新元古代雪球事件和真核生物的早期演化

（包括宏体藻类的起源和早期演化）


寒武纪大爆发
埃迪卡拉动物群
真核生物的辐射
叠层石微生物生态席
宏体炭质
压膜化石
真核生物出现
最古老的化石
最早的生命活动
固体地球形成
亿年
5.44
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25
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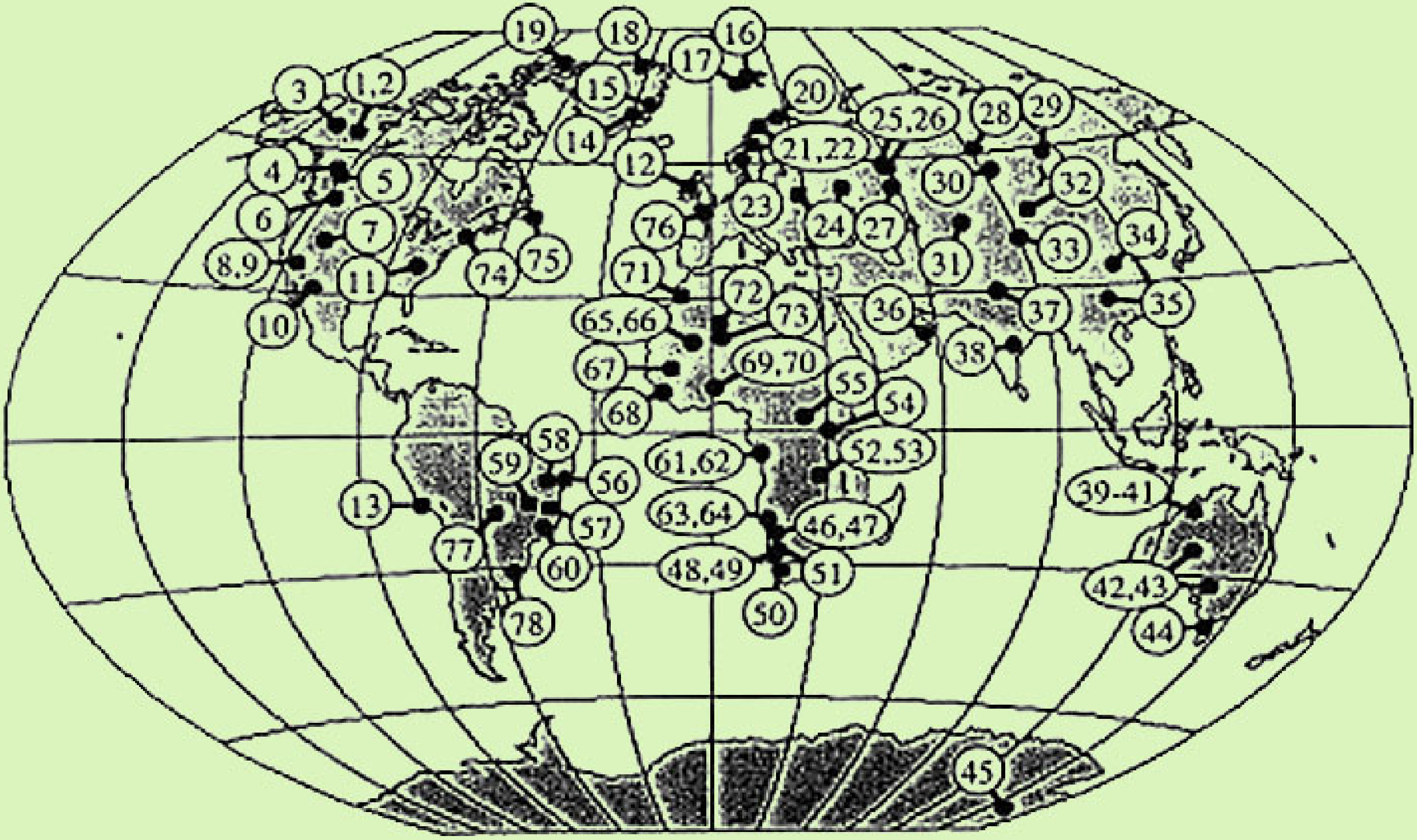
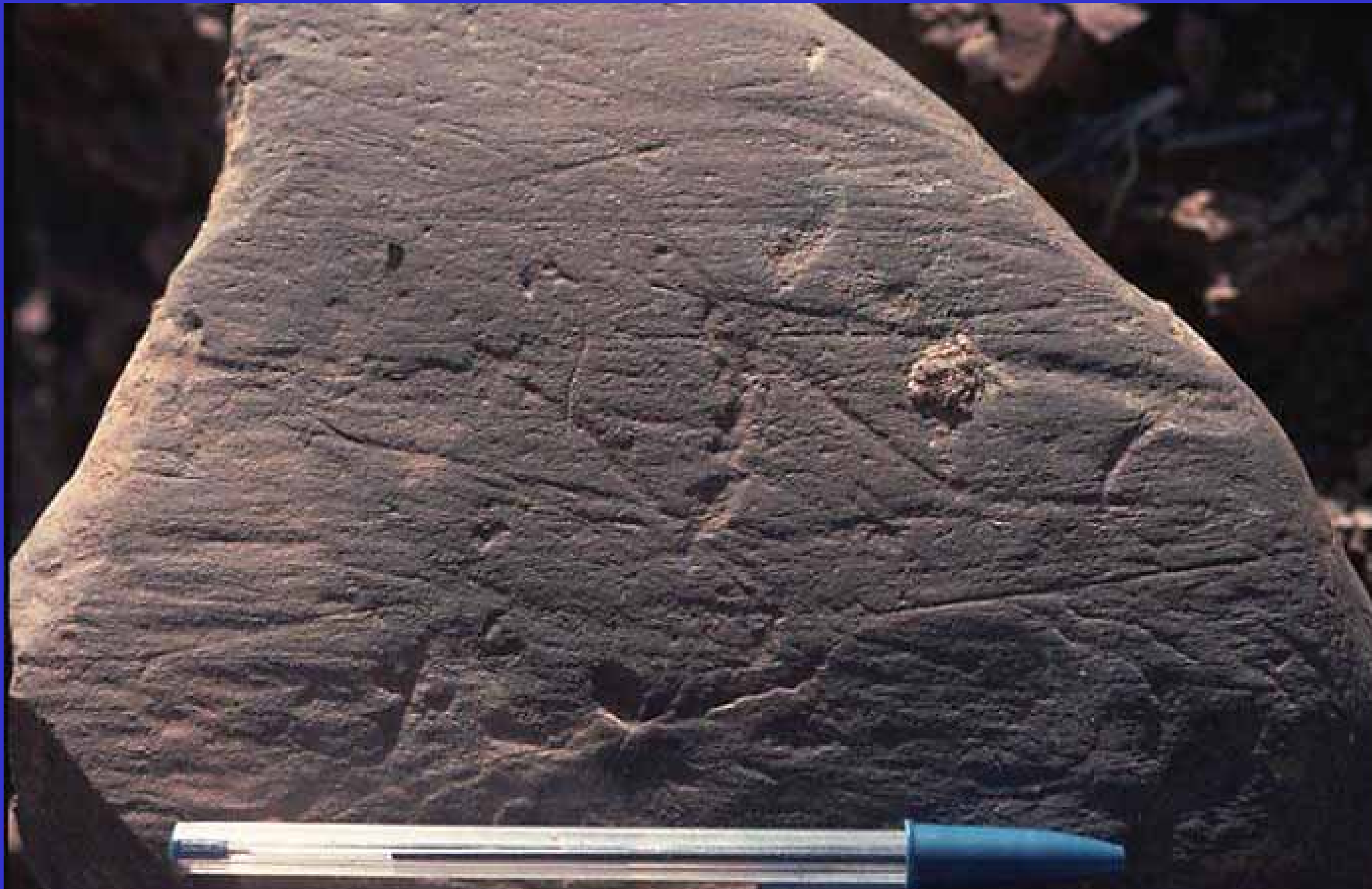
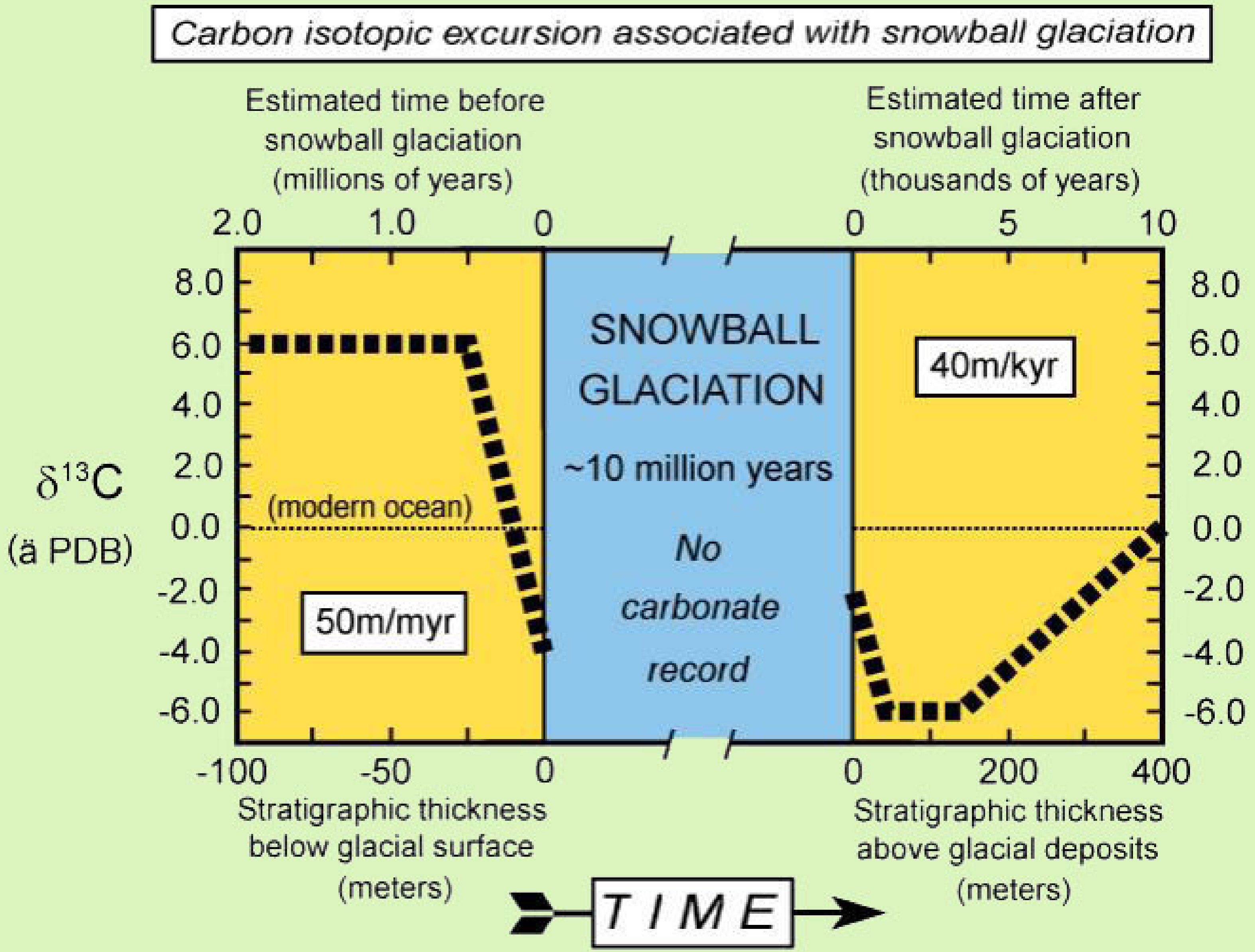
Є
PreЄ
早期生命重大演化事件

新元古代雪球事件？

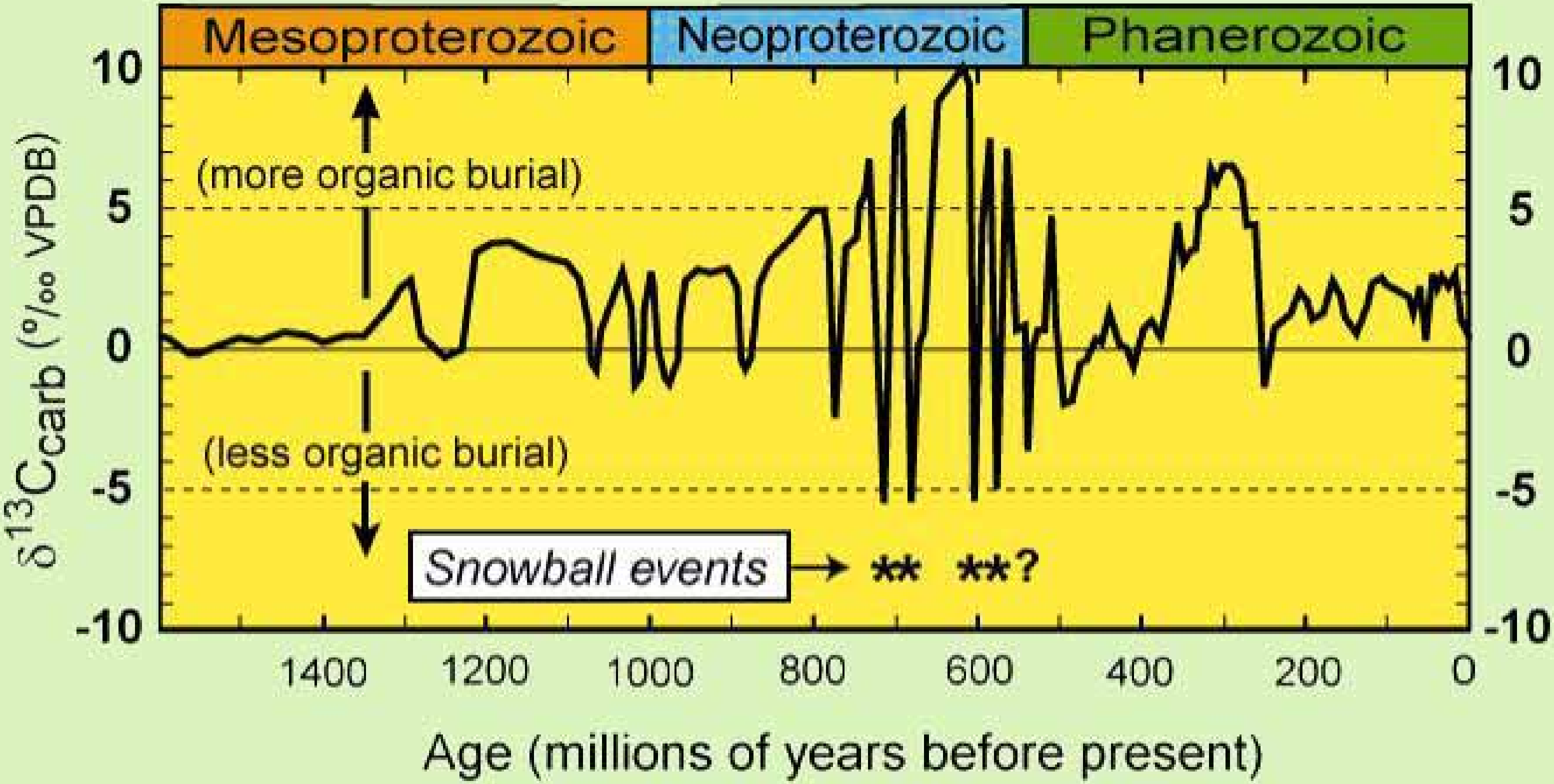


Neoproterozoic glaciogenic rocks (David Evans, Am. J. Sci., 2000)



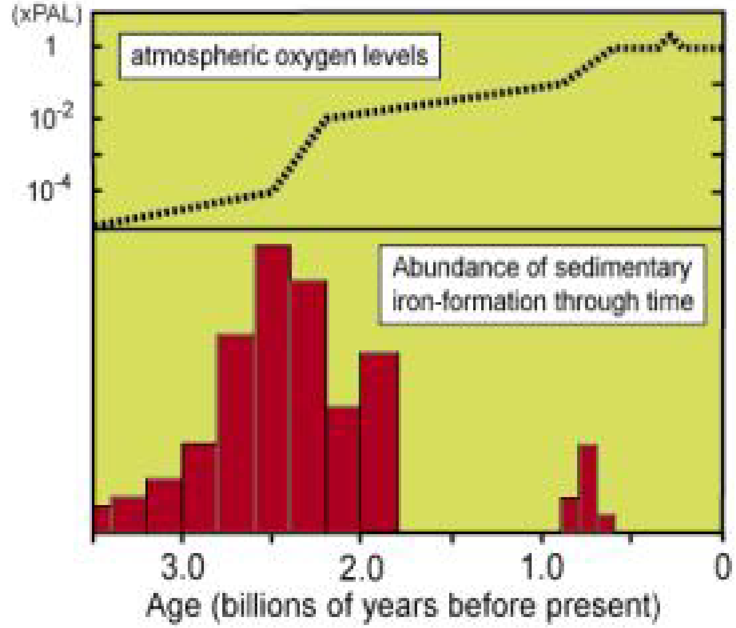


Carbon isotopic excursion associated with snowball glaciation
Estimated time before snowball glaciation (millions of years)
2.0
1.0
0
Estimated time after snowball glaciation (thousands of years)
0
5
10
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
δ13C
(ä PDB)
(modern ocean)
50m/myr
SNOWBALL GLACIATION
~10 million years
No carbonate record
40m/kyr
-100
-50
0
0
200
400
Stratigraphic thickness below glacial surface (meters)
Stratigraphic thickness above glacial deposits (meters)
TIME



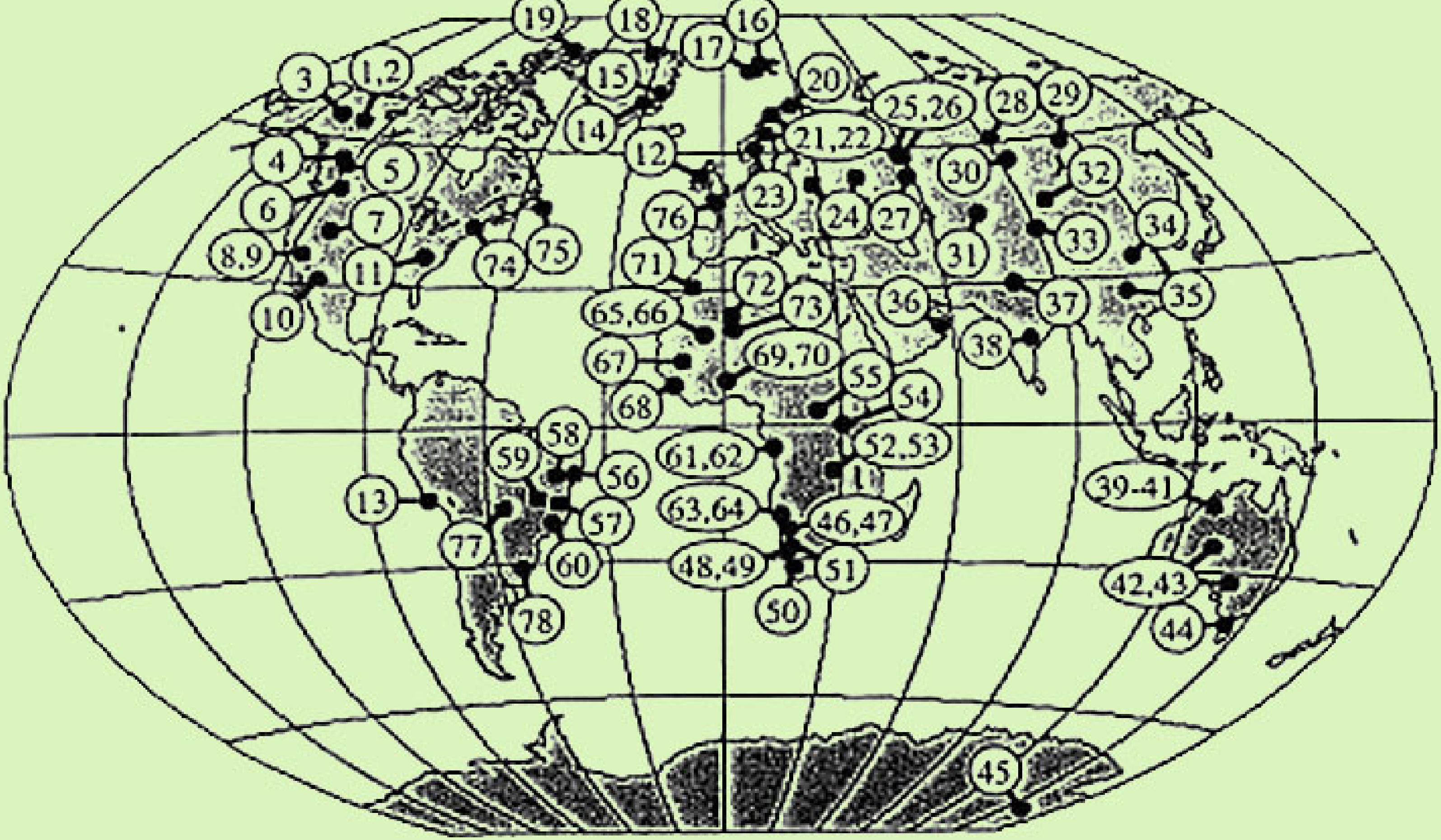
Secular variation in carbon isotopic composition of shallow marine carbonates over the last 1600 million years (adapted from Kaufman, 1997; Kah et al., 1999).

If O_2 is absent, iron is soluble as ferrous (Fe^{2+}) ion.
If O_2 is present, iron is insoluble as ferric (Fe^{3+}) ion.



Snowball earth: anoxic ocean

Deglaciation: ocean ventilation



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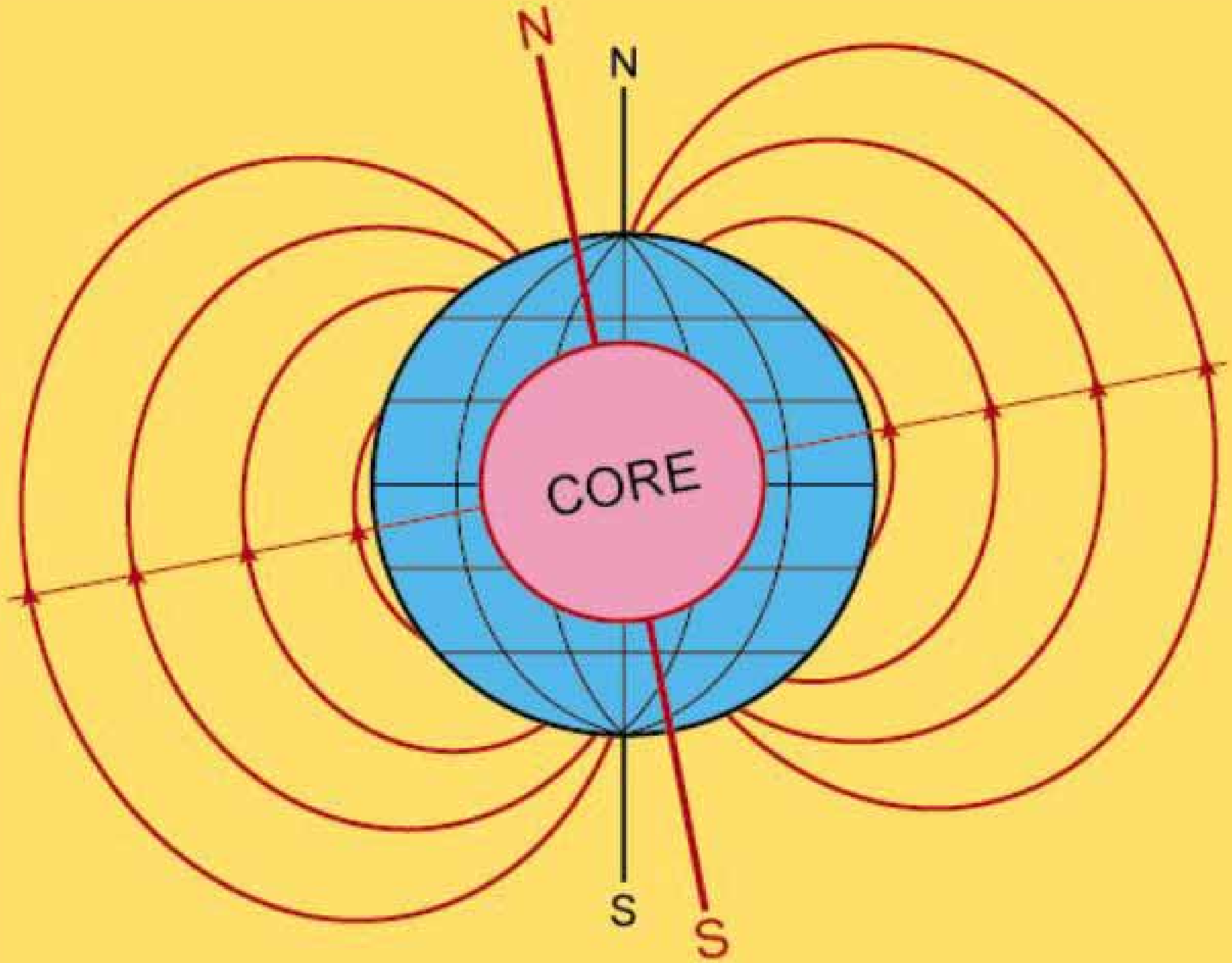
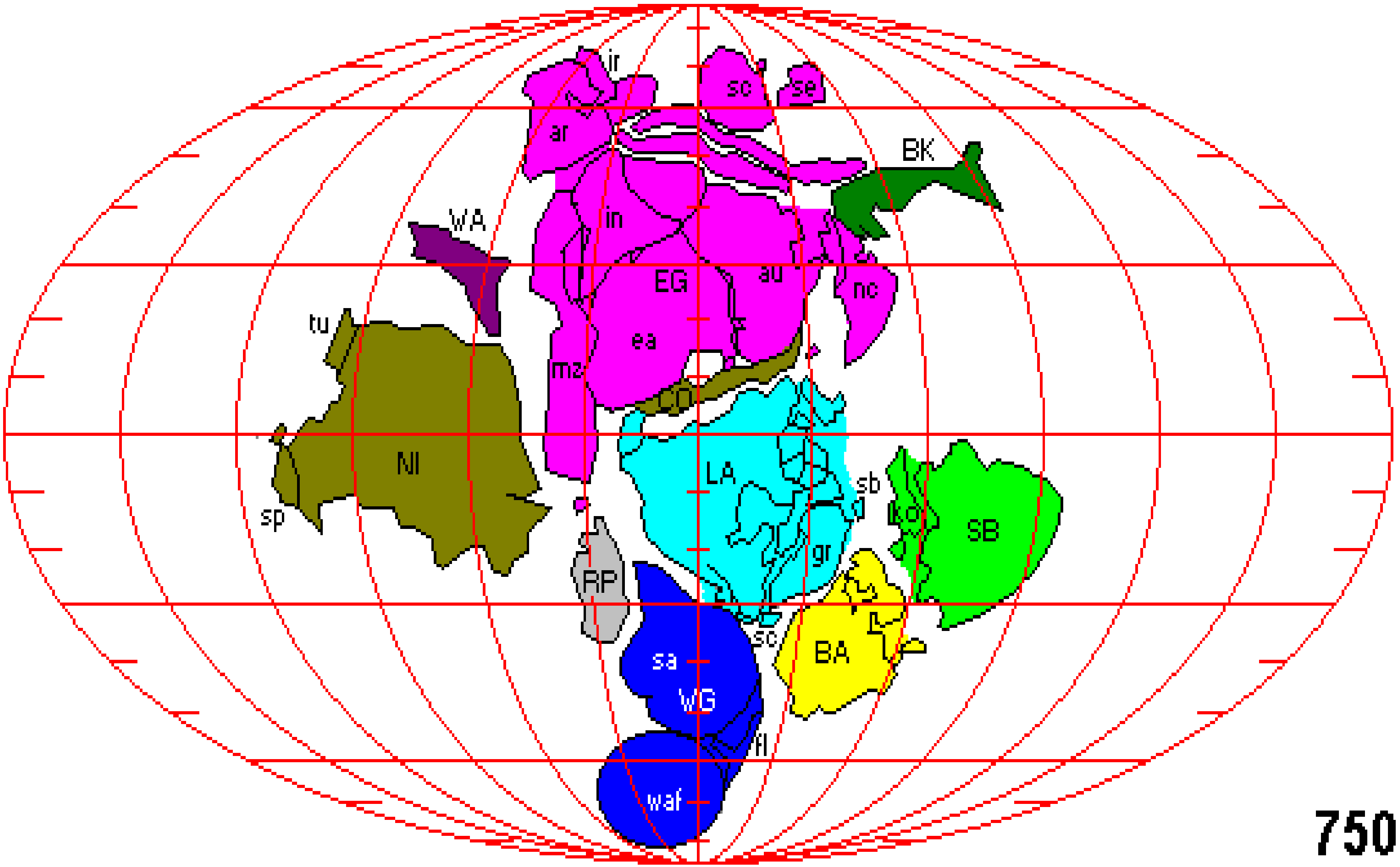


THE EARTH'S DIPOLAR MAGNETIC FIELD



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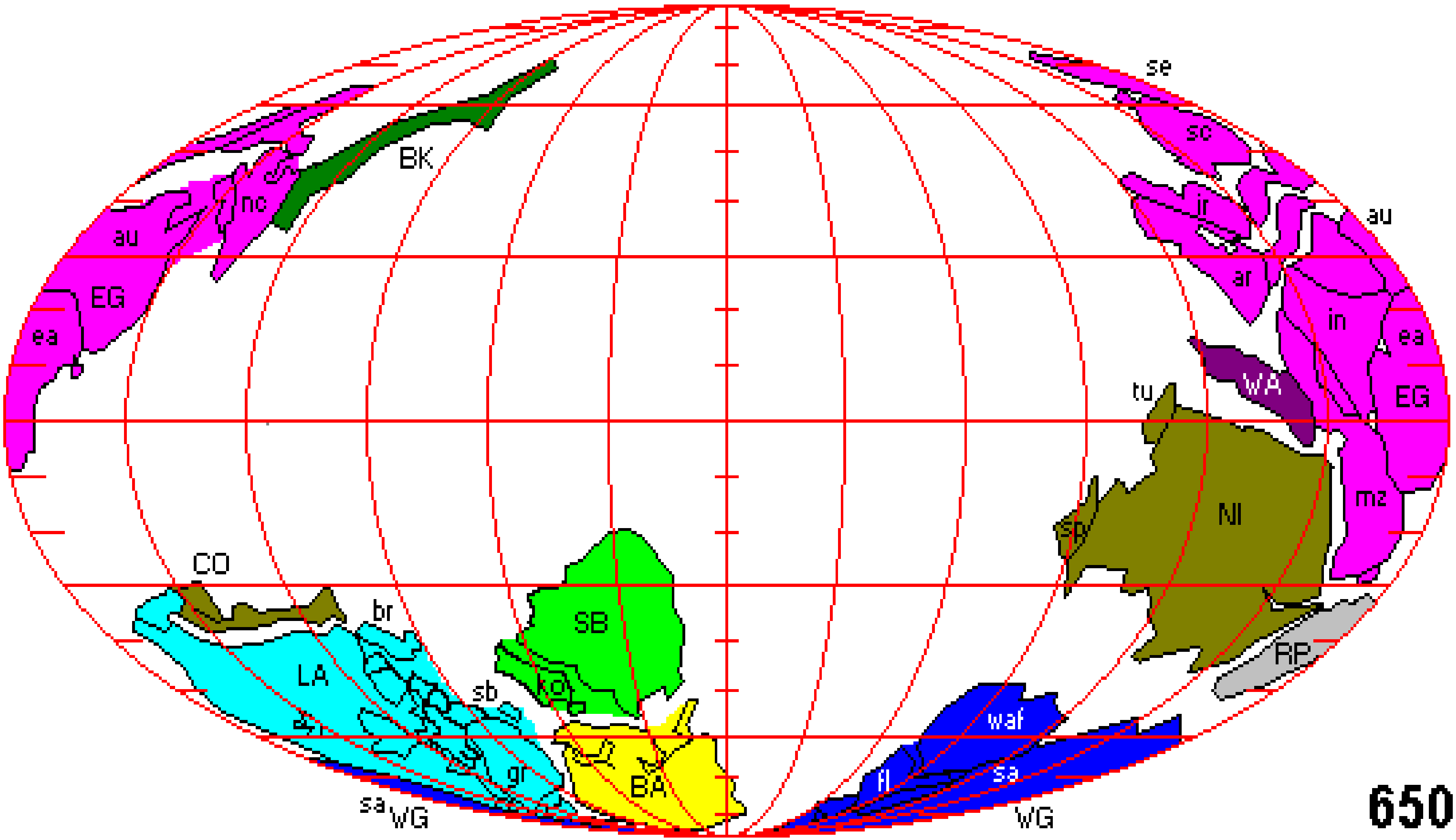
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650

Hypothetical Neoproterozoic paleogeography

Consequences:

1. Organic production is focused in the tropical ocean, which becomes anoxic. Organic carbon burial is enhanced, causing ^{13}C enrichment.

2. Meridional heat transport is reduced, causing colder poles and hotter tropics. Polar sea-ice expands, increasing ice-albedo feedback.

3. Continental fragmentation enhances silicate weathering and global temperatures fall. Polar sea ice grows but continents remain ice-free.

鲍尔--霍夫曼（Paul F. Hoffman）1998年：在距今六到八亿年间（即新元古代晚期）地球曾经历过数次极端寒冷的”雪球”事件。在这几期冰期事件中，地表平均温度在摄氏零下50度以下，整个海洋覆盖着 1 到 2 公里厚的冰层，地球就像一个“大雪球”（snowball），每期冰期事件持续几百万年。冰期结束后，地球又转而进入一个温室时期，在此其间地表平均温度在摄氏零上50度以上。

CARBONATE WEATHERING

weathering:

$CO_2 + H_2O + CaCO_3 \rightarrow$

transport:

$Ca^{2+} + 2HCO_3^- \rightarrow$

sedimentation:

$CaCO_3 + H_2O + CO_2$

SILICATE WEATHERING

weathering:

$2CO_2 + 2H_2O + CaSiO_3 \rightarrow$

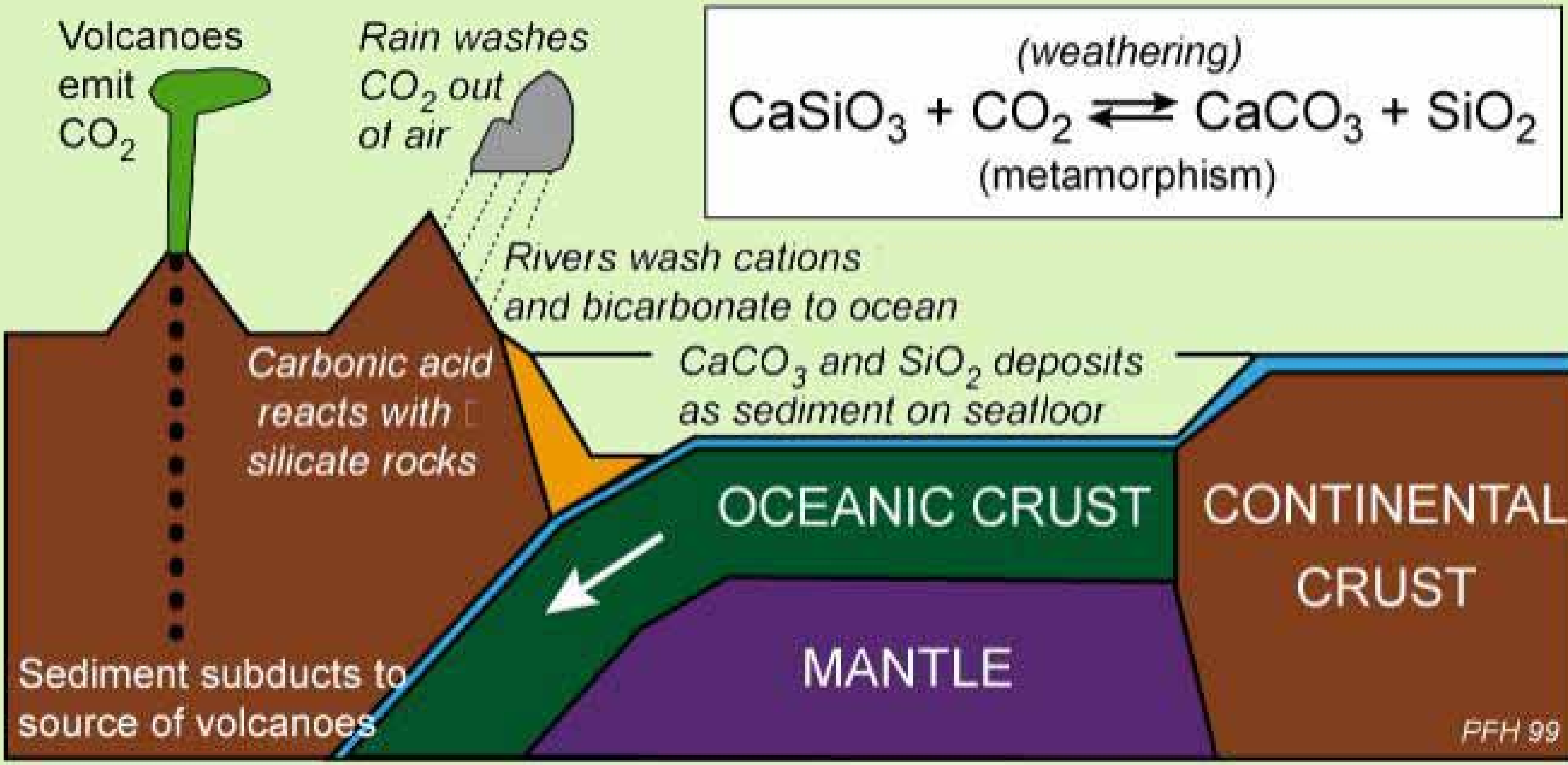
transport:

$Ca^{2+} + 2HCO_3^- + 2H^+ + SiO_3^{2-} \rightarrow$

deposition:

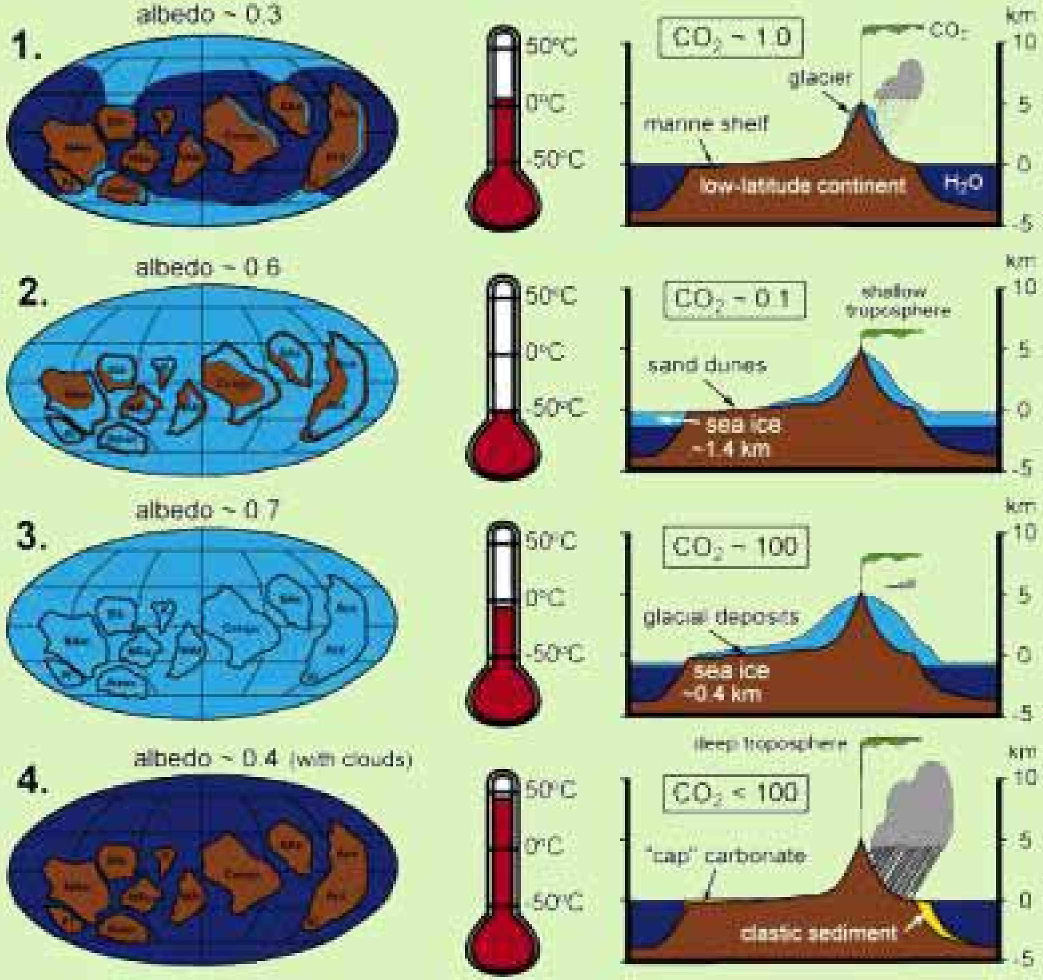
$CaCO_3 + SiO_2.H_2O + H_2O + CO_2$

THE CARBON CYCLE

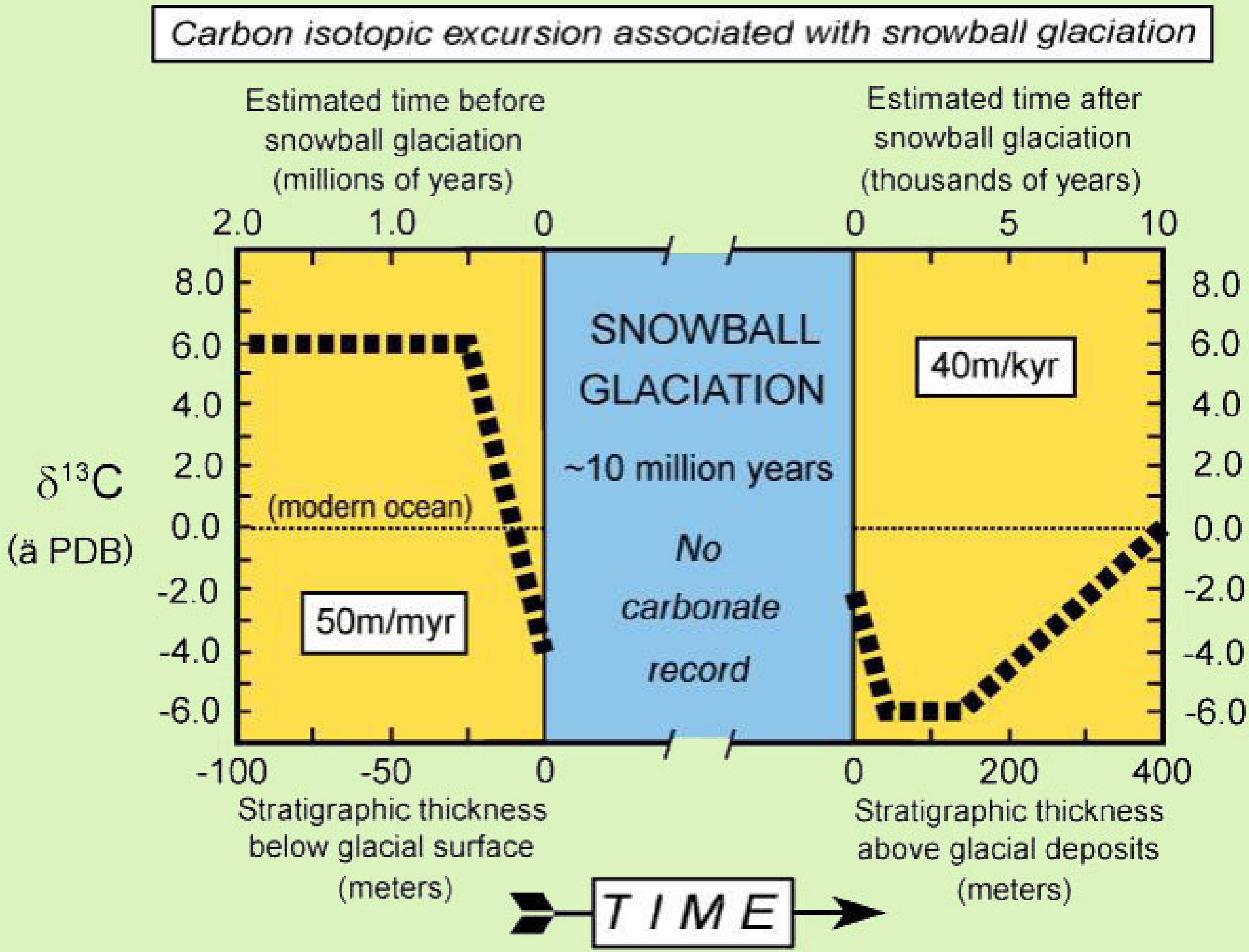


[Processes in italics are inoperative in a snowball Earth]

SNOWBALL FREEZE-FRY SCENARIO



Cartoon of one complete 'snowball' episode, showing variations in planetary albedo, atmospheric carbon dioxide, surface temperature, tropospheric depth, precipitation, glacial extent, and sea ice thickness. Stage 1, incipient glaciation; 2, runaway ice-albedo (onset of 'snowball'); 3, end of 'snowball'; 4, transient 'hothouse' aftermath.



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δ13C
(ä PDB)
(modern ocean)
50m/myr
SNOWBALL GLACIATION
~10 million years
No carbonate record
40m/kyr
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-50
0
0
200
400
Stratigraphic thickness below glacial surface (meters)
Stratigraphic thickness above glacial deposits (meters)
TIME

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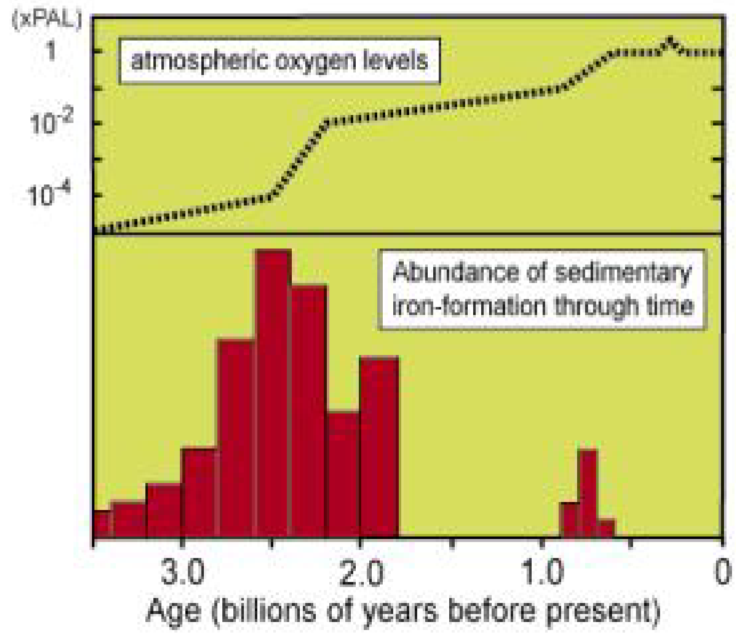
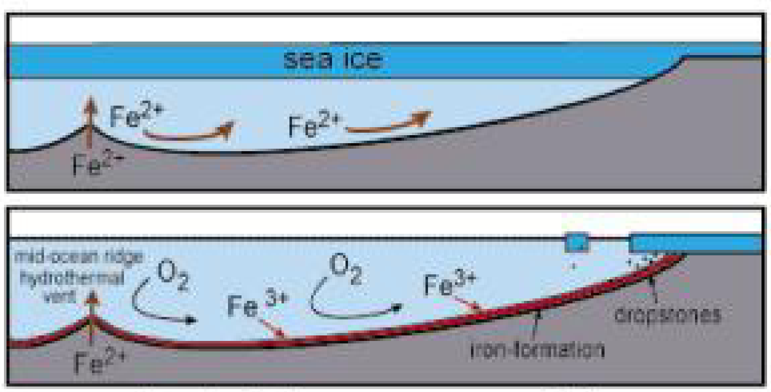
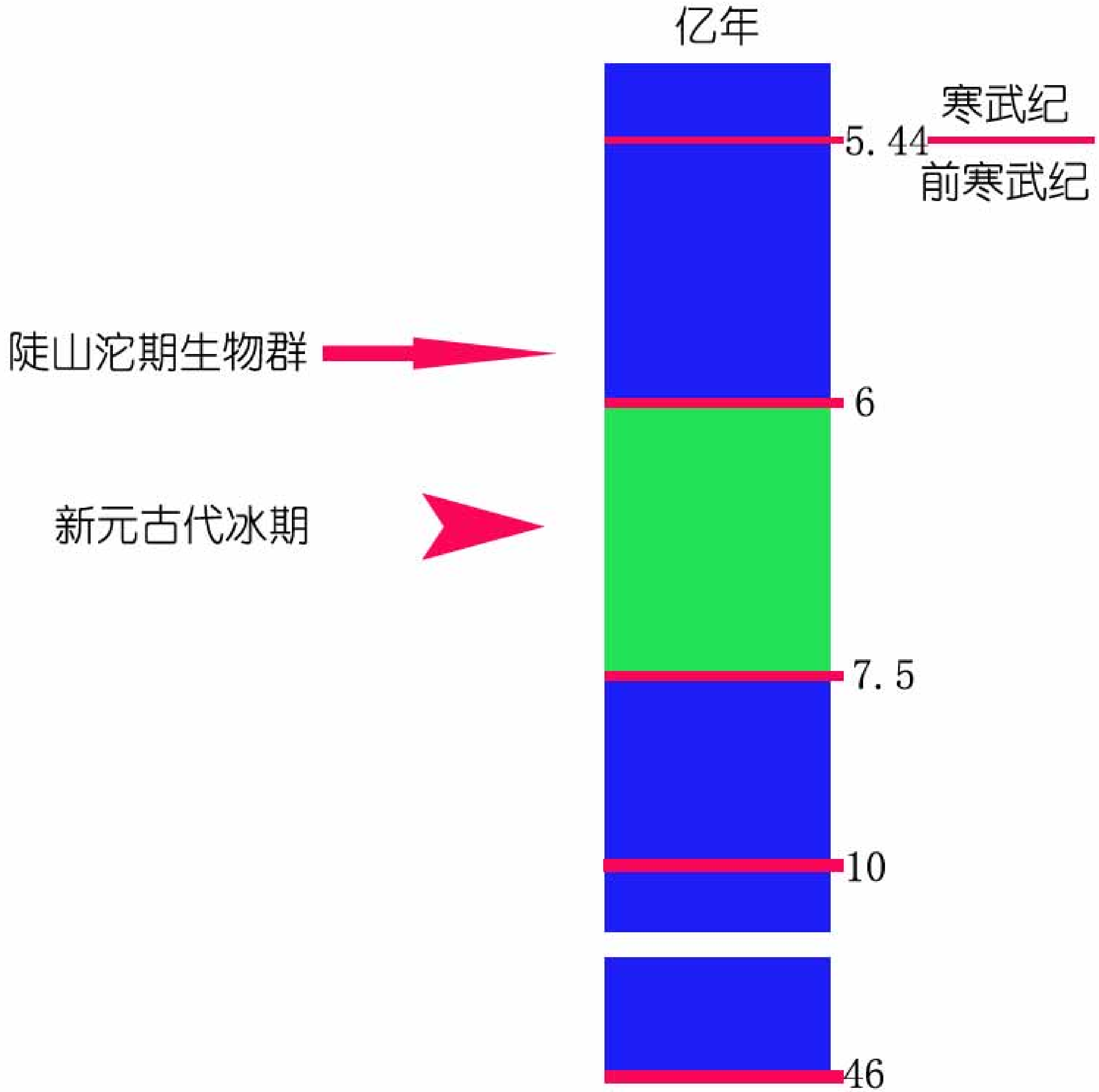


Snowball earth: anoxic ocean



Deglaciation: ocean ventilation

真核生物的早期演化


亿年
寒武纪
5.44
前寒武纪
陡山沱期生物群
6
新元古代冰期
7.5
10
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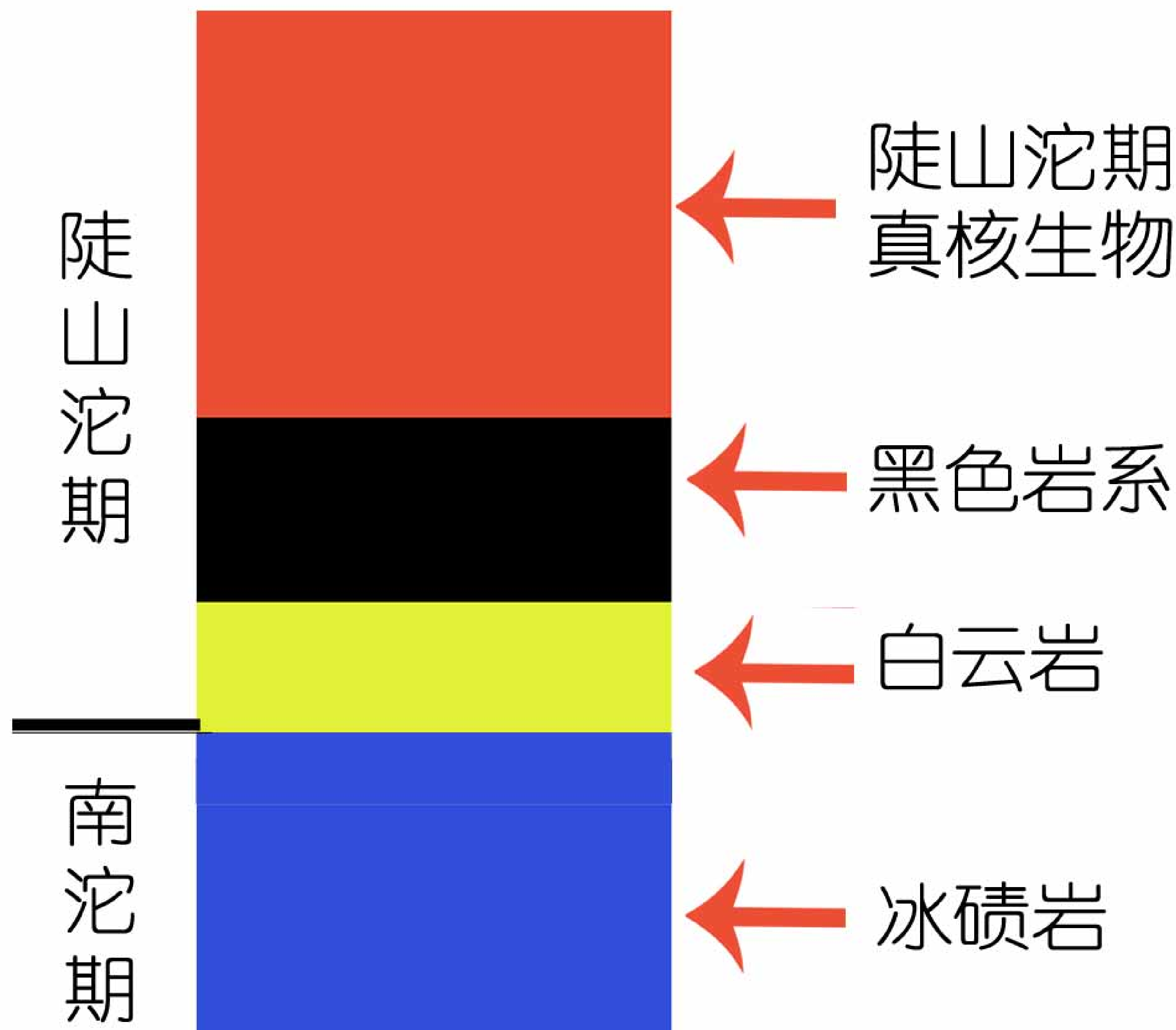
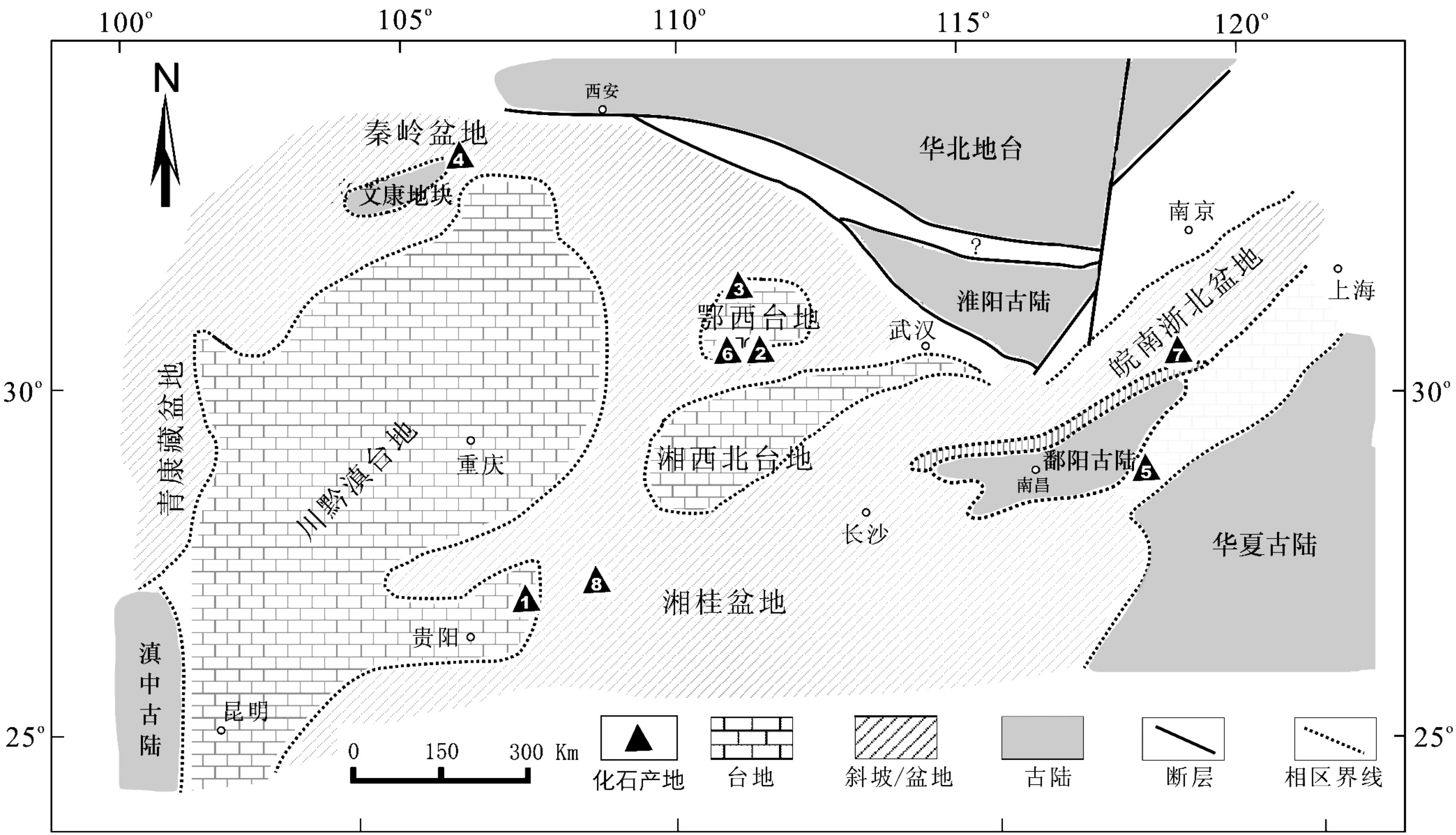

陡山沱期
南沱期
陡山沱期
真核生物
黑色岩系
白云岩
冰碛岩



Late Precambrian DST Formation

陡山沱期真核生物

一、浮游单细胞类型——疑源类

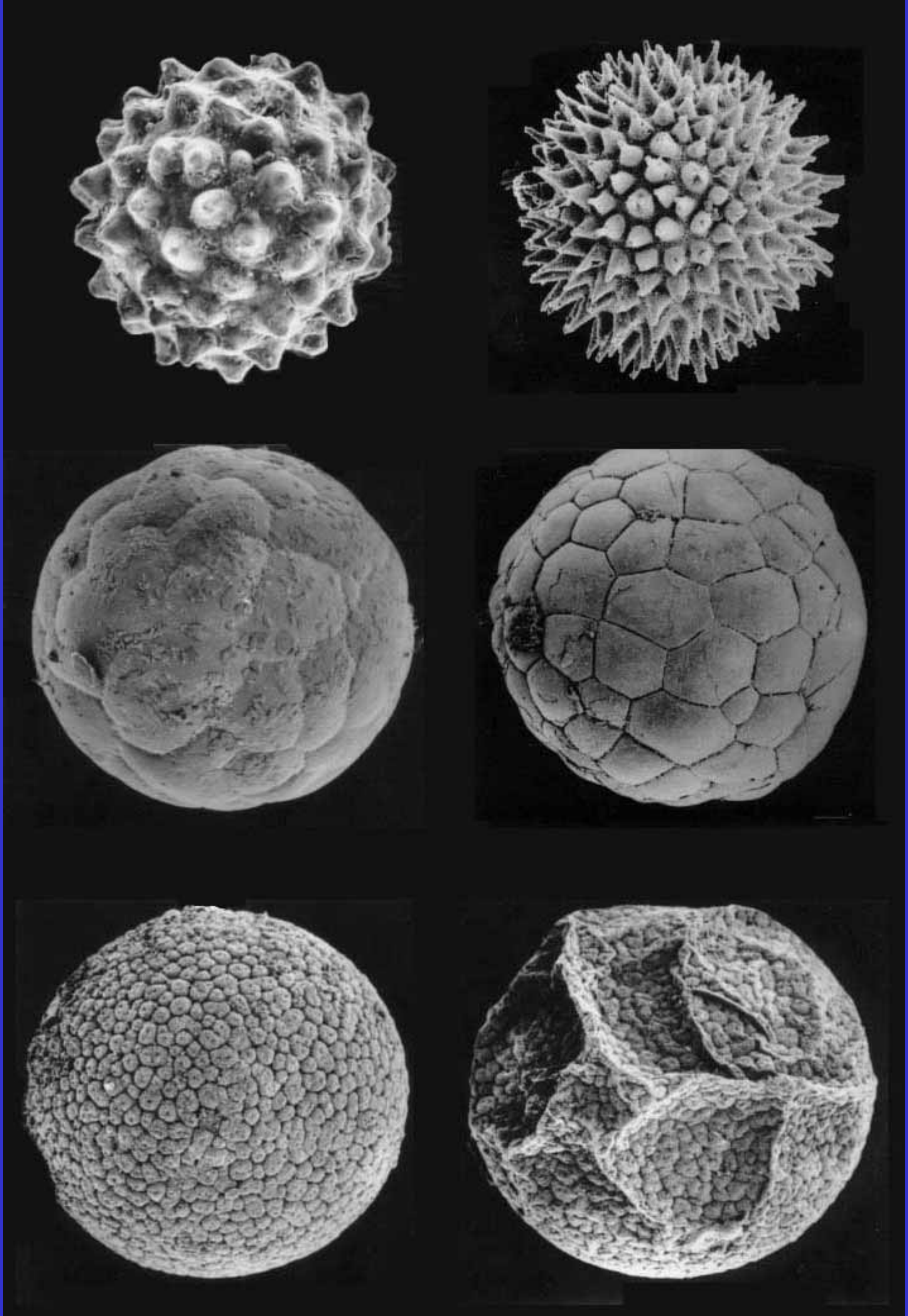
二、底栖多细胞藻类

（**1**）红藻

（**2**）褐藻

（**3**）绿藻

三、动物化石

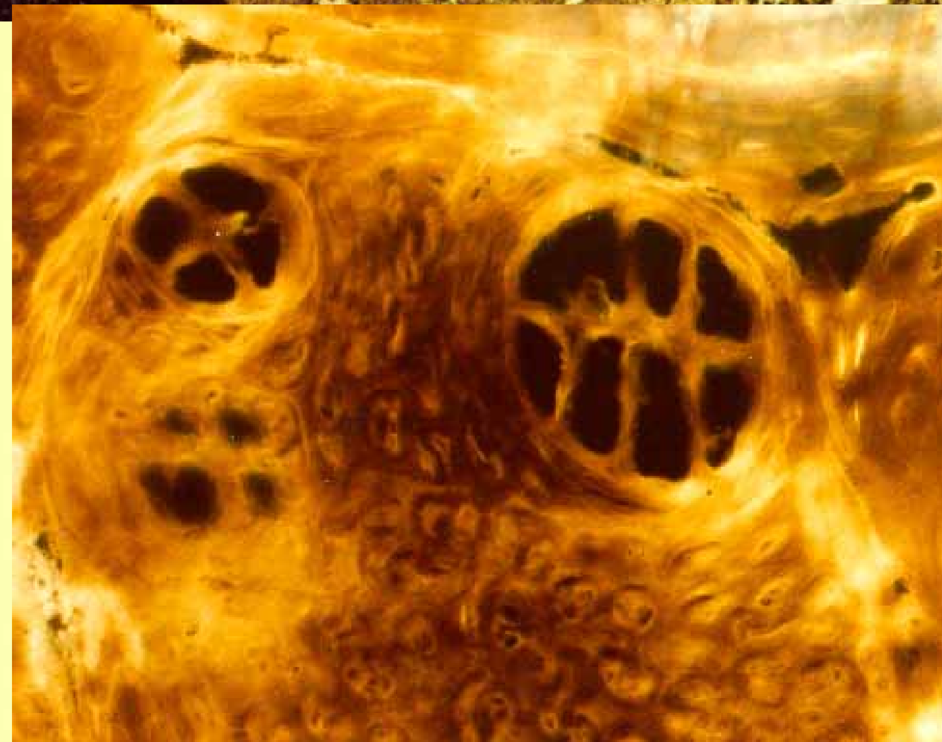


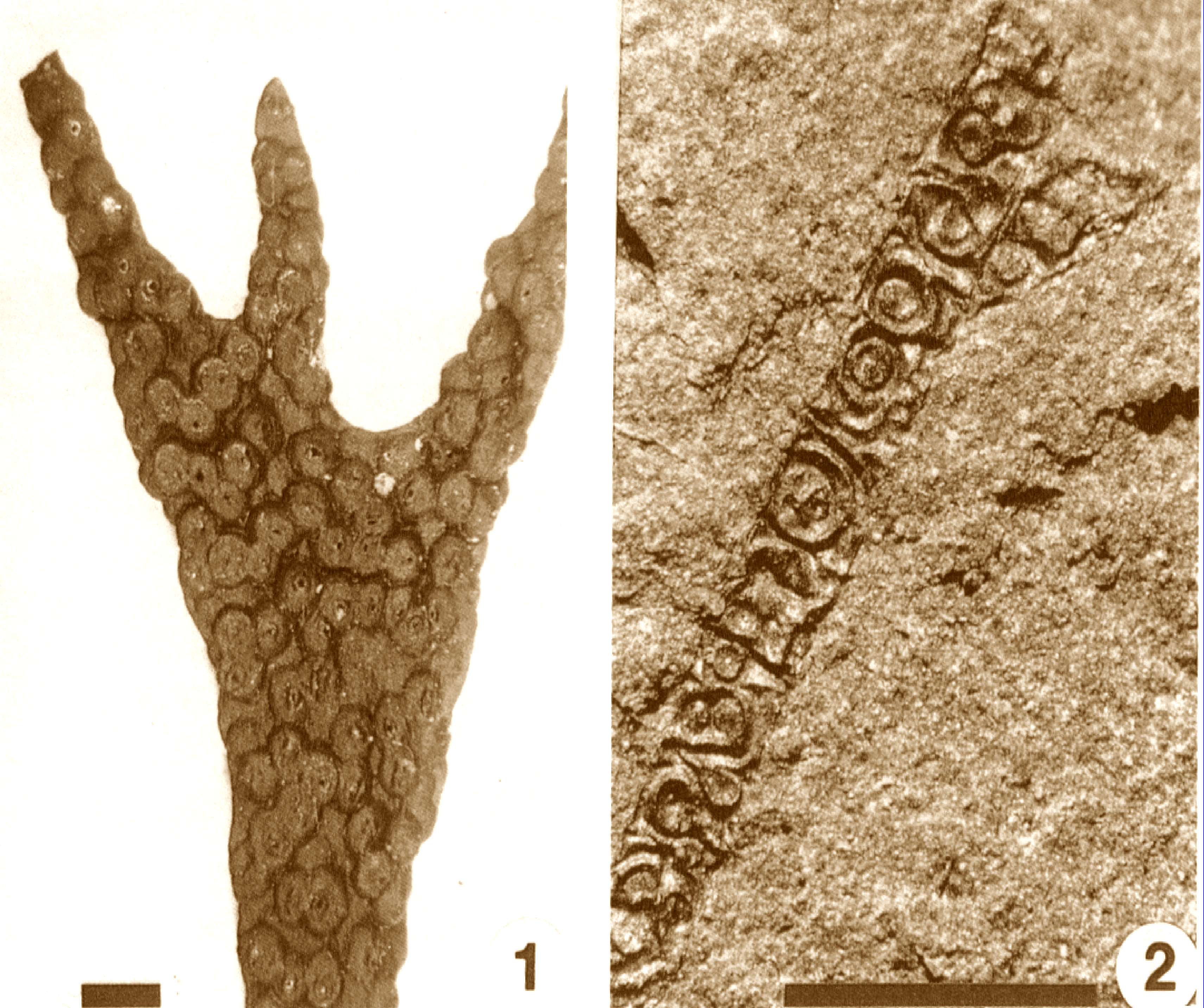
真核的浮游类群30余属

底栖多细胞藻类60多种

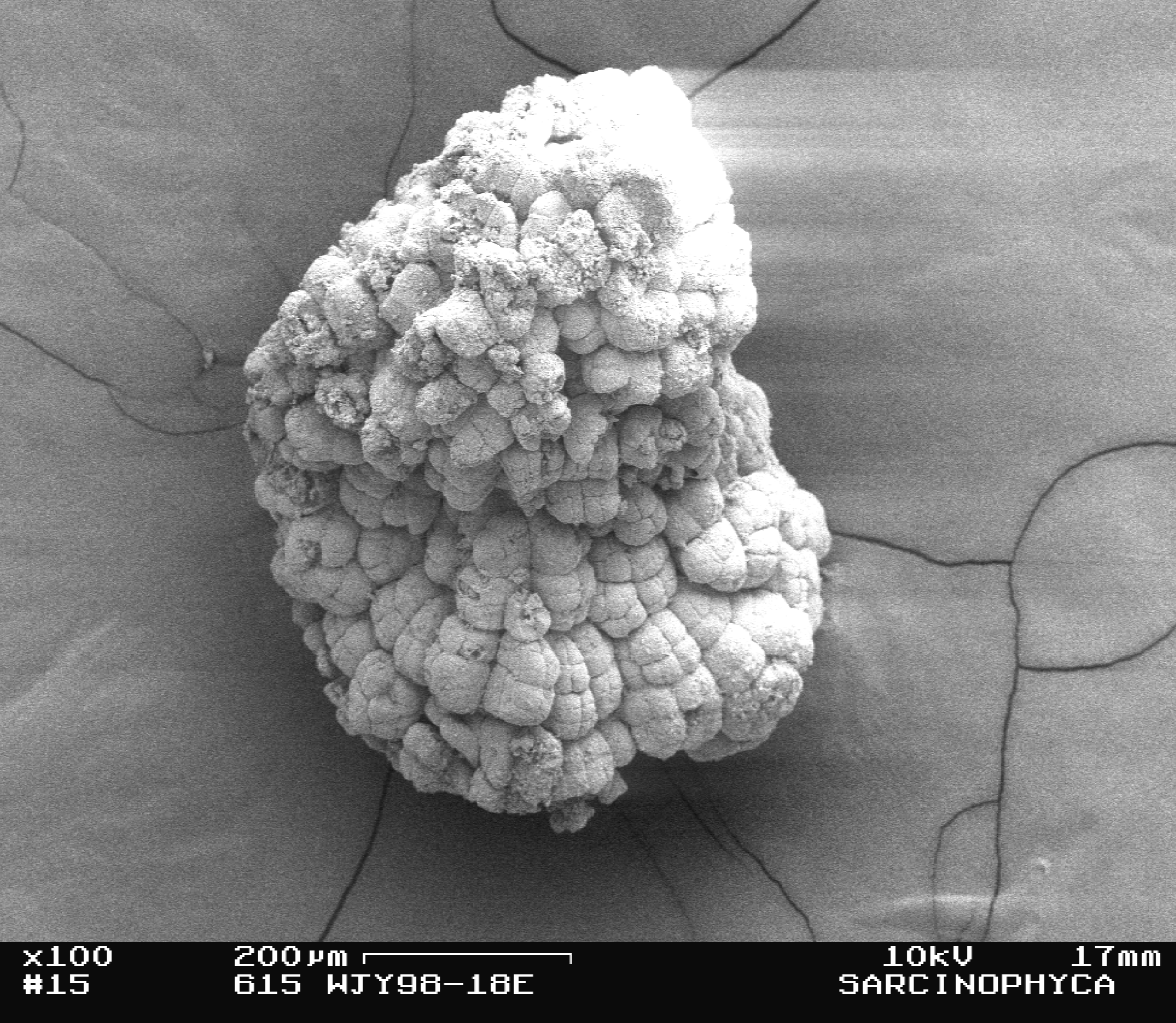
红藻


陡山沱期
红藻化石
Solenopora
Craticula
Sporolithon
Corallina
志留纪
陡山沱期



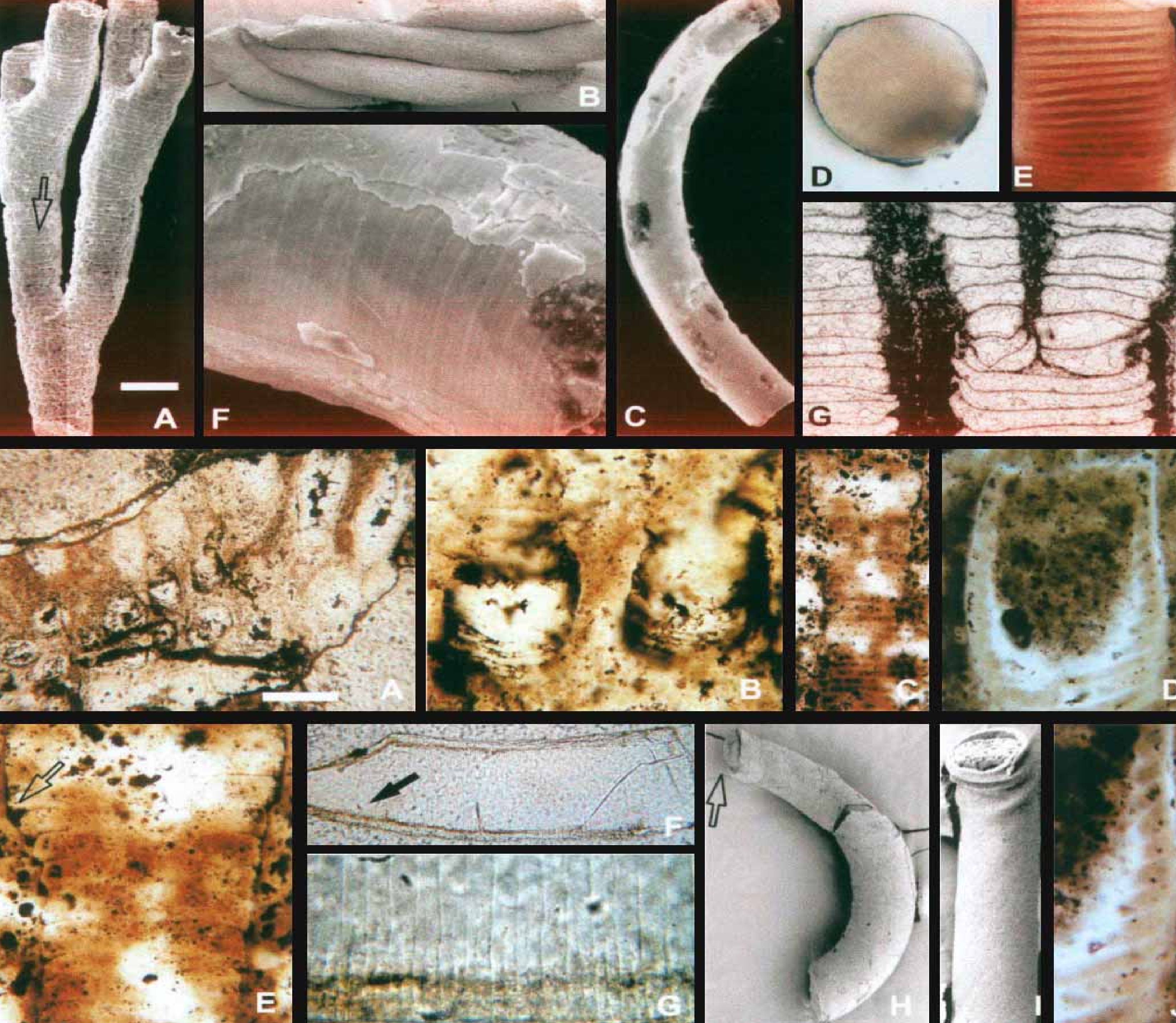


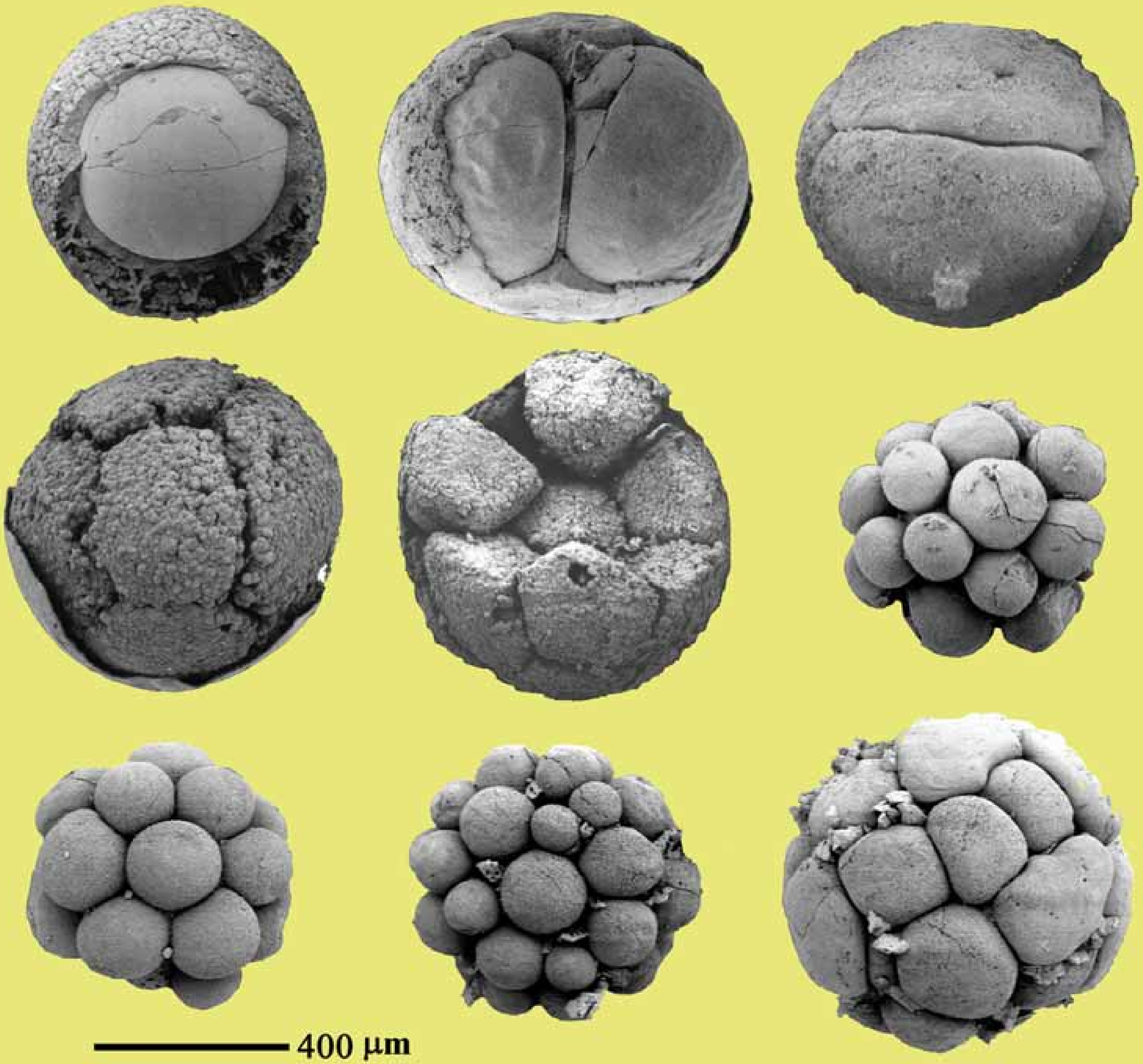
褐藻



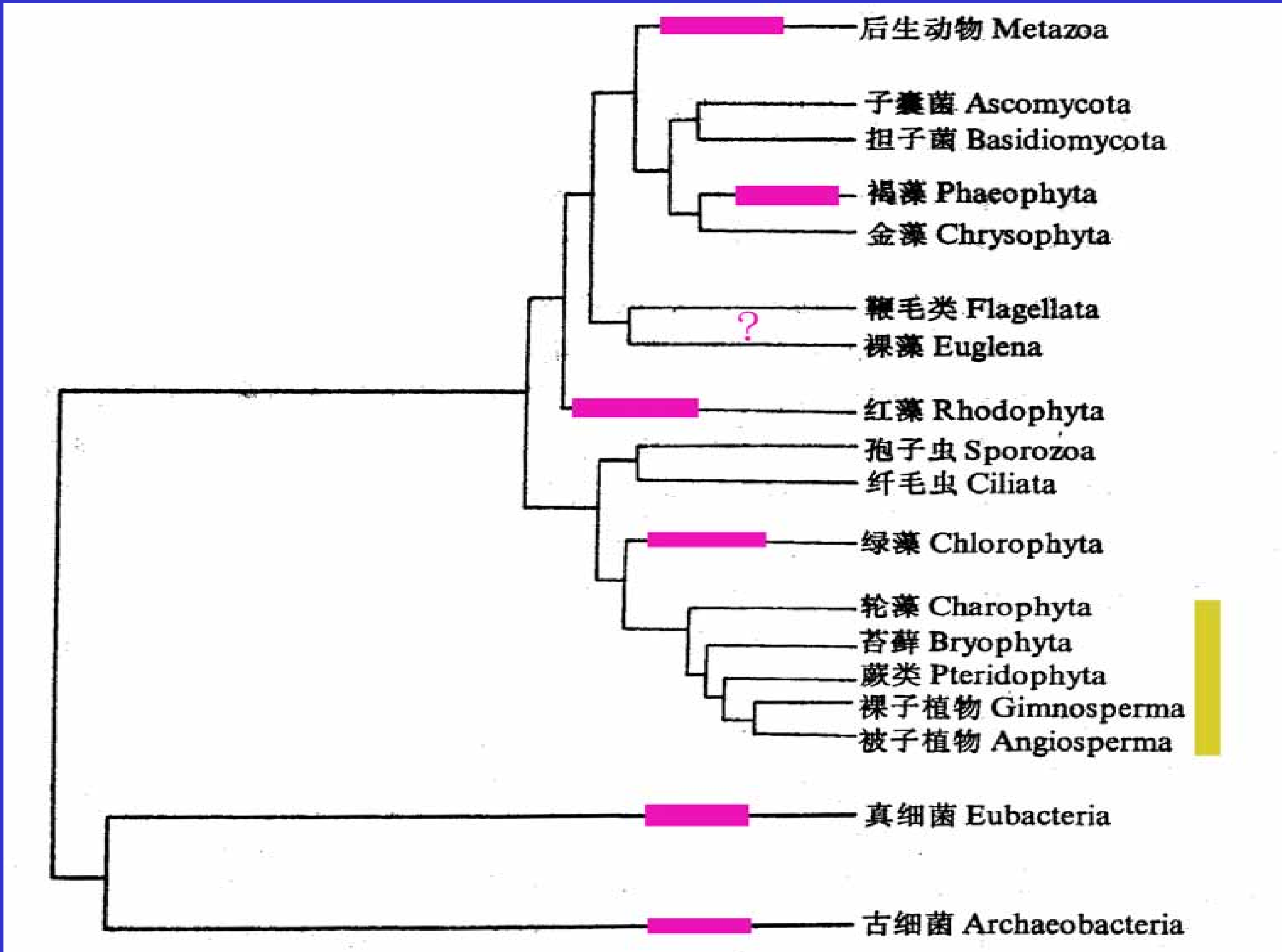
绿藻

动物化石——腔肠动物

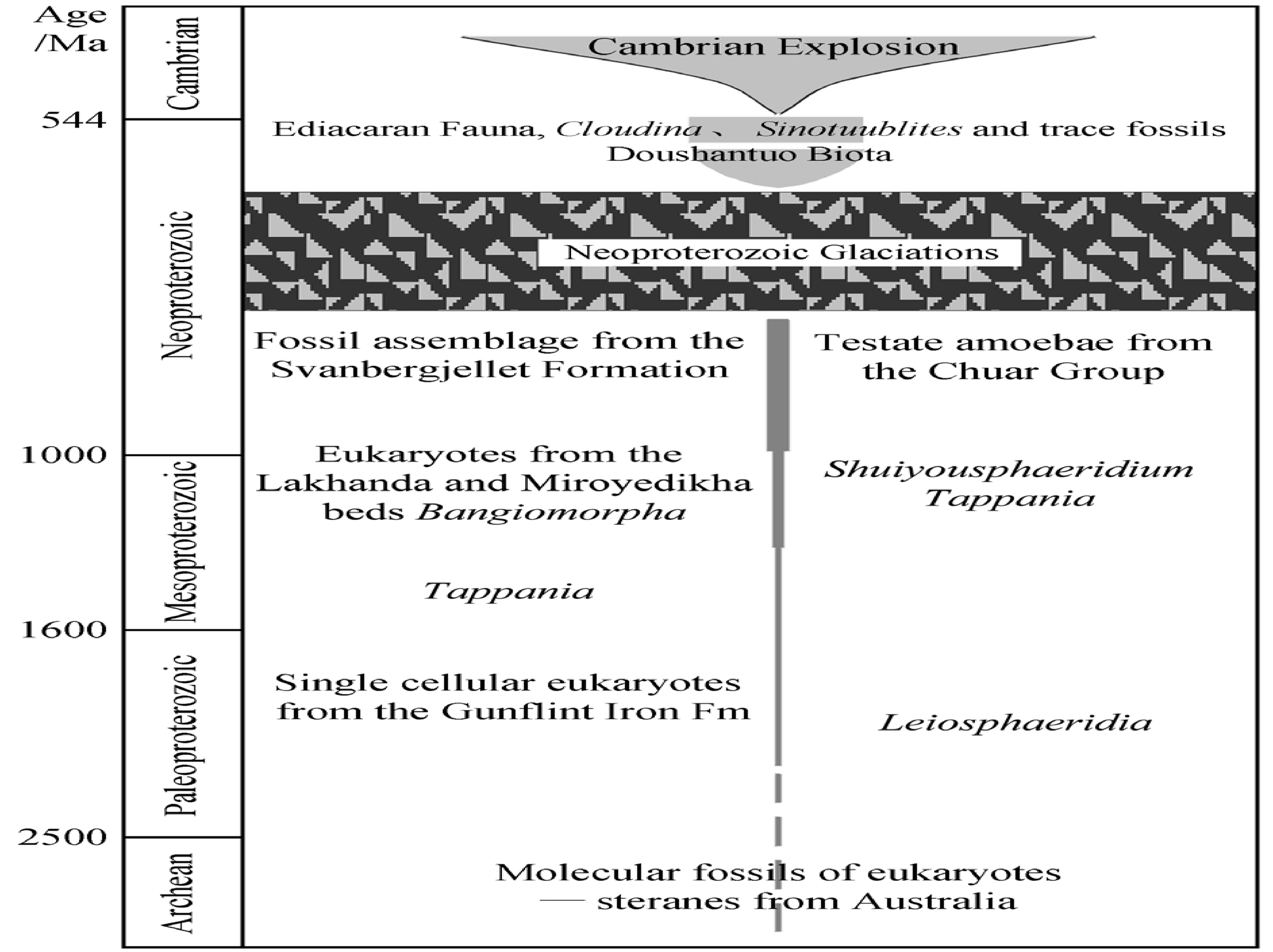


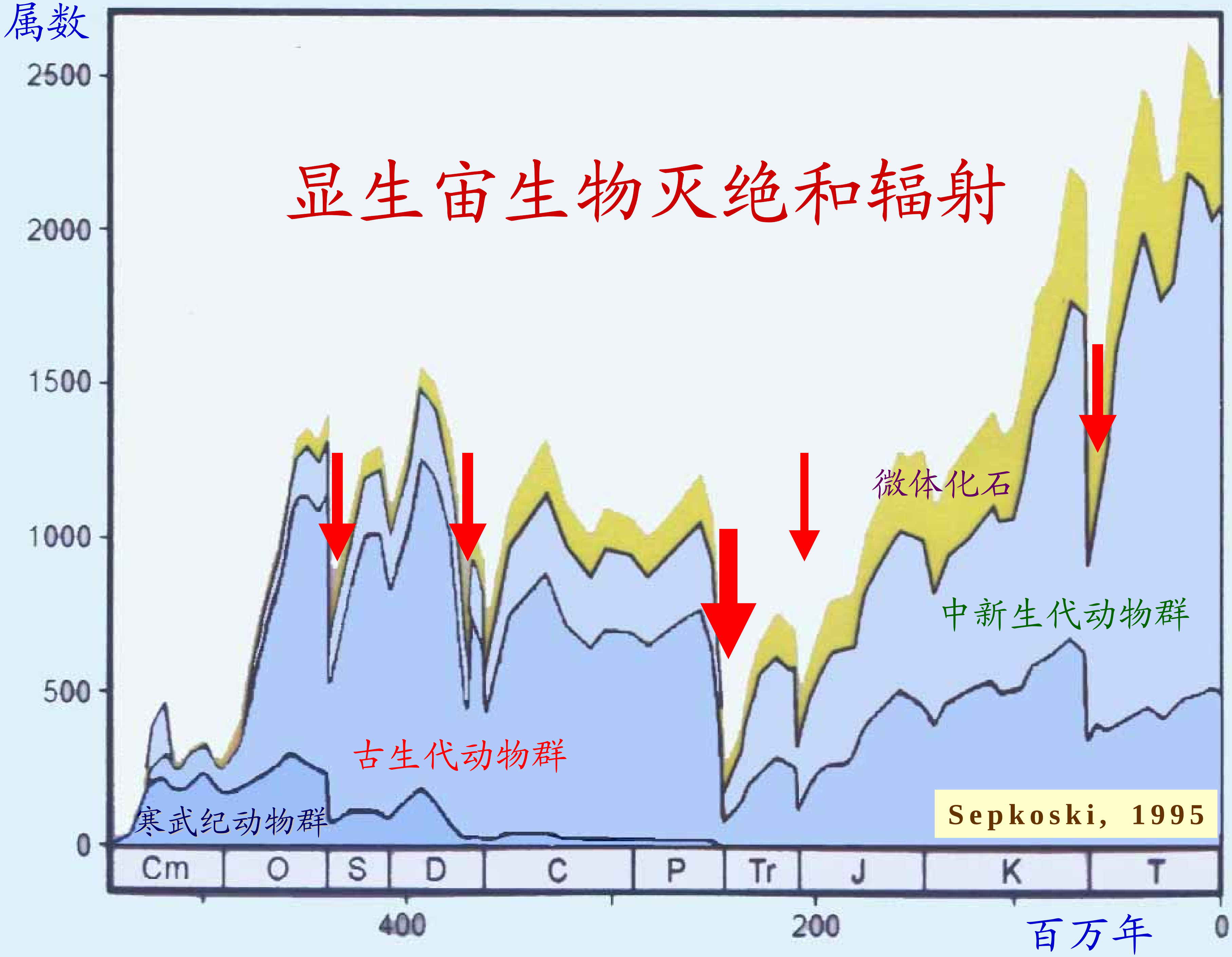


动物化石——动物胚胎化石



陡山沱期生物群在系统演化上的位置


Age /Ma
Cambrian
544
Neoproterozoic
1000
Mesoproterozoic
1600
Paleoproterozoic
2500
Archean
Cambrian Explosion
Ediacaran Fauna, Cloudina、Sinotuublites and trace fossils
Doushantuo Biota
Neoproterozoic Glaciations
Fossil assemblage from the Svanbergjellet Formation
Testate amoebae from the Chuar Group
Eukaryotes from the Lakhanda and Miroyedikha beds Bangiomorpha
Shuiyousphaeridium
Tappania
Tappania
Single cellular eukaryotes from the Gunflint Iron Fm
Leiosphaeridia
Molecular fossils of eukaryotes — steranes from Australia



属数
显生宙生物灭绝和辐射
2500
2000
1500
1000
500
0
微体化石
中新生代动物群
古生代动物群
寒武纪动物群
Sepkoski, 1995
Cm
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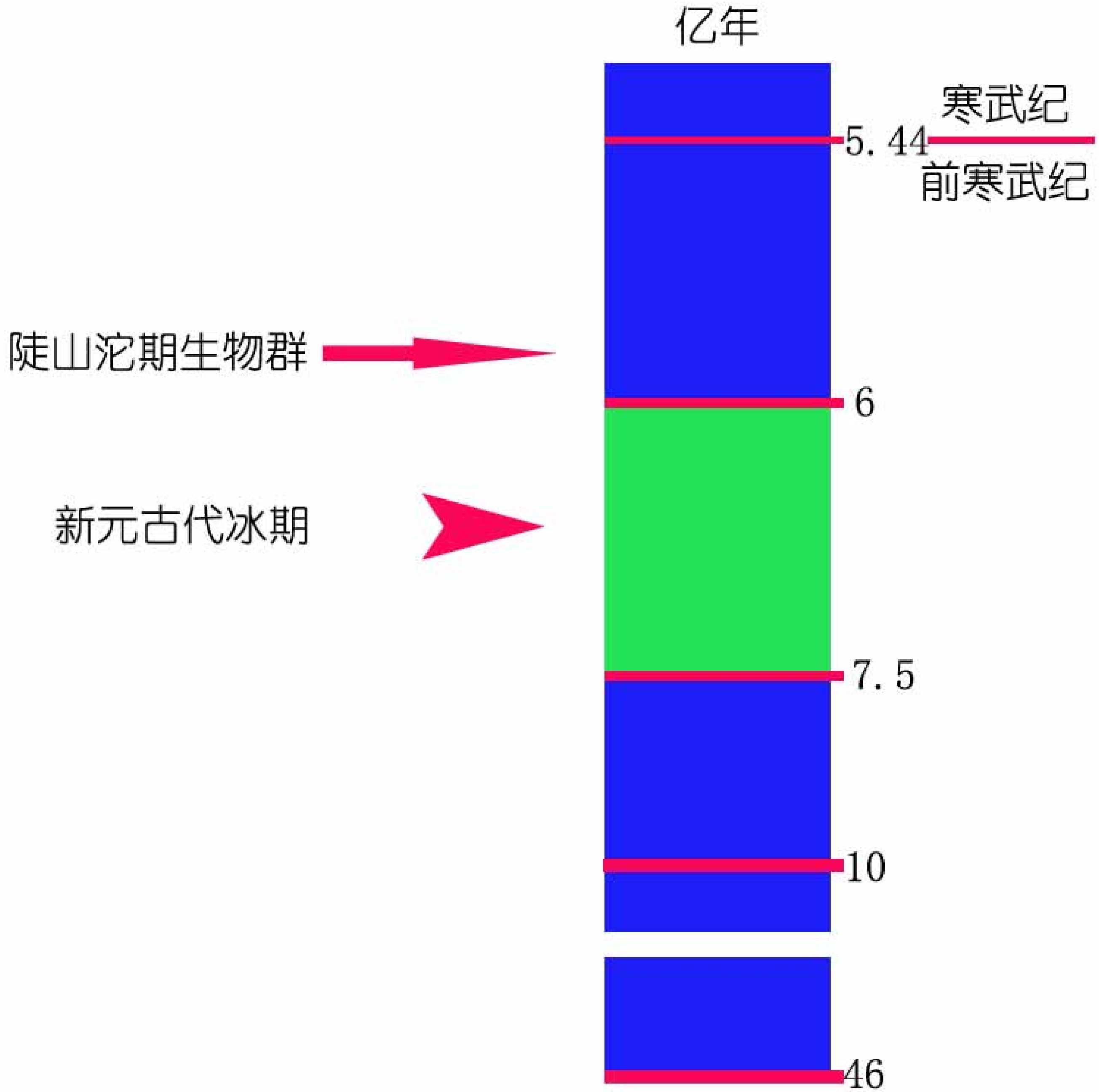
陆山沱期真核生物辐射的原因？

它的辐射模式？



亿年
寒武纪
5.44
前寒武纪
陡山沱期生物群
6
新元古代冰期
7.5
10
46

第一，全球性的寒冷气候可能使冰期前后的生态系统产生了较大的变化。

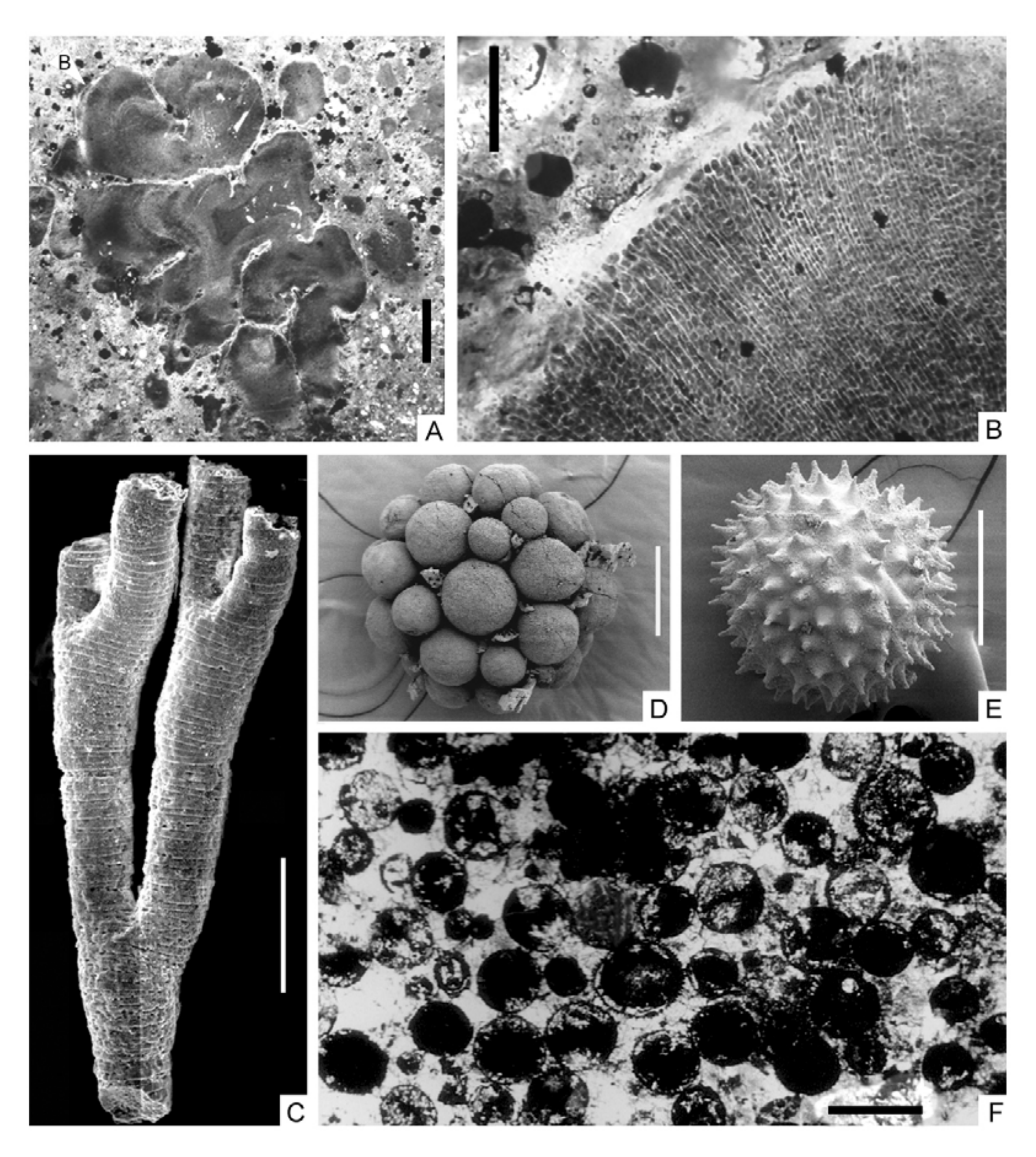
第二，氧含量在一个相对较短的时间内可能有一个明显的升高。

第三，与新元古代冰期之后相比，早、中元古代的海水分层明显，虽然在18亿年前海洋表面可能已经氧化，但直到中元古代晚期的海水表面之下仍然是缺氧的、硫化海洋环境，这种环境中的Fe、Mo、Cu等金属离子的含量极低，真核生物的含Mo官能团的生物酶固氮作用受到限制，这一因素也可能阻碍了真核生物的多样化进程(Anbar and Knoll, 2002)。

第四，生物体必需的磷元素在冰期过后的快速化学风化中也可能被大量带入海洋中，在离大陆稍远的较深海区域，浮游低等藻类的繁盛并在死亡后的遗体中富集了大量的磷元素，上升洋流作用把这些磷沉积带到了温暖的浅海。富含磷的海水也为陡山沱期真核生物的辐射带来了契机。

第五，新元古代大冰期也给予了真核生物本身巨大的选择压，一些生物在极端寒冷事件中灭绝，而在巨大的选择压力下，另外一些类群的遗传物质可能发生了质的变化，再加上广泛分布的冰川产生了生物地理隔离以及冰期之后温暖浅海中可能存在多样化的生境，这些都与冰期之后真核生物多样性的发生关系密切。

台地相微体真核生物的辐射模式

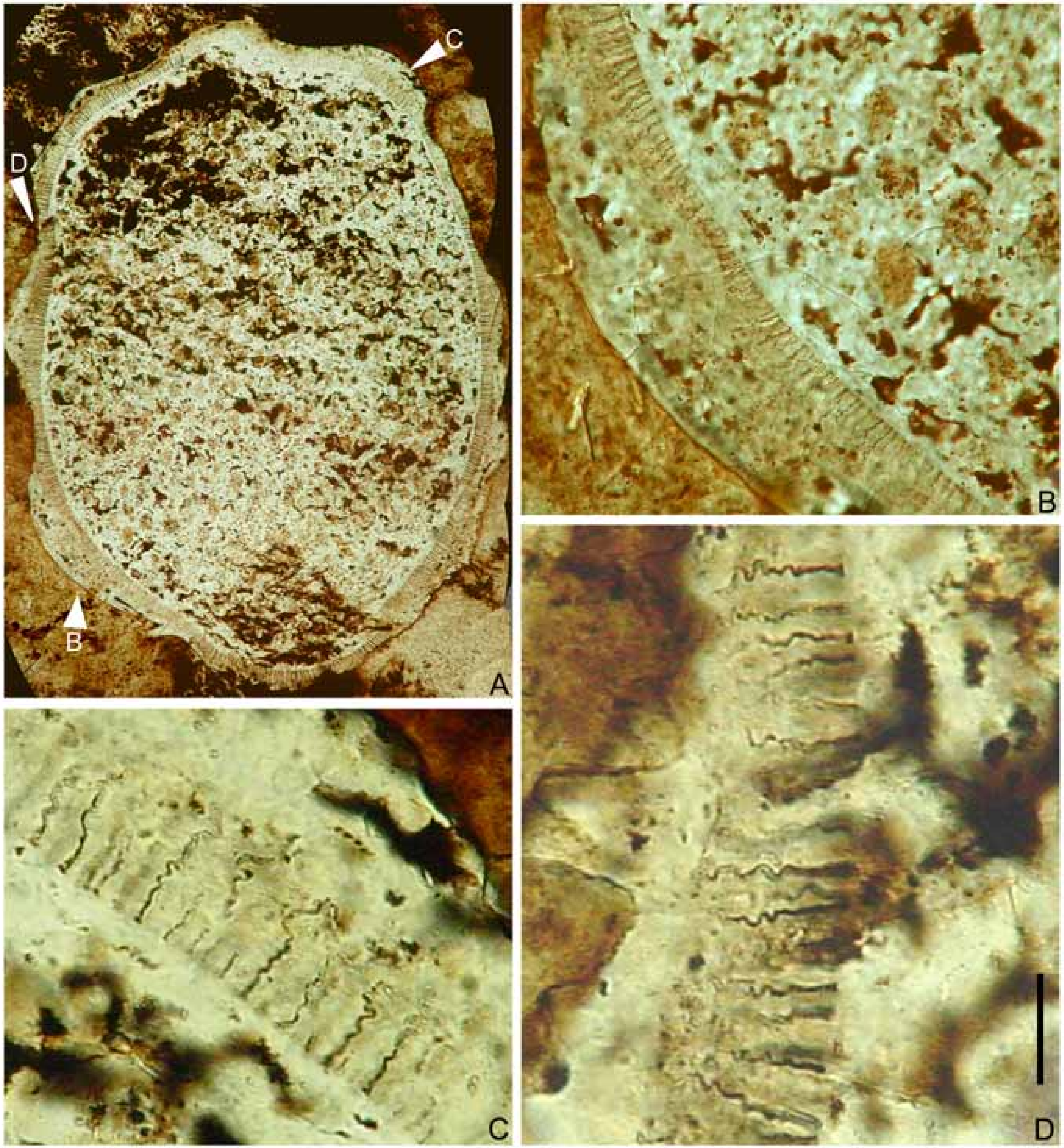


一、微小真核生物的辐射可能与原生动物的捕食有关

（1）原生动物的捕食在现代生态系统中扮演了非常重要的角色

（2）原生动物在元古代已经大量出现

（3）原生动物捕食的选择压能使陡山沱期的微小真核生物产生多样性

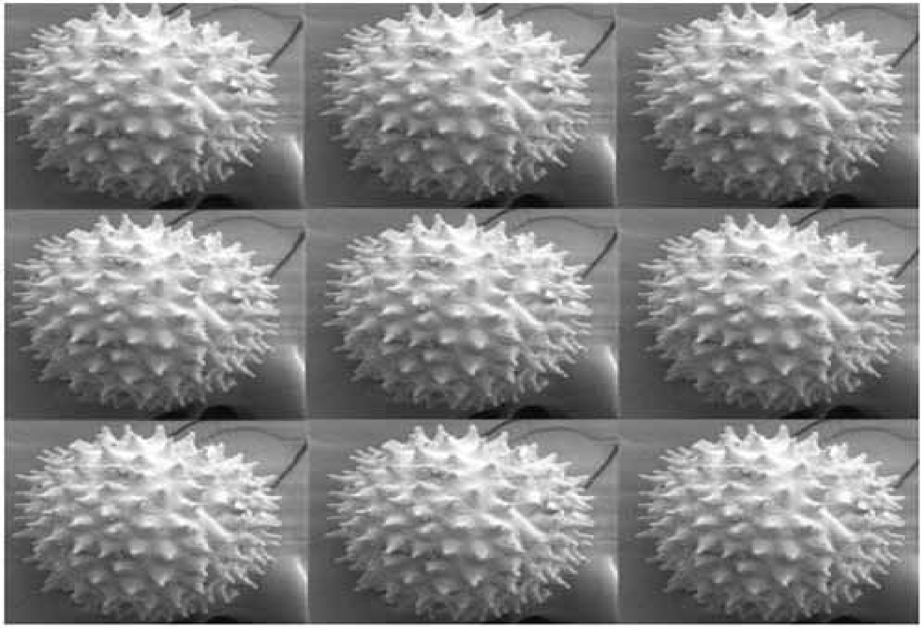
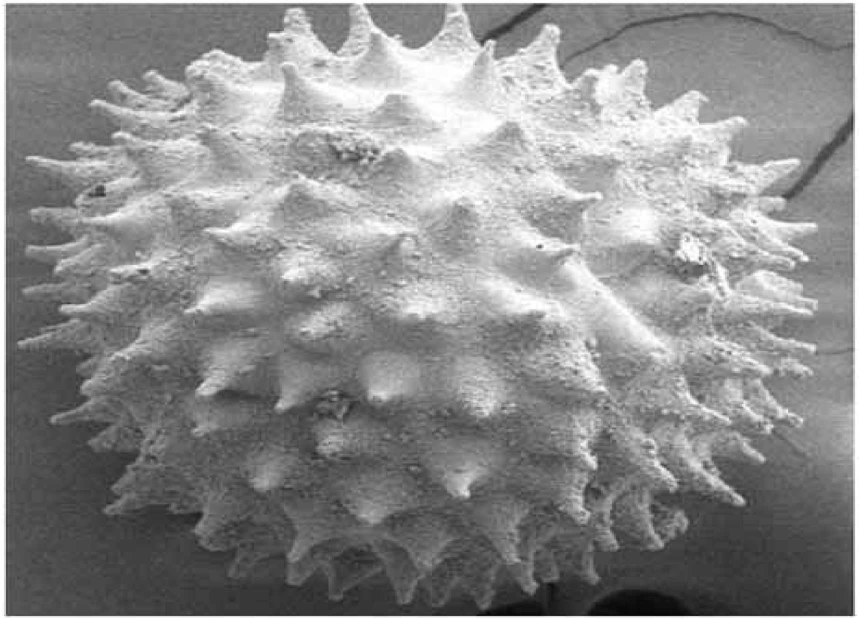

C
D
B
A
B
C
D

捕食压

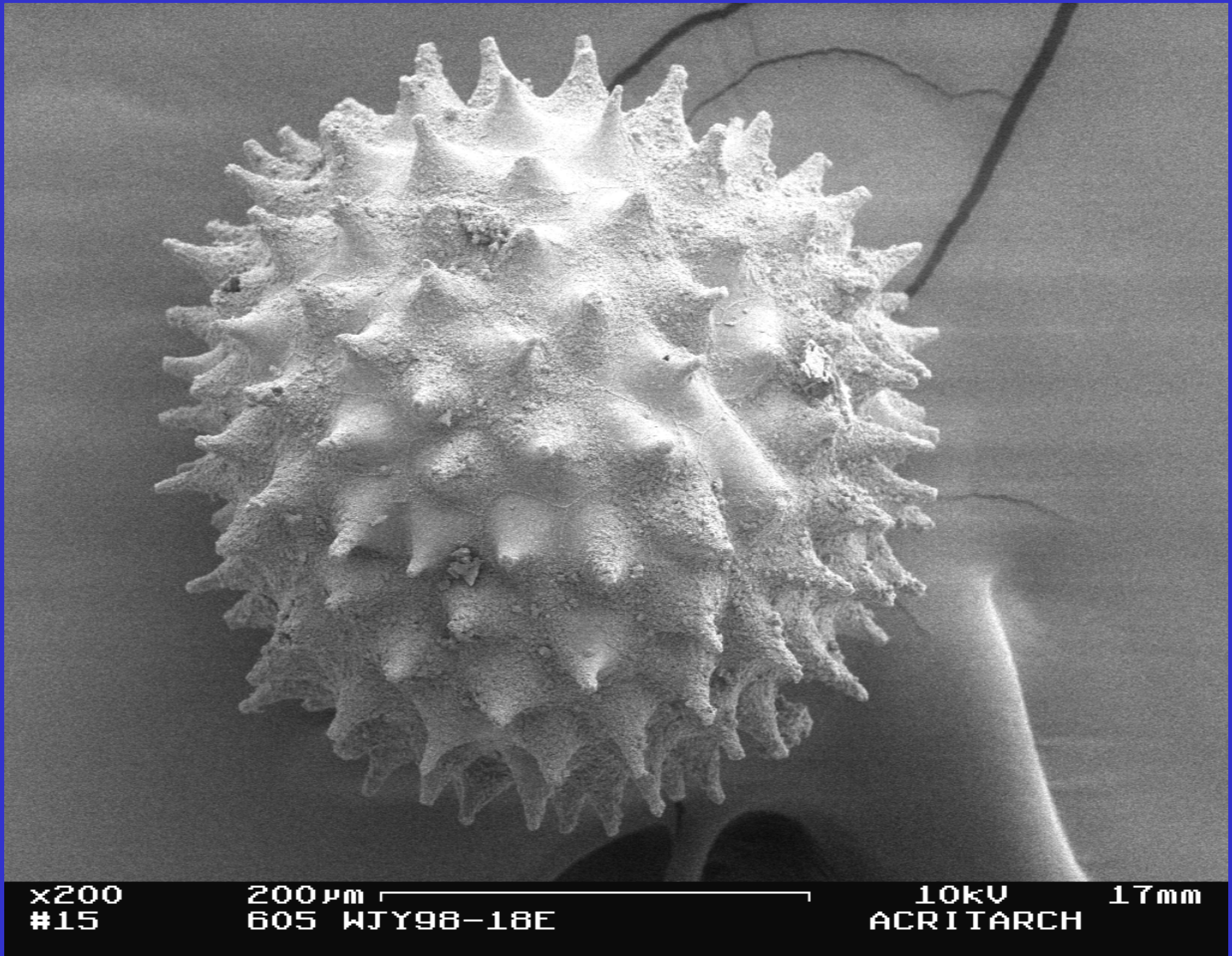
过度繁殖

防御能力

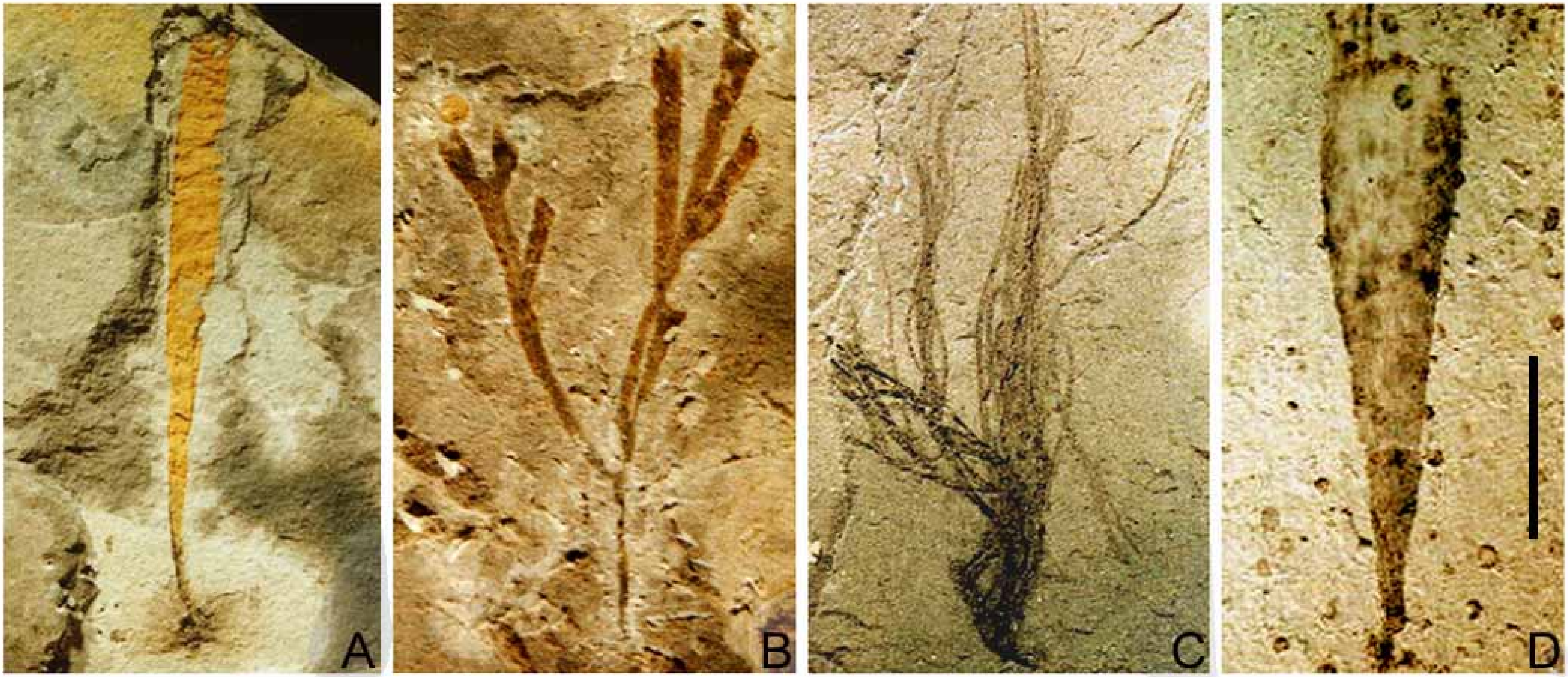
 

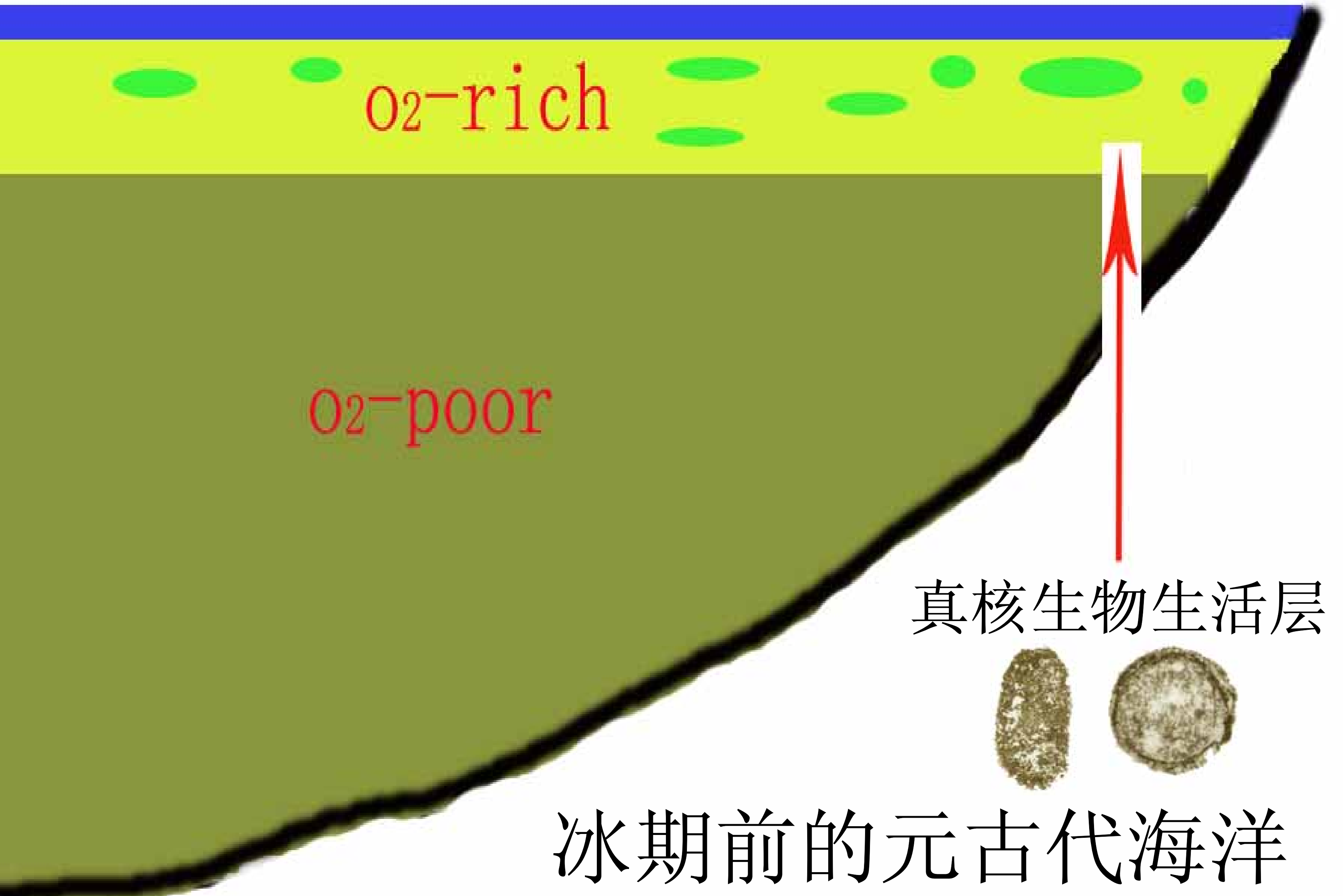
二、微小真核生物的辐射可能

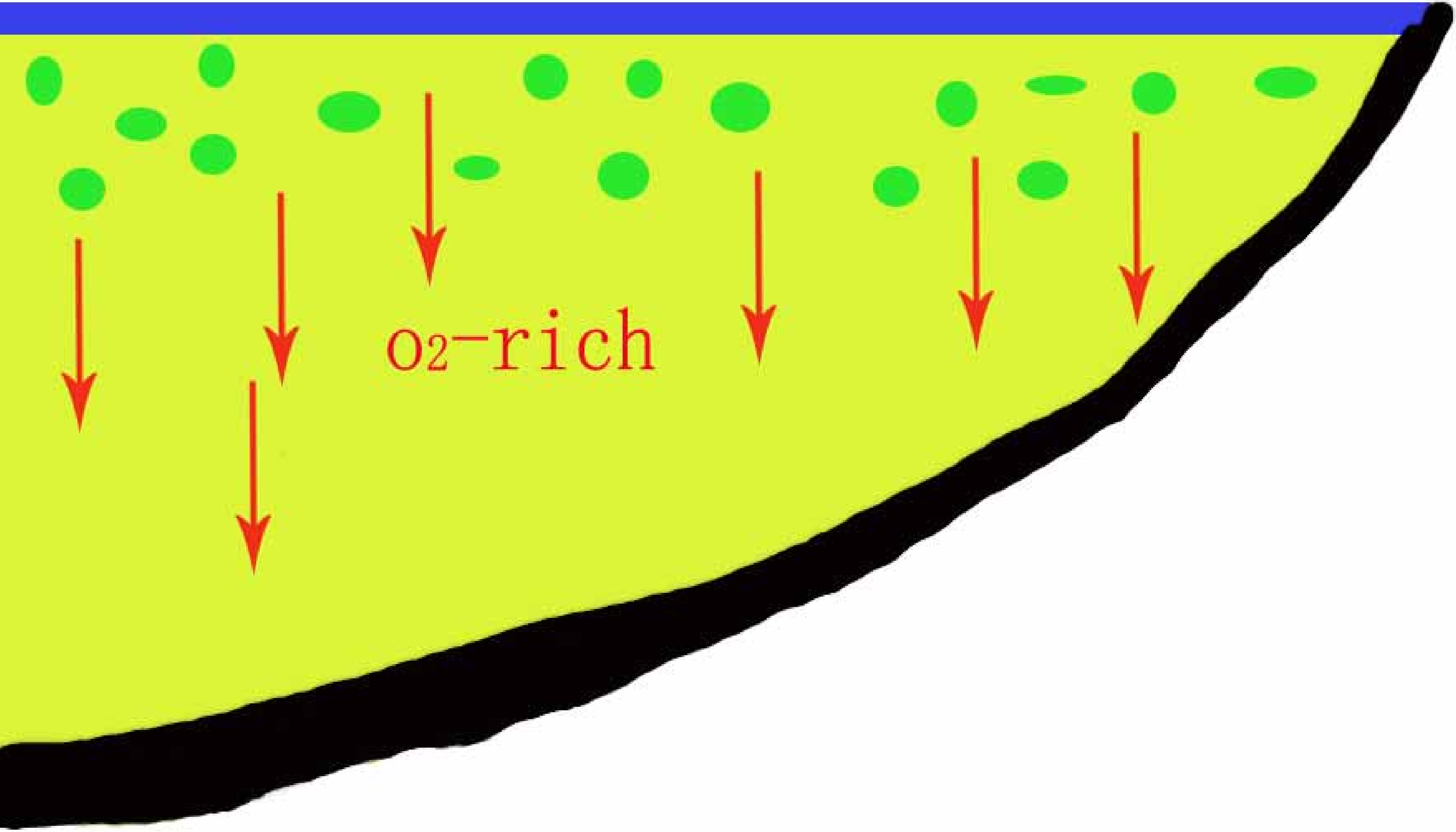
是生态空间竞争的结果



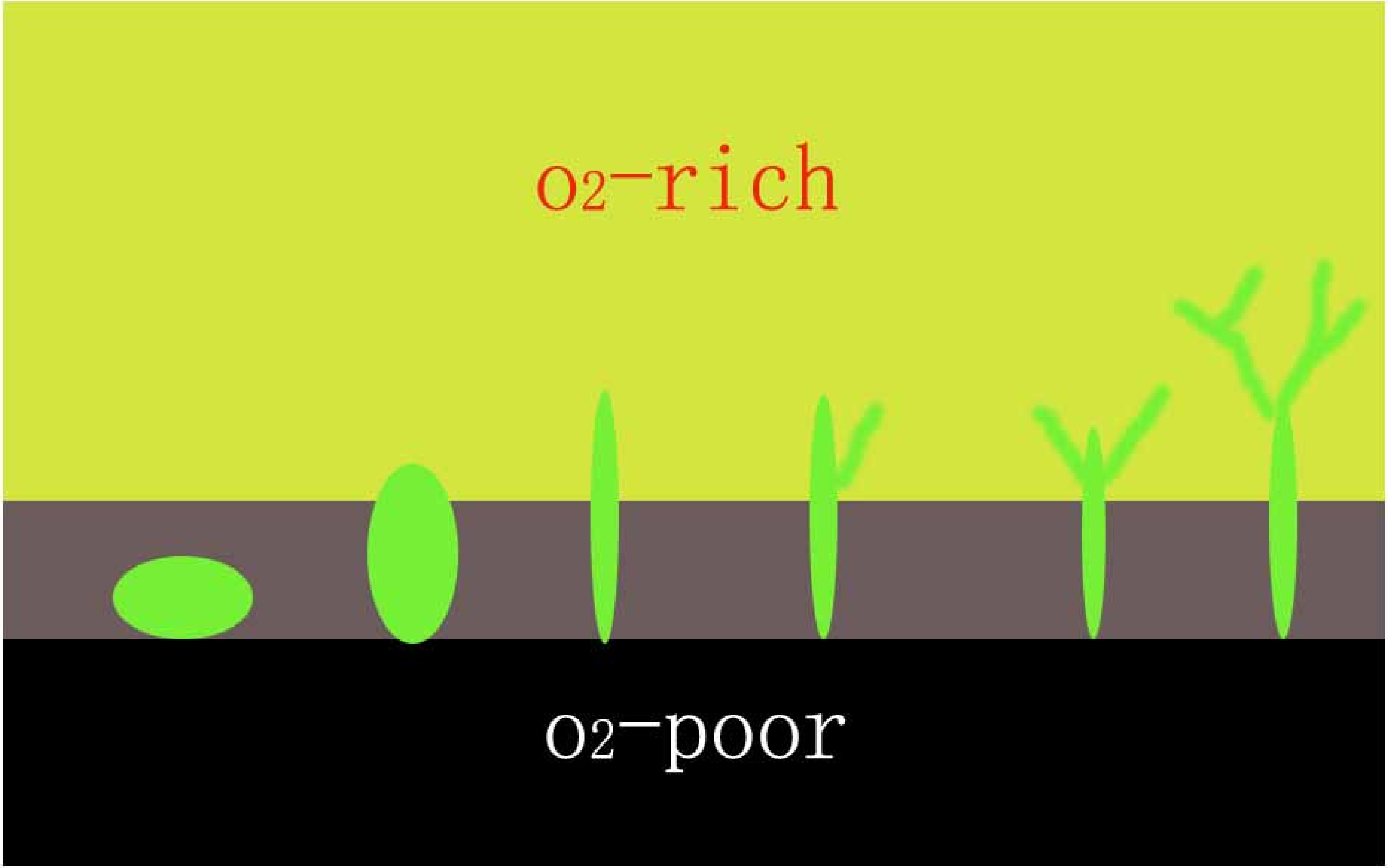
台地边缘或盆地静水环境中的宏体藻类辐射模式



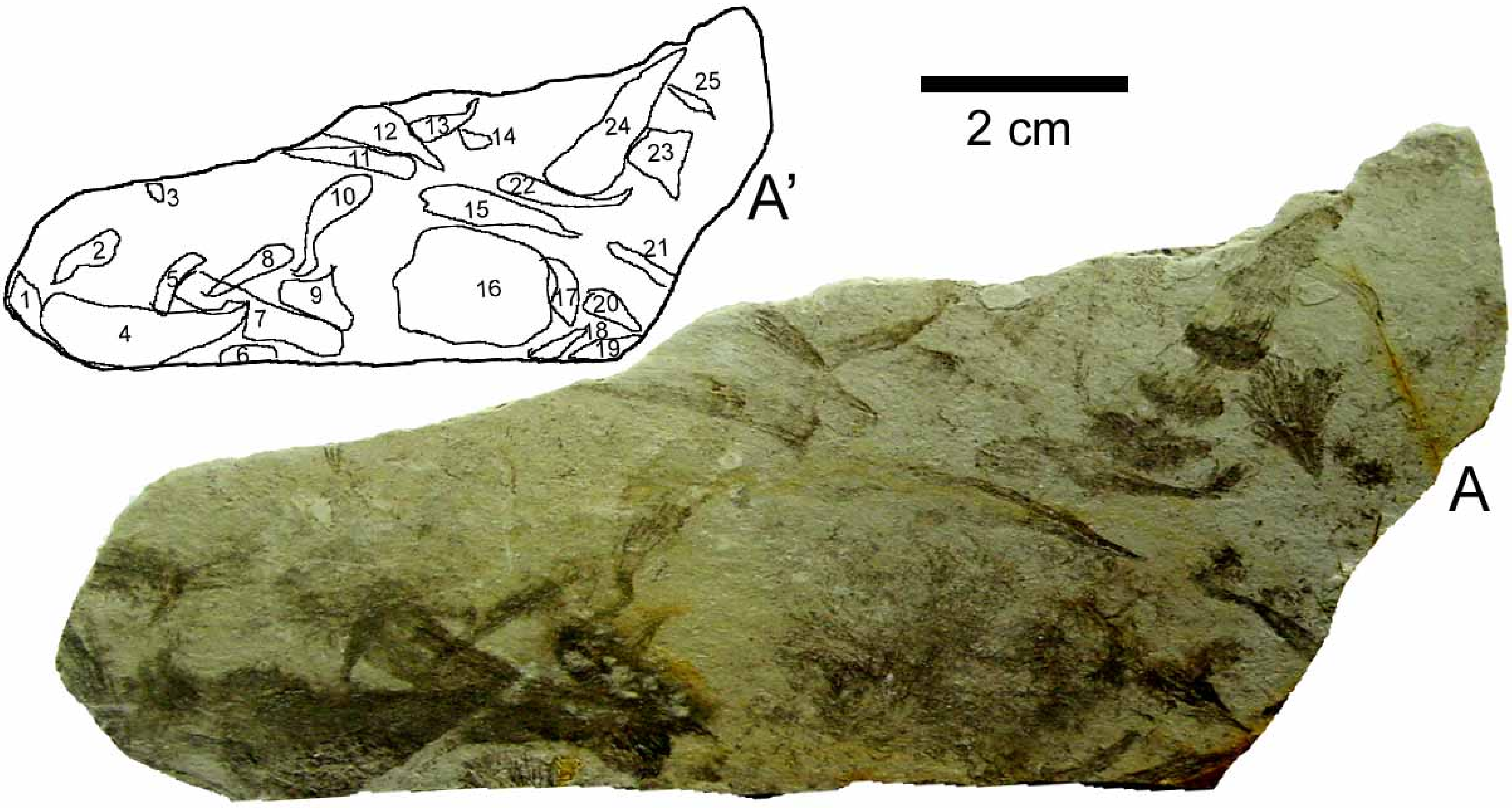

O2-rich
O2-poor
真核生物生活层
冰期前的元古代海洋



冰期后的局部静水海洋环境



陡山沱期宏体藻类的辐射模式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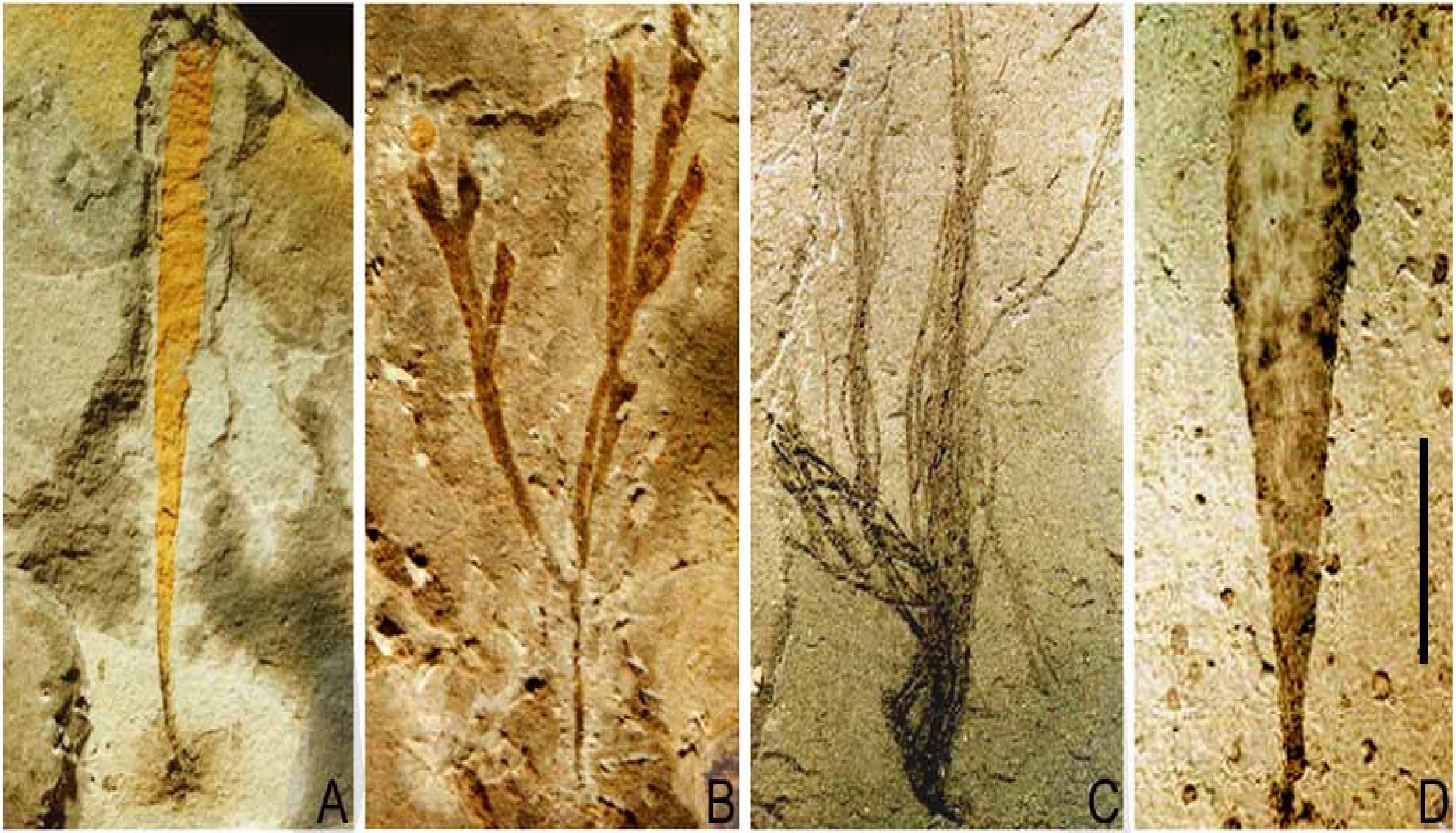
A


A
B
C
D


谢 谢！