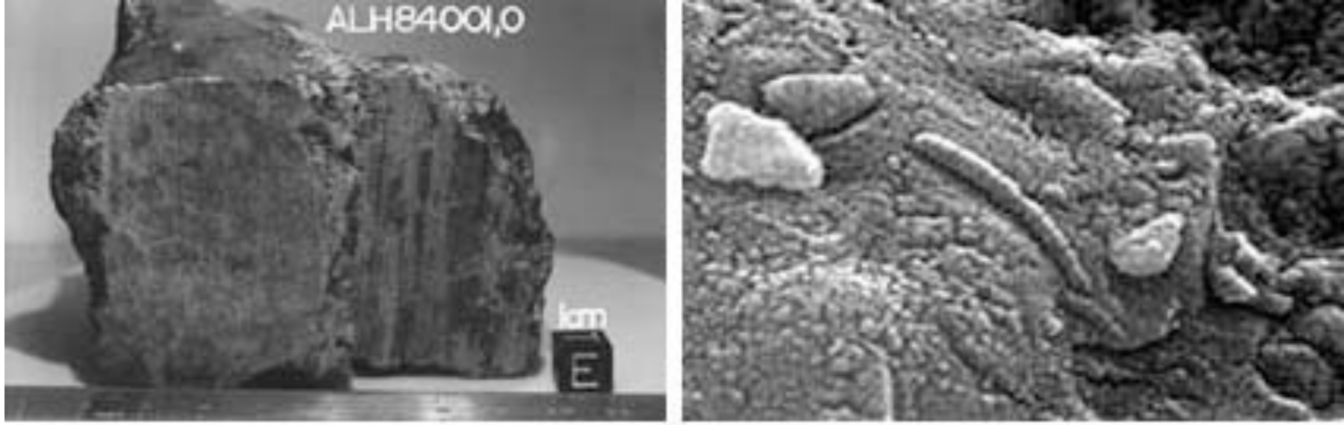
Alguns asteróides famosos…

- ☑ ALH84001 (Antártica): presença de um tipo de magnetita que somente é criado na presença de bactérias - não foi possível reproduzir o resultado no laboratório
- ☑ Murchison (Austrália): forte presença de estruturas bioquímicas, incluindo diversos aminoácidos conhecidos - proporção racêmica igual descarta origem de vida extraterrestre
- ☑ Yamato 000593 (Antártica): estudo em andamento sobre a possível origem marciana das estruturas presentes, baseadas em carbono (White et al., Astrobiology, 14, 2, pp. 170 - 181 (2014)

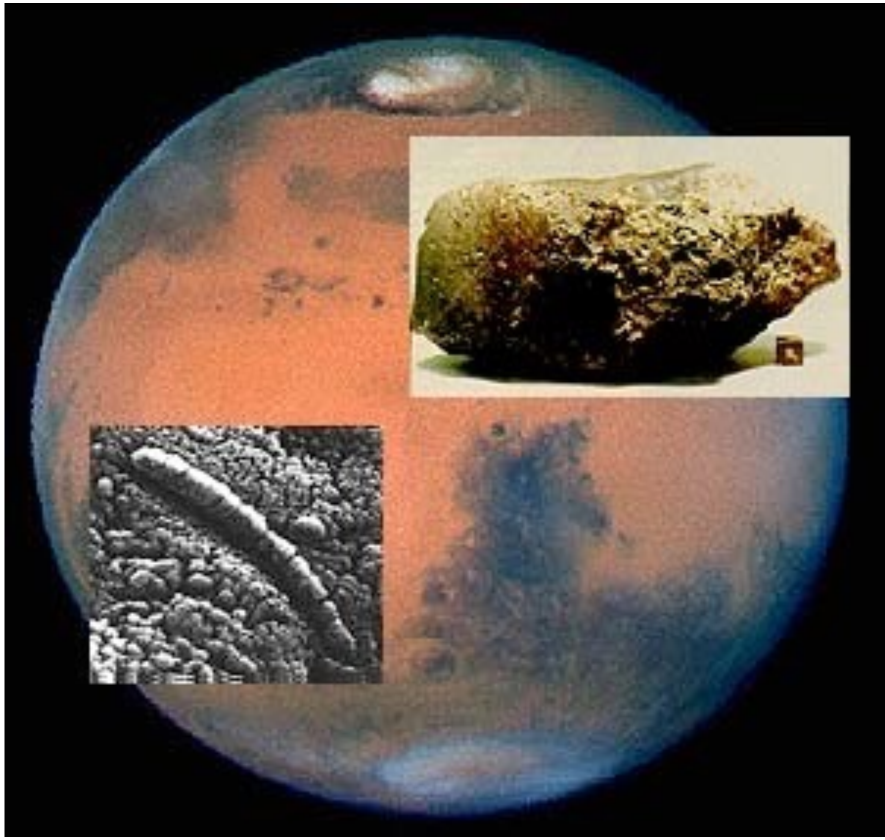


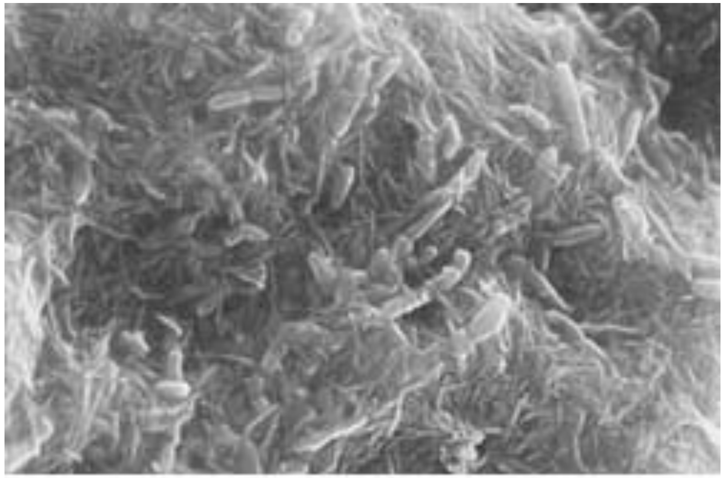


Images of microorganisms on Earth (top, thick rods about 3 micrometers long) and of possible fossils of microorganisms found within a rock from Mars (bottom, rods about 0.1 micrometers long) hint that life might be found beyond Earth.



A meteorite called ALH84001 (left) found on the Antarctic ice-fields proved to be an ancient Martian rock. Slices of the rock (right) contain organic material and, more controversially, evidence for fossilized microbes.





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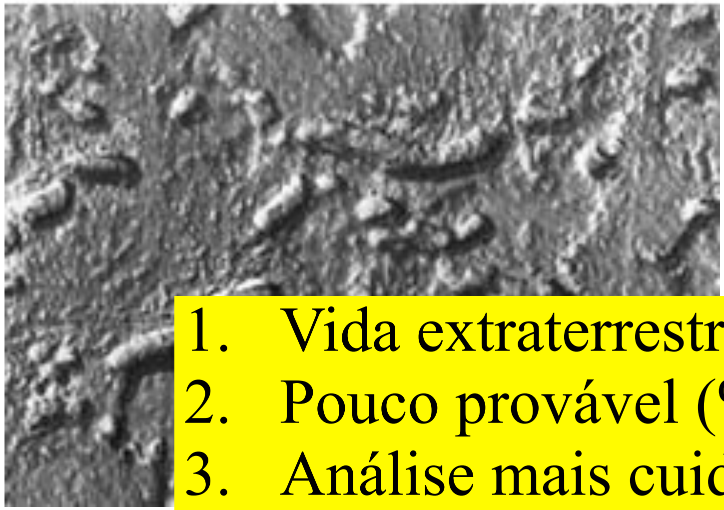

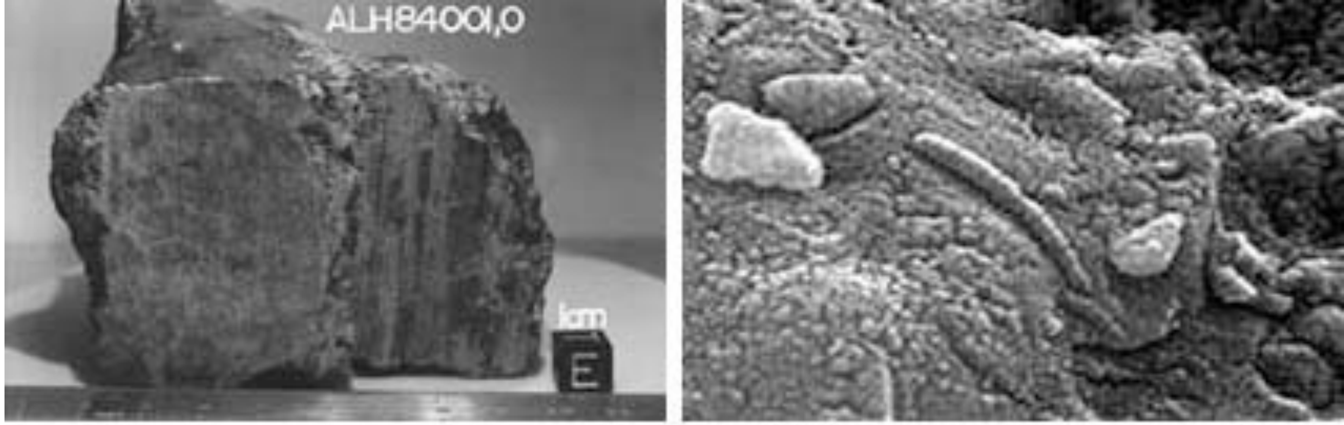

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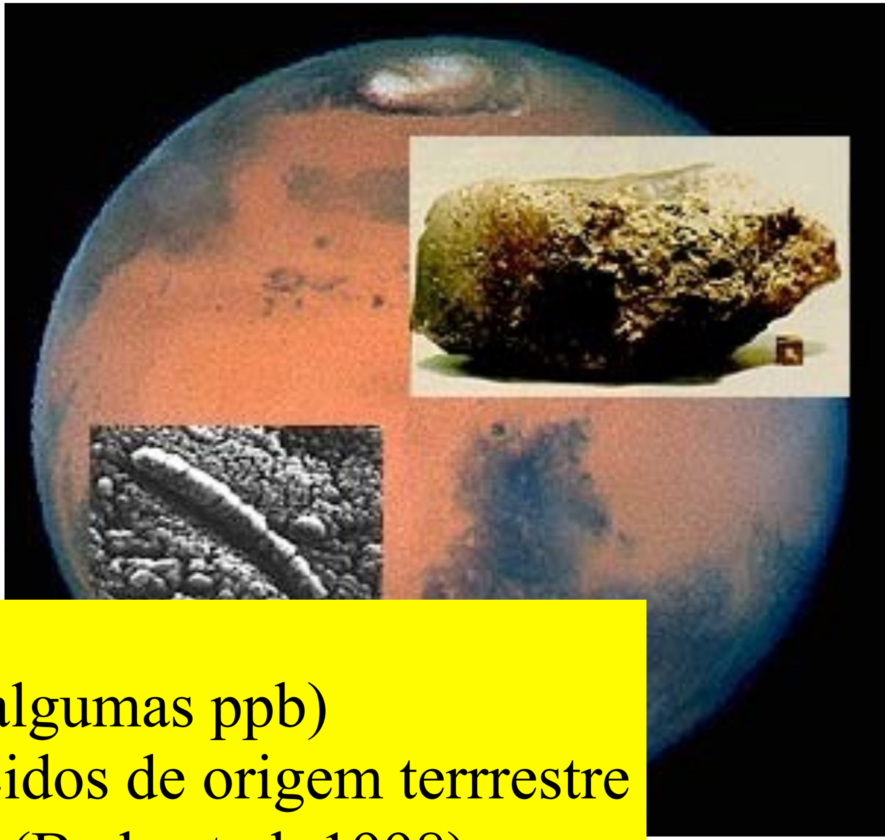


1. Vida extraterrestre? (McKay, 1996)
2. Pouco provável (% aminoácidos ~ algumas ppb)
3. Análise mais cuidadosa ⇒Aminoácidos de origem terrrestre
4. Possível fração "marciana" < 1 ppb (Bada et al. 1998)

O asteróide Yamato 000593

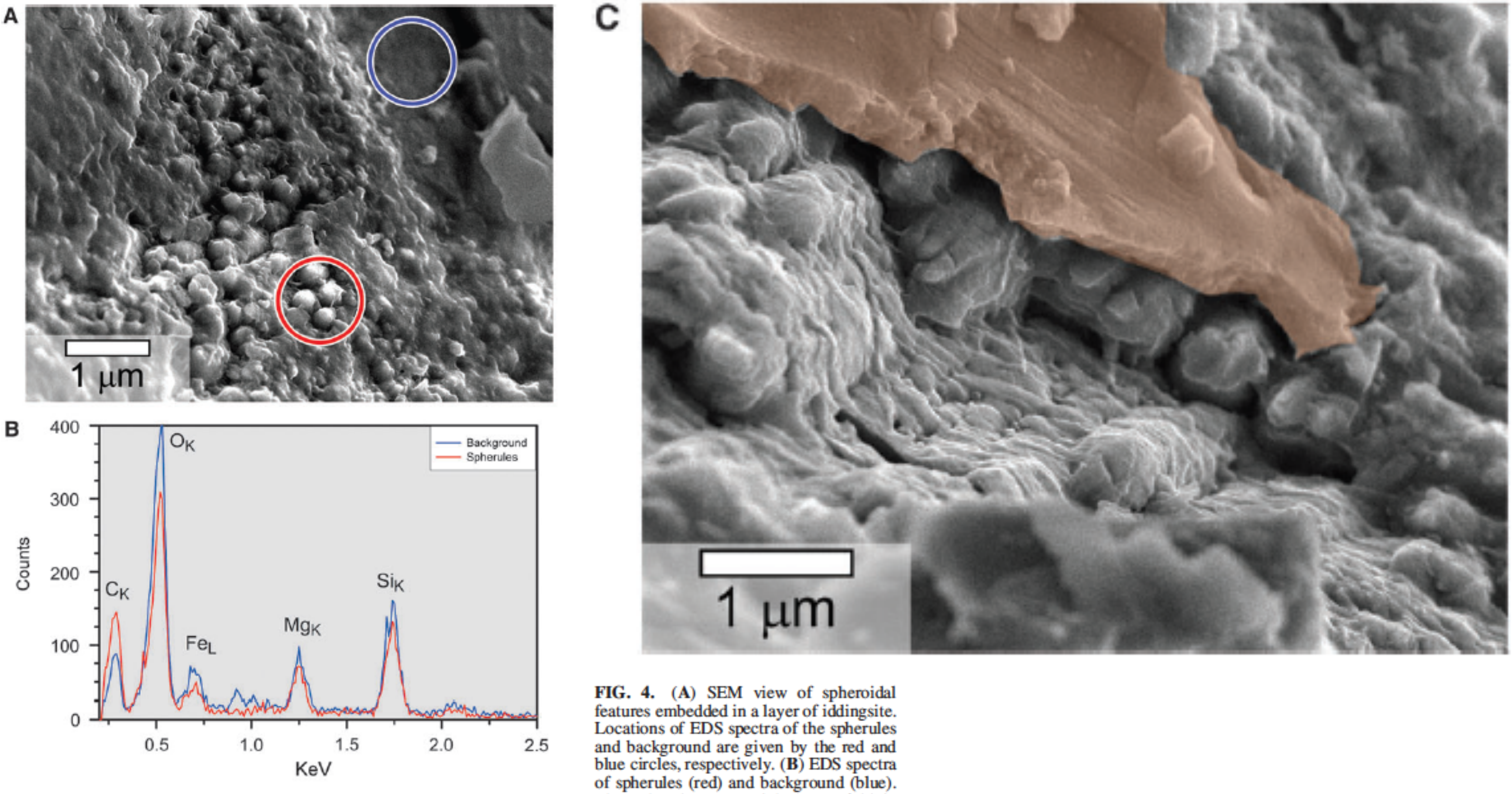
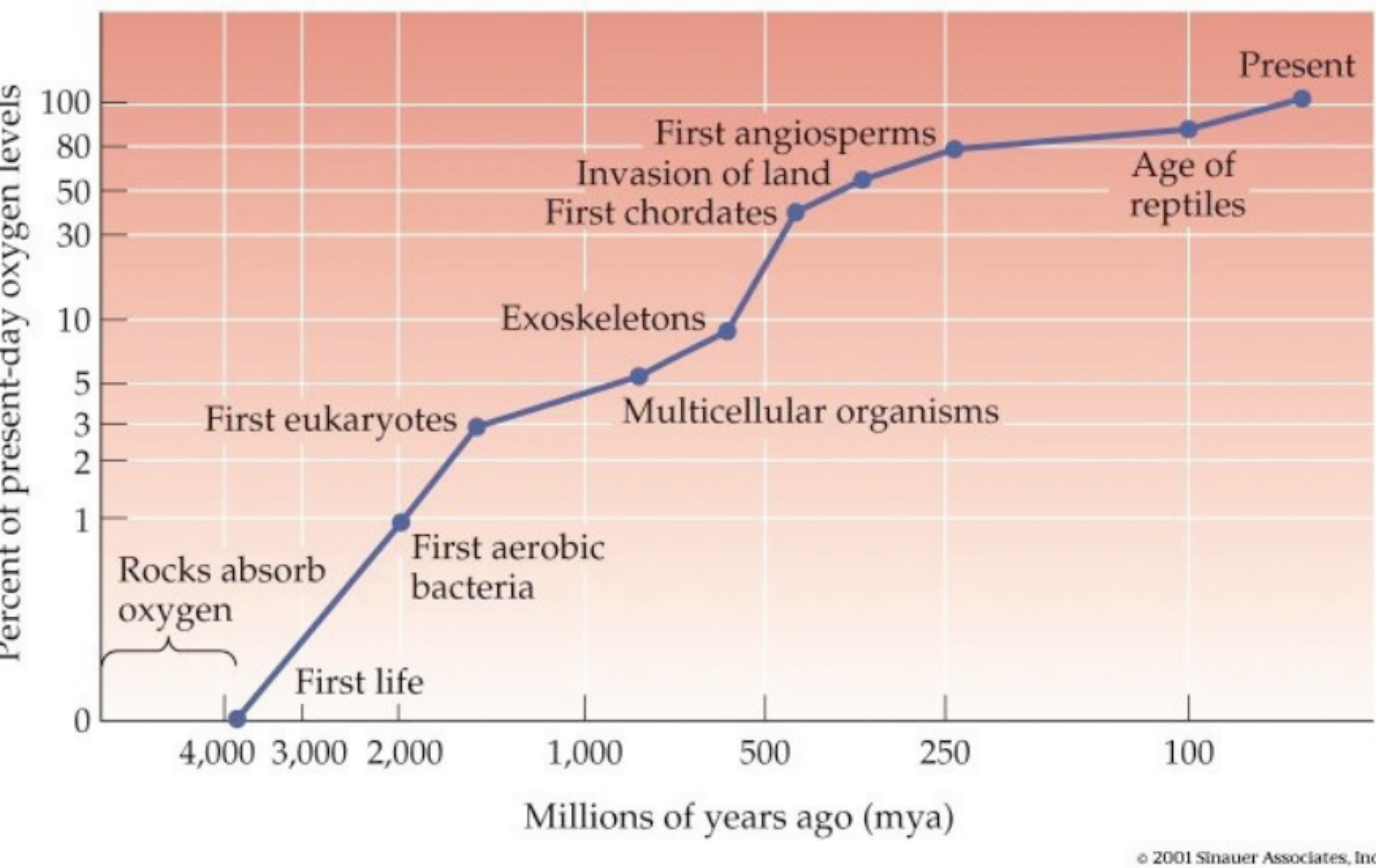


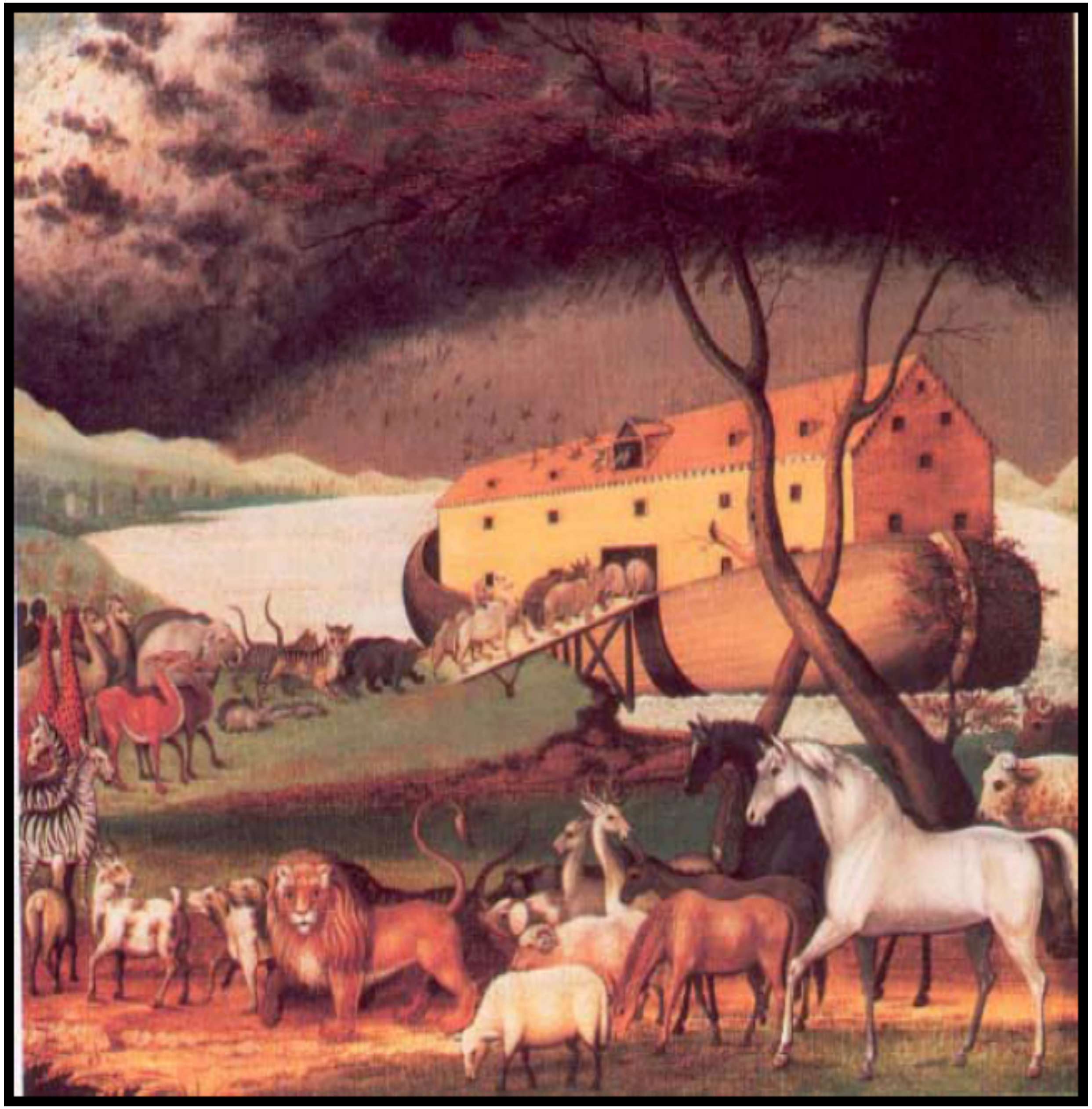
FIG. 4. **(A)** SEM view of spheroidal features embedded in a layer of iddingsite. Locations of EDS spectra of the spherules and background are given by the red and blue circles, respectively. **(B)** EDS spectra of spherules (red) and background (blue). The spherules are enriched ~2 fold in carbon compared to the background. **(C)** SEM view of spherulitic features encased in both an upper (false-colored orange) and lower layer of iddingsite.

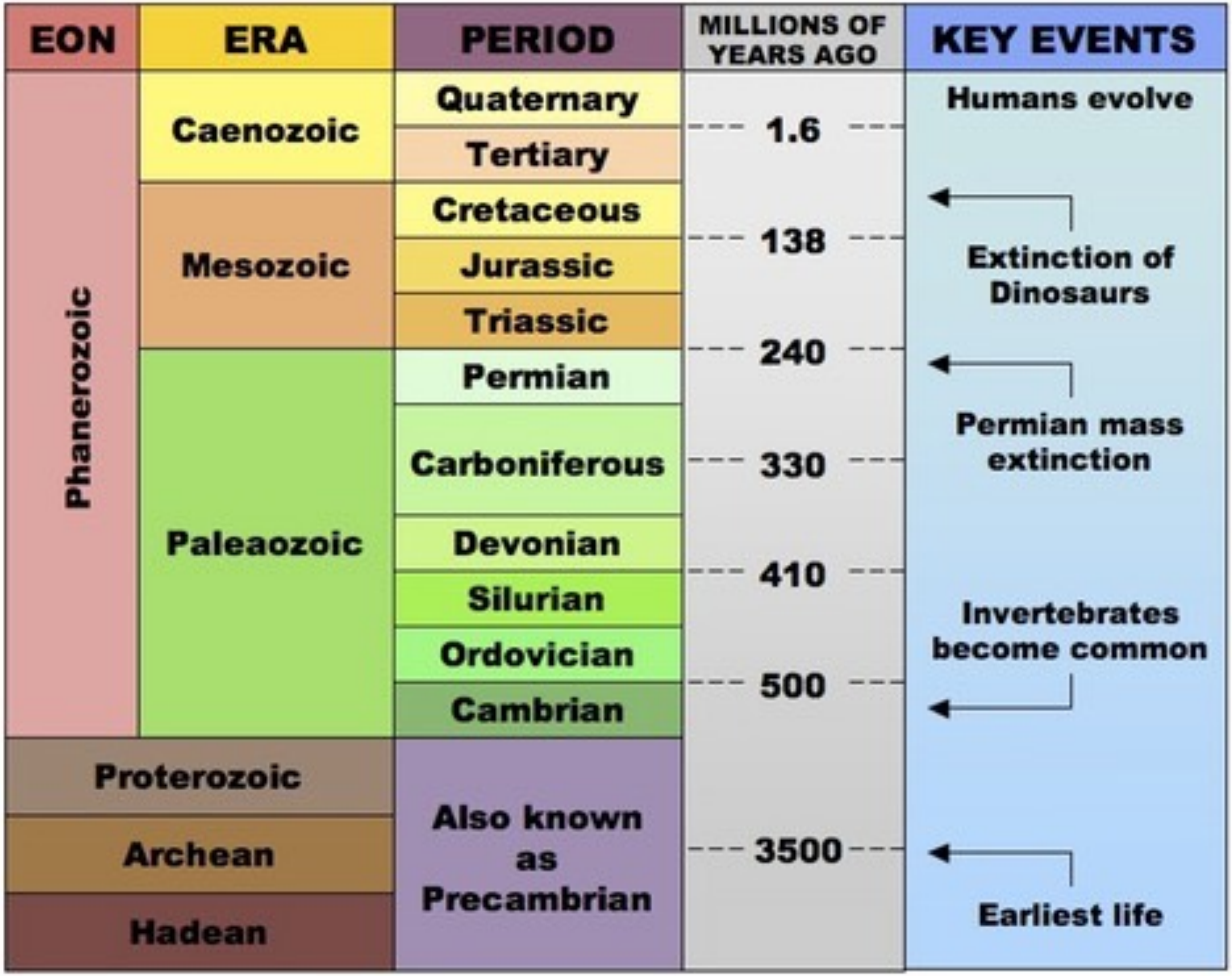

Percent of present-day oxygen levels
100
80
50
30
10
5
3
2
1
0
Present
First angiosperms
Invasion of land
First chordates
Age of reptiles
Exoskeletons
Multicellular organisms
First eukaryotes
First aerobic bacteria
Rocks absorb oxygen
First life
4,000
3,000
2,000
1,000
500
250
100
Millions of years ago (mya)

Terra “Bola de Neve”

- ☑ 2,4–2,2 bilhões de anos
  - ✓consequência: células eucarióticas
- ☑ 0,73-0,6 bilhões de anos
  - ✓conseqüência: explosão do Cambriano
- ☑ Cruciais para a evolução ou fator de aceleração ?
- ☑ Por que após a explosão do Cambriano não ocorreram inovações evolutivas da mesma magnitude?
  - ✓Restrições ecológicas
  - ✓Restrições genômicas

As grandes extinções





EON	ERA	PERIOD	MILLIONS OF YEARS AGO	KEY EVENTS
Phanerozoic	Caenozoic	Quaternary		Humans evolve
		Tertiary	1.6	
	Mesozoic	Cretaceous		Extinction of Dinosaurs
		Jurassic	138	
		Triassic		
	Paleaozoic	Permian	240	Permian mass extinction
		Carboniferous	330	
		Devonian		
		Silurian	410	
		Ordovician		
		Cambrian	500	Invertebrates become common
Proterozoic		Also known as Precambrian		
Archean			3500	Earliest life
Hadean				

As 5 grandes extinções em massa

Event	Estimated Epoch	Proposed causes	Estimated devastation
Ordovician	ended ~ 443 Myr ago; within 3.3 to 1.9 Myr	Onset of alternating glacial and interglacial episodes. Sequestration of CO2.	57% of genera, 86% of species.
Devonian	ended ~359 Myr ago; within 29 to 2 Myr	Global cooling/warming, drawdown of global CO2. Evidence for widespread deep-water. Impact???	35% of genera, 75% of species
Permian	ended ~251 Myr ago; within 2.8 Myr to 160 Kyr	Siberian volcanism. Global warming. Spread of deep marine anoxic waters. Impact???	**56% of genera, 96% of species**
Triassic	ended ~200 Myr ago; within 8.3 Myr to 600 Kyr	elevated atmospheric CO2 levels, increasing global temperatures, calcification crisis in the world ocean	47% of genera, 80% of species
Cretaceous	ended ~65 Myr ago; within 2.5 Myr to less than a year	impact in the Yucatán led to a global cataclysm and caused rapid cooling. CO2 spike just before extinction, drop during extinction	40% of genera, 76% of species

Carlos Alexandre Wuensche (2019)

As 5 grandes extinções em massa

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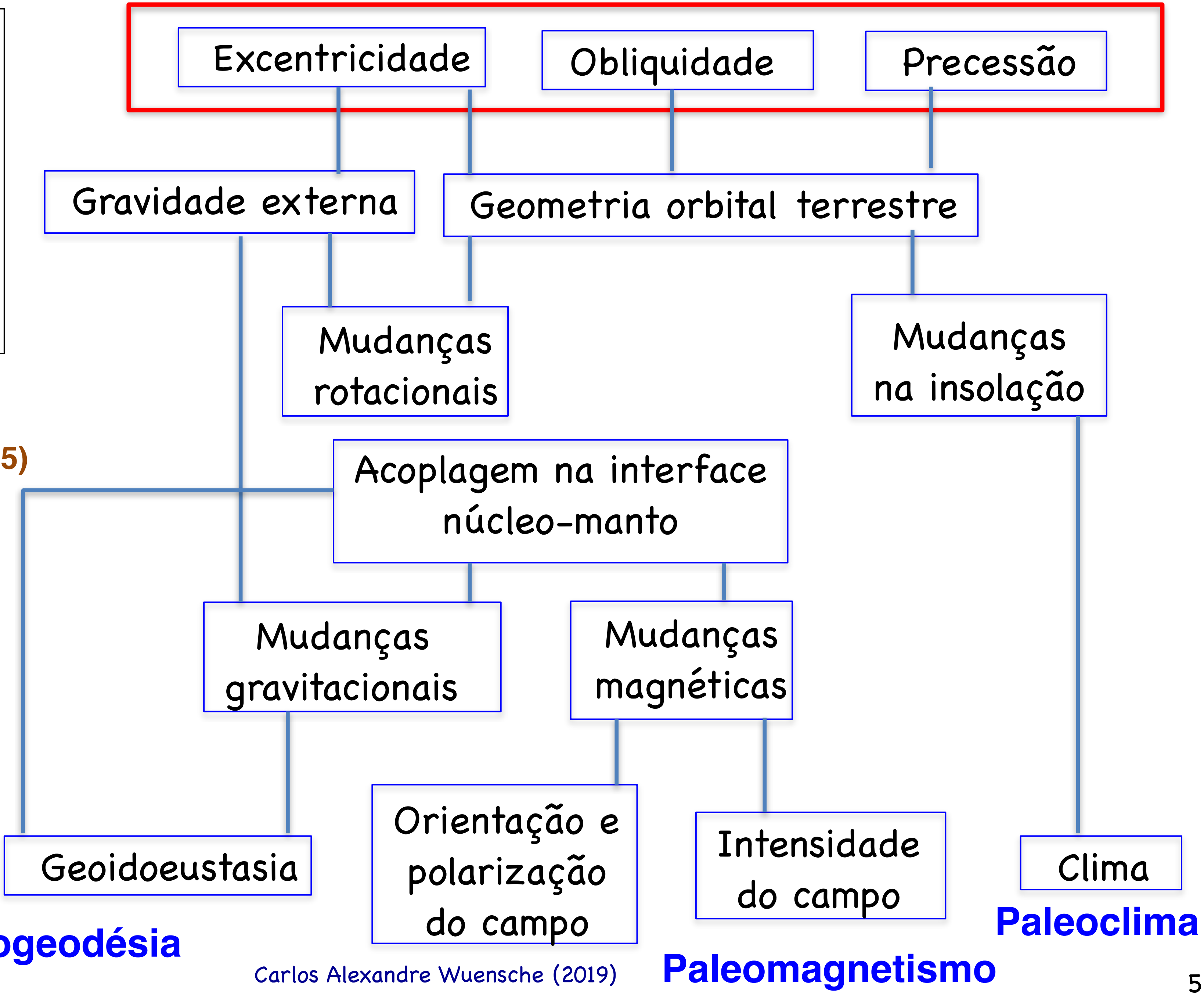
Has the Earth’s sixth mass extinction already arrived?

Anthony D. Barnosky et al. *Nature* **471**, 51–57 (03 March 2011)

Variáveis de Milankovitch

Modelo de previsão climática baseado em três variáveis de caráter astronômico

Fonte: Adaptada de Suguio & Suzuki (2015)



Excentricidade

Obliquidade

Precessão

Gravidade externa

Geometria orbital terrestre

Mudanças rotacionais

Mudanças na insolação

Acoplagem na interface núcleo-manto

Mudanças gravitacionais

Mudanças magnéticas

Geoidoeustasia

Orientação e polarização do campo

Intensidade do campo

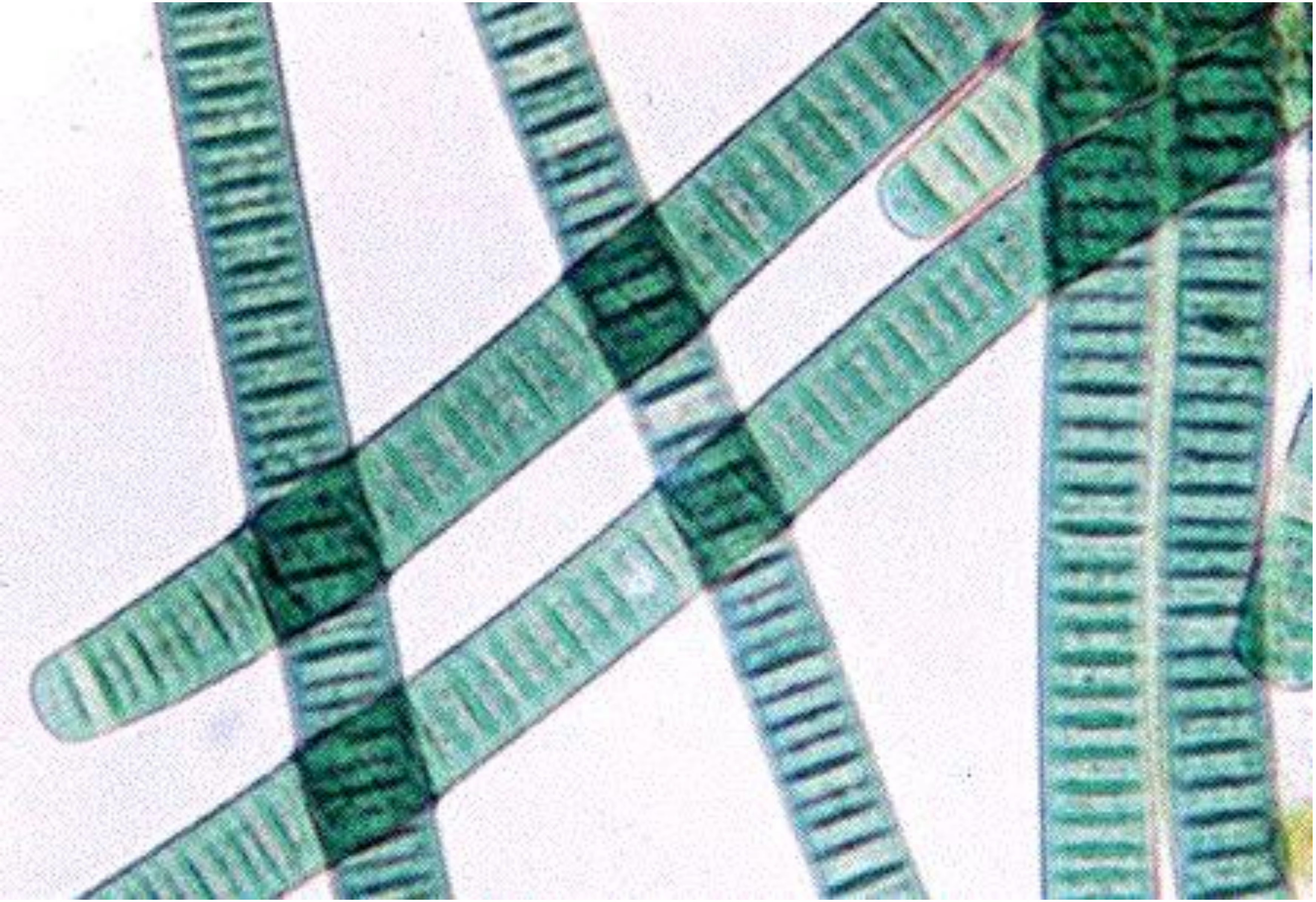
Clima

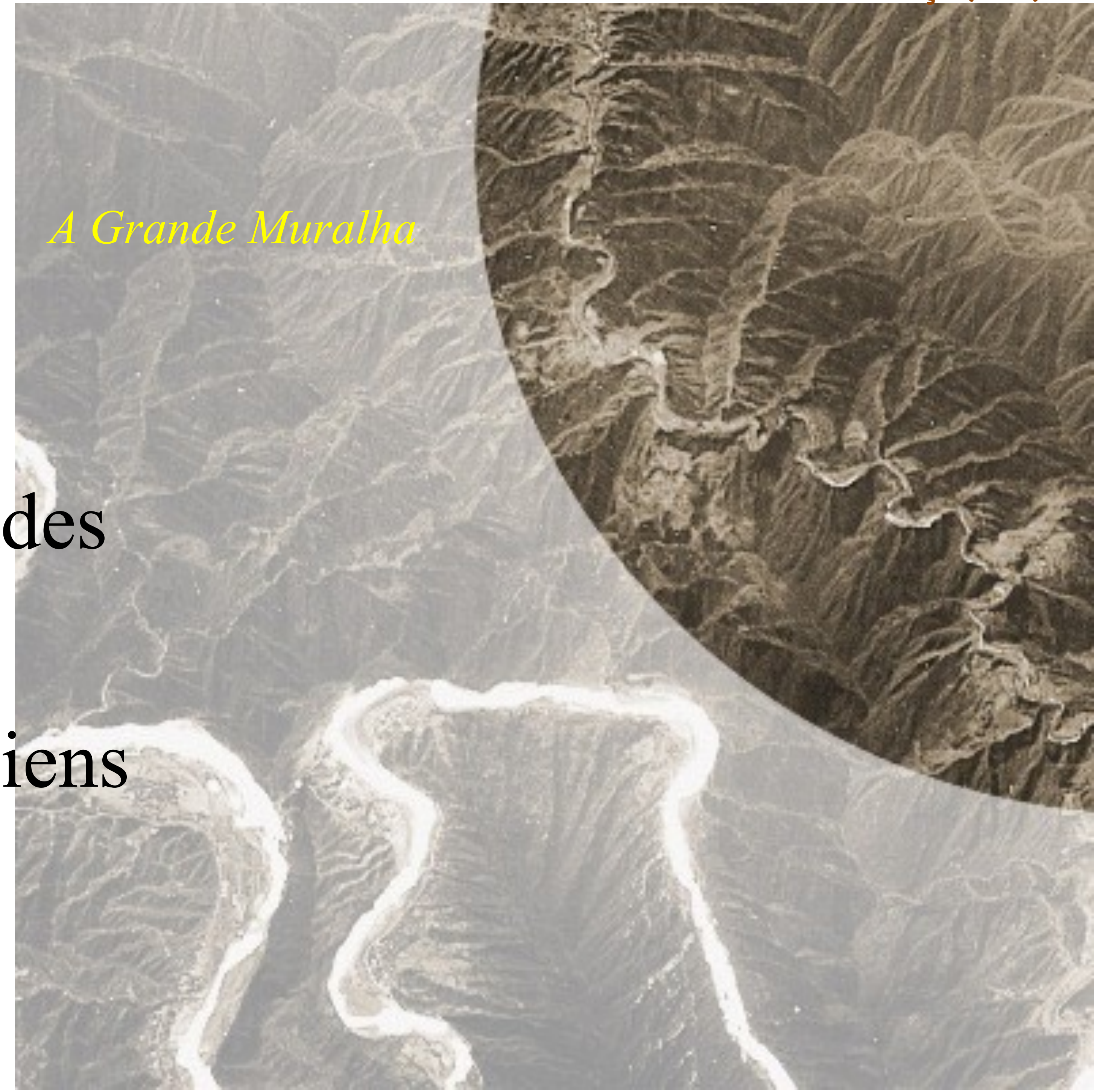
Paleogeodésia

Paleomagnetismo

Paleoclima

Os Dois Grandes Atores: I- Cianobactérias

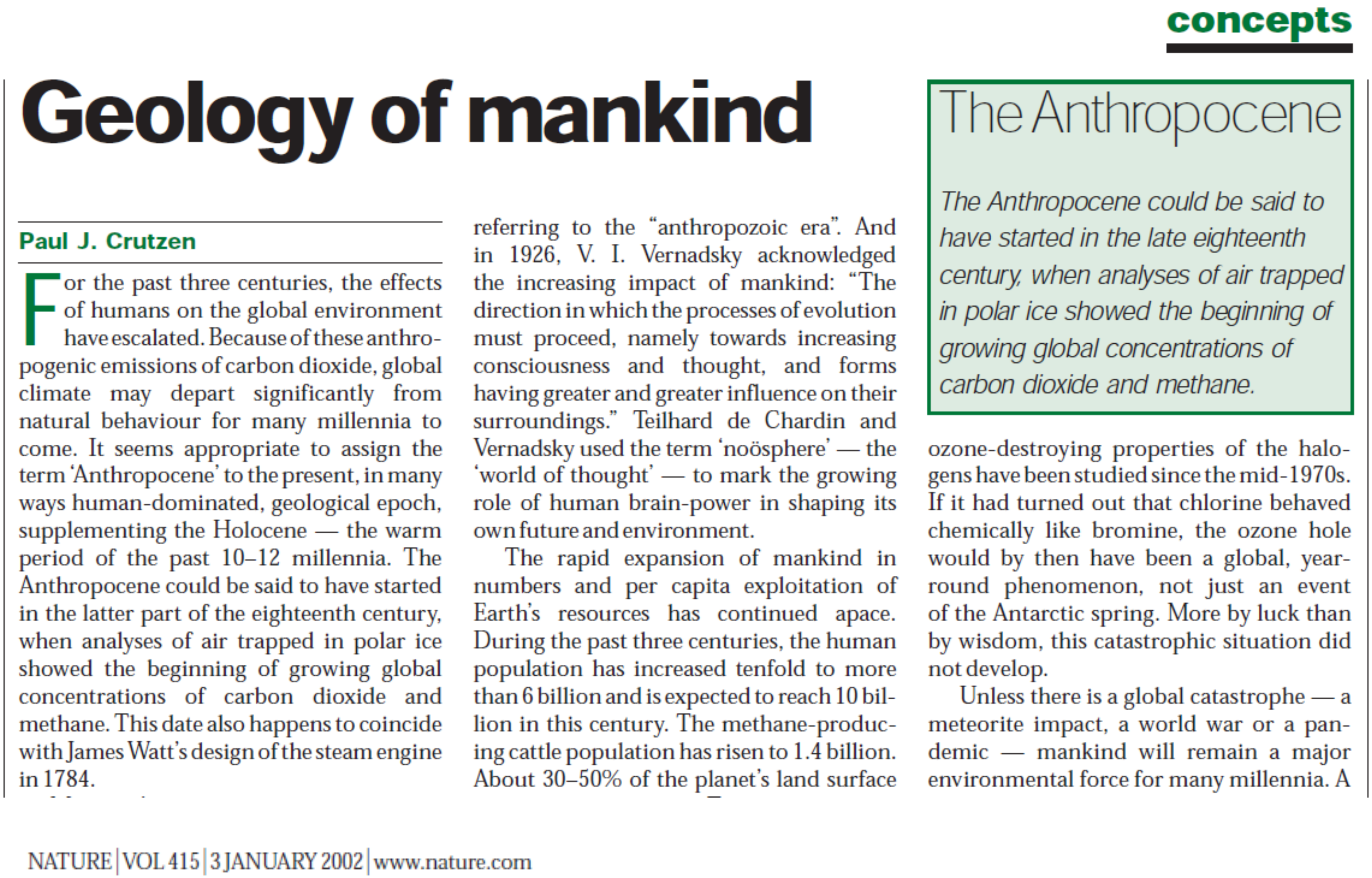




Os Dois Grandes Atores

II- Homo Sapiens

Slide: Amancio Friaça (2011)



concepts

Geology of mankind

Paul J. Crutzen

For the past three centuries, the effects of humans on the global environment have escalated. Because of these anthropogenic emissions of carbon dioxide, global climate may depart significantly from natural behaviour for many millennia to come. It seems appropriate to assign the term 'Anthropocene' to the present, in many ways human-dominated, geological epoch, supplementing the Holocene — the warm period of the past 10–12 millennia. The Anthropocene could be said to have started in the latter part of the eighteenth century, when analyses of air trapped in polar ice showed the beginning of growing global concentrations of carbon dioxide and methane. This date also happens to coincide with James Watt's design of the steam engine in 1784.

referring to the "anthropozoic era". And in 1926, V. I. Vernadsky acknowledged the increasing impact of mankind: "The direction in which the processes of evolution must proceed, namely towards increasing consciousness and thought, and forms having greater and greater influence on their surroundings." Teilhard de Chardin and Vernadsky used the term 'noösphere' — the 'world of thought' — to mark the growing role of human brain-power in shaping its own future and environment.

The rapid expansion of mankind in numbers and per capita exploitation of Earth's resources has continued apace. During the past three centuries, the human population has increased tenfold to more than 6 billion and is expected to reach 10 billion in this century. The methane-producing cattle population has risen to 1.4 billion. About 30–50% of the planet's land surface

The Anthropocene

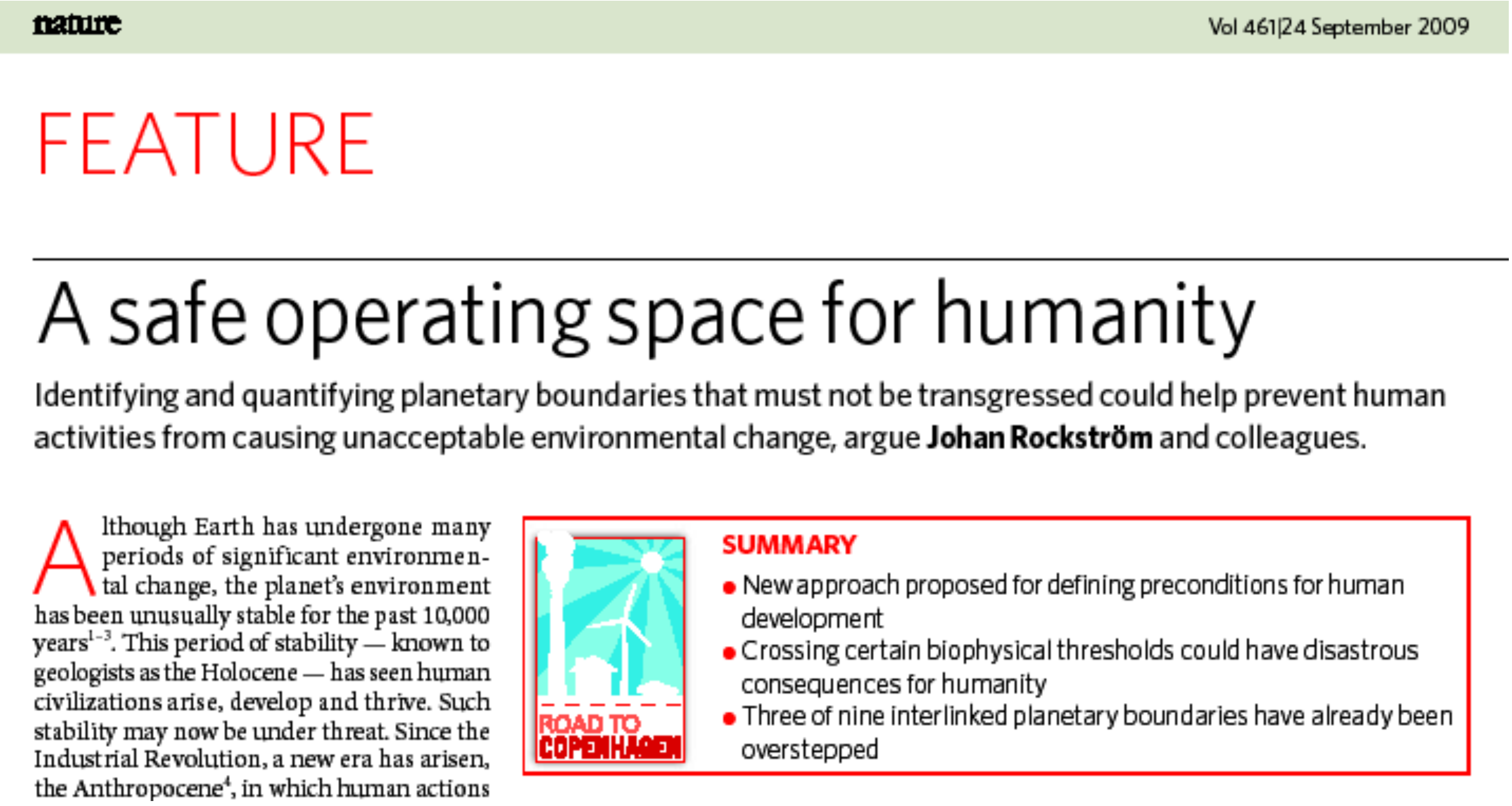
The Anthropocene could be said to have started in the late eighteenth century, when analyses of air trapped in polar ice showed the beginning of growing global concentrations of carbon dioxide and methane.

ozone-destroying properties of the halogens have been studied since the mid-1970s. If it had turned out that chlorine behaved chemically like bromine, the ozone hole would by then have been a global, year-round phenomenon, not just an event of the Antarctic spring. More by luck than by wisdom, this catastrophic situation did not develop.

Unless there is a global catastrophe — a meteorite impact, a world war or a pandemic — mankind will remain a major environmental force for many millennia. A

NATURE | VOL 415 | 3 JANUARY 2002 | www.nature.com

Slide: Amancio Friaça (2011)



nature Vol 461|24 September 2009

FEATURE

A safe operating space for humanity

Identifying and quantifying planetary boundaries that must not be transgressed could help prevent human activities from causing unacceptable environmental change, argue **Johan Rockström** and colleagues.

Although Earth has undergone many periods of significant environmental change, the planet's environment has been unusually stable for the past 10,000 years[1–3]. This period of stability — known to geologists as the Holocene — has seen human civilizations arise, develop and thrive. Such stability may now be under threat. Since the Industrial Revolution, a new era has arisen, the Anthropocene[4], in which human actions

SUMMARY

- New approach proposed for defining preconditions for human development
- Crossing certain biophysical thresholds could have disastrous consequences for humanity
- Three of nine interlinked planetary boundaries have already been overstepped

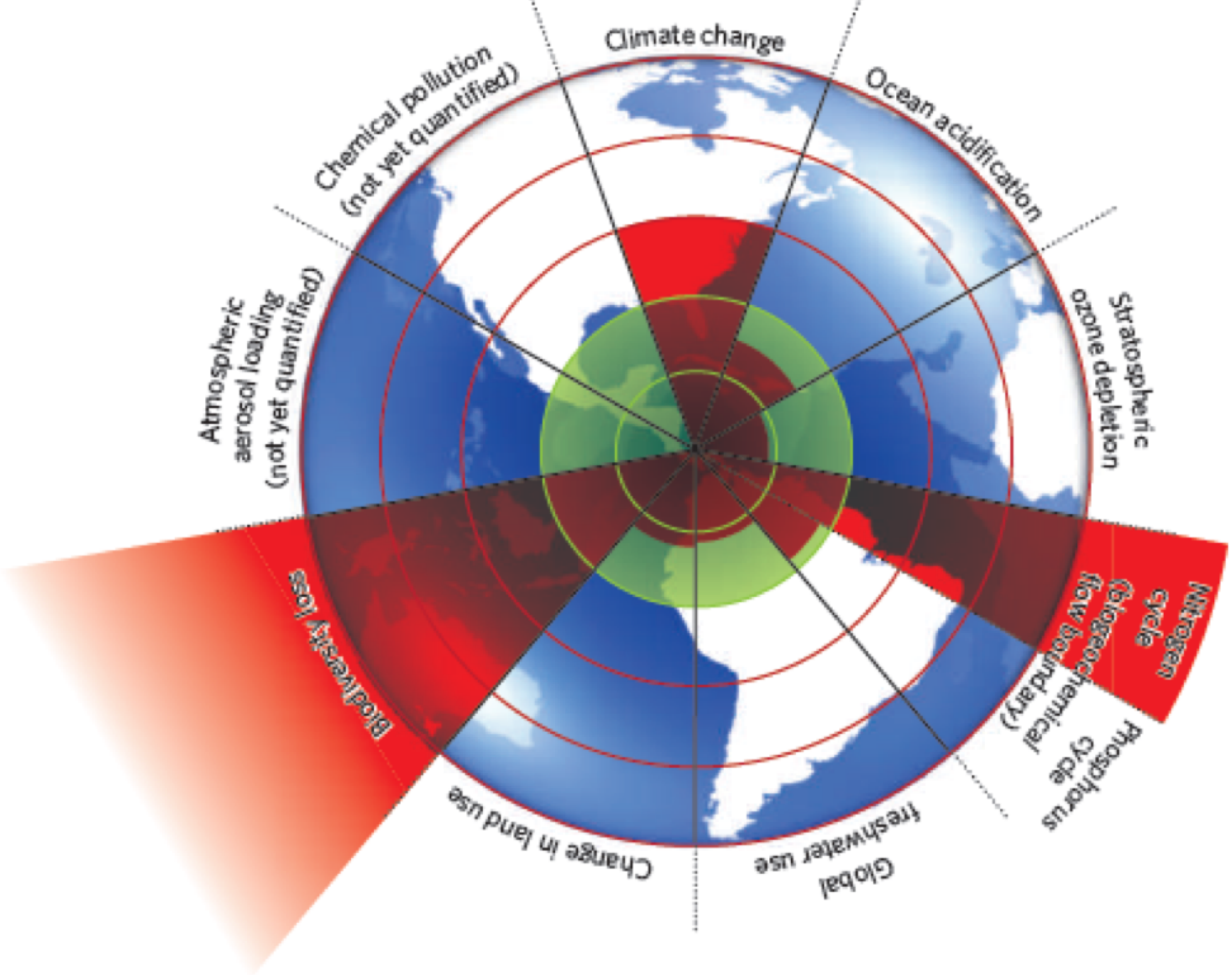
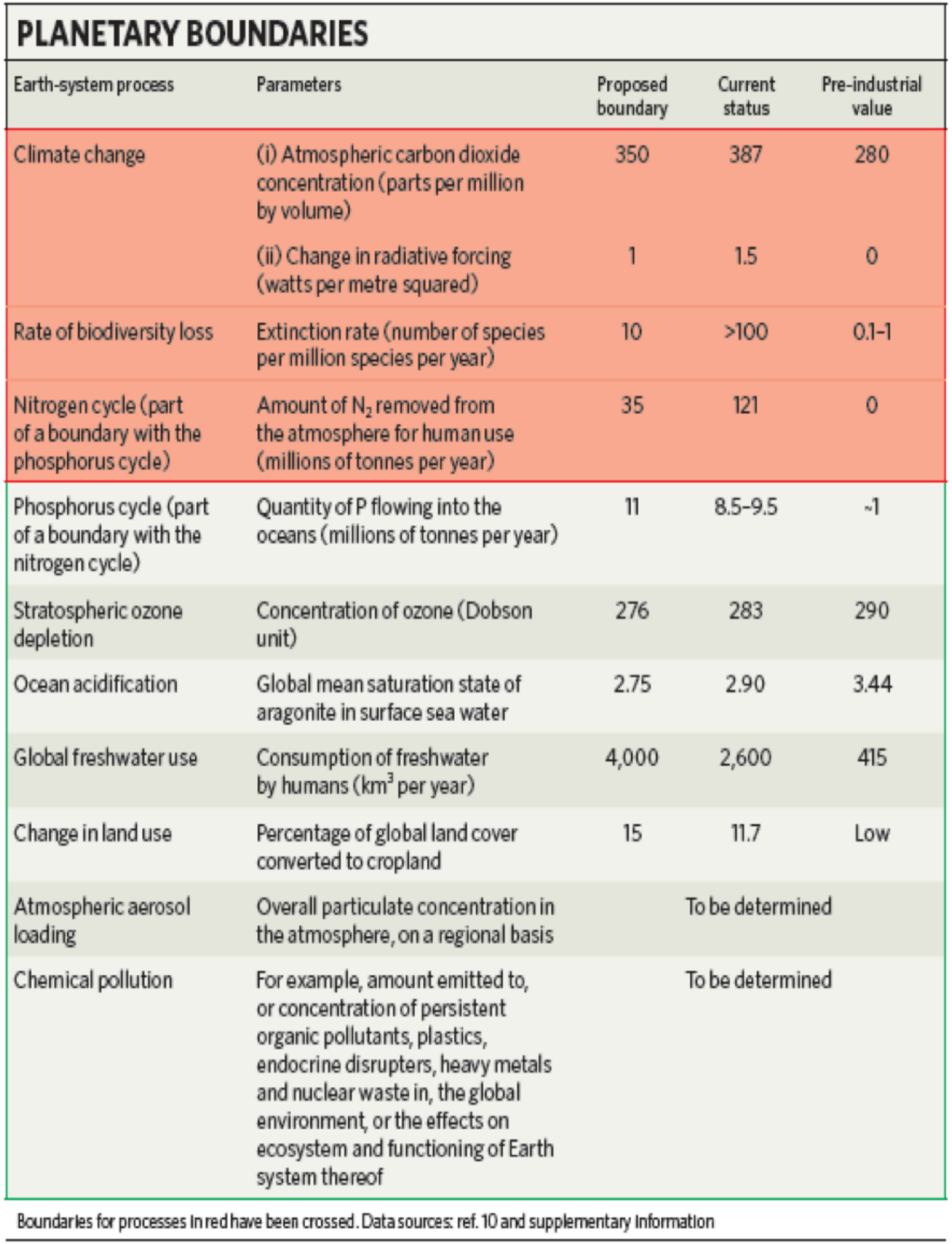


Figure 1 | Beyond the boundary. The inner green shading represents the proposed safe operating space for nine planetary systems. The red wedges represent an estimate of the current position for each variable. The boundaries in three systems (rate of biodiversity loss, climate change and human interference with the nitrogen cycle), have already been exceeded.

Slide: Amancio Friaça (2011)

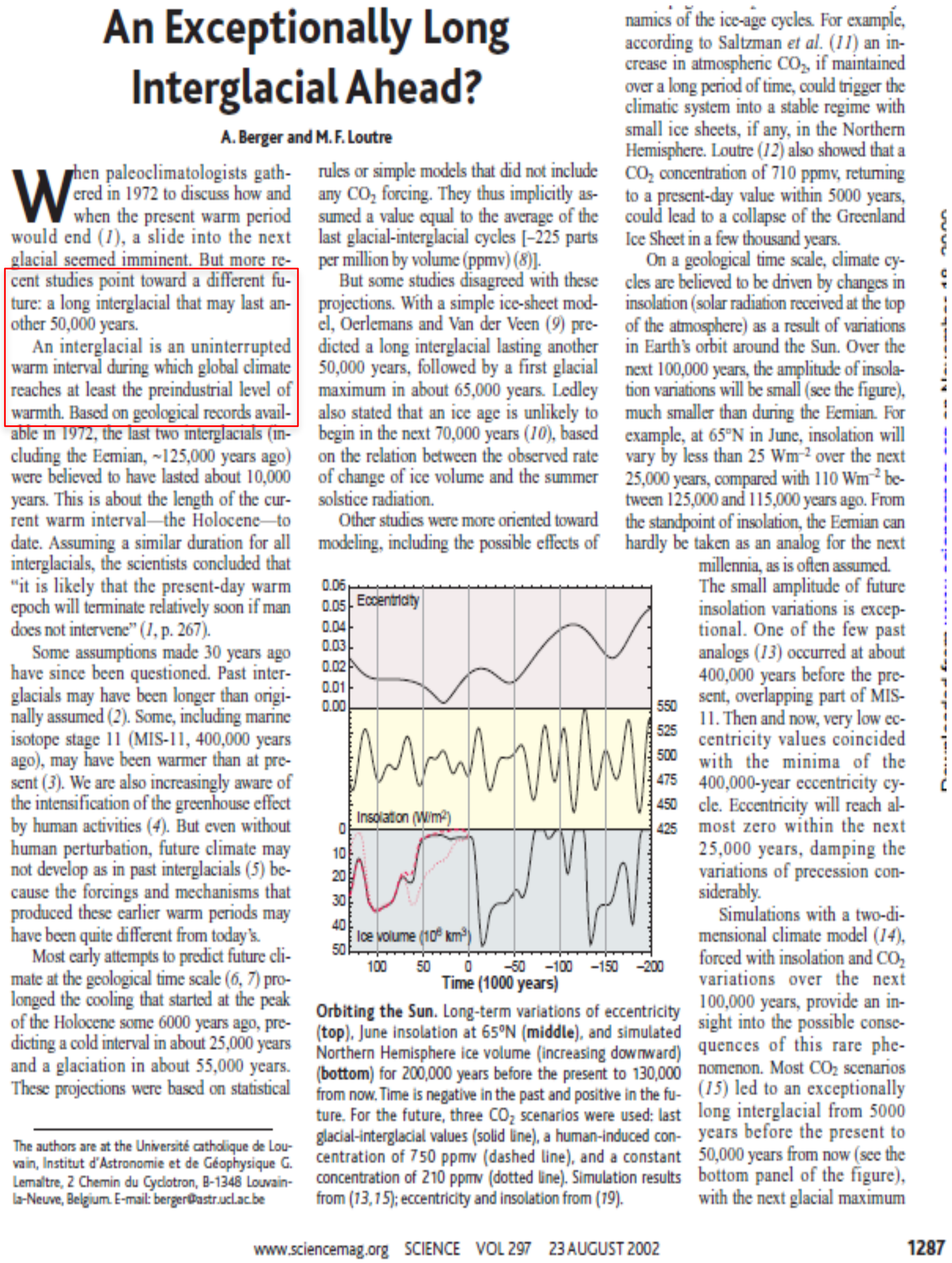


PLANETARY BOUNDARIES

Earth-system process	Parameters	Proposed boundary	Current status	Pre-industrial value
Climate change	(i) Atmospheric carbon dioxide concentration (parts per million by volume)	350	387	280
	(ii) Change in radiative forcing (watts per metre squared)	1	1.5	0
Rate of biodiversity loss	Extinction rate (number of species per million species per year)	10	>100	0.1–1
Nitrogen cycle (part of a boundary with the phosphorus cycle)	Amount of N_2 removed from the atmosphere for human use (millions of tonnes per year)	35	121	0
Phosphorus cycle (part of a boundary with the nitrogen cycle)	Quantity of P flowing into the oceans (millions of tonnes per year)	11	8.5–9.5	~1
Stratospheric ozone depletion	Concentration of ozone (Dobson unit)	276	283	290
Ocean acidification	Global mean saturation state of aragonite in surface sea water	2.75	2.90	3.44
Global freshwater use	Consumption of freshwater by humans (km^3 per year)	4,000	2,600	415
Change in land use	Percentage of global land cover converted to cropland	15	11.7	Low
Atmospheric aerosol loading	Overall particulate concentration in the atmosphere, on a regional basis	To be determined		
Chemical pollution	For example, amount emitted to, or concentration of persistent organic pollutants, plastics, endocrine disrupters, heavy metals and nuclear waste in, the global environment, or the effects on ecosystem and functioning of Earth system thereof	To be determined		

Boundaries for processes in red have been crossed. Data sources: ref. 10 and supplementary information

Slide: Amancio Friaça (2011)



An Exceptionally Long Interglacial Ahead?

A. Berger and M. F. Loutre

When paleoclimatologists gathered in 1972 to discuss how and when the present warm period would end (*1*), a slide into the next glacial seemed imminent. But more recent studies point toward a different future: a long interglacial that may last another 50,000 years.

An interglacial is an uninterrupted warm interval during which global climate reaches at least the preindustrial level of warmth. Based on geological records available in 1972, the last two interglacials (including the Eemian, ~125,000 years ago) were believed to have lasted about 10,000 years. This is about the length of the current warm interval—the Holocene—to date. Assuming a similar duration for all interglacials, the scientists concluded that "it is likely that the present-day warm epoch will terminate relatively soon if man does not intervene" (*1*, p. 267).

Some assumptions made 30 years ago have since been questioned. Past interglacials may have been longer than originally assumed (*2*). Some, including marine isotope stage 11 (MIS-11, 400,000 years ago), may have been warmer than at present (*3*). We are also increasingly aware of the intensification of the greenhouse effect by human activities (*4*). But even without human perturbation, future climate may not develop as in past interglacials (*5*) because the forcings and mechanisms that produced these earlier warm periods may have been quite different from today's.

Most early attempts to predict future climate at the geological time scale (*6*, *7*) prolonged the cooling that started at the peak of the Holocene some 6000 years ago, predicting a cold interval in about 25,000 years and a glaciation in about 55,000 years. These projections were based on statistical rules or simple models that did not include any CO_2 forcing. They thus implicitly assumed a value equal to the average of the last glacial-interglacial cycles [~225 parts per million by volume (ppmv) (*8*)].

But some studies disagreed with these projections. With a simple ice-sheet model, Oerlemans and Van der Veen (*9*) predicted a long interglacial lasting another 50,000 years, followed by a first glacial maximum in about 65,000 years. Ledley also stated that an ice age is unlikely to begin in the next 70,000 years (*10*), based on the relation between the observed rate of change of ice volume and the summer solstice radiation.

Other studies were more oriented toward modeling, including the possible effects of

namics of the ice-age cycles. For example, according to Saltzman *et al.* (*11*) an increase in atmospheric CO_2, if maintained over a long period of time, could trigger the climatic system into a stable regime with small ice sheets, if any, in the Northern Hemisphere. Loutre (*12*) also showed that a CO_2 concentration of 710 ppmv, returning to a present-day value within 5000 years, could lead to a collapse of the Greenland Ice Sheet in a few thousand years.

On a geological time scale, climate cycles are believed to be driven by changes in insolation (solar radiation received at the top of the atmosphere) as a result of variations in Earth's orbit around the Sun. Over the next 100,000 years, the amplitude of insolation variations will be small (see the figure), much smaller than during the Eemian. For example, at 65°N in June, insolation will vary by less than 25 Wm^{-2} over the next 25,000 years, compared with 110 Wm^{-2} between 125,000 and 115,000 years ago. From the standpoint of insolation, the Eemian can hardly be taken as an analog for the next millennia, as is often assumed.

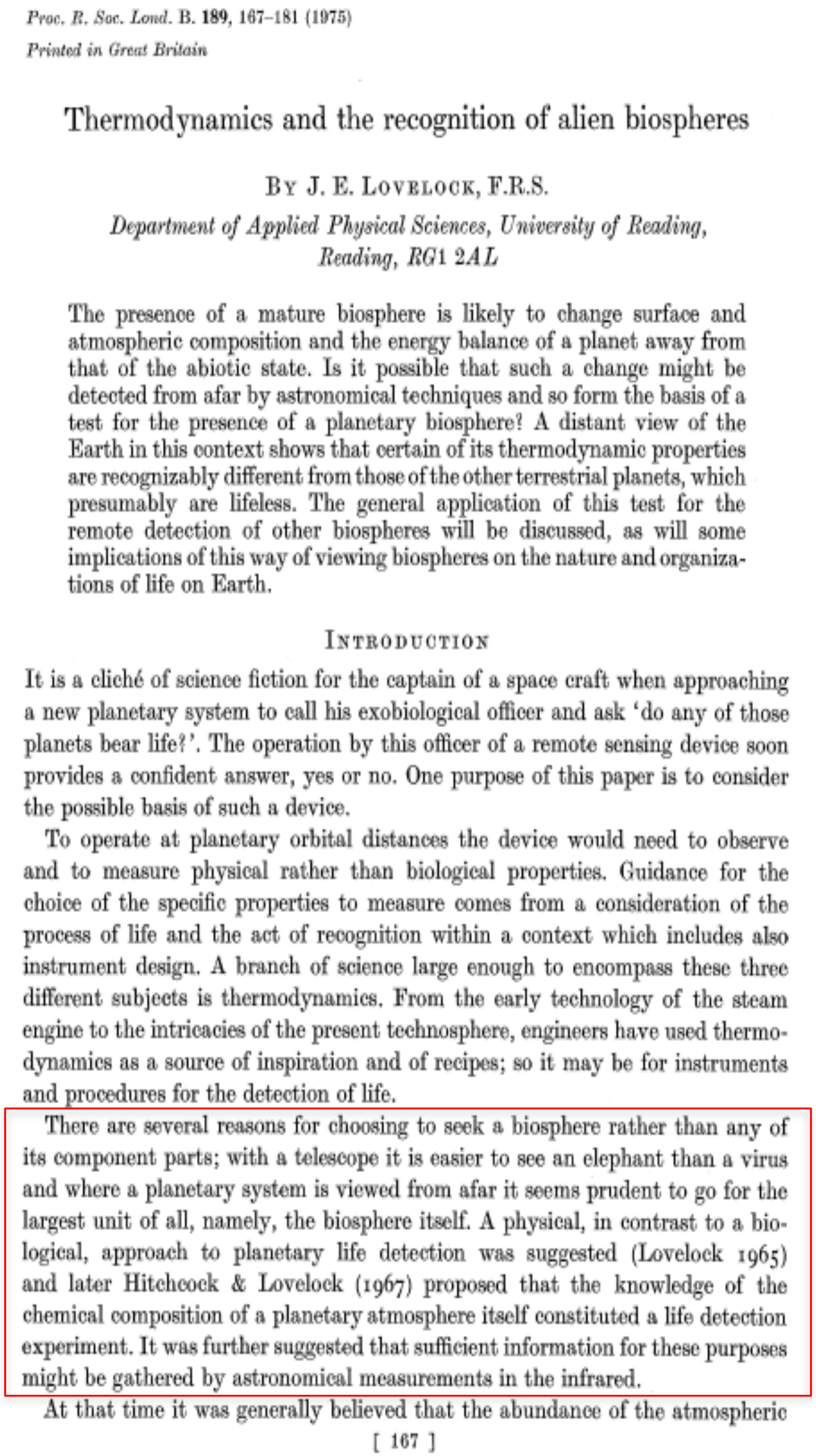
The small amplitude of future insolation variations is exceptional. One of the few past analogs (*13*) occurred at about 400,000 years before the present, overlapping part of MIS-11. Then and now, very low eccentricity values coincided with the minima of the 400,000-year eccentricity cycle. Eccentricity will reach almost zero within the next 25,000 years, damping the variations of precession considerably.

Simulations with a two-dimensional climate model (*14*), forced with insolation and CO_2 variations over the next 100,000 years, provide an insight into the possible consequences of this rare phenomenon. Most CO_2 scenarios (*15*) led to an exceptionally long interglacial from 5000 years before the present to 50,000 years from now (see the bottom panel of the figure), with the next glacial maximum

Orbiting the Sun. Long-term variations of eccentricity (**top**), June insolation at 65°N (**middle**), and simulated Northern Hemisphere ice volume (increasing downward) (**bottom**) for 200,000 years before the present to 130,000 from now. Time is negative in the past and positive in the future. For the future, three CO_2 scenarios were used: last glacial-interglacial values (solid line), a human-induced concentration of 750 ppmv (dashed line), and a constant concentration of 210 ppmv (dotted line). Simulation results from (*13*, *15*); eccentricity and insolation from (*19*).

The authors are at the Université catholique de Louvain, Institut d'Astronomie et de Géophysique G. Lemaître, 2 Chemin du Cyclotron, B-1348 Louvain-la-Neuve, Belgium. E-mail: berger@astr.ucl.ac.be

Slide: Amancio Friaça (2011)



Proc. R. Soc. Lond. B. **189**, 167–181 (1975)
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Thermodynamics and the recognition of alien biospheres

By J. E. Lovelock, F.R.S.
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Reading, RG1 2AL

The presence of a mature biosphere is likely to change surface and atmospheric composition and the energy balance of a planet away from that of the abiotic state. Is it possible that such a change might be detected from afar by astronomical techniques and so form the basis of a test for the presence of a planetary biosphere? A distant view of the Earth in this context shows that certain of its thermodynamic properties are recognizably different from those of the other terrestrial planets, which presumably are lifeless. The general application of this test for the remote detection of other biospheres will be discussed, as will some implications of this way of viewing biospheres on the nature and organizations of life on Earth.

INTRODUCTION

It is a cliché of science fiction for the captain of a space craft when approaching a new planetary system to call his exobiological officer and ask 'do any of those planets bear life?'. The operation by this officer of a remote sensing device soon provides a confident answer, yes or no. One purpose of this paper is to consider the possible basis of such a device.

To operate at planetary orbital distances the device would need to observe and to measure physical rather than biological properties. Guidance for the choice of the specific properties to measure comes from a consideration of the process of life and the act of recognition within a context which includes also instrument design. A branch of science large enough to encompass these three different subjects is thermodynamics. From the early technology of the steam engine to the intricacies of the present technosphere, engineers have used thermodynamics as a source of inspiration and of recipes; so it may be for instruments and procedures for the detection of life.

There are several reasons for choosing to seek a biosphere rather than any of its component parts; with a telescope it is easier to see an elephant than a virus and where a planetary system is viewed from afar it seems prudent to go for the largest unit of all, namely, the biosphere itself. A physical, in contrast to a biological, approach to planetary life detection was suggested (Lovelock 1965) and later Hitchcock & Lovelock (1967) proposed that the knowledge of the chemical composition of a planetary atmosphere itself constituted a life detection experiment. It was further suggested that sufficient information for these purposes might be gathered by astronomical measurements in the infrared.

At that time it was generally believed that the abundance of the atmospheric

(2019)

Composition of the Atmosphere

Air is composed of a mixture of gases:

	Gas	concentration (%)	
	N_2	**78**	
	O_2	**21**	
	Ar	**0.9**	
	H_2O	**variable**	
greenhouse gases	**CO_2**	**0.037**	**370 ppm**
	CH_4		**1.7**
	N_2O		**0.3**
	O_3		**1.0 to 0.01** (stratosphere-surface)

The living Earth

James Lovelock

Imagine a science-based civilization far distant in the Galaxy that had built an interferometer of such resolving power that it could analyse the chemical composition of our atmosphere. Simply from this analysis, they could confidently conclude that Earth, alone among the planets of the Solar System, had a carbon-based life and an industrial civilization. They would have seen methane and oxygen coexisting in the upper atmosphere, and their chemists would have known that these gases are continually consumed and replaced. The odds of this happening by chance inorganic chemistry are very long indeed. Such persistent deep atmospheric disequilibrium reveals the low entropy characteristic of life. They would conclude that ours was a live planet — and the presence of CFCs in the atmosphere would suggest an industry unwise enough to have allowed their escape.

As part of NASA's planetary exploration team in 1965, thoughts such as these led me to propose atmospheric analysis for detecting life on Mars. I also wondered what could be keeping Earth's chemically unstable atmosphere constant and so appropriate for life, and what kept the climate tolerable despite a 30% increase in solar luminosity since the Earth formed. Together, these thoughts led me to the hypothesis that living organisms regulate the atmosphere in their own interest, and the novelist William Golding suggested Gaia as its name. Although the concept of a live Earth is ancient, Newton was the first scientist to compare the Earth to an animal or a vegetable. Hutton, Huxley and Vernadsky expressed similar views but, lacking quantitative evidence, these earlier ideas remained anecdotal. In 1925 Alfred Lotka conjectured that it would be easier to model the evolution of organisms and their material environment coupled as a single entity than either of them separately. Gaia had its origins in these earlier thoughts, from the evidence gathered by the biogeochemists Alfred Redfield and Evelyn Hutchinson and from the mind-wrenching top-down view provided by NASA.

Although welcomed by atmospheric scientists, Earth scientists were cautious. Biologists, especially Ford Doolittle and Richard Dawkins, argued strongly that global self-regulation could never have evolved, as the organism was the unit of selection, not the biosphere. In time I realized that they were right — but still I thought, something keeps the Earth habitable. In 1981 I composed a model of dark- and light-coloured plants that competed for growth on a planet in progressively increasing sunlight. My intention was not to make a blueprint for the Earth, but a model to show that Gaia is consistent with natural selection. This 'Daisyworld' regulated its temperature close to that fittest for plant growth and — unusually for an evolutionary model made from coupled differential equations — it was stable, insensitive to initial conditions and resistant to perturbation. Daisyworld is darwinian, but the evolution of the organisms and the evolution of temperature proceed as a single, coupled process. The model was much criticized, but so far has resisted falsification. It was easy to show that Daisyworld tolerates 'cheats' — daisies that grow but offer nothing towards self-regulation. Other critics claimed that daisies would adapt to changing temperature and therefore simply track temperature change, not regulate it. But the restraining function connecting growth with temperature is not negotiable; chemistry, not biology, sets its constants.

At this stage, the Gaia theory was missing plausible control mechanisms. The first discovered was a biological process that redressed the imbalance of the nutritious elements sulphur and iodine — these are abundant in the oceans, but deficient on the land surface. It was widely assumed that hydrogen sulphide and sea salt aerosol drifted from the ocean to the land. In 1971 I discovered that methyl iodide and dimethyl sulphide were ubiquitous in the Atlantic surface waters, and from my measurements Peter Liss calculated their fluxes in 1974. He argued that these biogenic gases were the main carriers of the natural elemental cycles of sulphur and iodine.

Then in 1982, the geochemists James Walker, P. B. Hayes and Jim Kasting suggested that the weathering of calcium silicate rock could regulate carbon dioxide and climate. Greater warmth leads to more rainfall and a faster removal of carbon dioxide from the atmosphere by rock weathering, which provides a negative feedback on temperature. This plausible mechanism is by itself too small to account for the observed rate of weathering. Organisms on the rocks and in the soil bring it to life as a Gaian mechanism; their growth varies with temperature and their presence amplifies the rate of weathering.

In 1986, there was the awesome discovery by Robert Charlson, James Lovelock, Meinrat Andreae and Steven Warren of a connection between biogenic dimethyl sulphide gas — the product of ocean algae — its oxidation in the atmosphere to form cloud condensation nuclei, and the subsequent effect of the clouds formed on climate. We wondered whether this could be a Gaian regulatory mechanism through the feedback between climate change and algal growth.

By the end of the 1980s there was sufficient evidence, models and mechanisms, to justify a provisional Gaia theory. Briefly, it states that organisms and their material environment evolve as a single coupled system, from which emerges the sustained self-regulation of climate and chemistry at a habitable state for whatever is the current biota.

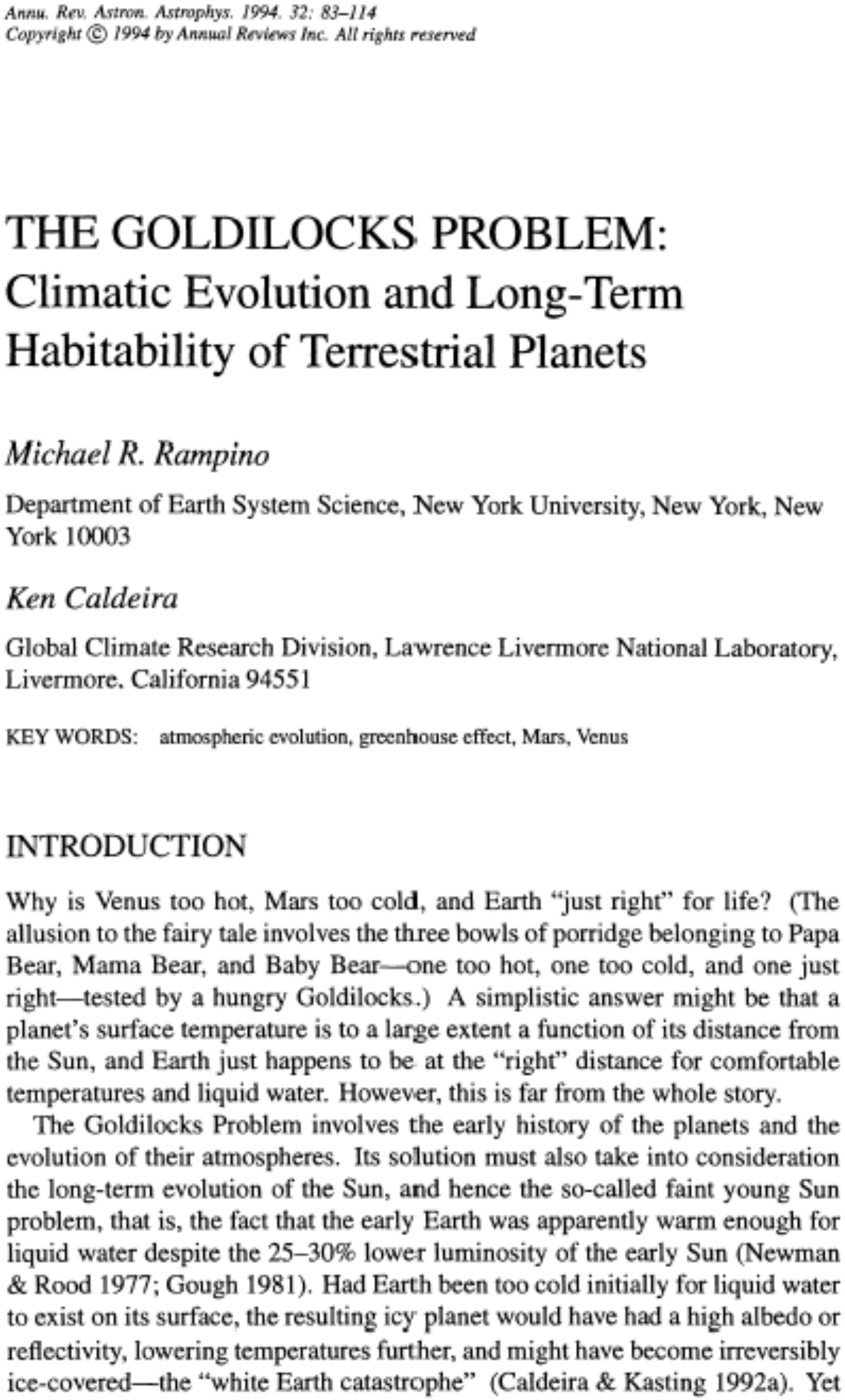
Like life, Gaia is an emergent phenomenon, comprehensible intuitively, but difficult or impossible to analyse by reduction — not surprisingly it is often misunderstood. A simple automatic mechanism, like a

Gaia

Organisms and their environment evolve as a single, self-regulating system

J. Lovelock. *Nature*, 426, 770-771 (2003)

Our planet in perspective: Gaia theory explains the constancy of our unstable atmosphere.



Annu. Rev. Astron. Astrophys. 1994. 32: 83–114

THE GOLDILOCKS PROBLEM:
Climatic Evolution and Long-Term Habitability of Terrestrial Planets

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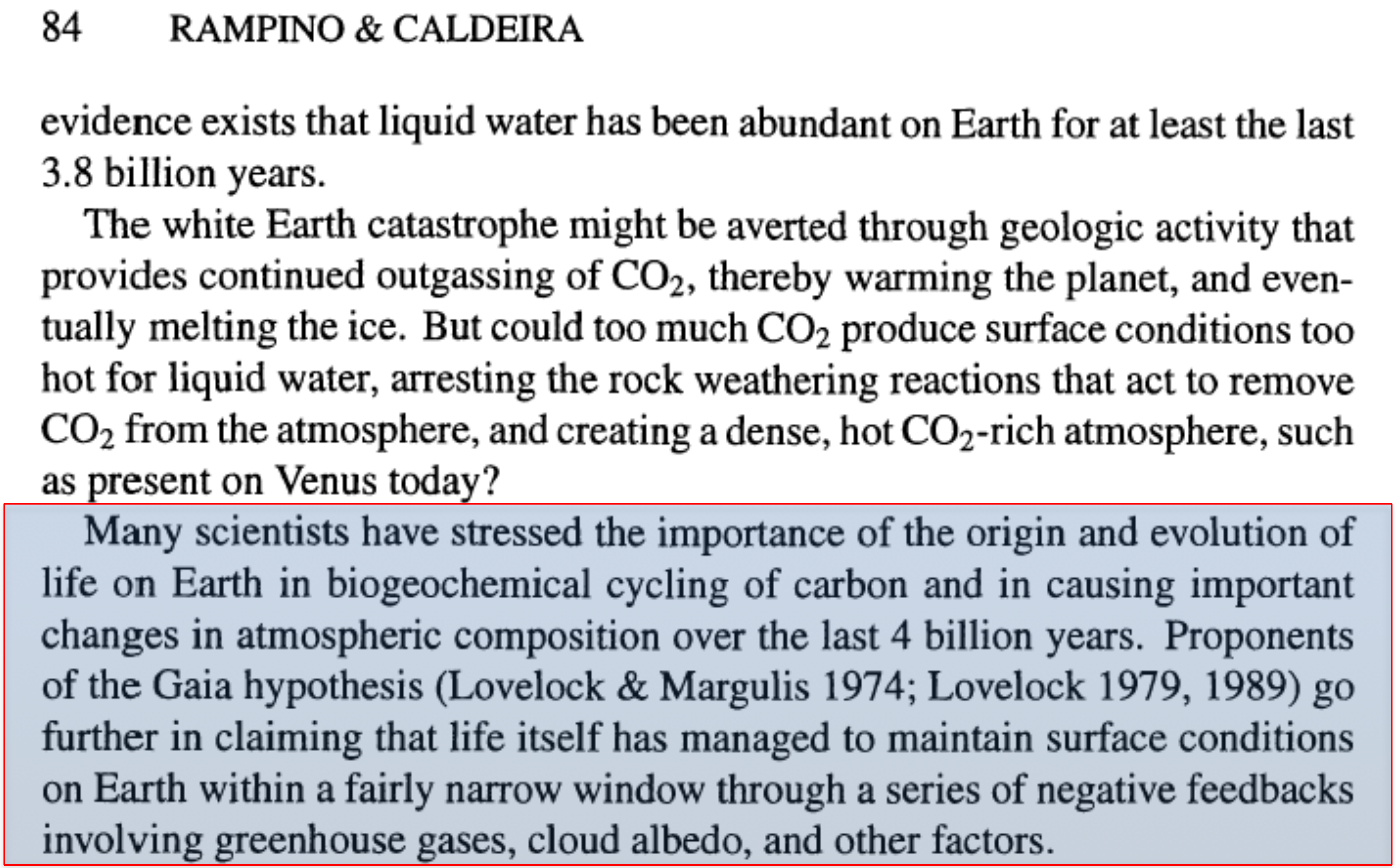
KEY WORDS: atmospheric evolution, greenhouse effect, Mars, Venus

INTRODUCTION

Why is Venus too hot, Mars too cold, and Earth "just right" for life? (The allusion to the fairy tale involves the three bowls of porridge belonging to Papa Bear, Mama Bear, and Baby Bear—one too hot, one too cold, and one just right—tested by a hungry Goldilocks.) A simplistic answer might be that a planet's surface temperature is to a large extent a function of its distance from the Sun, and Earth just happens to be at the "right" distance for comfortable temperatures and liquid water. However, this is far from the whole story.

The Goldilocks Problem involves the early history of the planets and the evolution of their atmospheres. Its solution must also take into consideration the long-term evolution of the Sun, and hence the so-called faint young Sun problem, that is, the fact that the early Earth was apparently warm enough for liquid water despite the 25–30% lower luminosity of the early Sun (Newman & Rood 1977; Gough 1981). Had Earth been too cold initially for liquid water to exist on its surface, the resulting icy planet would have had a high albedo or reflectivity, lowering temperatures further, and might have become irreversibly ice-covered—the "white Earth catastrophe" (Caldeira & Kasting 1992a). Yet

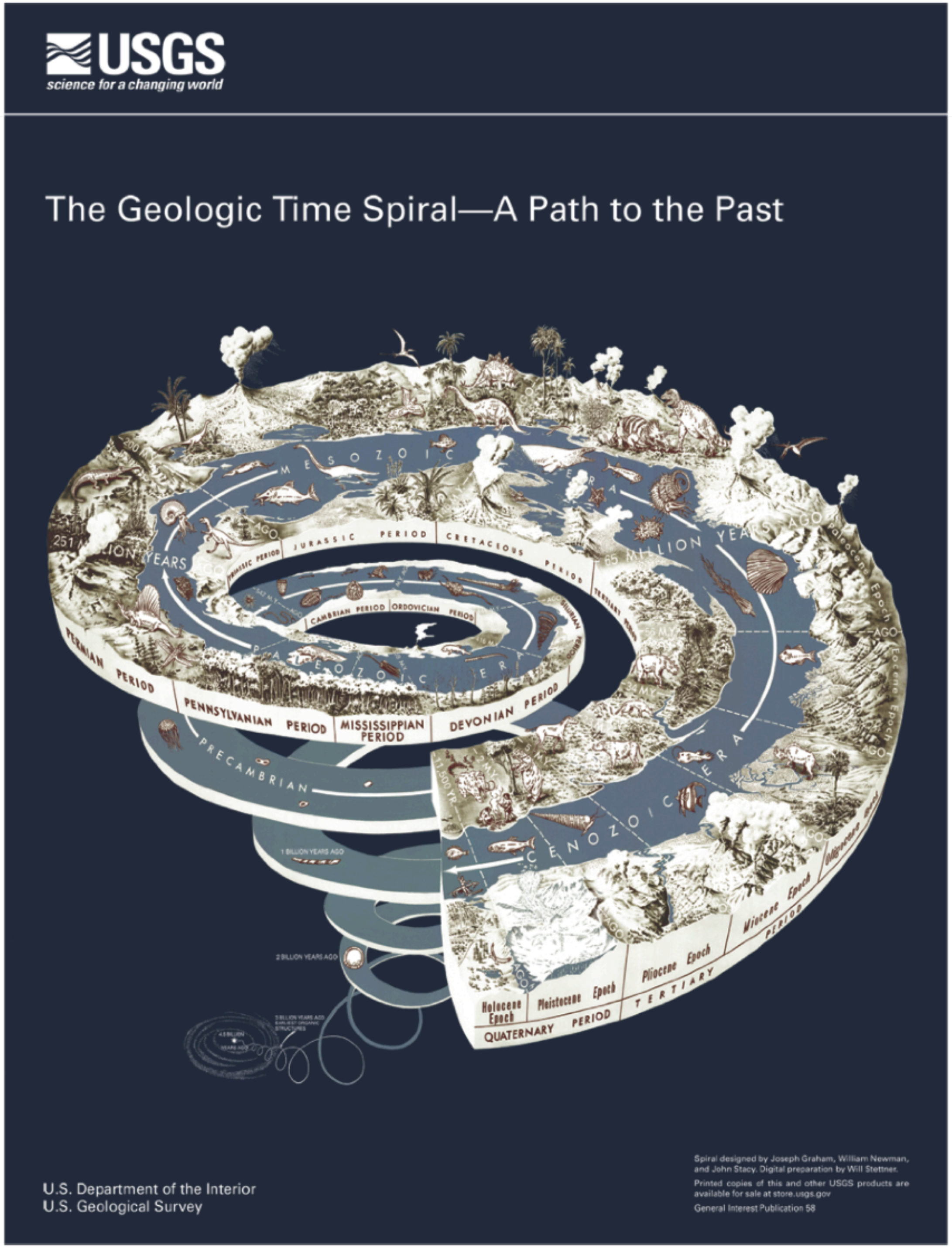


84 RAMPINO & CALDEIRA

evidence exists that liquid water has been abundant on Earth for at least the last 3.8 billion years.

The white Earth catastrophe might be averted through geologic activity that provides continued outgassing of CO_2, thereby warming the planet, and eventually melting the ice. But could too much CO_2 produce surface conditions too hot for liquid water, arresting the rock weathering reactions that act to remove CO_2 from the atmosphere, and creating a dense, hot CO_2-rich atmosphere, such as present on Venus today?

Many scientists have stressed the importance of the origin and evolution of life on Earth in biogeochemical cycling of carbon and in causing important changes in atmospheric composition over the last 4 billion years. Proponents of the Gaia hypothesis (Lovelock & Margulis 1974; Lovelock 1979, 1989) go further in claiming that life itself has managed to maintain surface conditions on Earth within a fairly narrow window through a series of negative feedbacks involving greenhouse gases, cloud albedo, and other factors.



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The Geologic Time Spiral—A Path to the Past

U.S. Department of the Interior
U.S. Geological Survey

Spiral designed by Joseph Graham, William Newman, and John Stacy. Digital preparation by Will Stettner.

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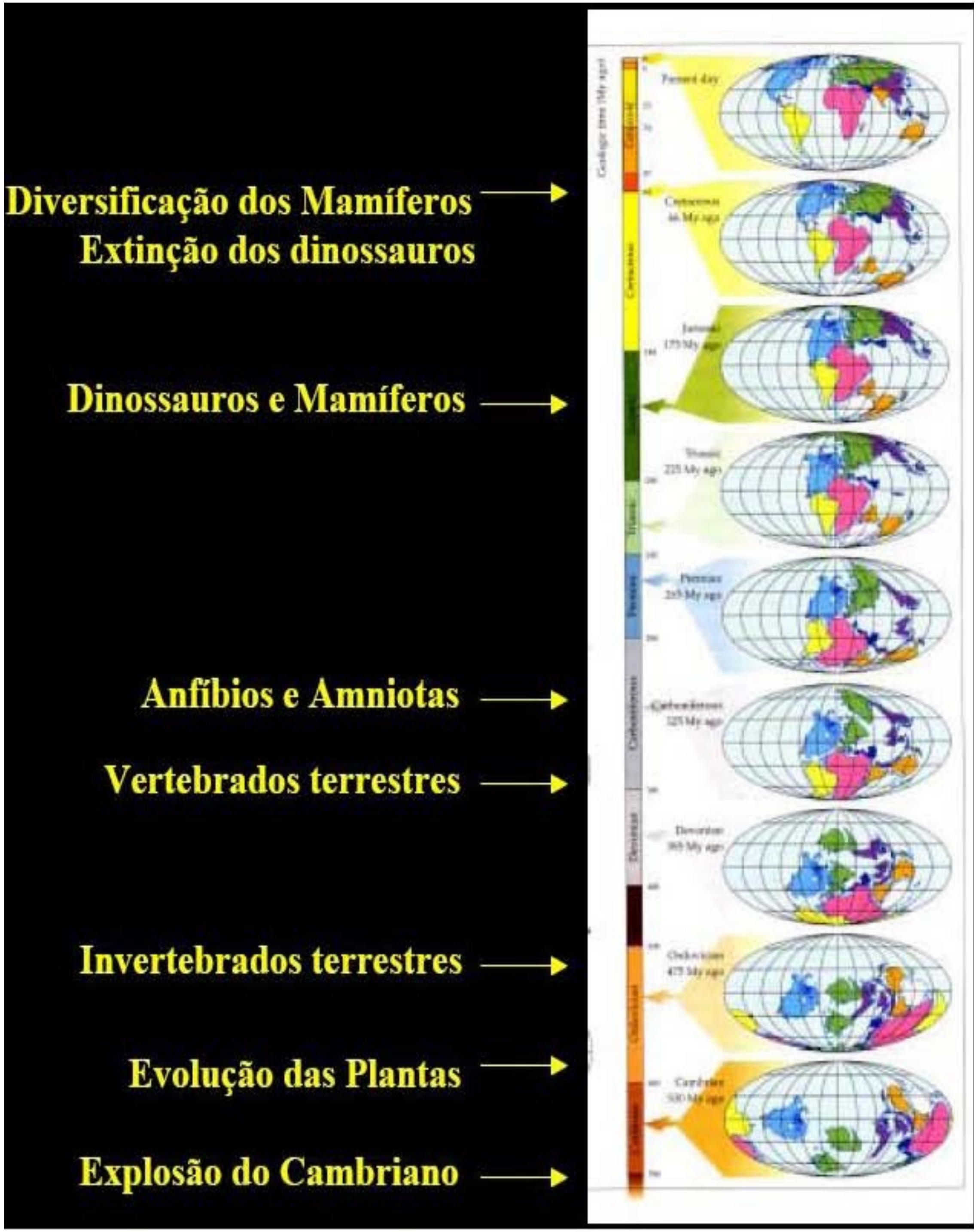
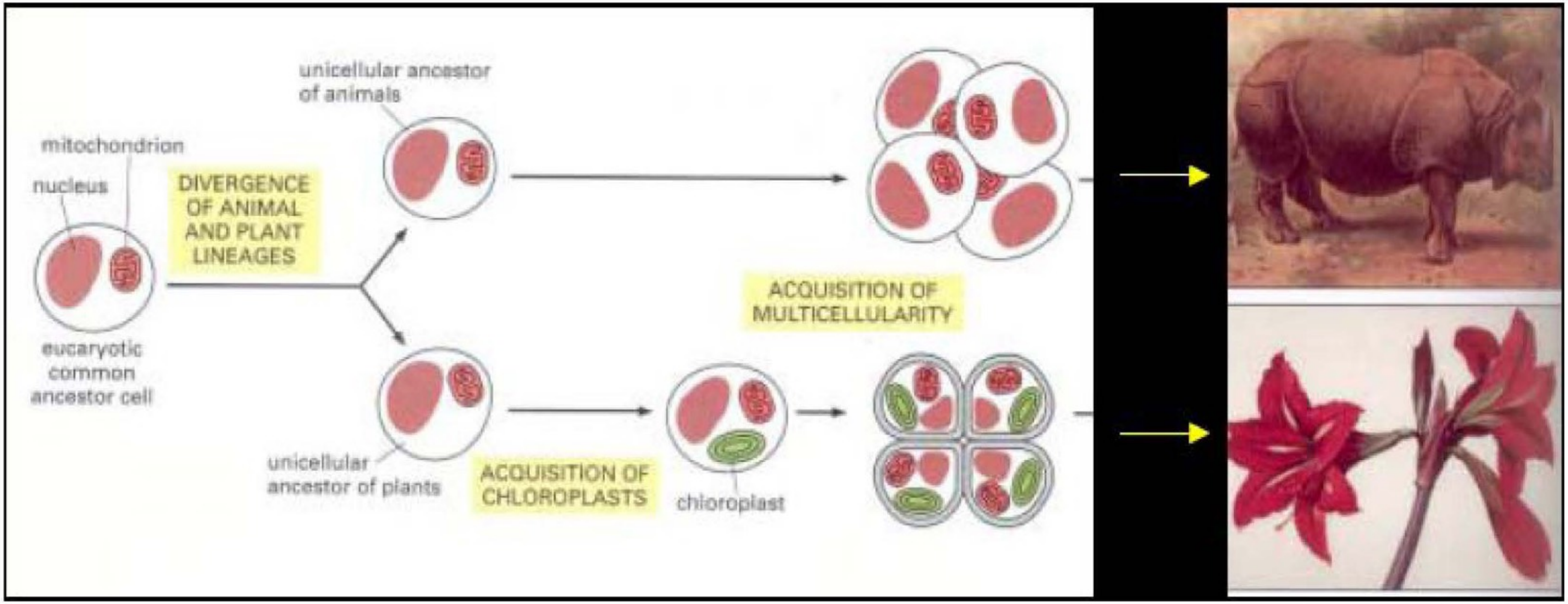


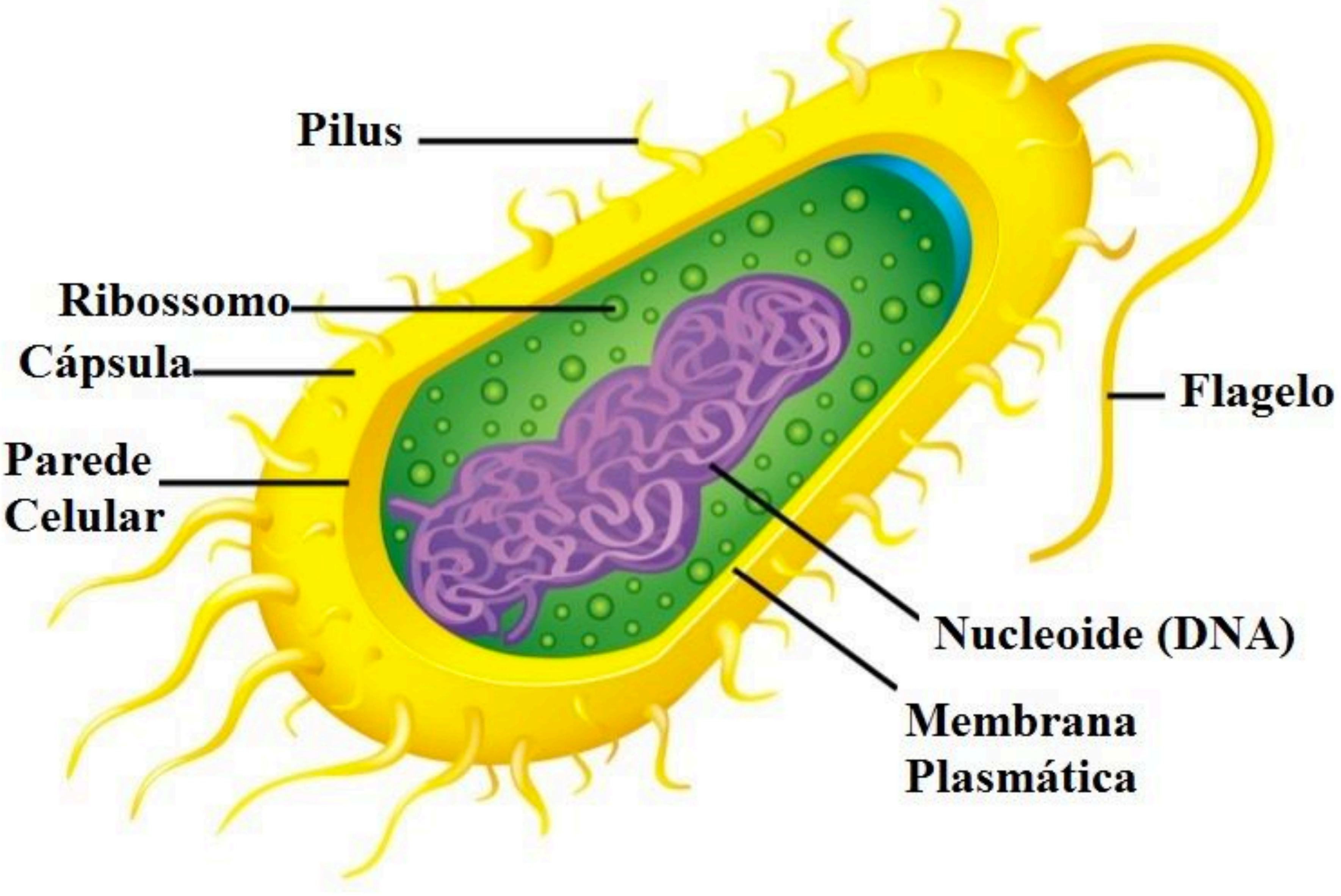
Origem da multicelularidade

- ☑ Data de aparecimento estimada: 800 – 600 milhões de anos
- ☑ Tendência à agregação de várias células, formando colônias (diferenciação)
- ☑ Crescimento de células com divisão nuclear, permitindo individualização a posteriori

Origem da multicelularidade



Procariotas (procariontes)



Procariotas (procariontes)

☑ Semelhante ao "LUCA"

☑ Dimensões ~ 0,1 – 10 microns

☑ Baixa variabilidade metabólica

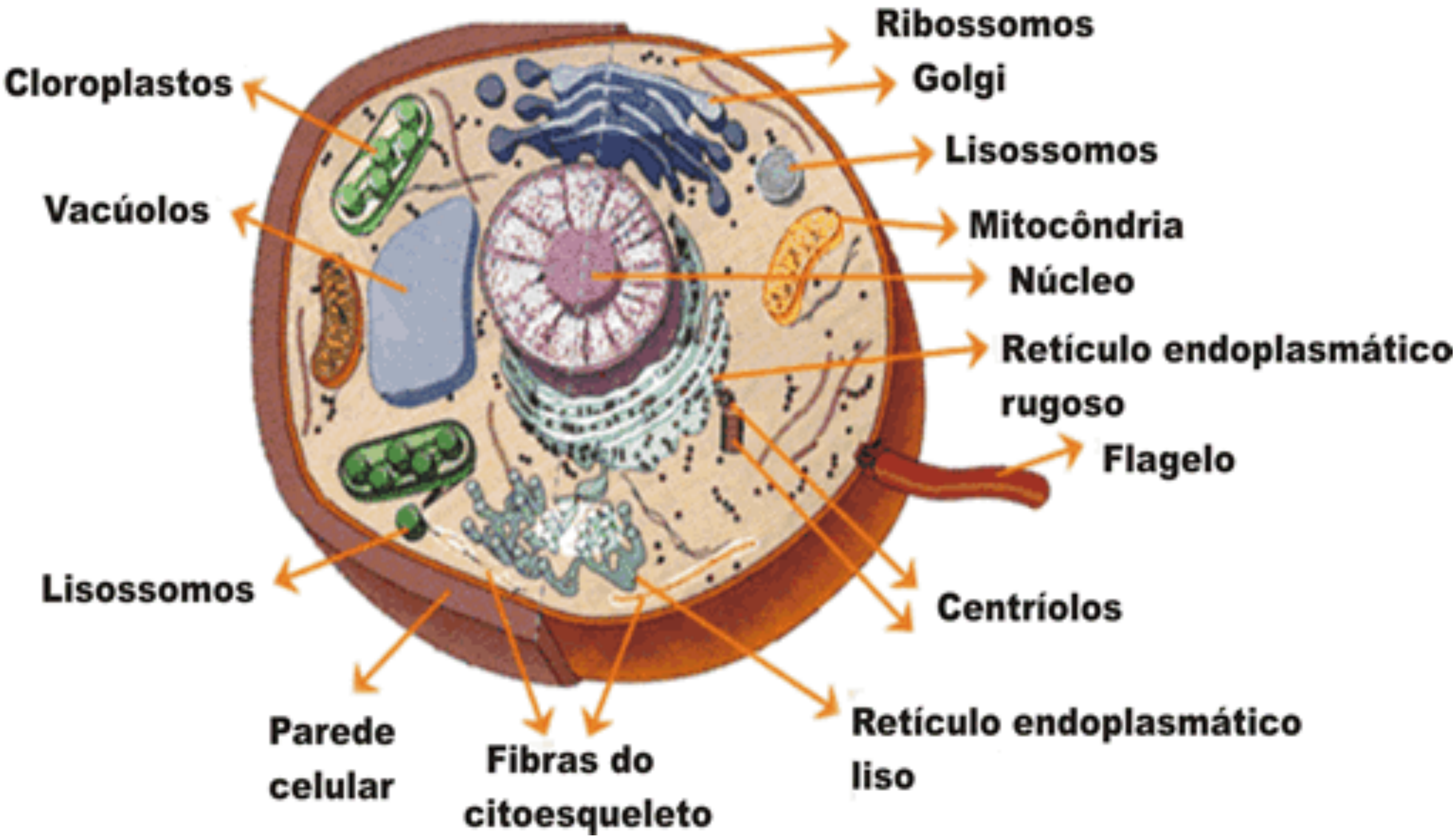
☑ Ausência de organelas

☑ Uma única molécula de DNA

☑ Ausência de citoesqueleto

☑ Divisão simples

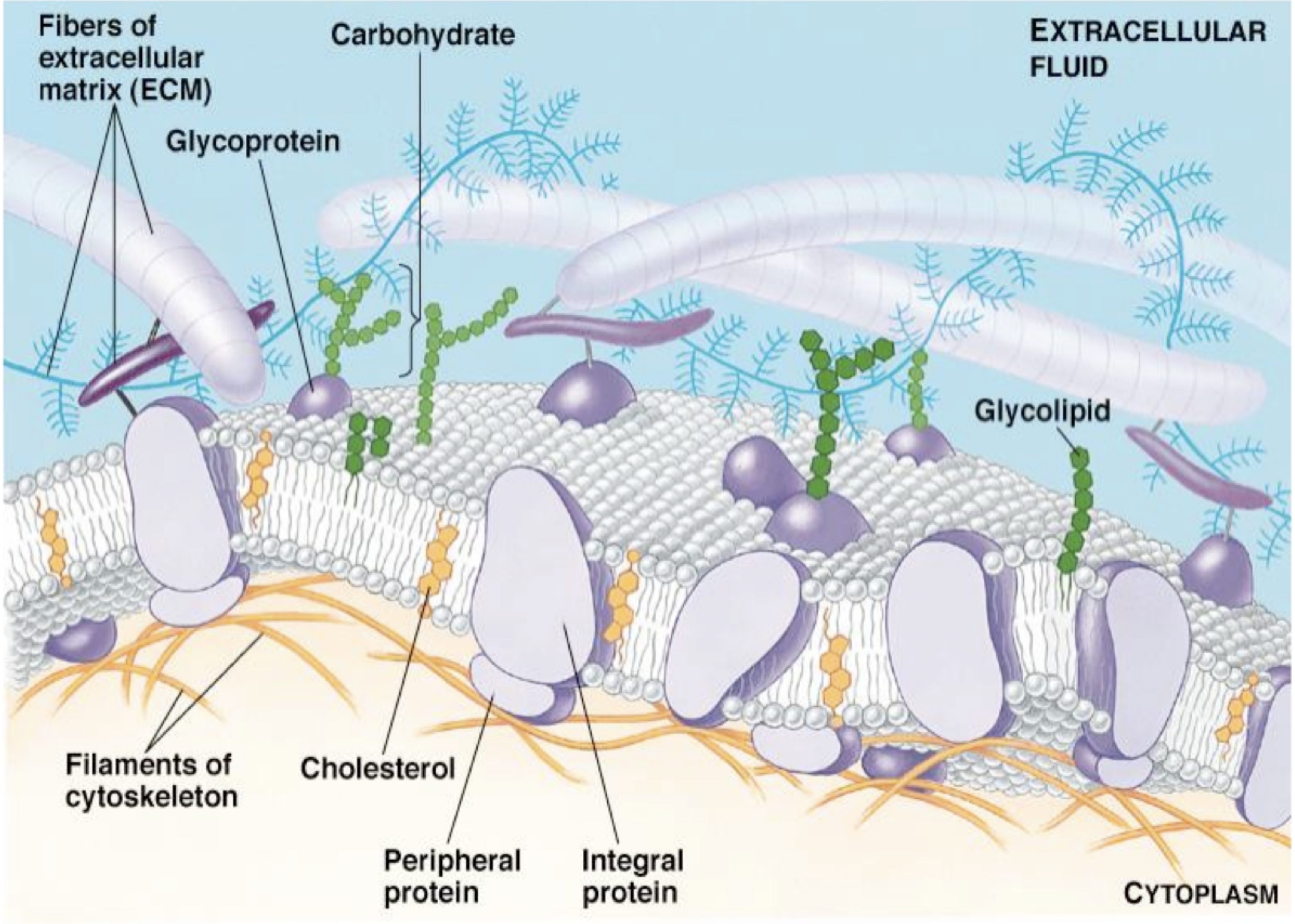
Eucariotas (eucariontes)



Eucariotas (eucariontes)

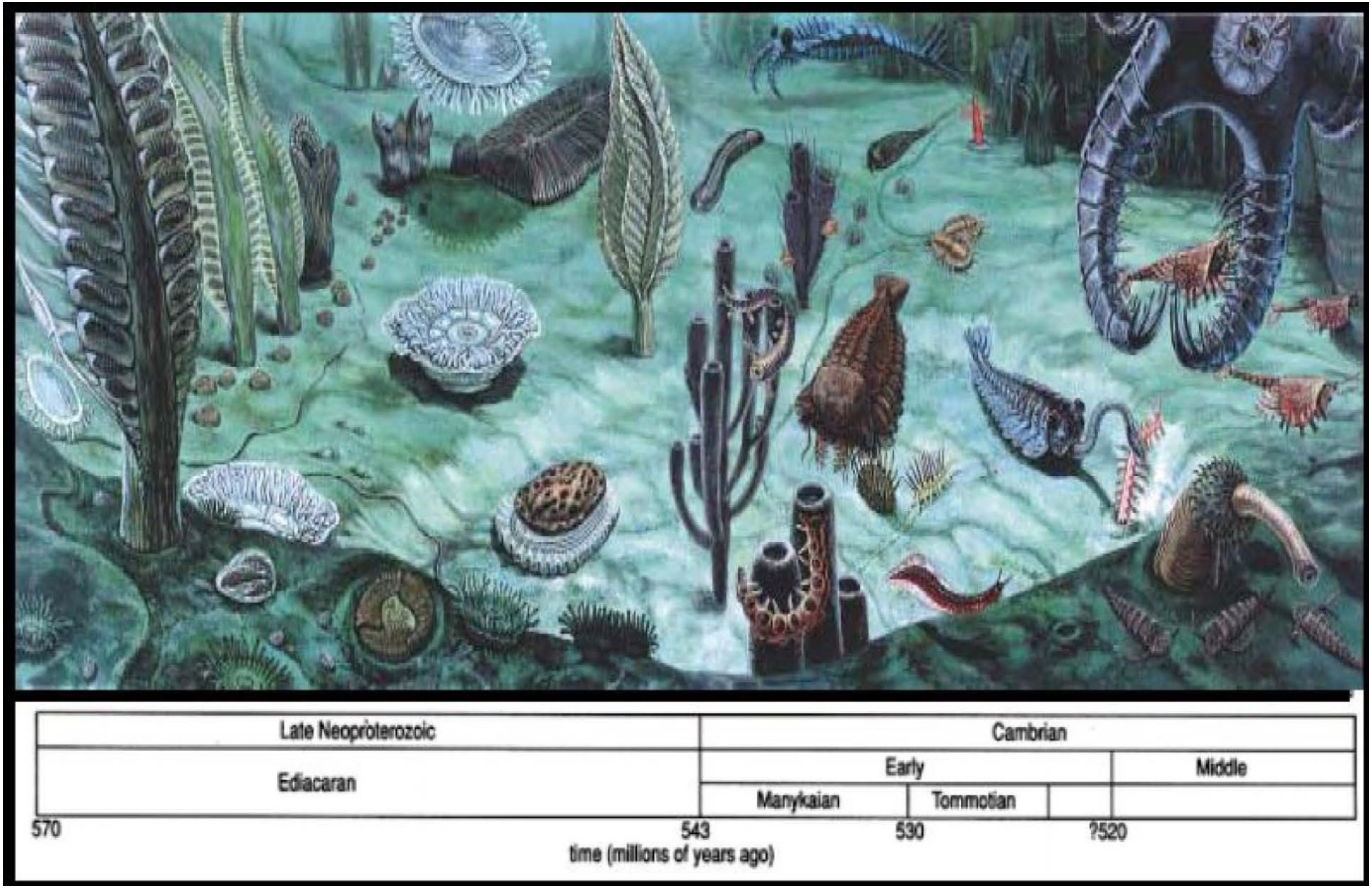
- ☑ Surgimento provavelmente posterior às procariotas (talvez ~ 2,5 bilhões de anos)
- ☑ Dimensões ~ 10 – 100 mícrons
- ☑ Genoma com DNA e proteínas
- ☑ Presença de citoesqueleto e organelas
- ☑ Divisão por mitose e meiose
- ☑ Metabolismo oxidativo

Complexidade biológica



Fonte: Addison Wesley Longman, Inc. (1999)

A diversidade biológica



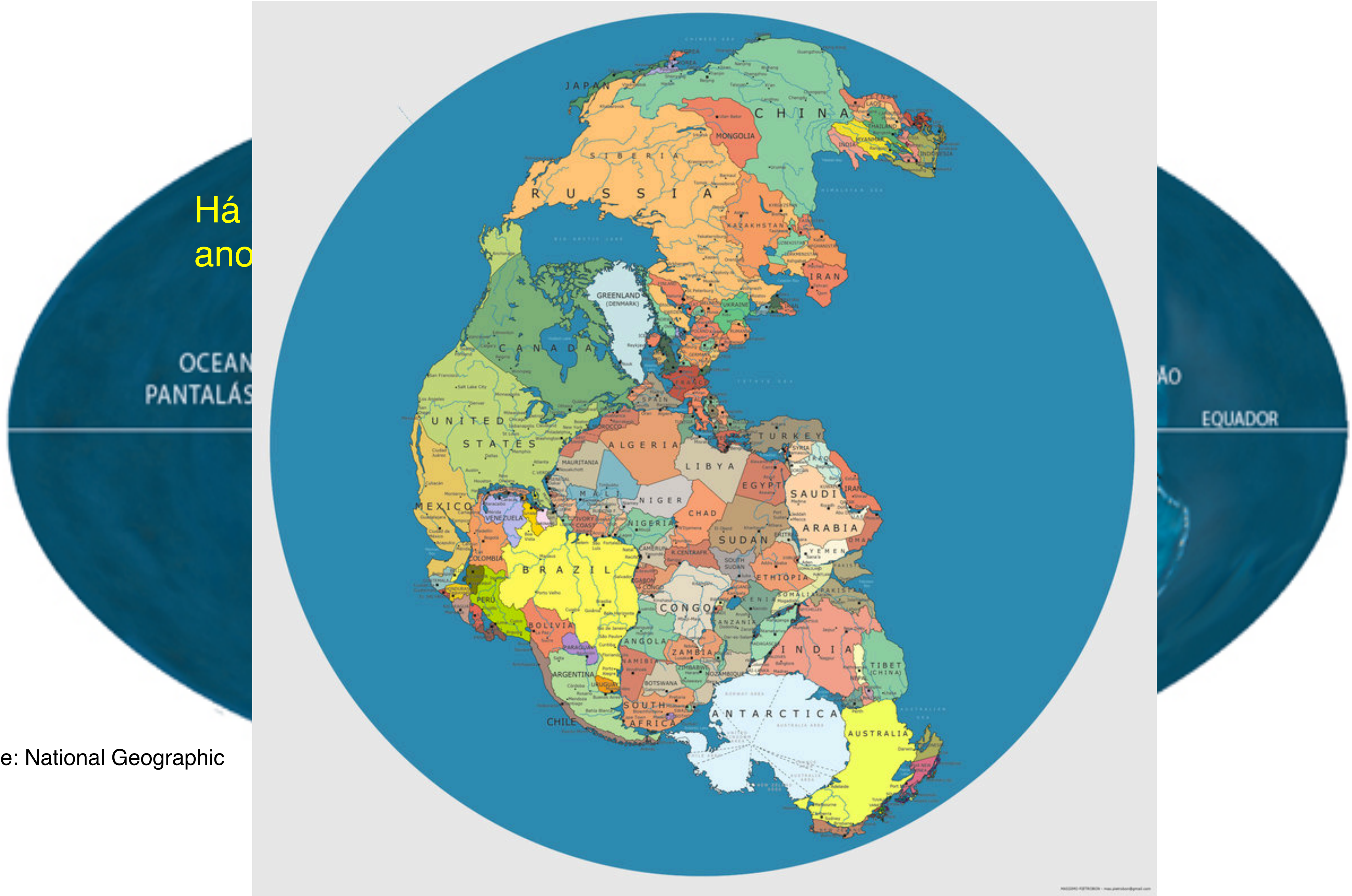
Explosão Cambriana

- ☑ Causas ambientais
  - ✓ Limiar crítico de crescimento definido pela abundância de oxigênio
  - ✓ Grande disponibilidade de nutrientes
  - ✓ Temperaturas moderadas após a Terra "Bola de Neve"
- ☑ Causas biológicas
  - ✓ Advento de exoesqueletos
  - ✓ Hipótese da "ação predatória"
  - ✓ Transposição de limiares evolutivos

Curiosidade - PANGEA

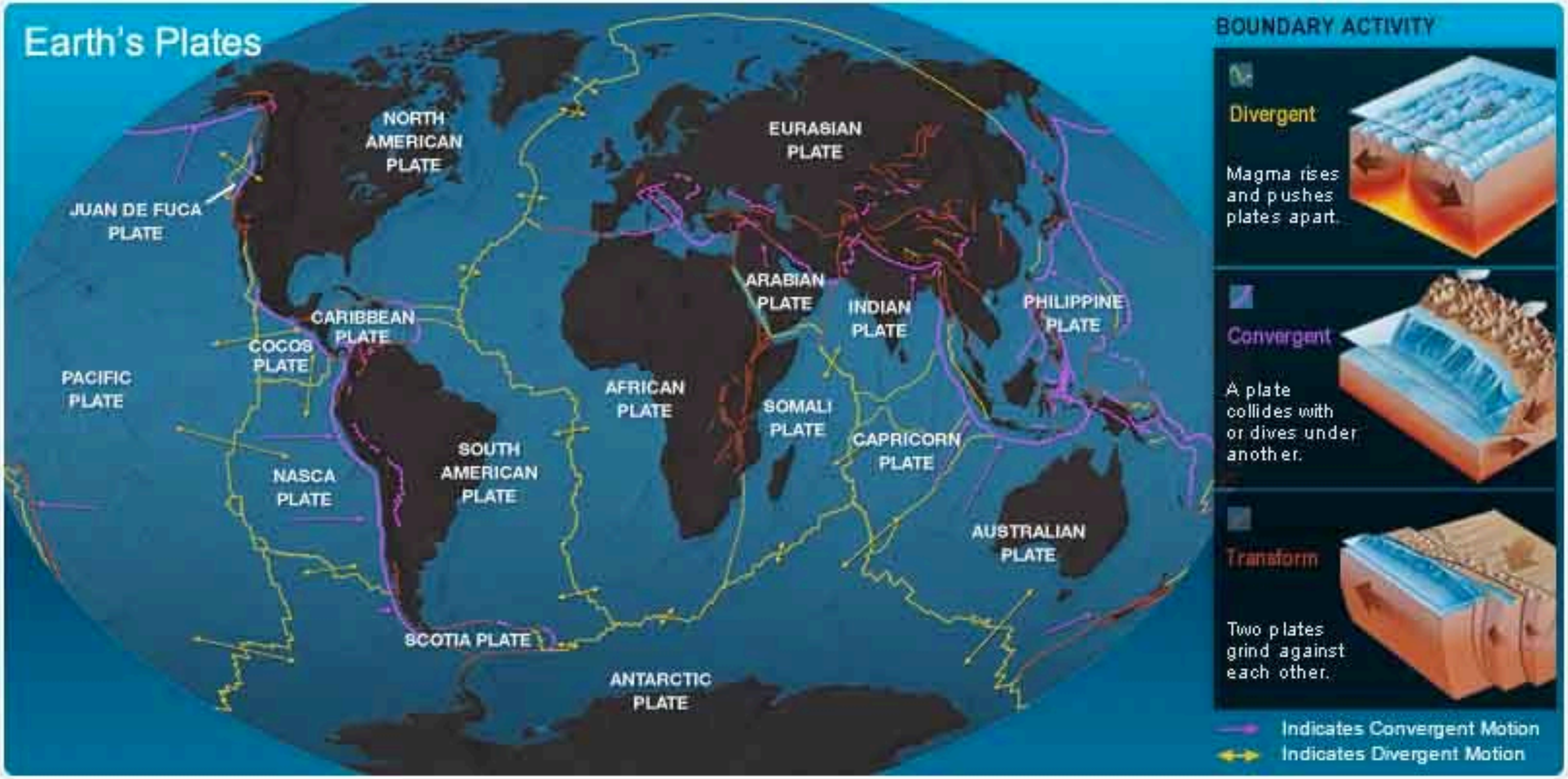
Fonte: National Geographic

Curiosidade – PANGEA



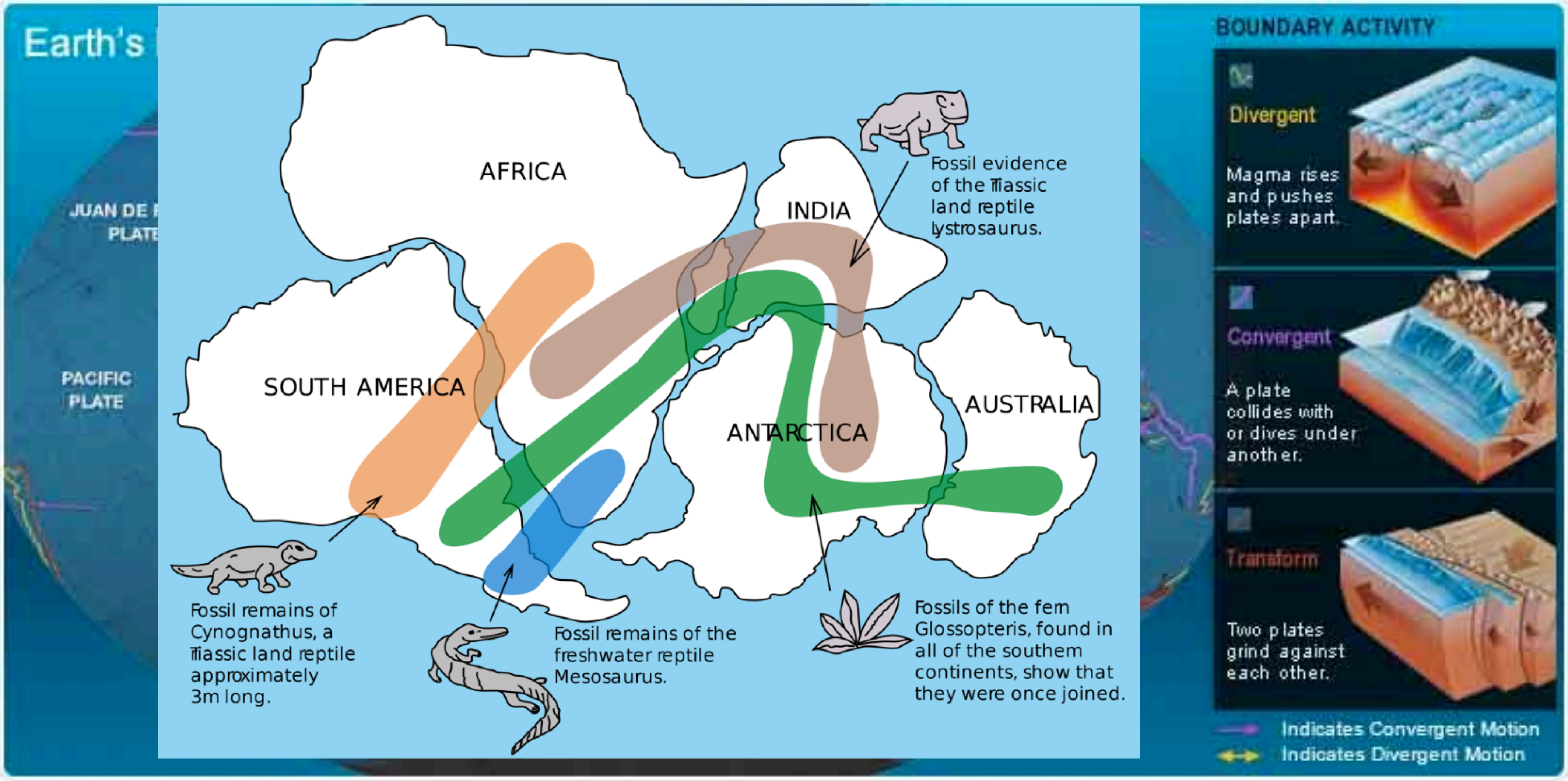
Fonte: National Geographic

Curiosidade - PANGEA



Fonte: National Geographic

Curiosidade - PANGEA



Fossil evidence of the Triassic land reptile lystrosaurus.

Fossil remains of Cynognathus, a Triassic land reptile approximately 3m long.

Fossil remains of the freshwater reptile Mesosaurus.

Fossils of the fern Glossopteris, found in all of the southern continents, show that they were once joined.

Magma rises and pushes plates apart.

A plate collides with or dives under another.

Two plates grind against each other.

Fonte: National Geographic

As diversas faunas antes/após a explosão Cambriana

- ☑ Burgess Shale (505 milhões de anos)
- ☑ Chengjiang (520 milhões de anos)
- ☑ Small Shellies (Manykaian Stage) (544-530 milhões de anos)
- ☑ Ediacara (575-545 milhões de anos)
- ☑ Doushantuo (580-570 milhões de anos)

Evidências de um mecanismo evolutivo

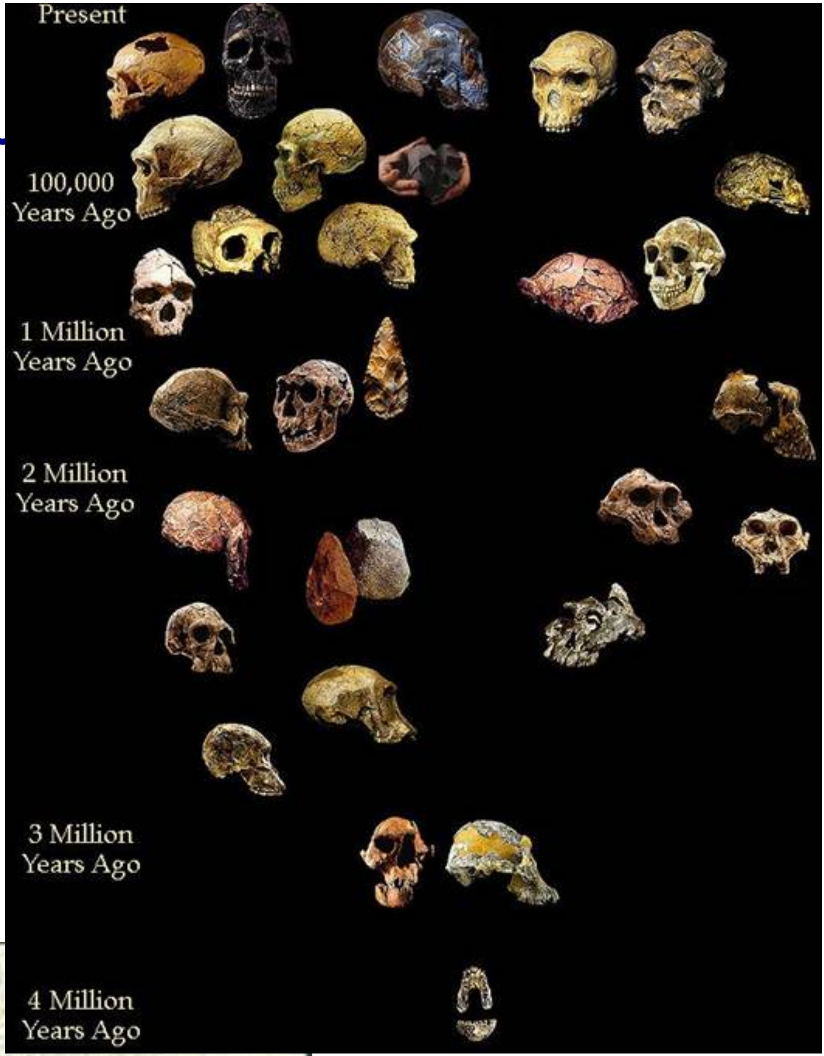
- ☑ Biogeografia
- ☑ Registros fósseis
- ☑ Classificação
- ☑ Anatomia comparativa
- ☑ Mudanças observadas em pequena escala
- ☑ Genética

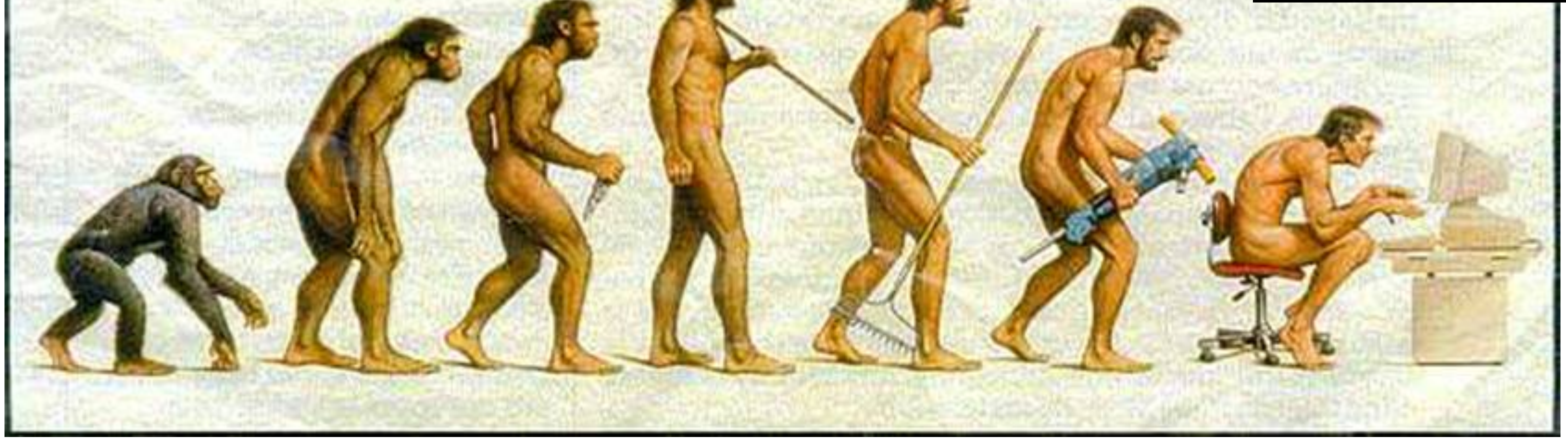
Biogeografia como evidência evolutiva

- ☑ Espécies são distribuídas em padrões que contam sua história
  - ✓ Espécies são diferentes em ambientes semelhantes, mas bastante separados
  - ✓ Espécies estão ausentes de ambientes potencialmente habitáveis por elas
  - ✓ Espécies similares (muito relacionadas) são frequentemente encontradas próximas umas às outras

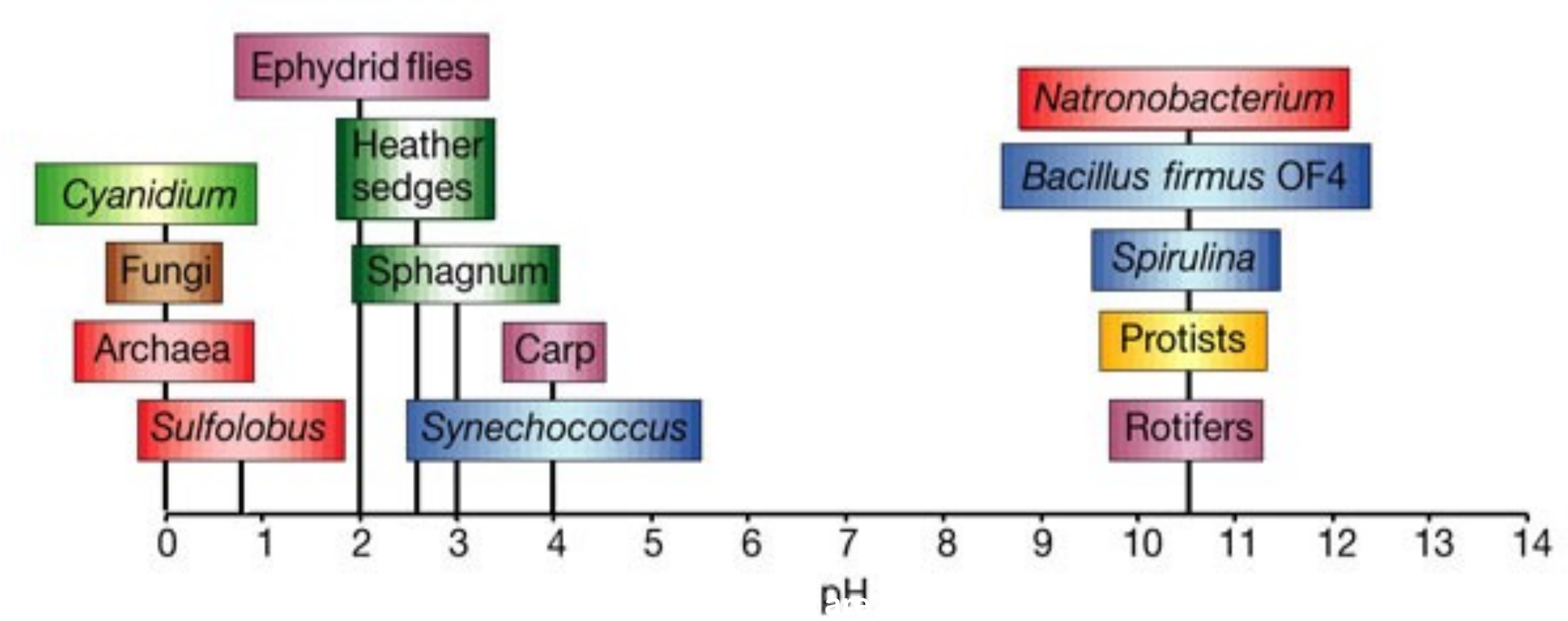
Registros fósseis como evidência evolu

- ☑ Padrões de sucessão biológica indicam continuidade com a mudança
  - ✓ Padrões em grande escala
  - ✓ Padrões em pequena escala





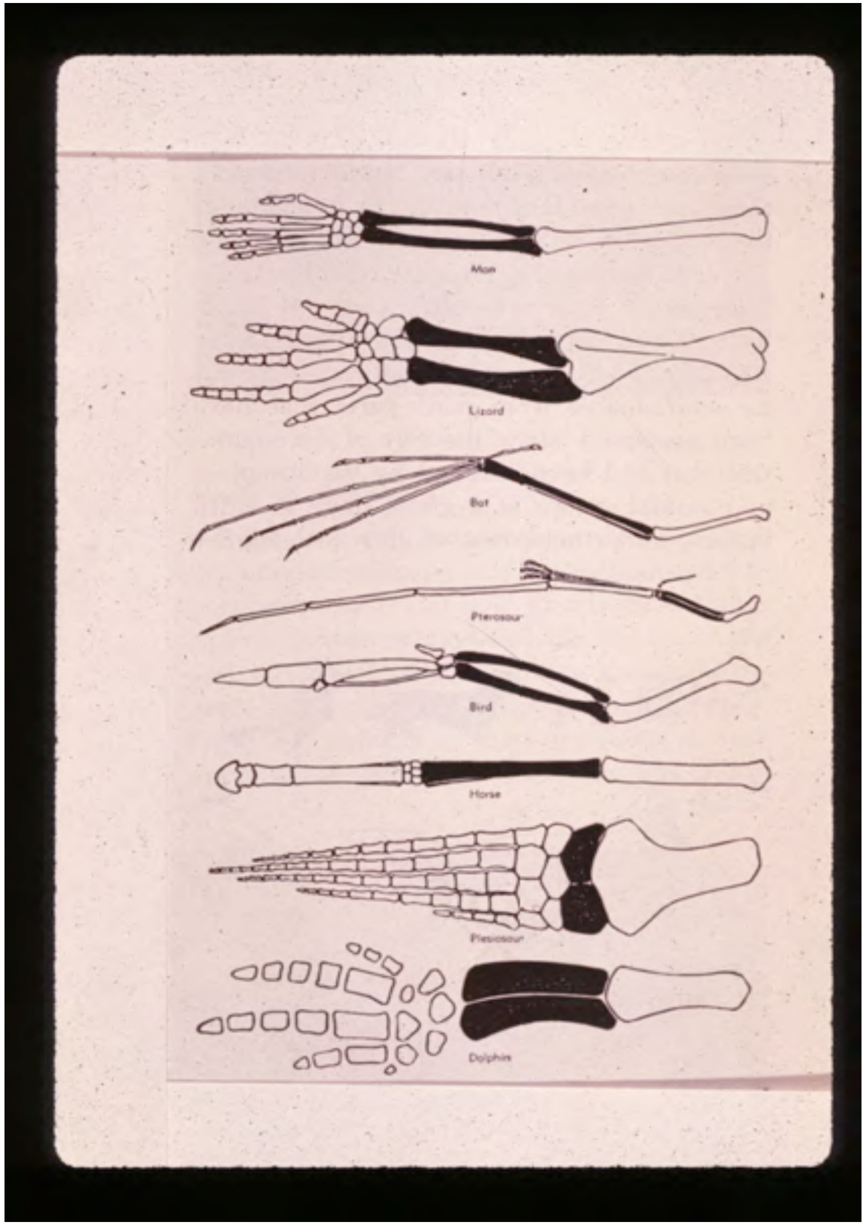
Os limites de pH

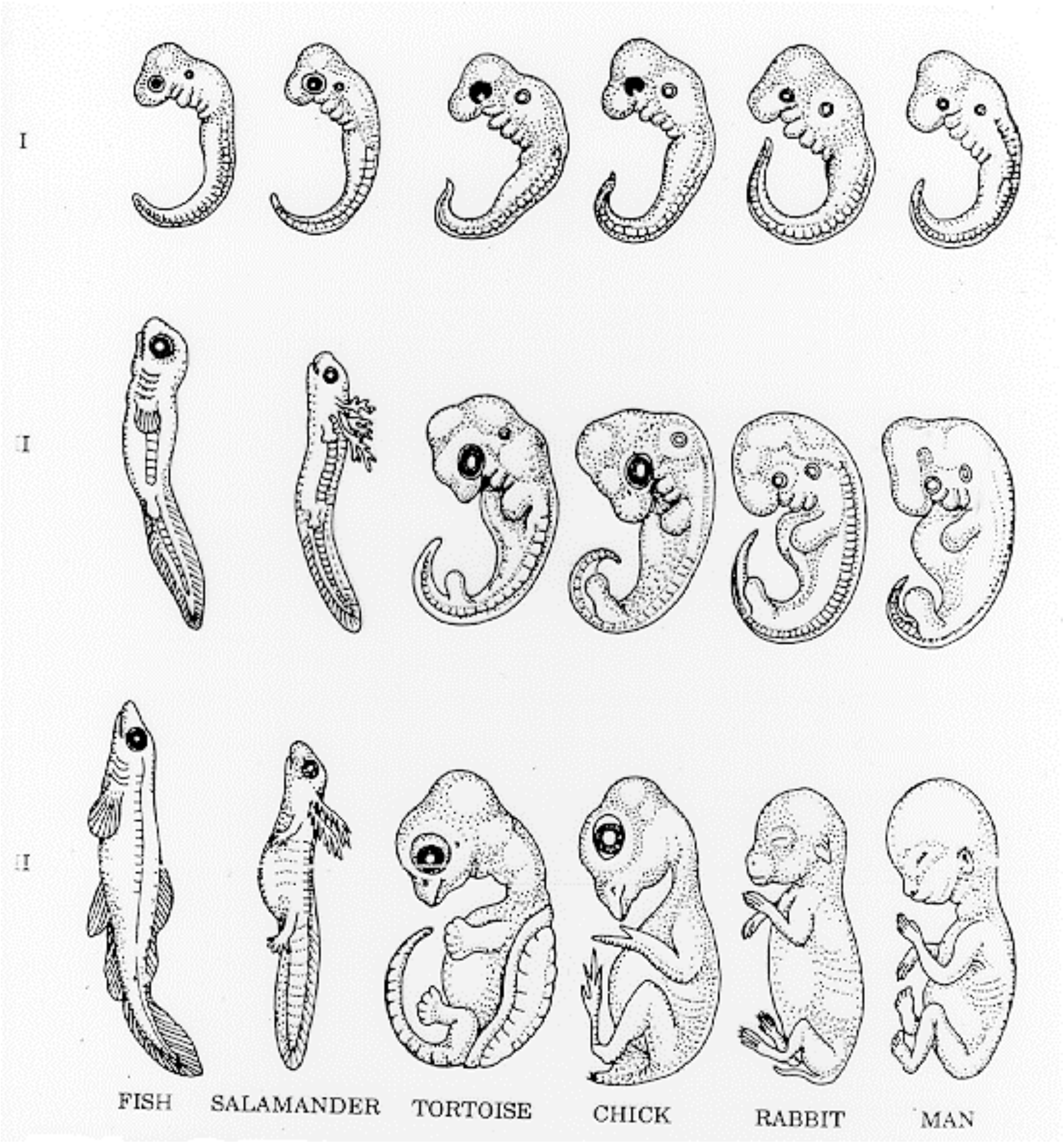


Exemplos de limites de pH conhecidos para a vida são mostrados. Archaea estão em vermelho, bactérias em azul, algas em verde claro, protistas variados em amarelo, fungos em marrom, plantas em verde escuro e animais em roxo.

Anatomia comparativa como evidência evolutiva

- ☑ Características de organismos que não parecem refletir suas funções atuais (“imperfeições”):
  - ✓ homologias
  - ✓ embriologia
  - ✓ órgãos vestigiais




I
II
III
FISH
SALAMANDER
TORTOISE
CHICK
RABBIT
MAN

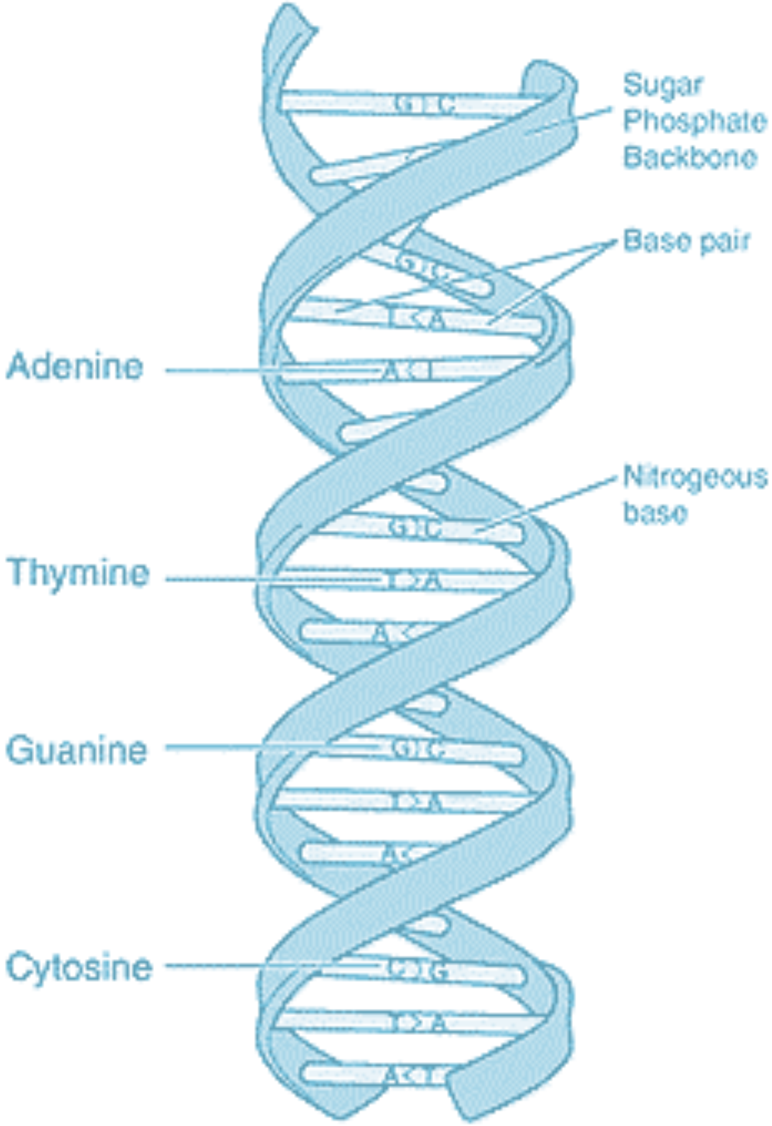
Classificação

- ☑ Cachorro, coiote, lobo, gato
- ☑ Cachorro, coiote, lobo, gato, leopardo, leão
- ☑ Cachorro, coiote, lobo, gato, leopardo, leão, antílope, búfalo
- ☑ Cachorro, coiote, lobo, gato, leopardo, leão, antílope, búfalo, lhama, camelo
- ☑ Cachorro, coiote, lobo, gato, leopardo, leão, antílope, búfalo, lhama, camelo, foca, leão marinho, lobo do mar

Mudanças observadas em pequena escala como evidência evolutiva

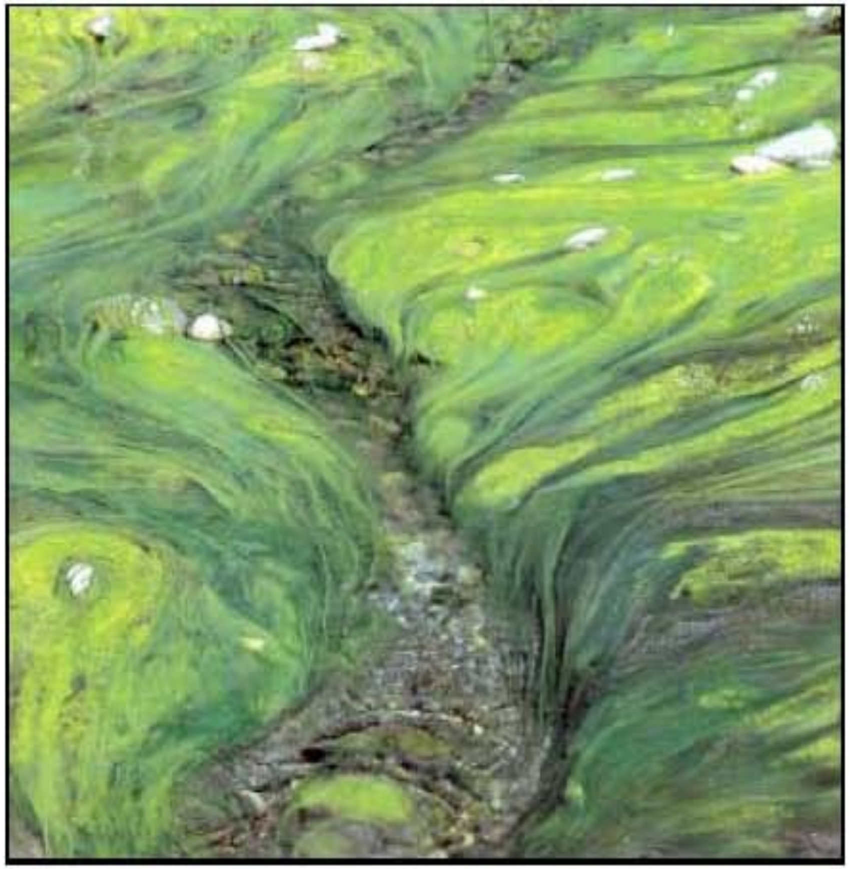
- ☑ Em organismos domesticados
- ☑ No laboratório
- ☑ Na natureza

Genética como evidência evolutiva

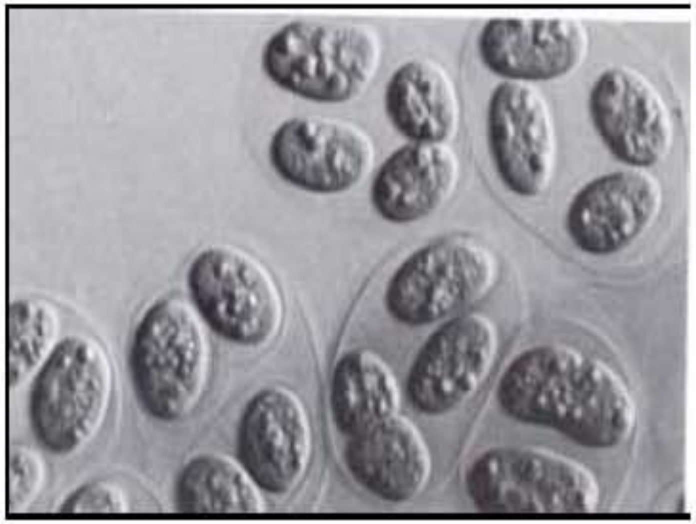


Atiividade biológica – pré-Cambriano

(> 600 milhões de anos)



Algas verdes



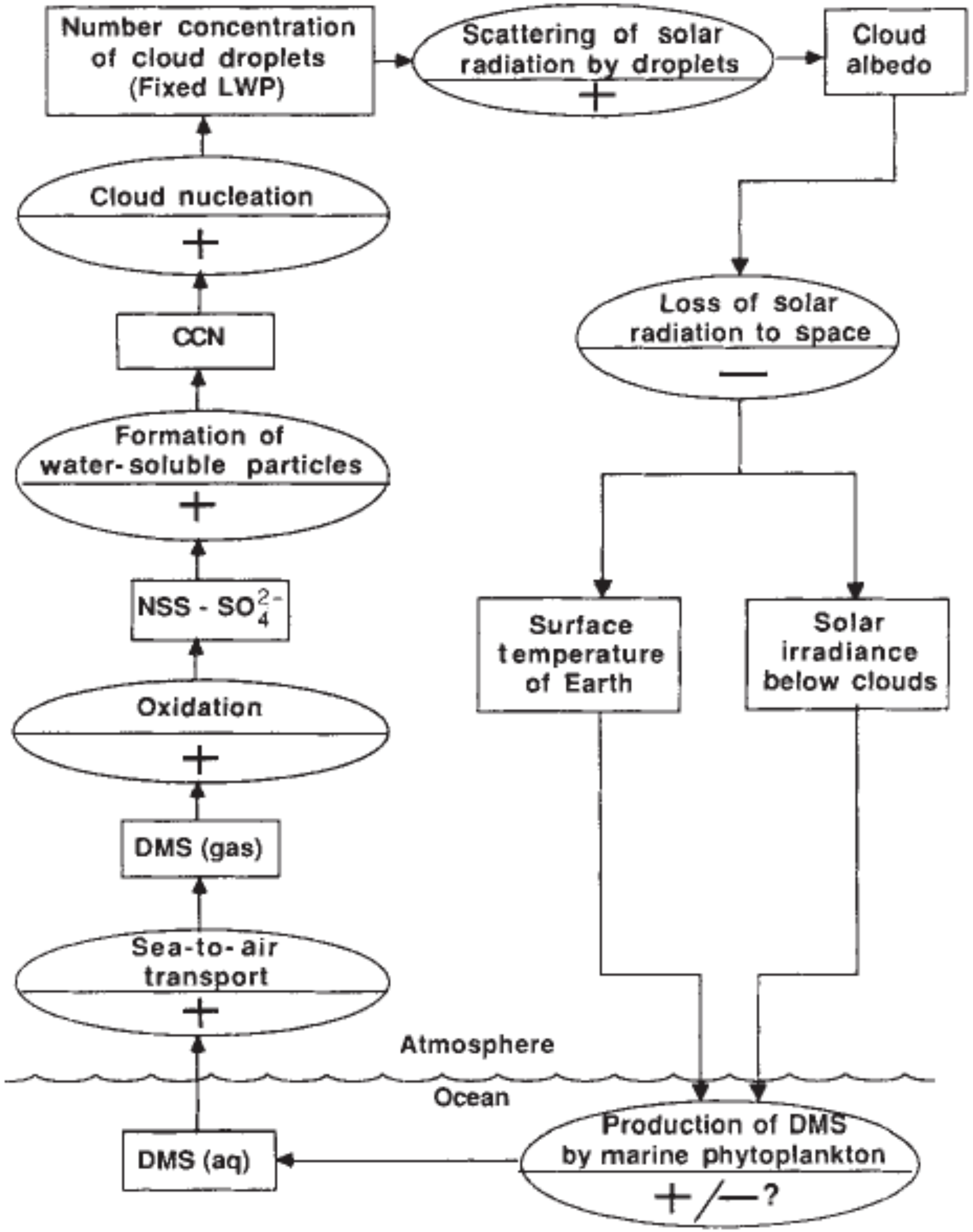
Cianobactérias

Oceanic phytoplankton, atmospheric sulphur, cloud albedo and climate

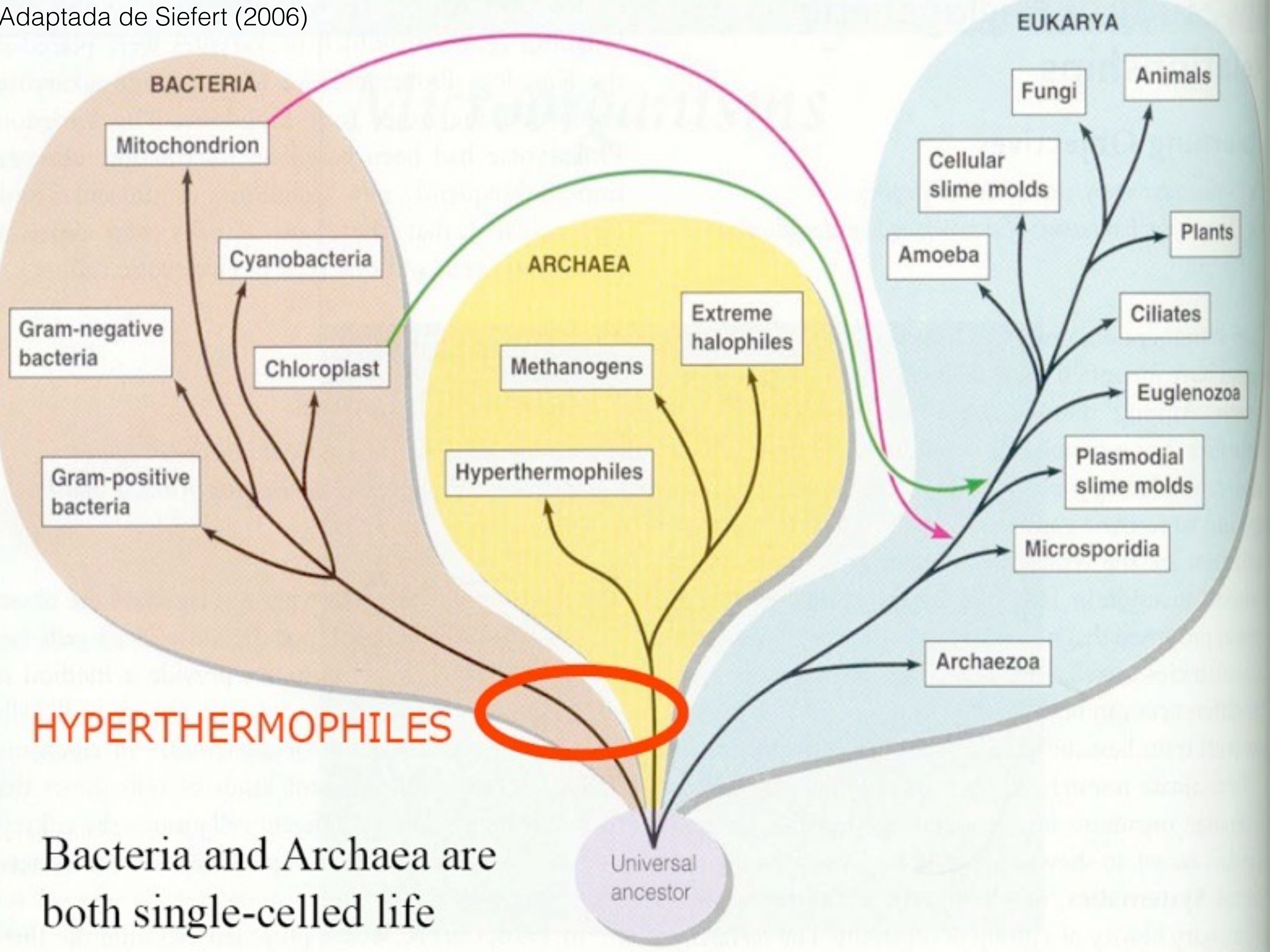
Robert J. Charlson[*], James E. Lovelock[†], Meinrat O. Andreae[‡] & Stephen G. Warren[*]

NATURE VOL. 326 16 APRIL 1987

CLAW

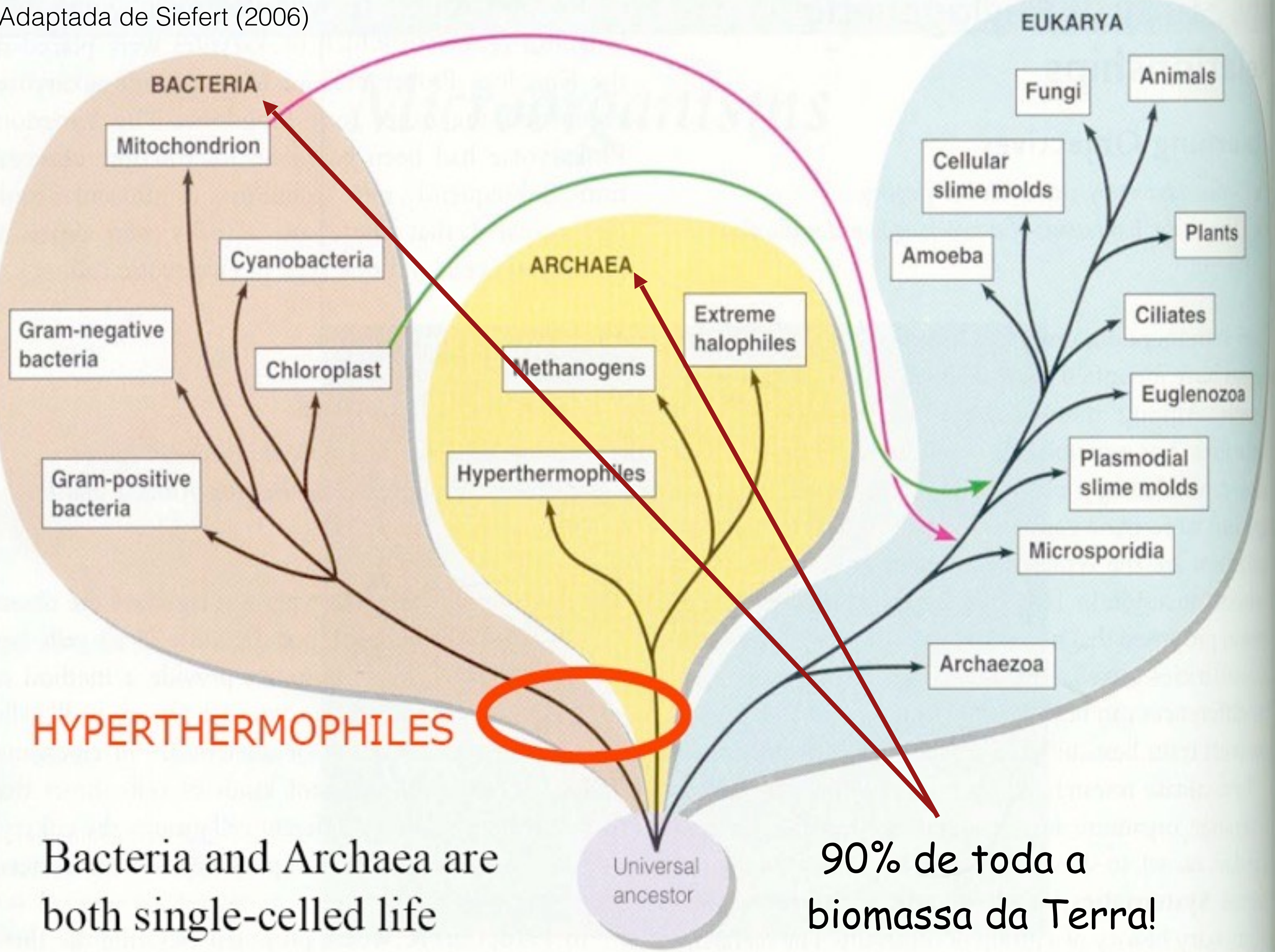


Adaptada de Siefert (2006)



Bacteria and Archaea are both single-celled life

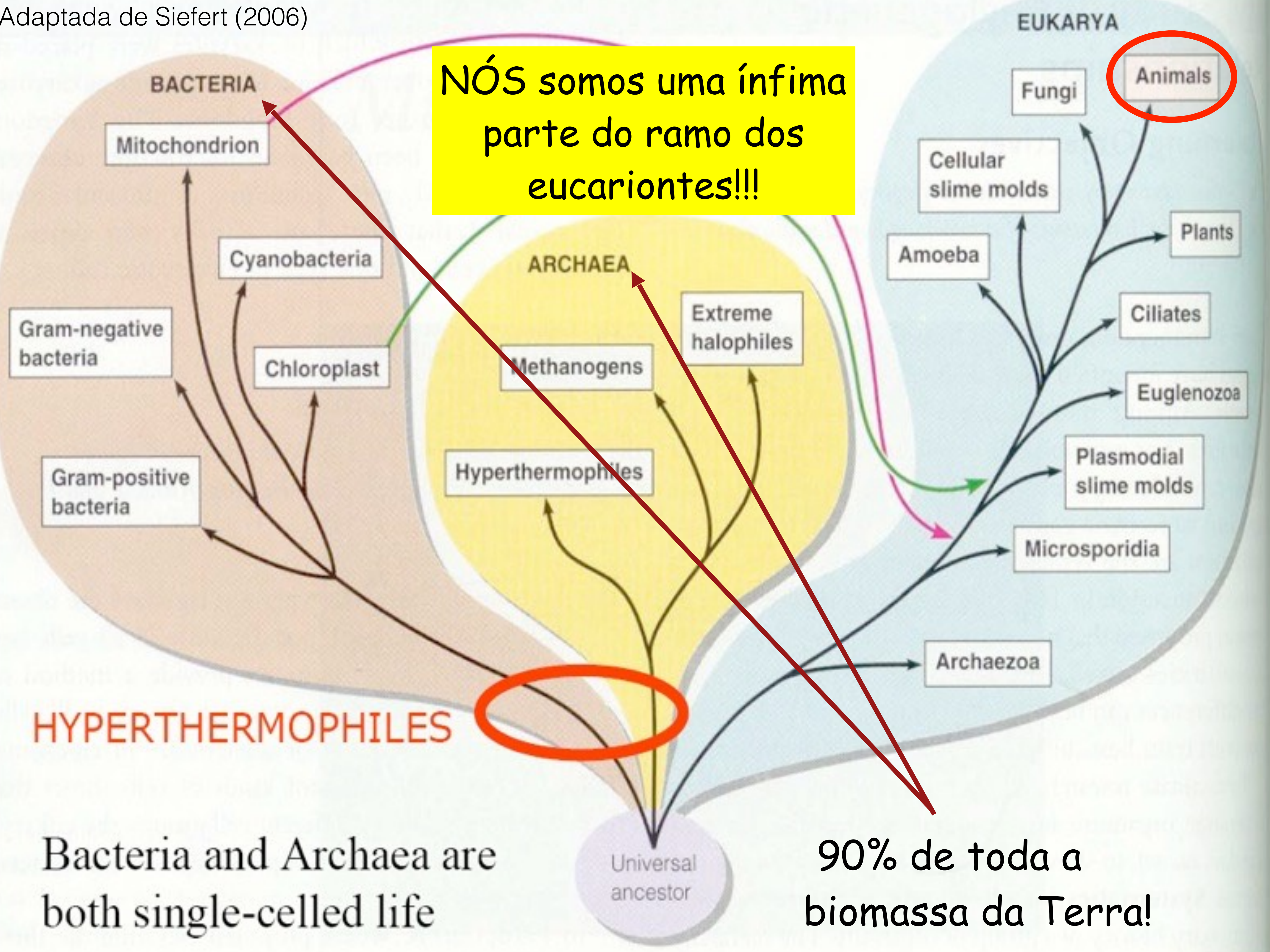
Adaptada de Siefert (2006)



Bacteria and Archaea are both single-celled life

90% de toda a biomassa da Terra!

Adaptada de Siefert (2006)

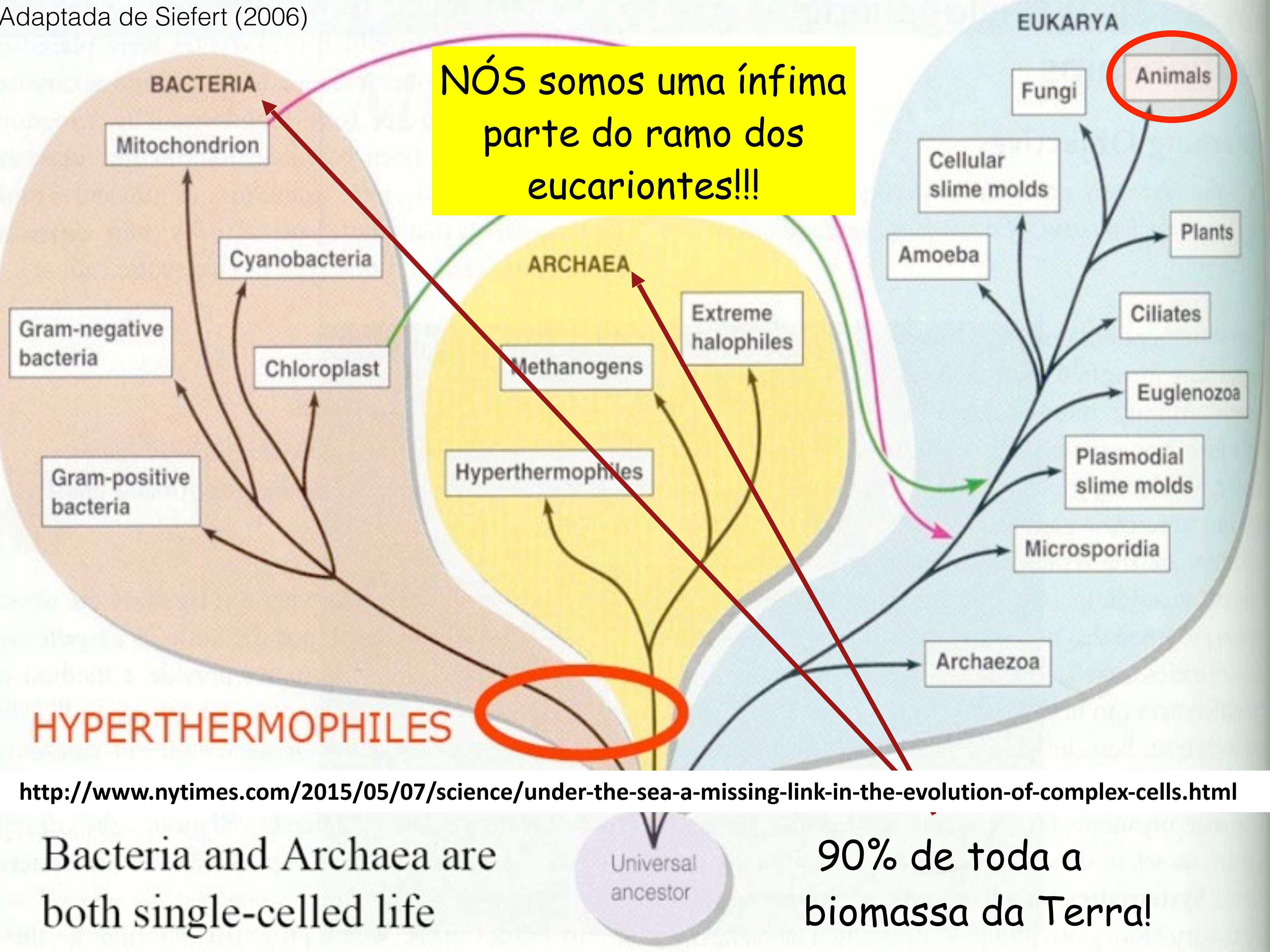


NÓS somos uma ínfima parte do ramo dos eucariontes!!!

90% de toda a biomassa da Terra!

Bacteria and Archaea are both single-celled life

Adaptada de Siefert (2006)



NÓS somos uma ínfima parte do ramo dos eucariontes!!!

http://www.nytimes.com/2015/05/07/science/under-the-sea-a-missing-link-in-the-evolution-of-complex-cells.html

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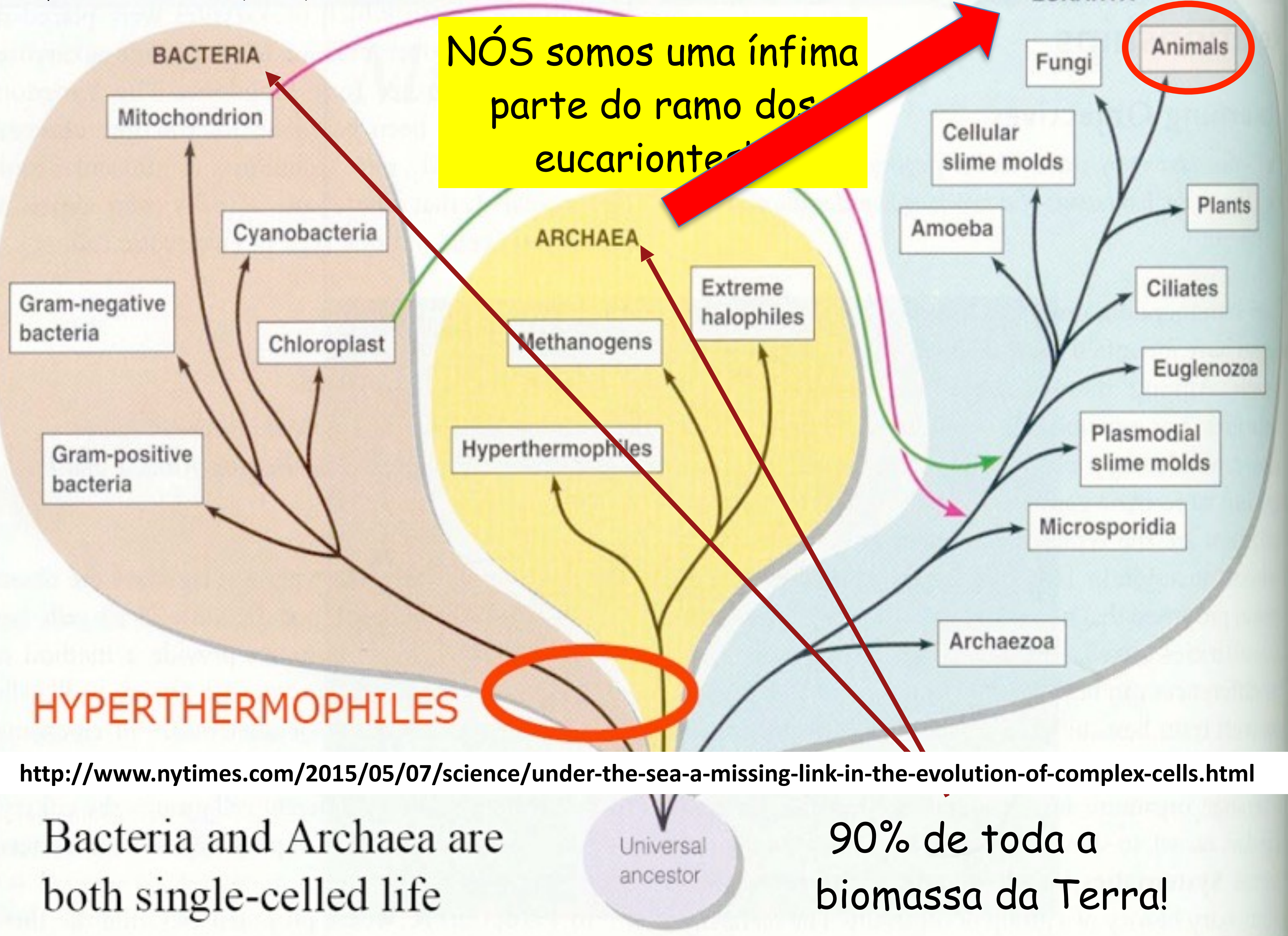

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Bacteria and Archaea are both single-celled life

90% de toda a biomassa da Terra!

Microorganismos extremófilos

Microorganismos extremófilos

- Temos mais células de micróbios (cerca de **1 trilhão na pele**, **10 bilhões na boca** e **100 trilhões no trato intestinal**) do que células humanas (10 trilhões) no nosso próprio corpo!!!
- A primeira forma de vida na Terra foi um micróbio, e foi a única existente durante os 3 primeiros bilhões de anos
- Há mais vida "dentro do solo" do que na superfície da Terra
- Micróbios podem viver em condições REALMENTE extremas.
- Candidatos **mais prováveis** a E.T!!!

Mas não serão os ETs dos filmes e sim extremófilos!!!

☑ Extremófilos são microorganismos que vivem em locais e condições extremos na Terra.

  ✓ Temperaturas extremas

  ✓ Ferventes ou congelantes, 100^{0}C to -1^{0}C (212F to 30F)

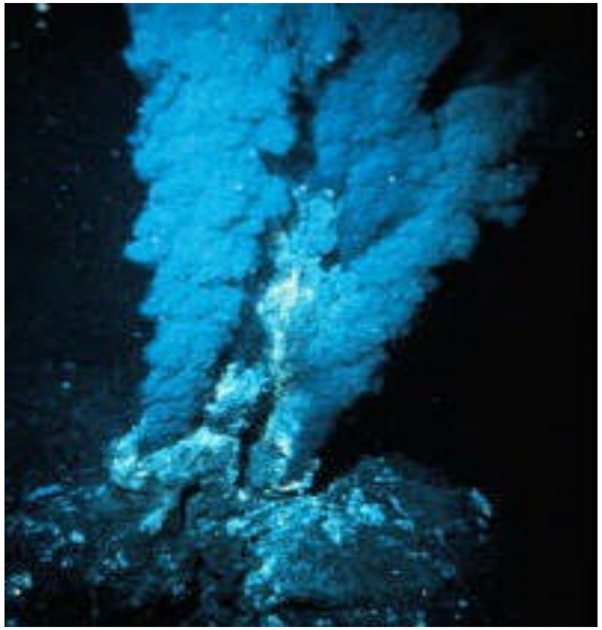
☑ Meios químicos extremos

  ✓ vinagre ou amônia (<5 pH or >9 pH)

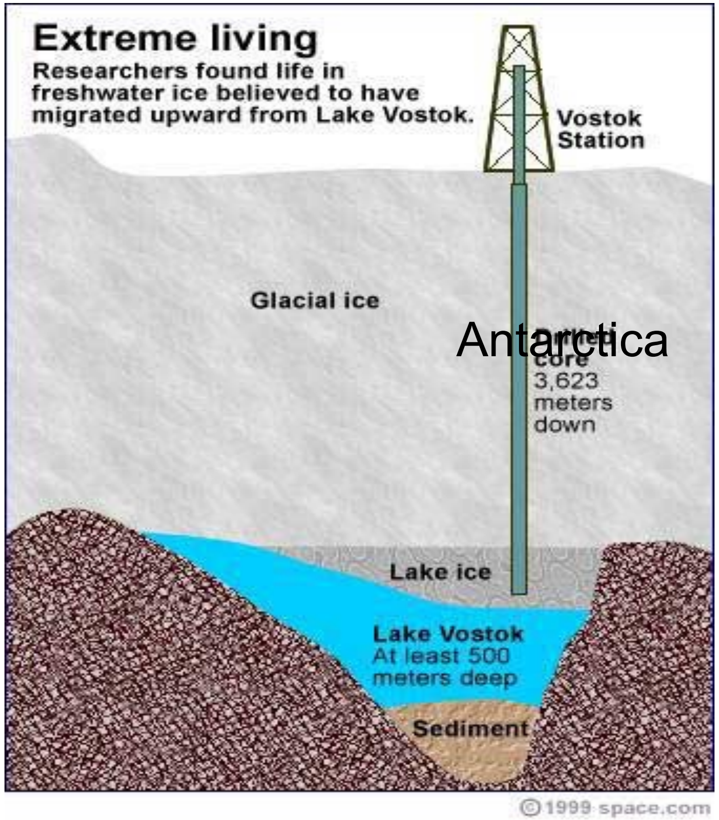
  ✓ Salobros (mais que 10 vezes a salinidade do mar)

  ✓ Candidato ideal para a vida fora da Terra

Extremófilos



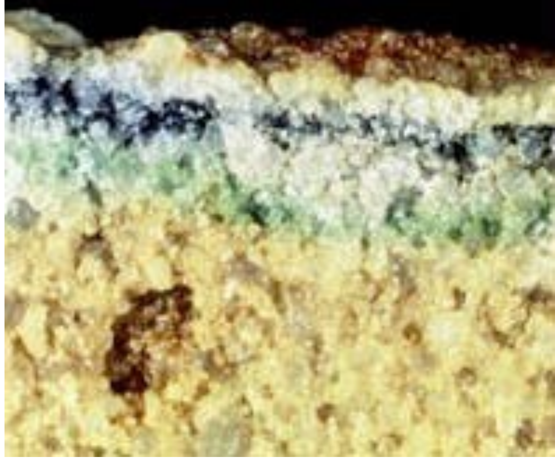
Chaminés hidrotermais



Antarctica

Camadas de gelo Antártico

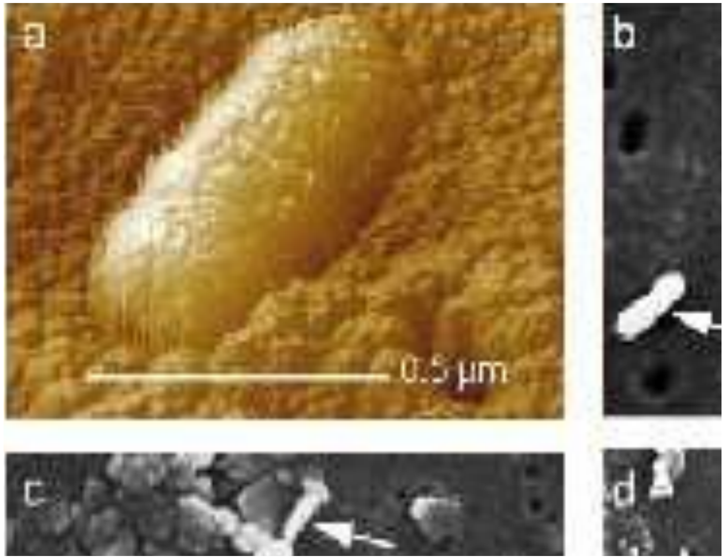
Regiões salinas

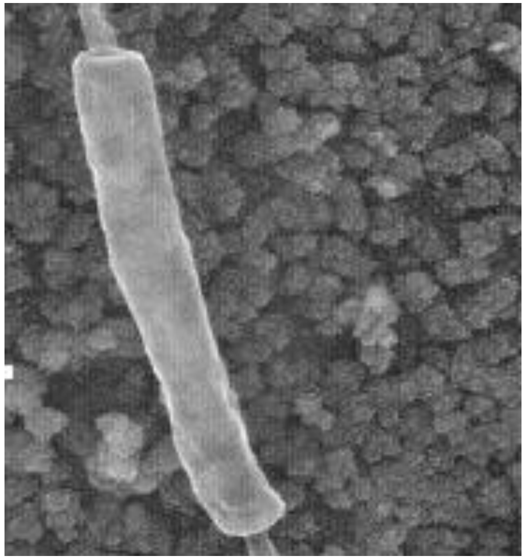


Criptoendolitos

Extremófilos

Minhocas marinhas (“tubeworms”)





Bactérias termófilas

Fontes quentes

Vale seco na Antártica

Suprimento energético

☑ Como esses seres viviam?

- ✓ Fotoautotrofia (fotossíntese)

$$6\ CO_2 + 6\ H_2O \Rightarrow C_6H_{12}O_6 + 6O_2$$

- ✓ Quimioautotrofia (metanogênese)

$$CO_2 + 4\ H_2 \Rightarrow CH_4 + 2\ H_2O$$

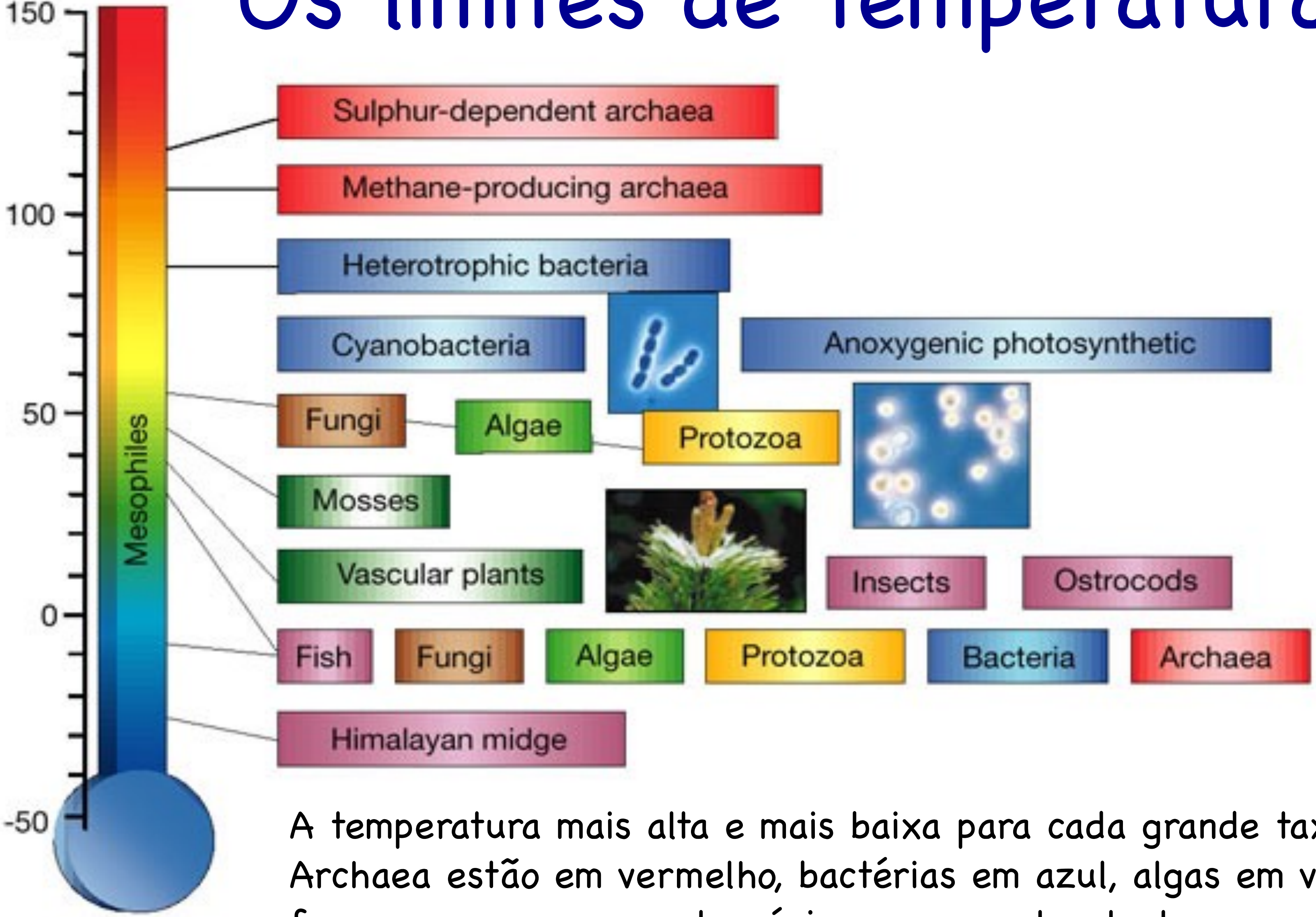
Guia de sobrevivência dos extremófilos

- ☑ Temperatura: -15° C < T < 230° C
- ☑ 0.06 < pH < 12.8
- ☑ 0 < Pressão < 1200 atm
- ☑ Metabolismo não necessariamente baseado em Oxigênio
- ☑ 20-40 milhões de anos de dormência
- ☑ 2 ½ anos no espaço, a -250 C, sem nutrientes, água e expostos à radiação (Strep. Mitis) – **RESULTADOS CONTROVERSOS DO PROGRAMA APOLO**
- ☑ Capaz de sobreviver à radiação de milhares de Grays

Limites da vida conhecida na Terra

Factor	Environment / source	Limits	Examples
High temperature	Submarine hydrothermal vents	110 °C to 121 °C	Pyrolobus fumarii, Pyrococcus furiosus
Low temperature	Ice	-17 °C to -20 °C	Synechococcus lividus
Alkalinesystems	Soda lakes	pH > 11	Psychrobacter, Vibrio, Arthrobacter, Natronobacterium
Acidic systems	Volcanic springs, acid mine drainage	pH -0.06 to 1.0	Bacillus, Clostridium paradoxum
Ionizing radiation	Cosmic rays, X-rays, radioactive decay	1,500 to 6,000 Gy	Deinococcus radiodurans, Rubrobacter, Thermococcus gammatolerans
UV radiation	Sunlight	5,000 J/m2	Deinococcus radiodurans, Rubrobacter, Thermococcus gammatolerans
High pressure	Mariana Trench	1,100 bar	Pyrococcus sp.
Salinity	High salt concentration	aw ~ 0.6	Halobacteriaceae, Dunaliella salina
Desiccation	Atacama Desert (Chile), McMurdo Dry Valleys(Antarctica)	~60% relative humidity	Chroococcidiopsis
Deep crust	accessed at some gold mines		Halicephalobus mephisto, Mylonchulus brachyurus, unidentified arthropods

Os limites de temperatura



A temperatura mais alta e mais baixa para cada grande taxon é dada. Archaea estão em vermelho, bactérias em azul, algas em verde claro, fungos em marrom, protozoários em amarelo, plantas em verde escuro e animais em roxo.

Life in extreme environments, LJ Rothschild & RL Mancinelli, Nature 409, 1092-1101 (22 February 2001)

Deinococcus Radiodurans: a superbactéria!

- ☑ Fase estacionária: célula com 4 cópias do genoma; em multiplicação rápida, 8-10 cópias do genoma.
- ☑ Várias bactérias de radioresistências comparáveis são agora conhecidas
- ☑ Capacidade única de reparar o DNA danificado, isolando segmentos danificados em uma área controlada e os reparando
- ☑ Capaz de reparar pequenos fragmentos de um cromossomo inteiro

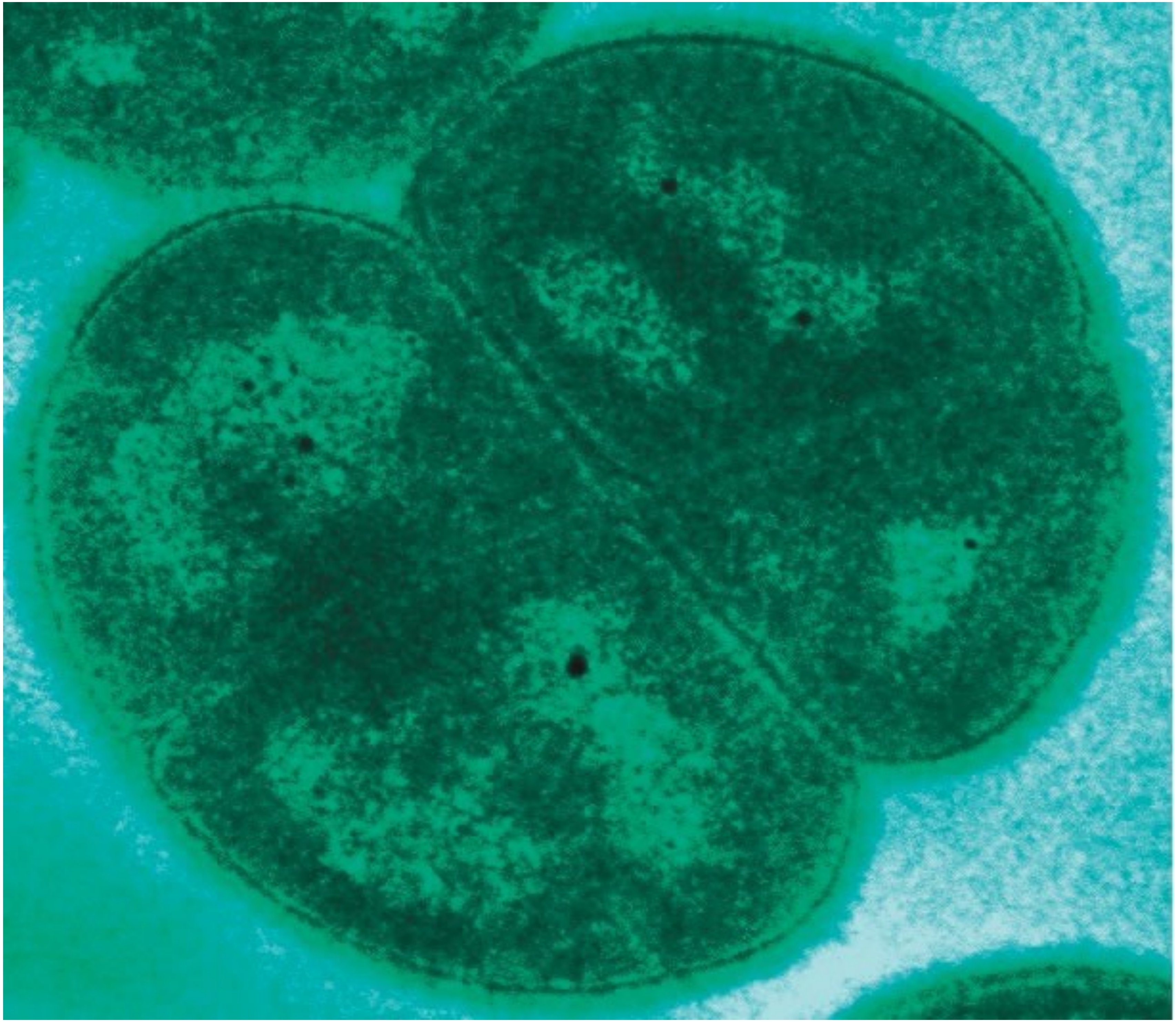
☑ Comparativos:

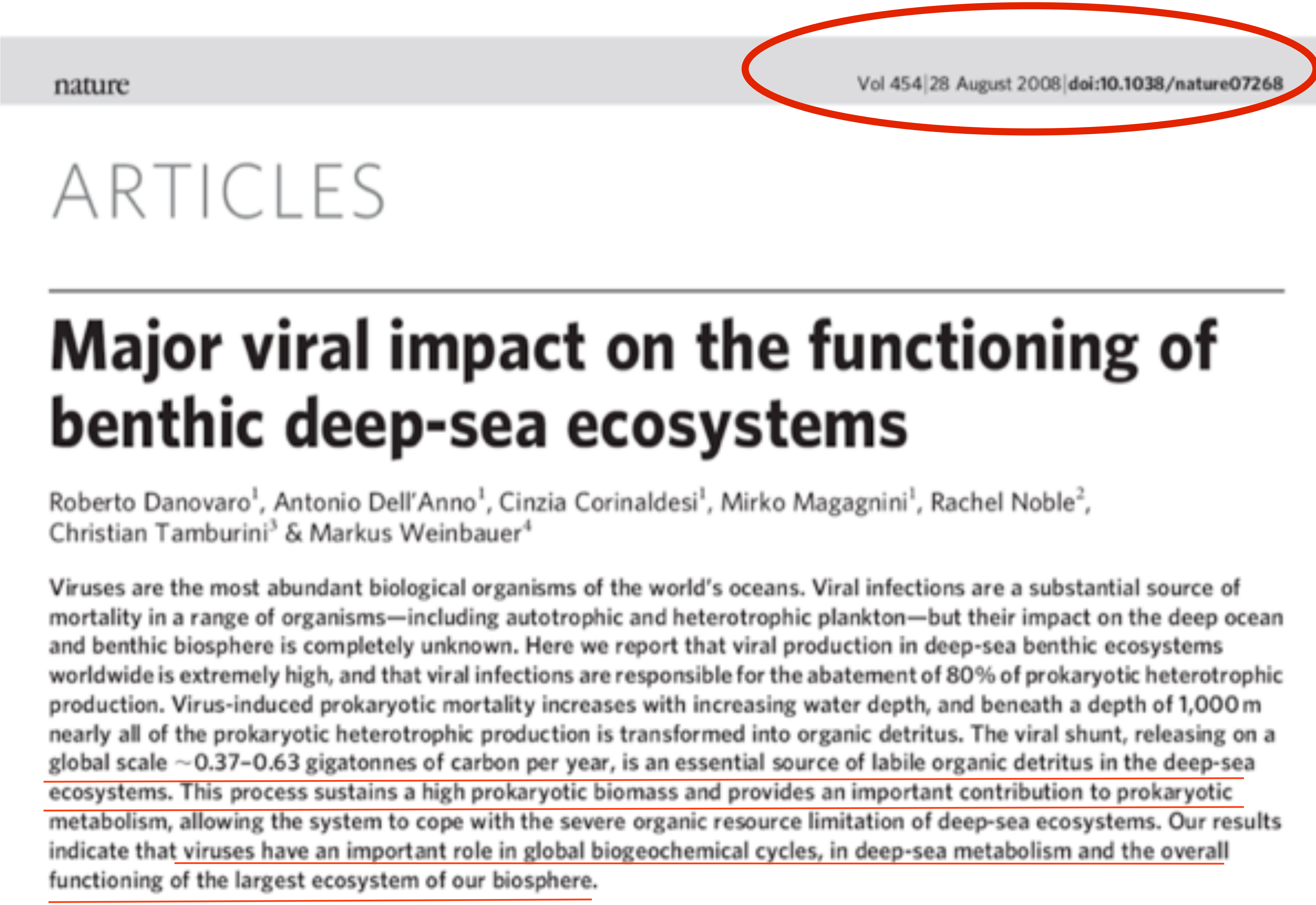
- ✓ Radiografia de tórax: ~ 1 mGy
- ✓ Missão da Apollo: ~ 1 mGy,
- ✓ Morte humana: > 5 Gy
- ✓ Morte E. Coli: > 200-800 Gy

☑ Comparativos:

- ✓ Morte tardígrado: > 4000 Gy
- ✓ D. radiodurans: suporta dose instantânea de até 5.000 Gy sem perda de viabilidade,
- ✓ Suporta dose instantânea de até 15.000 Gy com 37% de viabilidade.

Carlos Alexandre Wuensche (2019)





nature Vol 454|28 August 2008|doi:10.1038/nature07268

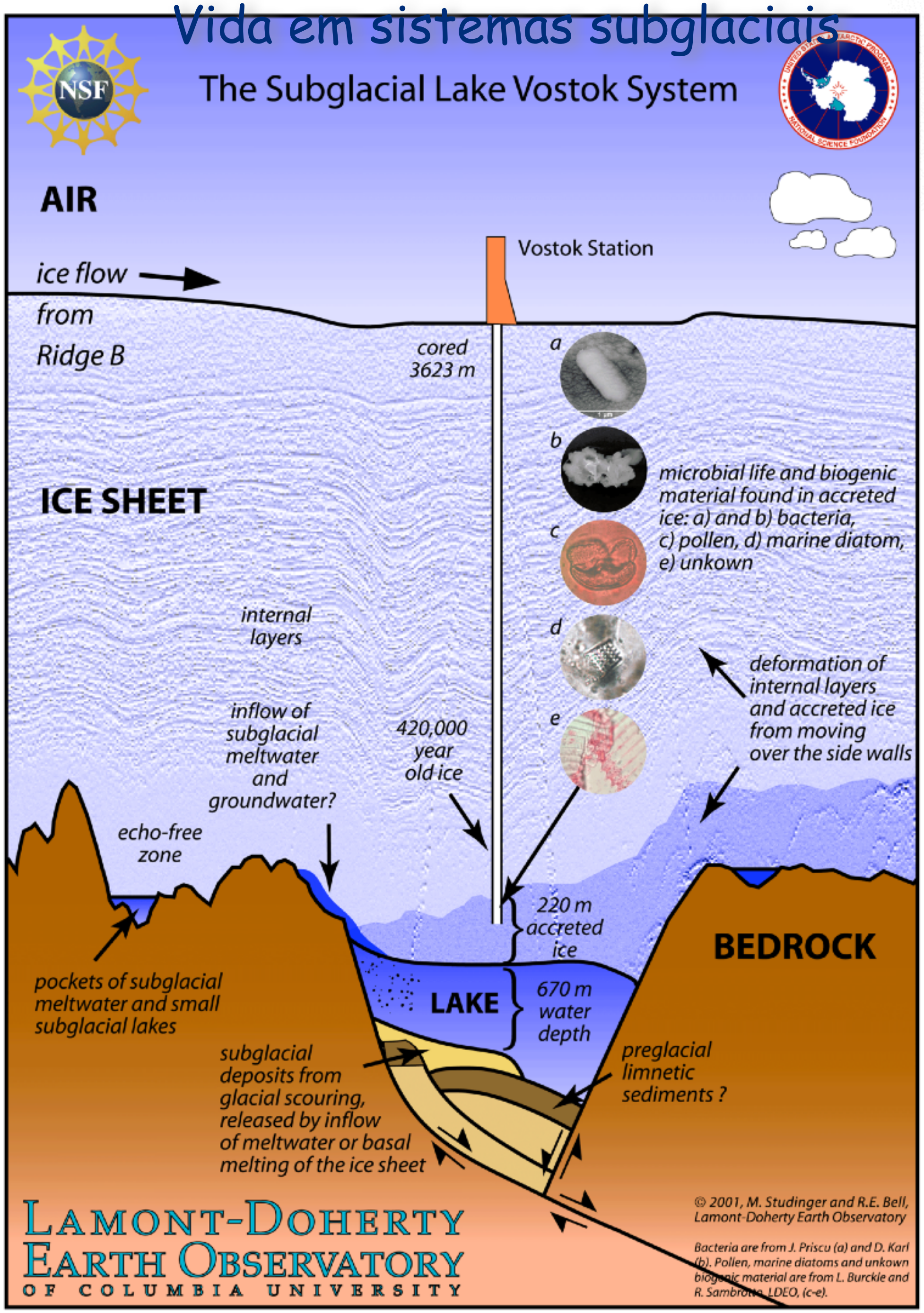
ARTICLES

Major viral impact on the functioning of benthic deep-sea ecosystems

Roberto Danovaro[1], Antonio Dell'Anno[1], Cinzia Corinaldesi[1], Mirko Magagnini[1], Rachel Noble[2], Christian Tamburini[3] & Markus Weinbauer[4]

Viruses are the most abundant biological organisms of the world's oceans. Viral infections are a substantial source of mortality in a range of organisms—including autotrophic and heterotrophic plankton—but their impact on the deep ocean and benthic biosphere is completely unknown. Here we report that viral production in deep-sea benthic ecosystems worldwide is extremely high, and that viral infections are responsible for the abatement of 80% of prokaryotic heterotrophic production. Virus-induced prokaryotic mortality increases with increasing water depth, and beneath a depth of 1,000 m nearly all of the prokaryotic heterotrophic production is transformed into organic detritus. The viral shunt, releasing on a global scale ~0.37–0.63 gigatonnes of carbon per year, is an essential source of labile organic detritus in the deep-sea ecosystems. This process sustains a high prokaryotic biomass and provides an important contribution to prokaryotic metabolism, allowing the system to cope with the severe organic resource limitation of deep-sea ecosystems. Our results indicate that viruses have an important role in global biogeochemical cycles, in deep-sea metabolism and the overall functioning of the largest ecosystem of our biosphere.

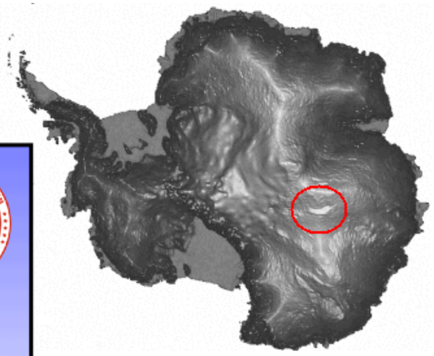
Vida em sistemas subglaciais



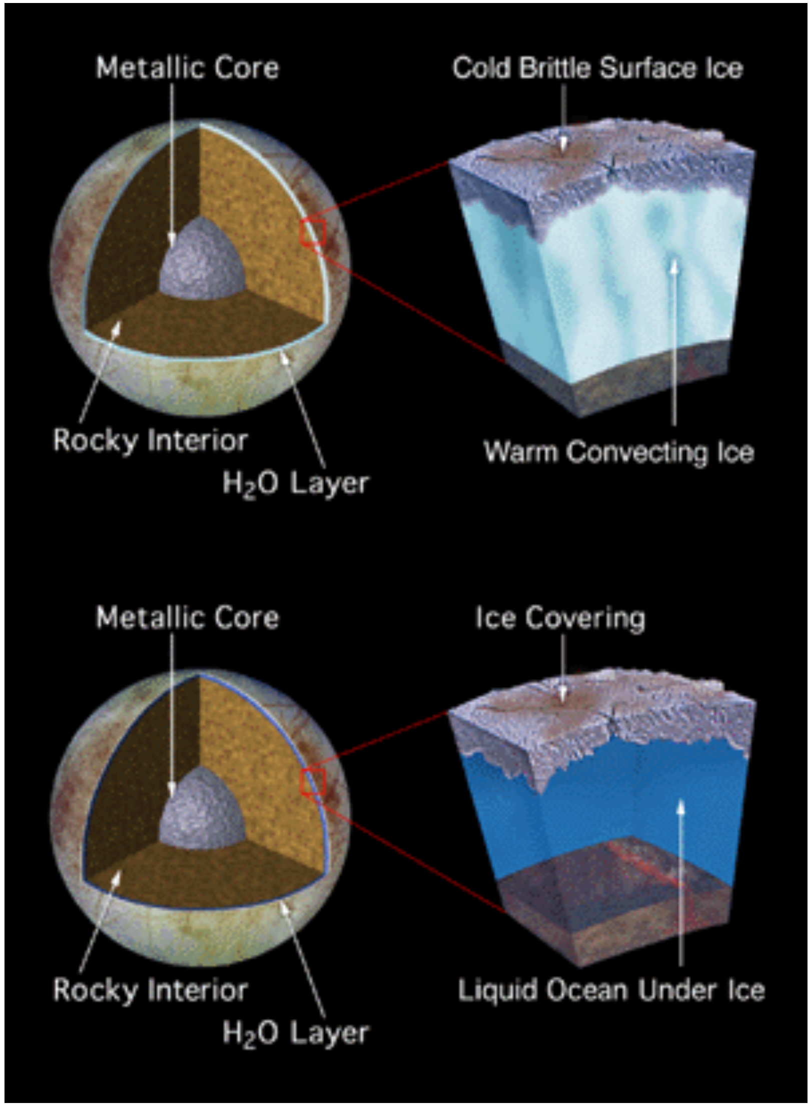
The Subglacial Lake Vostok System

© 2001, M. Studinger and R.E. Bell, Lamont-Doherty Earth Observatory

Bacteria are from J. Priscu (a) and D. Karl (b). Pollen, marine diatoms and unkown biogenic material are from L. Burckle and R. Sambrotto, LDEO, (c-e).



Vida em sistemas subglaciais



FIM DA AULA 5