The Early Animals (Ediacaran) of Earth – Nature's Experiments

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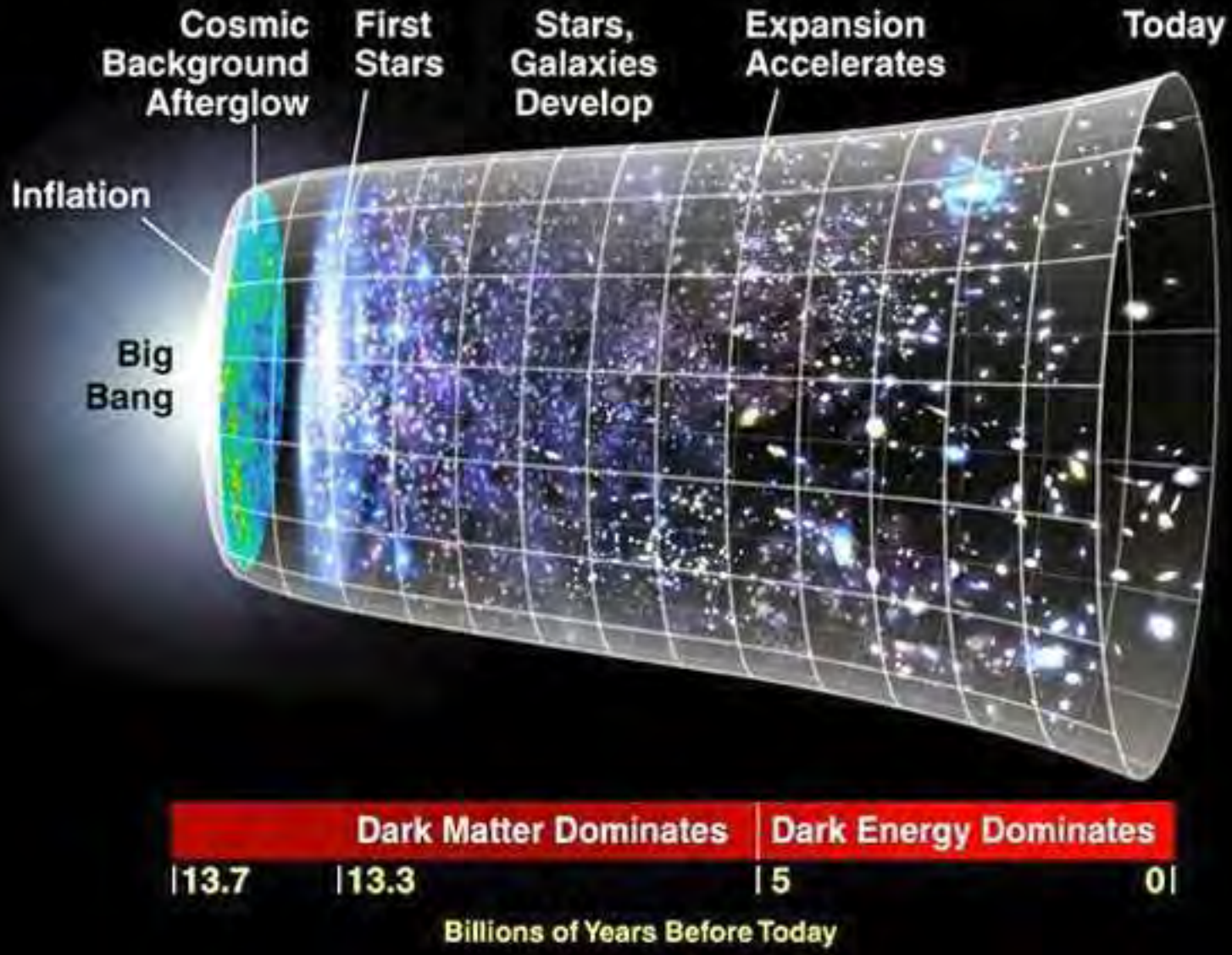
Presentation before Chicago Rocks and Mineral Society May 10, 2014

Illinois Famous for Pennsylvanian Fossils

The Expanding Universe: A Capsule History



In the Beginning: The Big Bang

- Earth formed 4.6 billion years ago

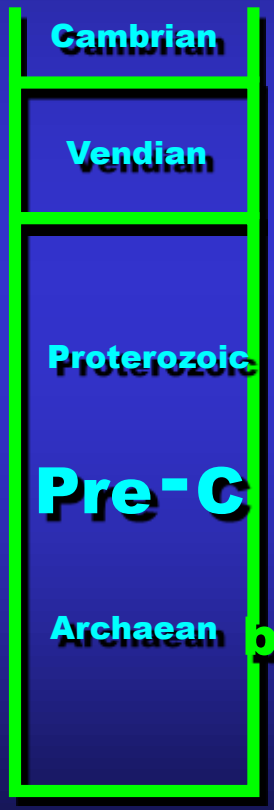
a

b

Fossil Record Order

95% of higher taxa: Random plant divisions

domains & kingdoms



Atdabanian Fauna

Tommotian Fauna

Ediacaran Fauna

protists

algae

bacteria

Fossil Order

Source: Kurt Wise Truett-McConnell College (Baptist)

The First Cells

- 3.8 billion years ago, oxygen levels in atmosphere and seas were low
  - Early prokaryotic cells probably were anaerobic
  - Stromatolites
- Divergence separated bacteria from ancestors of archaeans and eukaryotes

Stromatolites Dominated the Earth

Stromatolites of cyanobacteria ruled the Earth from 3.8 b.y. to 600 m. [2.5 b.y.].

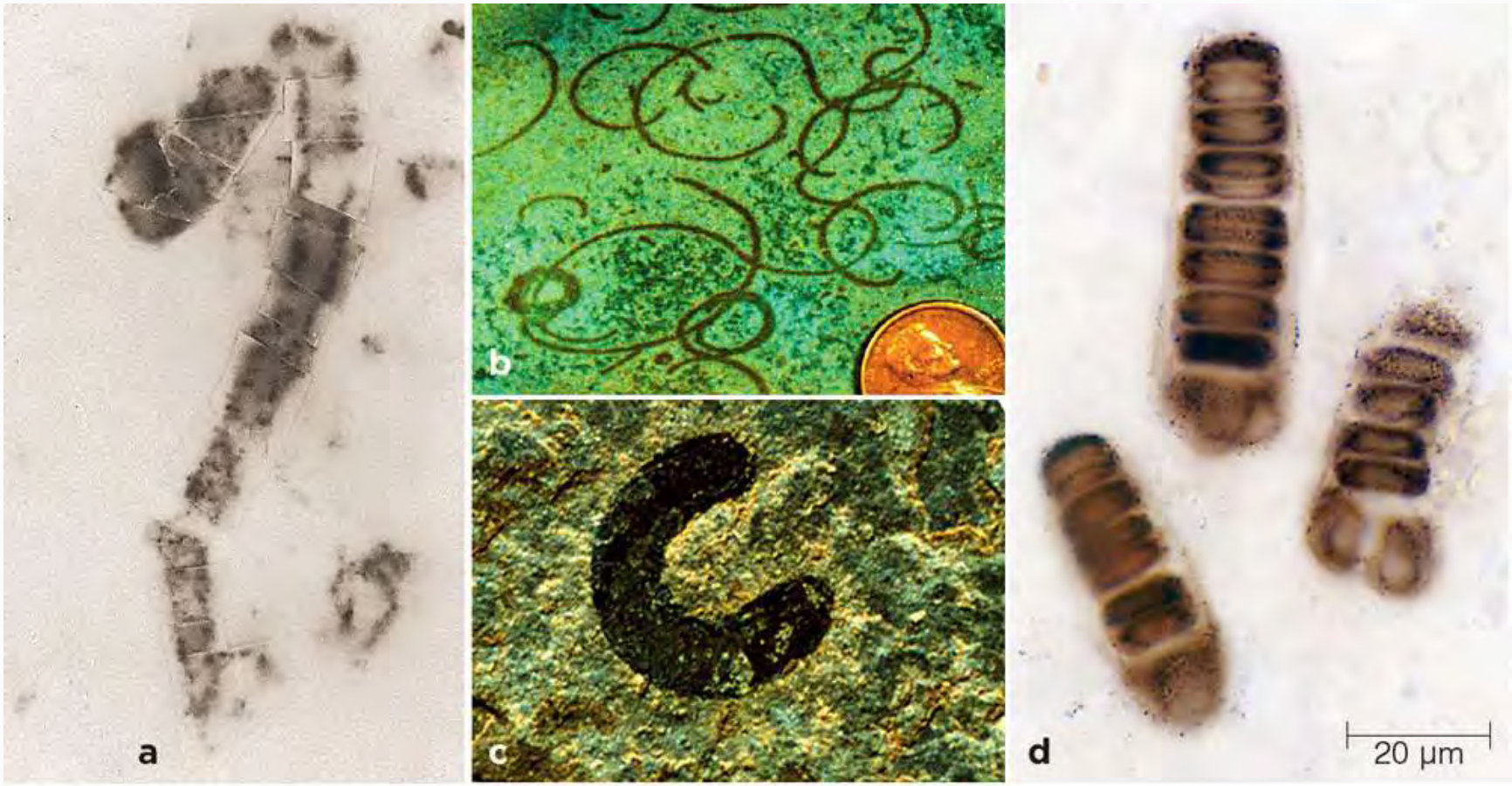
Believed that Earth glaciations are correlated with great demise of stromatolites world-wide.

The Oxygen Atmosphere

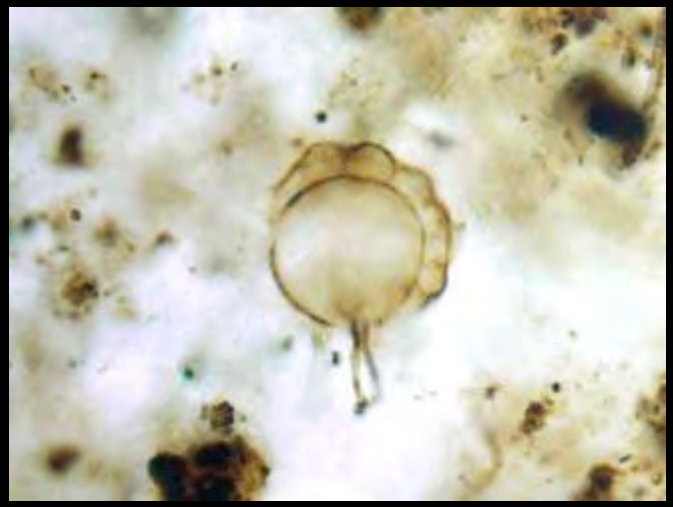
- Cyanobacteria evolved an oxygen-releasing, noncyclic pathway of photosynthesis
  - Changed Earth's atmosphere

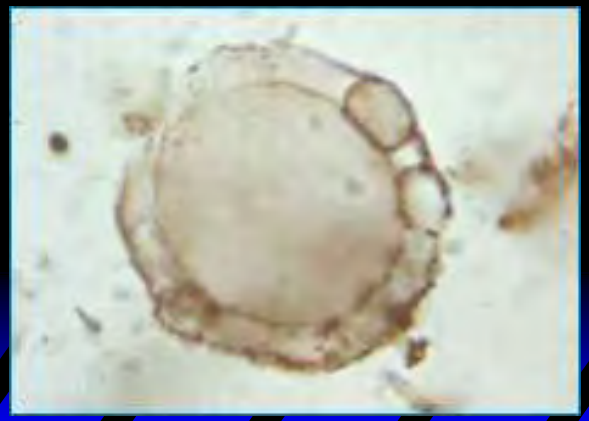
- Increased oxygen favored aerobic respiration

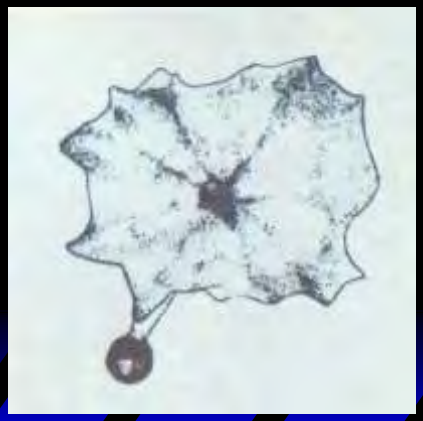
Early Multi-Cellular Life Was Born

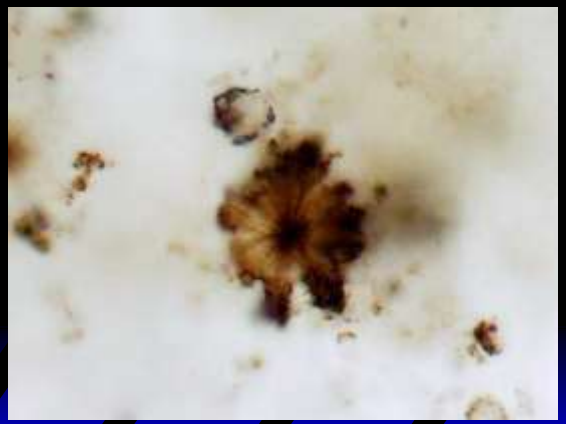


Eosphaera & Kakabekia at 2 b.y in Canada Gunflint Chert



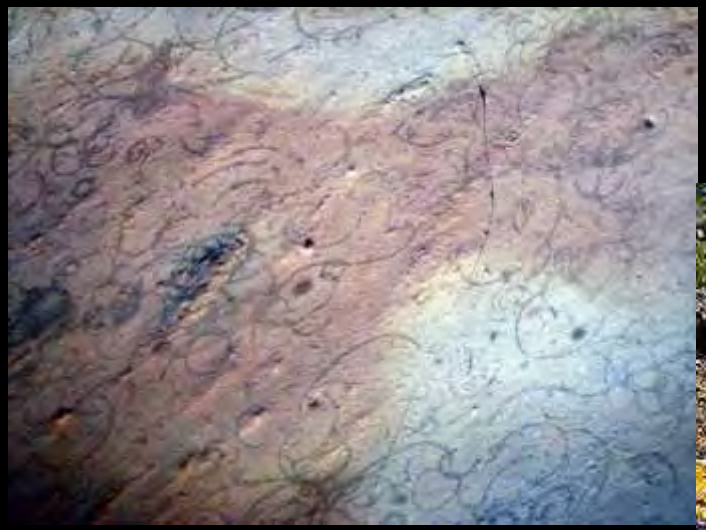






Earliest Multi-Cellular Metazoan Life (1)

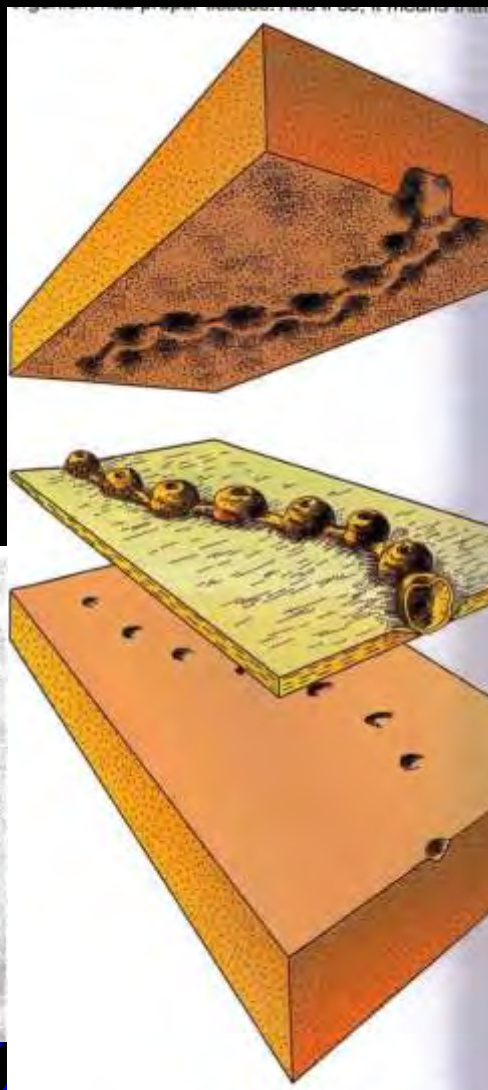
- Alga Eukaryote Grypania of MI at 1.85 b.y.



MI fossil outcrop

Earliest Multi-Cellular Metazoan Life (2)

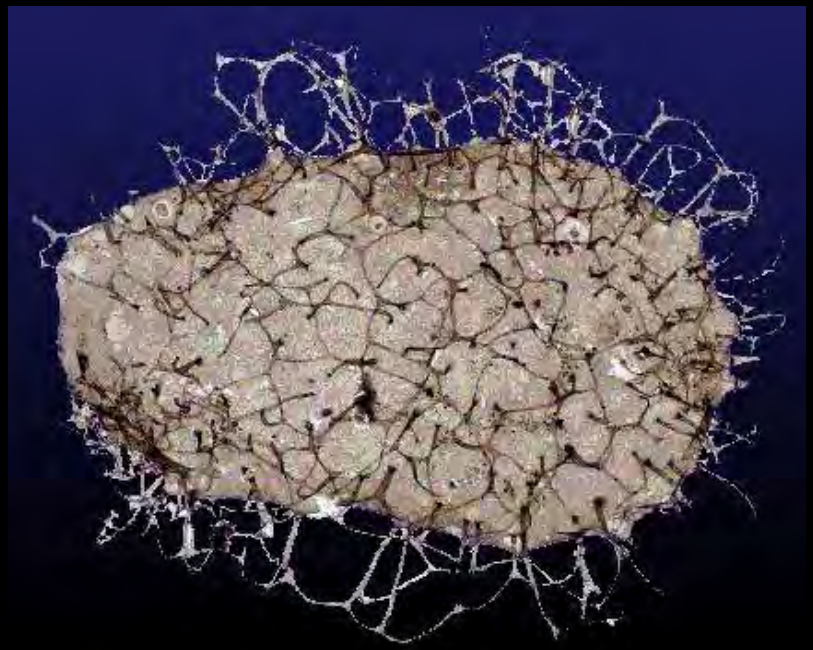
- Beads Horodyskia of MT and Aust. at 1.5 b.y. thought to be algae



Source: Fedonkin et al. 2007 Rise of Animals

Figure 48. Reconstruction of Horodyskia
the Bangemall Basin of Western Australia
K. Grey).

Tappania Fungus at 1.5 b.y



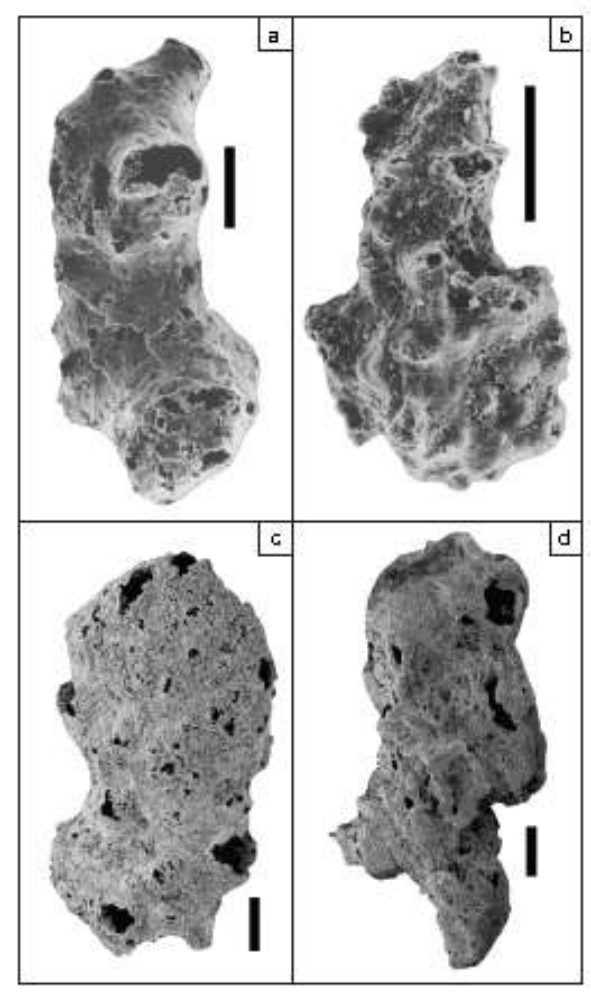
Described now from China, Russia, Canada, India, & Australia

Earliest Multi-Cellular Metazoan Animals (3)

- Worm-like Parmia of N.E. Russia at 1 b.y.

Source: Fedonkin et al. 2007 Rise of Animals

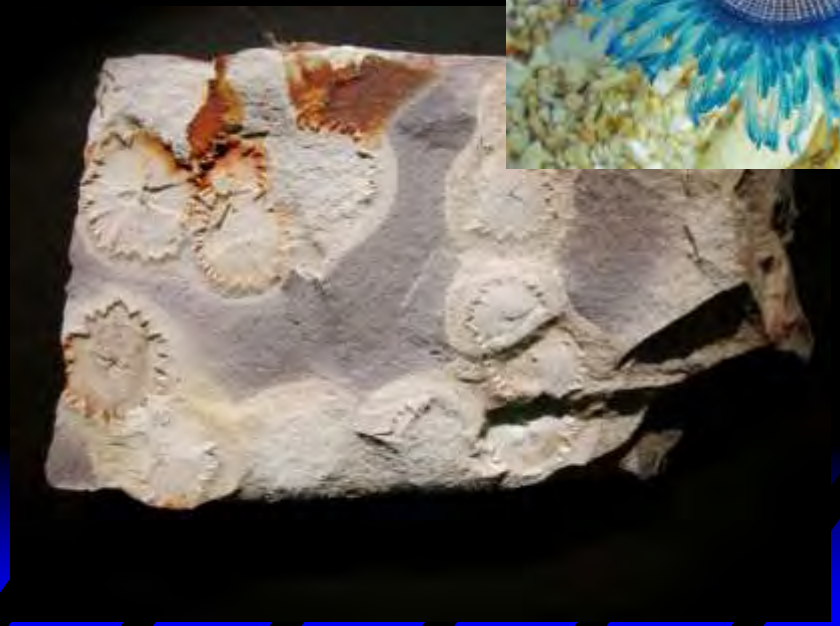
Earliest Animal Fossil at 760 m.y.

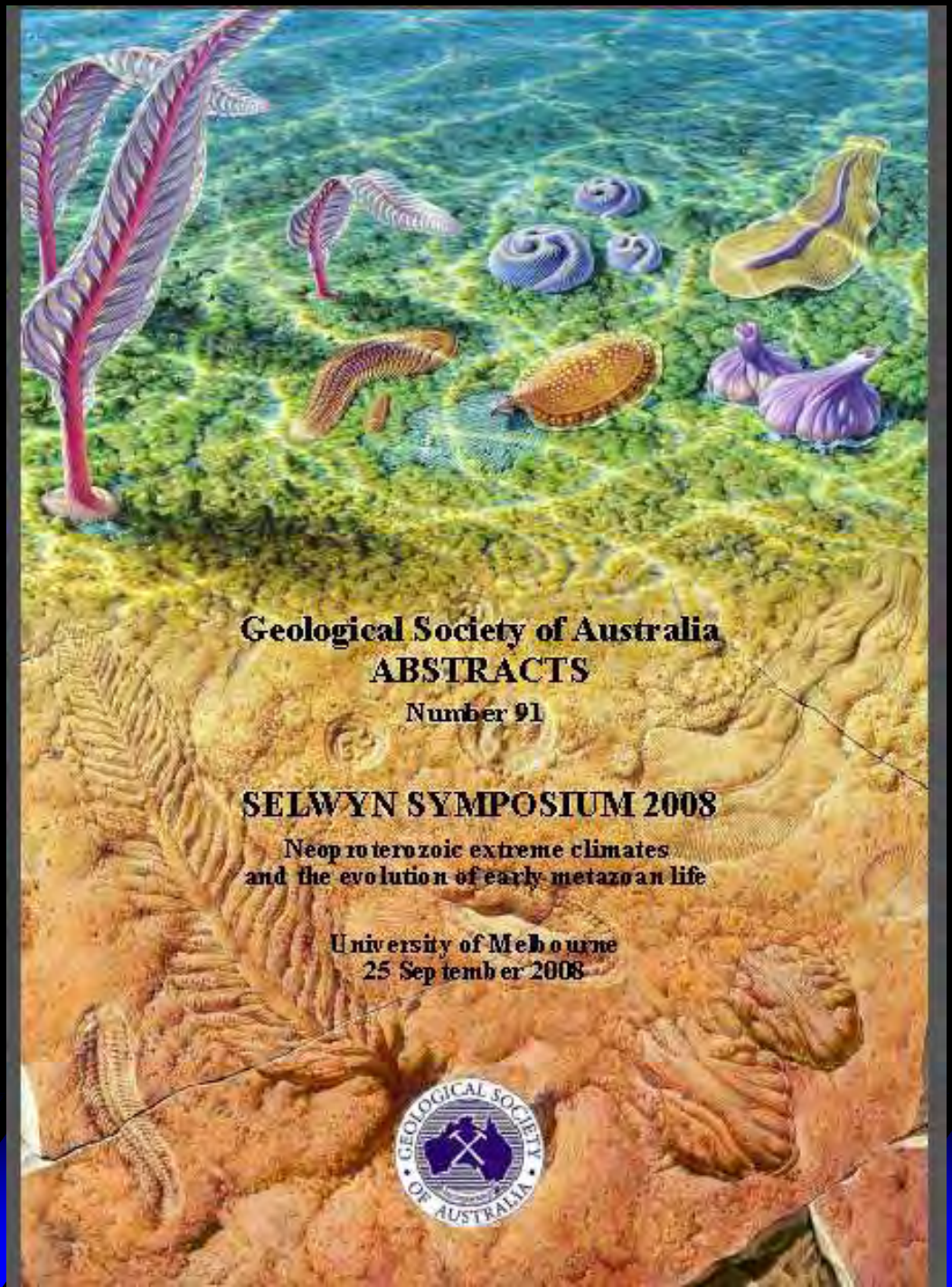


- Otavia antiqua phosphate body fossils described 2012 as earliest animal fossil;
- Found in Namibia rocks dated 760-550 m.y.;
- Evolved prior to first Neoproterozoic global (snowball Earth) glaciation & survived through climatic extremes associated with repeated snowball Earth episodes

Ref. C. Brian et al. 2012 S Afr J Sci

Australian Porpita Enigmatic Discoidal Fossils"
Early Cryogenian (670 m.y.o.)

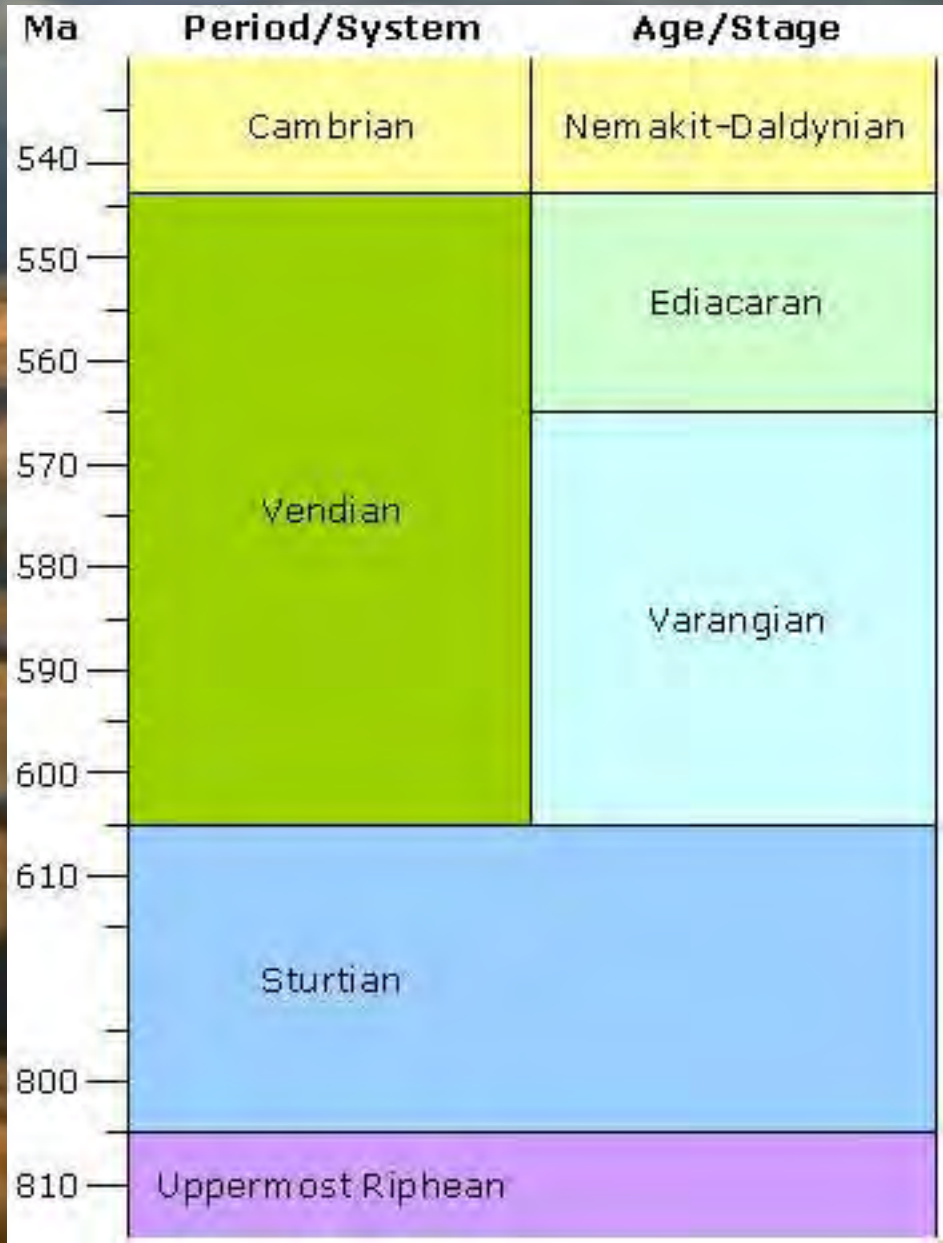



Geological Society of Australia
ABSTRACTS
Number 91
SELWYN SYMPOSIUM 2008
Neoproterozoic extreme climates
and the evolution of early metazoan life
University of Melbourne
25 September 2008
GEOLOGICAL SOCIETY OF AUSTRALIA

Most of 4 billion years of Earth evolution of life confined only to bacteria and multi-celled algae

Fossil Record reflects a major change in biota 635 m.y ago
The Vendian Biota (or Ediacaran Fauna) appeared

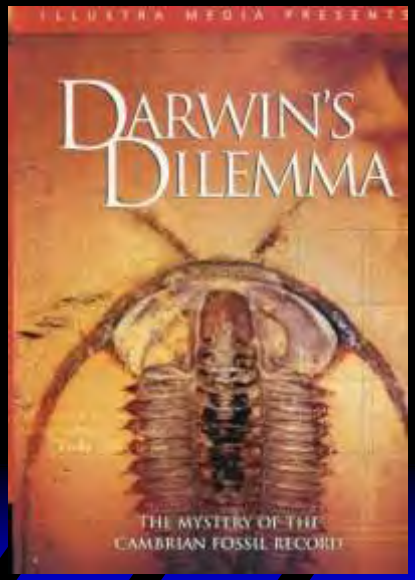
Ediacara, Australia

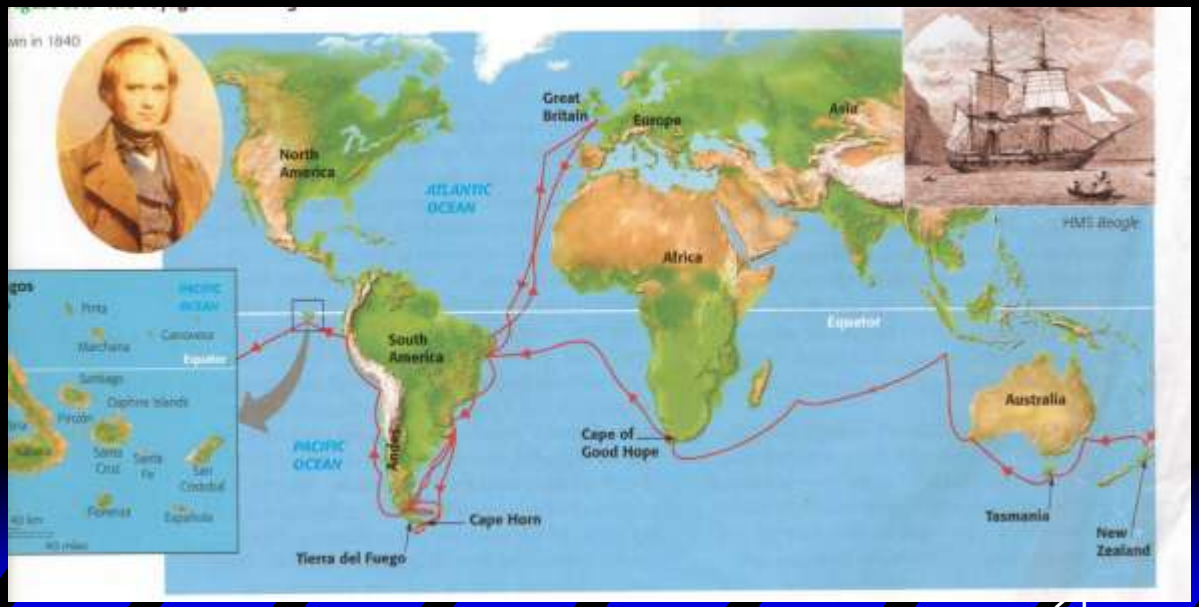


Vendian age rocks contain a diverse fauna

Ediacaran Early Recognition

"Darwin's Dilemma" = inability of earlier scientists to accept that fossil may occur pre-Cambrian & yet when did life begin before Cambrian Explosion?





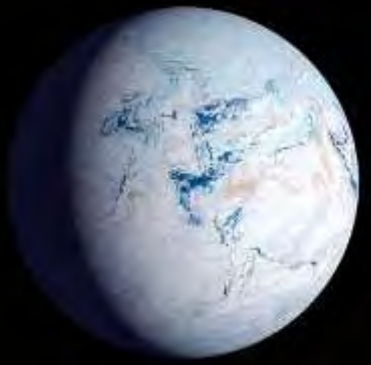
Darwin Focus on Shropshire

Darwin did pay attention to Long Mynd, Shropshire body fossils as Beltanelliformis & Medusinites as “inorganic impressions” [now believed (2009) as body fossils]

Reference: A. Lin 2011 Shropshire Geol Soc.

Named from Australia where these fossils were first found, the Ediacaran were soft-bodied jellyfish to worm-like animals unlike anything today. Considered "Failed Experiments" of Earth's first animal explosion, 20 m.y before the Cambrian Explosion of hard-bodied shelly animals.

The “ Avalon Explosion”
of the Ediacaran Fauna
occurred during and after the
repeated Snowball Earth Cryogenian
episodes when extensive glaciers
covered the Earth down to the
equator

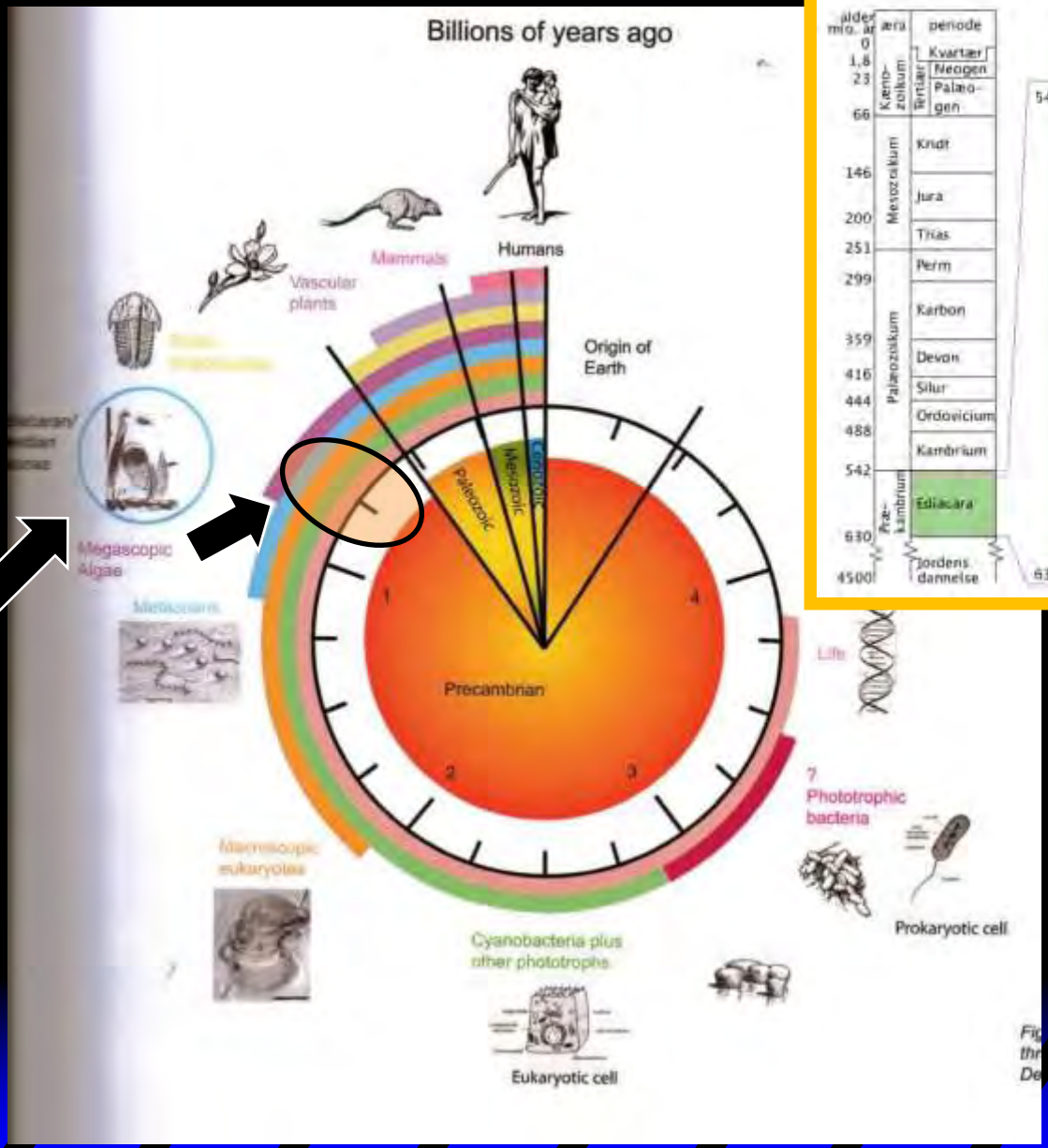


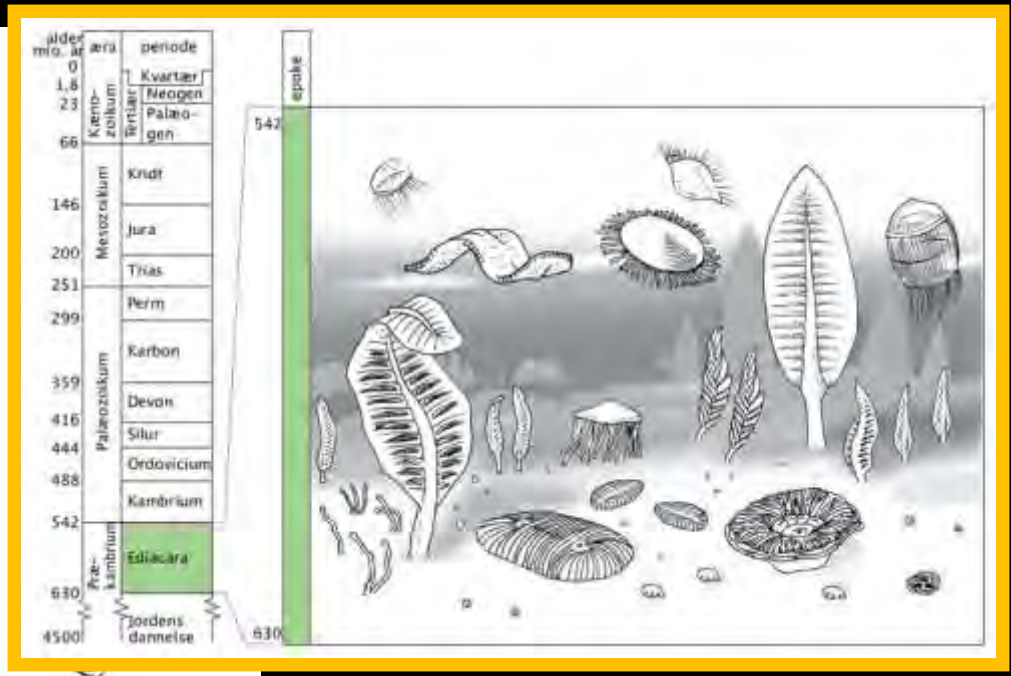
Ediacaran are prime examples of a
Cold Cradle of Animal Life

Ediacaran Early Recognition

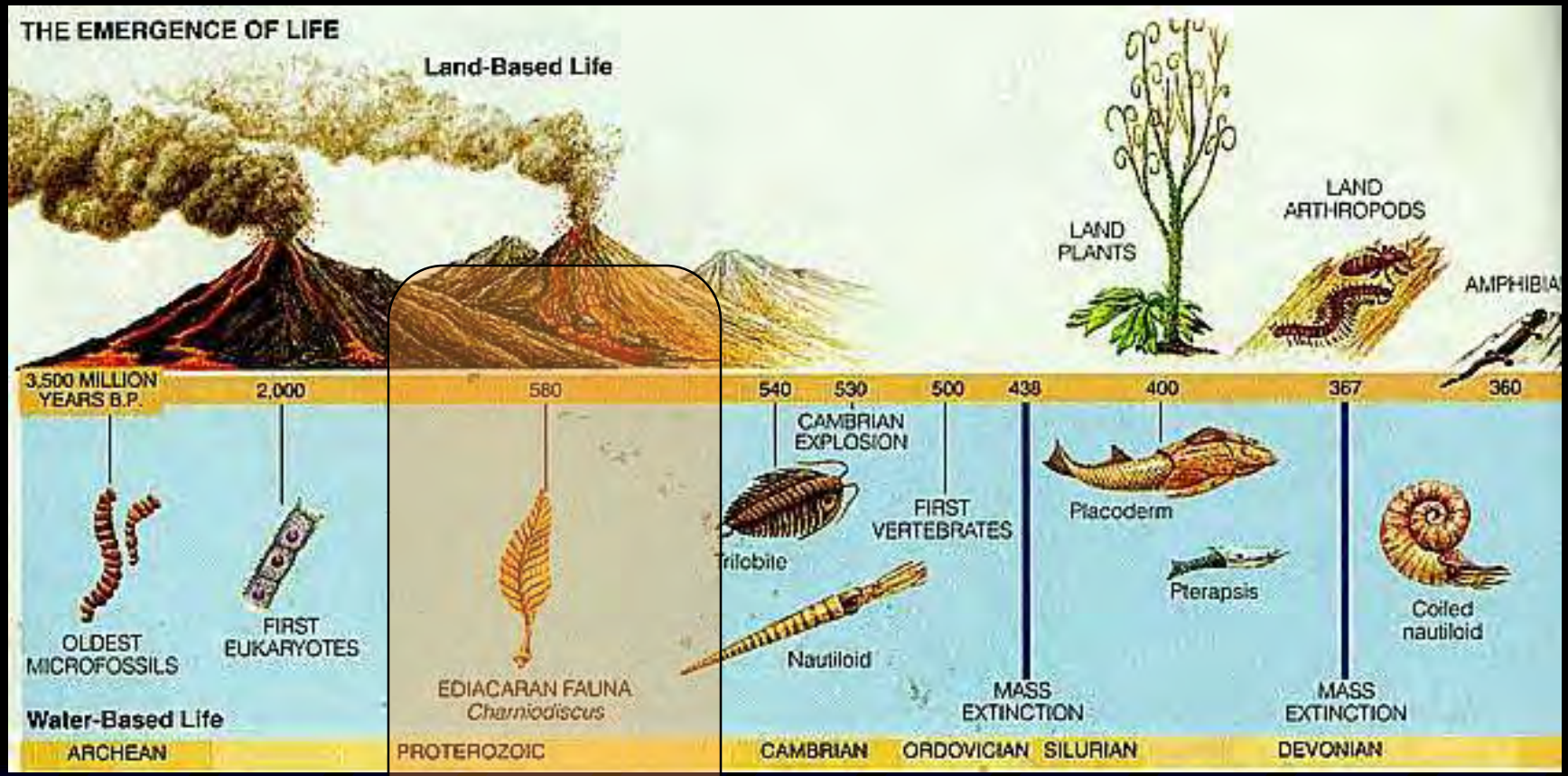
- Known since 1868 (Aspidella) in Newfoundland by geologist Alexander Murray
- Dismissed as sedimentary structures
- George Gurich in 1930's published on these "structures" from Namibia, Africa
- Reg Sprigg 1946 discovered/published no jellies from Flinders Range, Australia
- 1957 British discovery of Charnia in U.K.

Ediacaran in Time

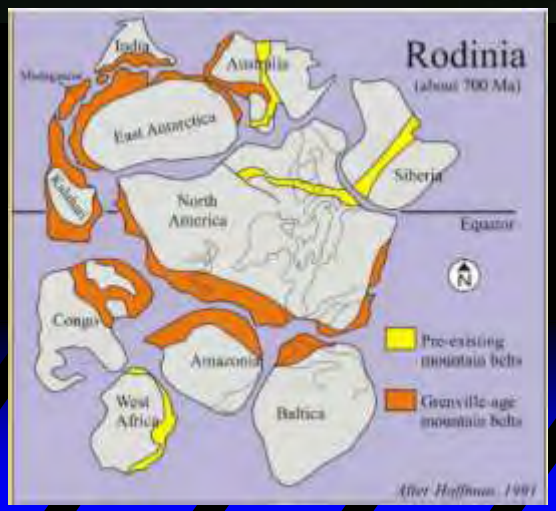




Ediacaran [635-541 m.y.] Timeline



Early Vendian World – Rodinia Breaks Apart & Lands Exposed

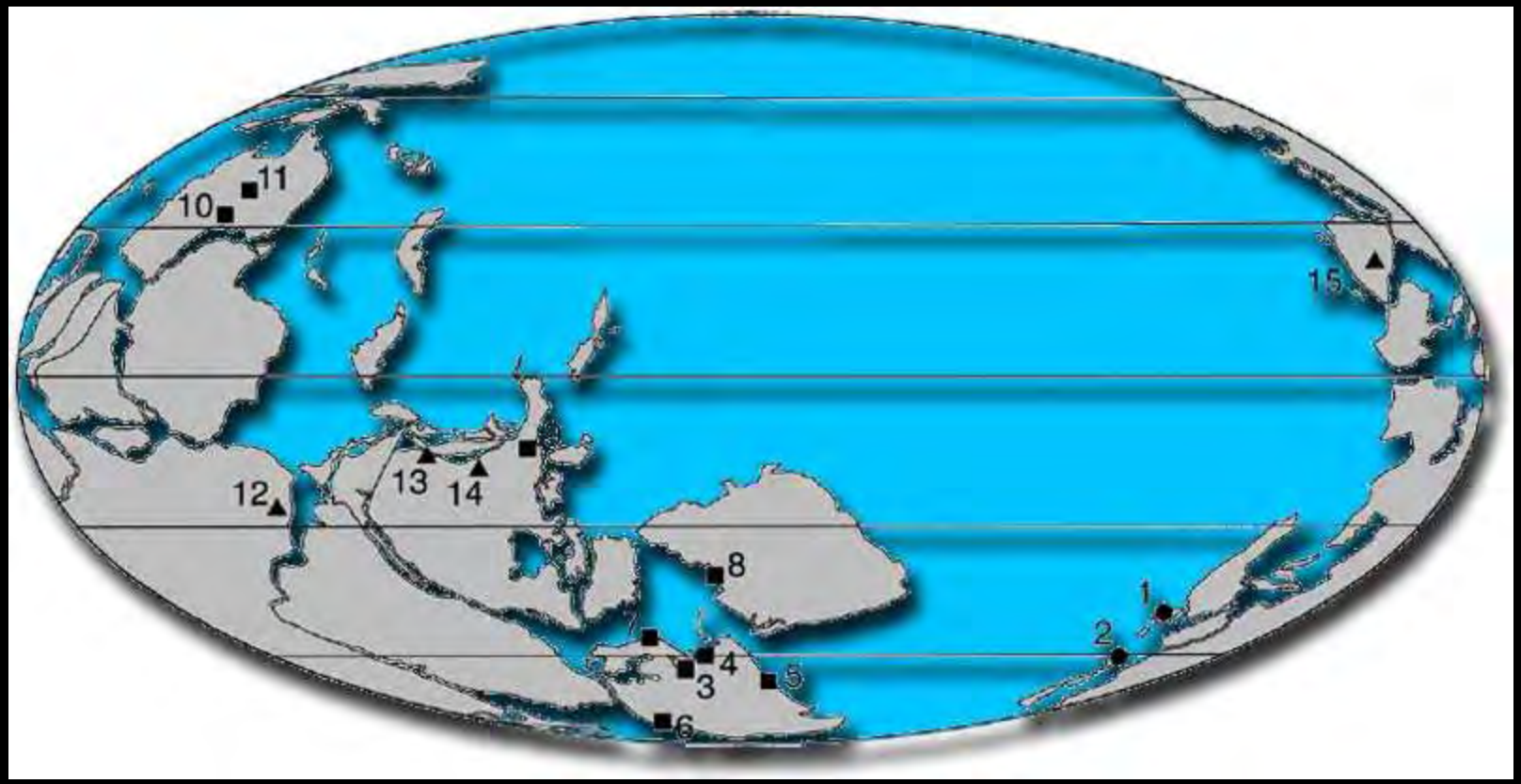


Source: Carmen Hewitt, Prezi

Figure 39. The supercontinent Pannotia-Gondwana, 580 million years ago (modified from Condie, 2001) (D. Gelt).

Source: Fedonkin et al. 2007 Rise of Animals

Peak Vendian World [560 m.y.]



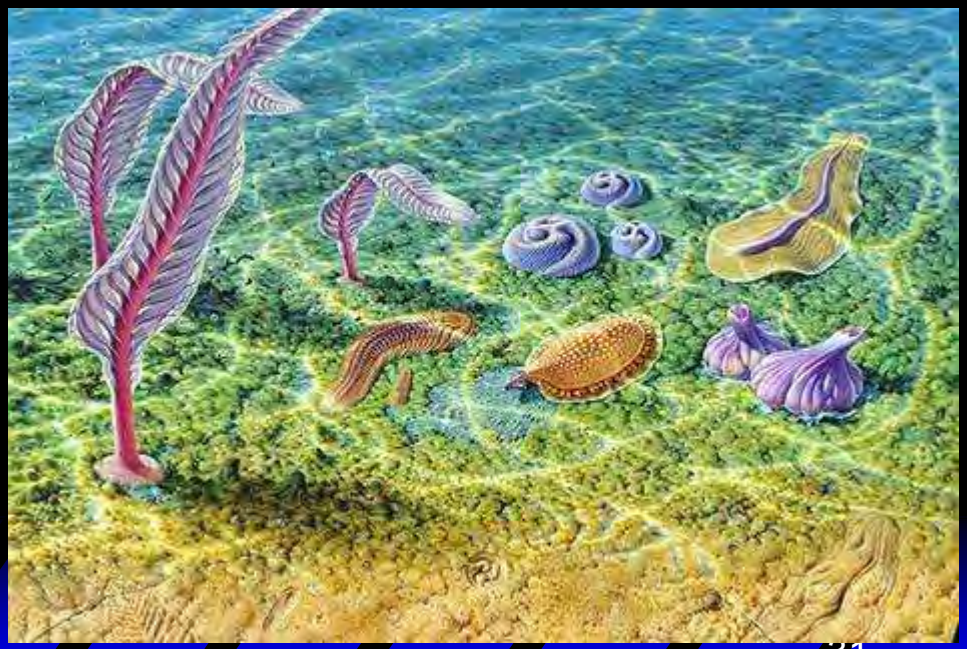
Ref, B. Waggoner 2003 Integr. Comp. Biol.

Neoproterozoic (800-542 m.y.)
"Snowball Earth" events early
Successive ice ages
Great fluctuations in climate
Base of Edicaran at 635 m.y.

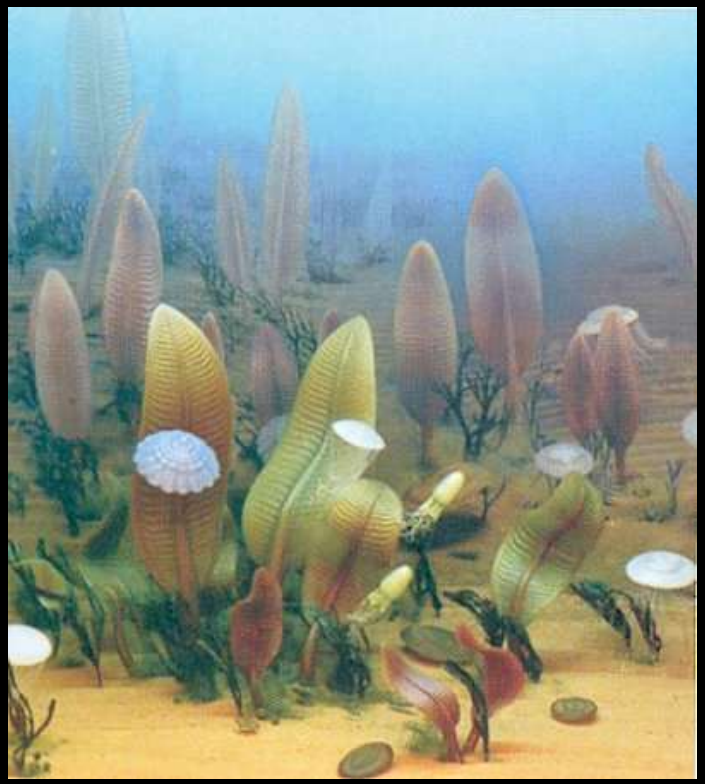
Most Extraordinary periods of Earth's History:

- ❖ most severe glacial conditions (snowball Earth) with ice at equator [est. 4-5 successive glaciations]
- ❖ followed by widespread tropical greenhouse conditions
- ❖ marked decline in stromatolites worldwide
- ❖ sudden appearance of soft-bodied metazoans adapted to grazing & burrowing

Ediacaran Habitat/Biota [565-541 m.y.]



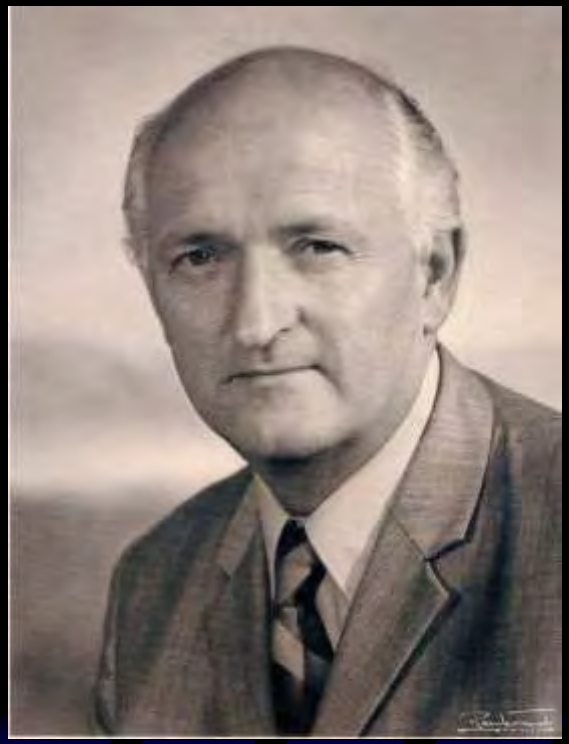
Ediacaran Habitat/Biota [565-541 m.y.]

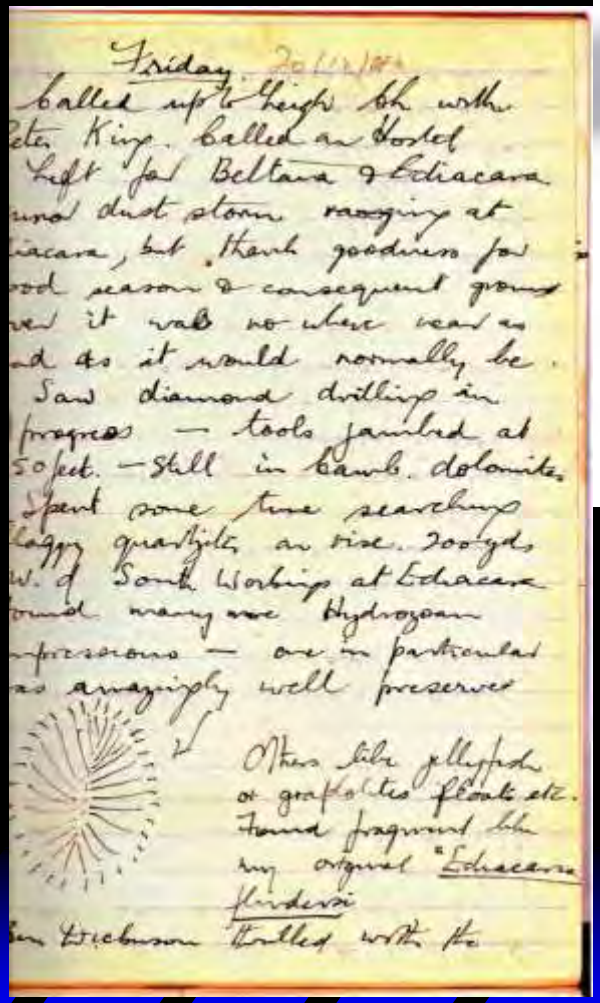


Ediacaran – First Formal Discovery

- 1946 Reg Sprigg, young Gov. Survey Geologist discovered first Ediacaran in Flinders Range, Australia (thought Cambrian) in 1947/49 papers
- Precambrian age establ. & true organic nature of the fossils by 1958 with discovery of Charnia “fronds” in the U.K.

Reginald Sprigg's 1946 Australia Discovery of Early Life





Friday 20/12/46

called up to Leigh Bh with
Peter King. called on Hostel
Left for Beltana & Ediacara
found dust storm ravaging at
Ediacara, but thank goodness for
good season & consequent grass
even it was no where near as
bad as it would normally be.
Saw diamond drilling in
progress — tools jammed at
50 feet. — Still in bank. dolomite.
Spent some time searching
flaggy quartzite on rise. 200 yds
W. of South Working at Ediacara
found many rare Hydrozoan
impressions — one in particular
as amazingly well preserved

Others like jellyfish
or graptolites float etc.
found fragment like
my original "Ediacara
flindersi"

Ben Dickinson thrilled with his

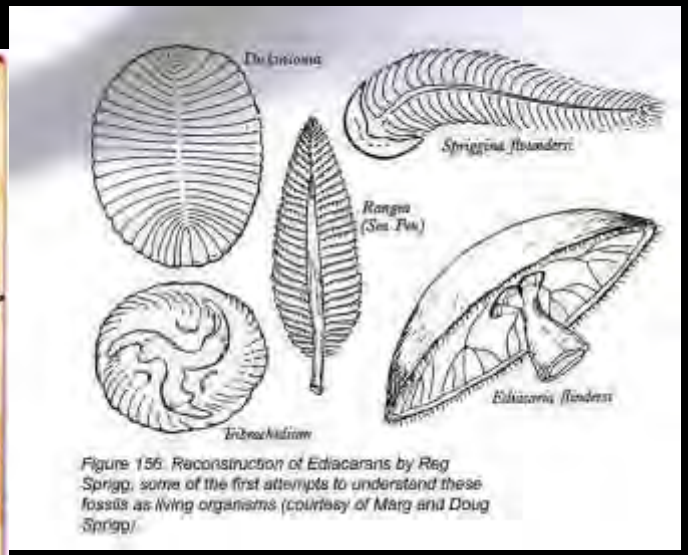


Figure 156. Reconstruction of Ediacarans by Reg Sprigg, some of the first attempts to understand these fossils as living organisms (courtesy of Marg and Doug Sprigg).

Source: Fedonkin et al. 2007 Rise of Animals

What Were the Ediacaran?

- Stephen Jay Gould and Adolf Seilacher propose that the Ediacaran fauna are where "failed experiments" in the evolution of multi-cellular animals.
- Univ. Oregon paleontologist Gregory Retallack believed Ediacaran fauna were actually lichens.
- Typical opinion today seems to be that a mix of early cnidarians, arthropods, echnoderms, fungi, and sponges.
- Historically all grouped into a new Kingdom [Vendobionta].

Ediacaran are Unique Animals

The Ediacaran Fauna represents the oldest collection of metazoan fossils on the planet, commencing in the fossil record around 610 m.y.

- Many have no living representatives;
- Shape very bizarre & all soft-bodied;
- Probably feed on surface microbial mats;
- Perhaps some hosted endosymbiont photosynthetic algae as food source;
- Did not dig burrows (anoxia under bacterial mats may have prevented burrowing);
- No predators among them (no bite marks);
- Envisioned as a peaceful ocean garden;
- Preserved by rapid burial by ash or sand, trapping them against mud or microbial mats.

Edicaran Distribution

- Known from 30 localities in 5 continents
- Found at over 35 specific localities worldwide
- Especially abundant & studied at:
  - Flinders Range, Australia
  - White Sea, Russia
  - Namibia, Africa
  - Avalon Peninsula, Newfoundland
  - Ukraine of Europe

Source: Fedonkin et al. 2007 Rise of Animals

the Major Ediacaran Sites

Ediacaran Sites

Source: Fedonkin et al. 2007 Rise of Animals

Mistaken Point, Newfoundland

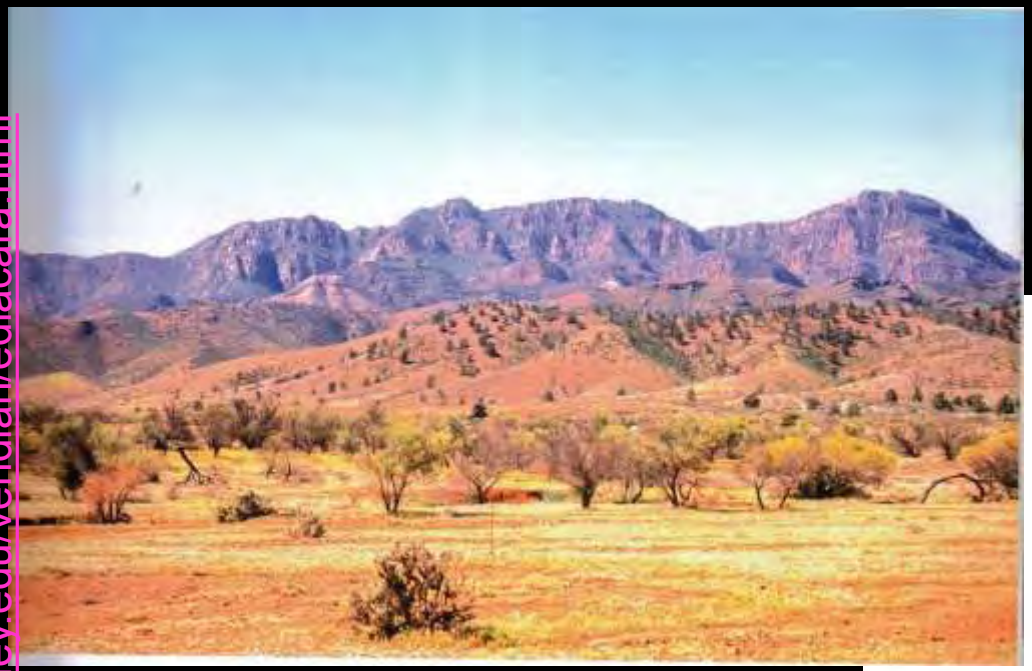
In 1967, geologist S. B. Misra, who at the time was a gra
Memorial University of Newfoundland, discovered and be
some unusual fossils of late Precambrian age, found in
exposed rock surfaces along the southern coast of the A
in Newfoundland (Anderson and Misra 1968; Misra 1969
famous locality where these fossils can be seen is at Mi

Typical biota are large frond-like Vendian fossils that lived in deep water; preserved by volcanic ash

Ref. http://www.ucmp.berkeley.edu/vendian/ediacara.html

Namibia, Africa

Ediacara Hills, Australia



In 1946, an Australian mining geologist named Reginal
exploring a range of mountains north of the city of Adel
known as the Ediacara Hills. Serendipitously, he found
of what were apparently soft-bodied organisms, prese
undersides of slabs of quartzite and sandstone. Most
shaped forms that Sprigg dubbed "medusoids" from th

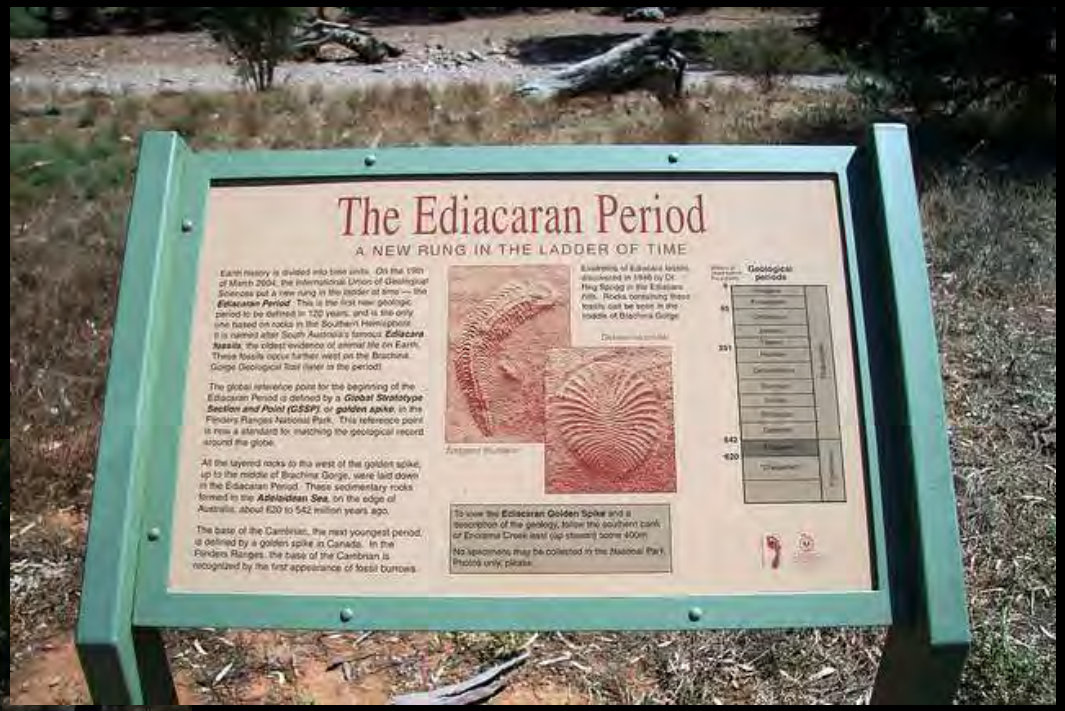
Discovered 1946 by Geologist Reginald Sprigg; medusoid forms common

Ref. http://www.ucmp.berkeley.edu/vendian/ediacara.html

Ediacaran Rocks of Australia

- 4 km thick succession of sediments
- Rise/Fall of global sea levels
- Lived in cooler ocean waters than Cambrian
- Large meteorite impact at 570 m.y. may have led to richest fauna

Australia Park for the Ediacaran



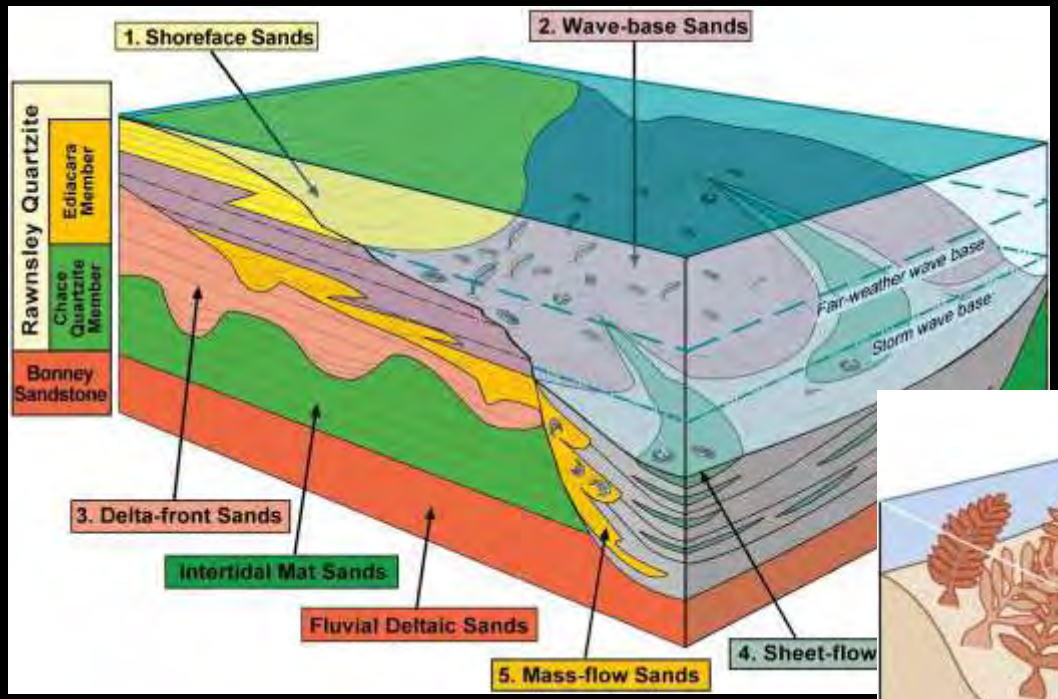
White Sea, Russia

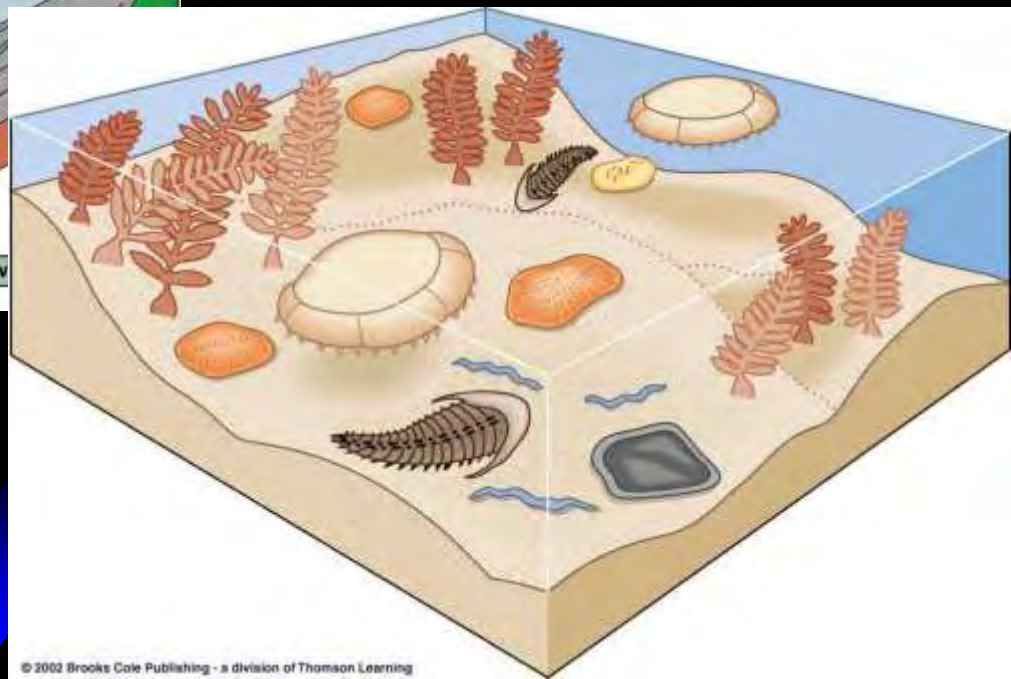
Figure 8: Coastal outcrops of Vendian strata in the White Sea-Arkhangelsk region, Russia.

Remote site containing one of richest diversity of Vendian; shallow marine

Ref. http://www.ucmp.berkeley.edu/vendian/whitesea.html

Ediacaran Habitat Recreated
[Australia]





Ediacaran Biota Boom due to massive increase in deep-sea oxygen levels and abundant organic matter from melting glaciers.

Conditions Favoring Origin of Metazoans in Proterozoic

Prokaryotic Stromatolites thought antagonistic towards eukaryotic metazoan populations

- Cold Water Environment from extensive glaciations, led to
- Extinction of competing cyano-bacteria stromatolites that released toxins &
- Colder water holds more oxygen (1-6X) until reached trigger levels to support eukaryote metazoans
- Grazing by new Ediacaran further accelerated stromatolite decline

Cited from M. Fedonkin 2003 Paleo Res.

Conditions Favoring Origin of Metazoans in Proterozoic (2)

Prokaryotic Stromatolites thought antagonistic towards eukaryotic metazoan populations

- Stromatolite competition for nutrients with enlarging algal colonies further affected stromatolites
- Increase in continental plate/land masses led to nutrients from erosion & water upwelling to recycling of organic matter to favor Ediacarans
- Geographical isolation of species increased (favor allopatric speciation) due to less ocean depths & growing land area margins from glaciers lowering ocean waters

Cited from M. Fedonkin 2003 Paleo Res.

Conditions Favoring Origin of Metazoans in Proterozoic (3)

- Colder oceans result in siliciclastic sedimentation
- Colder oceans result in intense vertical water circulation
- Decreased water levels result in higher concentrations of phosphates, nitrates & organic nutrients
- Geographical isolation of species increased (favor allopatric speciation) due to less ocean depths & growing land area margins from glaciers lowering ocean waters

Cited from M. Fedonkin 2003 Paleo Res.

Ediacaran Morphology Matches Expected Cold Water Origins in Proterozoic

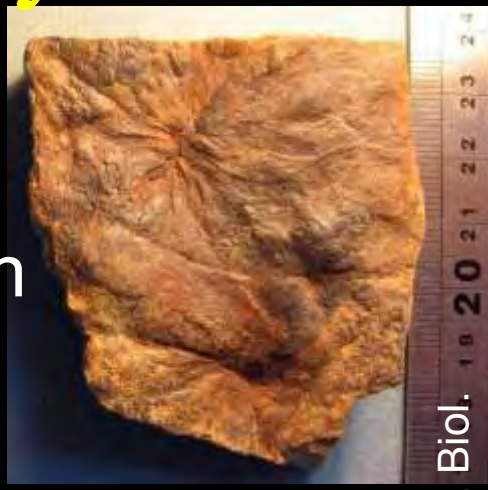
- Large number of aberrant morphologies;
- Larger size forms than in warmer waters;
- Dominance of attached forms in benthic communities;
- Dominance of soft-bodied forms;
- Extreme flattening & bag body constructions;
- Rare to have mineralized skeletons;
- Low biotic diversity & many cosmopolitan spp.;
- Dominance of sedentary & benthic forms;
- Ocean storms more abundant in colder waters, to favor preservation.

Cited from M. Fedonkin 2003 Paleo Res.


Morphology


- Over 30 different genera among ca. 100 valid species
- 4 main types found:
  - Most abundant are circular impressions, believed to be benthic dwellers like sea anemones (explaining their abundance)
  - Next most common are simple burrows made by bilaterian animals (whether or not they were made by annelids is not known)
  - Third are other benthic forms, some of which suggest affinities with annelids, arthropods, and echinoderms. Others in this group are bizarre enough to be problematic and unknown.
  - Least abundant are the "sea-fronds", although they are represented in all major finds.

Ediacaran Cladistic Analyses



Parsimony Analyses Group Ediacaran Biota into Three Major Clusters:

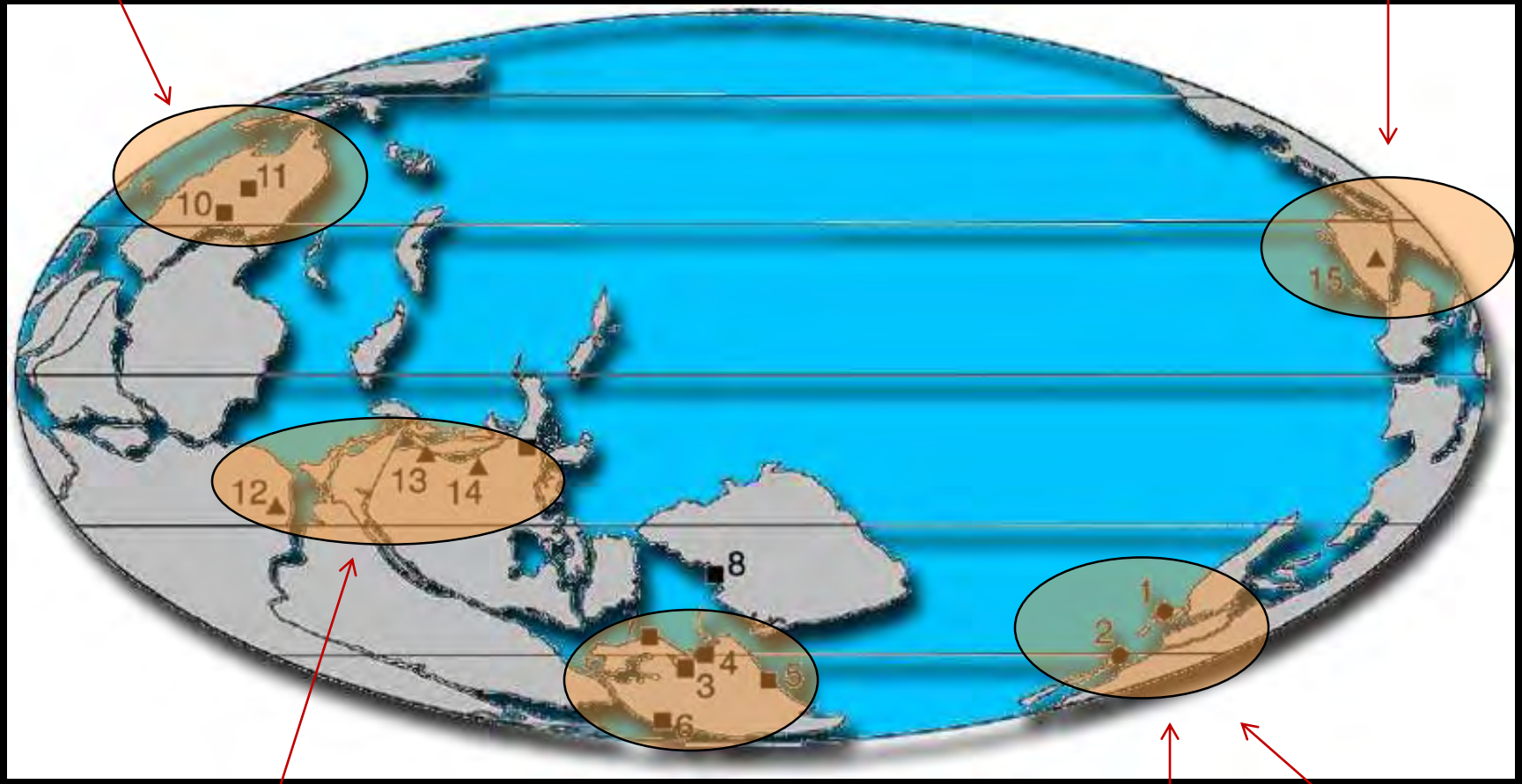
- Avalon Assemblages (oldest)
  - Newfoundland, England
- White Sea Assemblages (next oldest)
  - Russia, Australia, Canada, Norway
- Nama Assemblages (most recent)
  - Namibia, China, Canada

Ref. B.Waggoner 2003 Integr. Comp. Biol.

Peak Vendian World [560 m.y.]

White Sea Assemblage

Nama Assemblage



Nama Assemblage

White Sea Assemblage

Avalon Assemblage

Ref, B. Waggoner 2003 Integr. Comp. Biol.

Animal Groups among Ediacara

1. Anemone-like [Mawsonites]

2. Cnidaria frond-like [Aspidella]

3. Sponge-like [Palaeophragmodictya]

4. Worm-like [Dickinsonia]

Source: Fedonkin et al. 2007 Rise of Animals

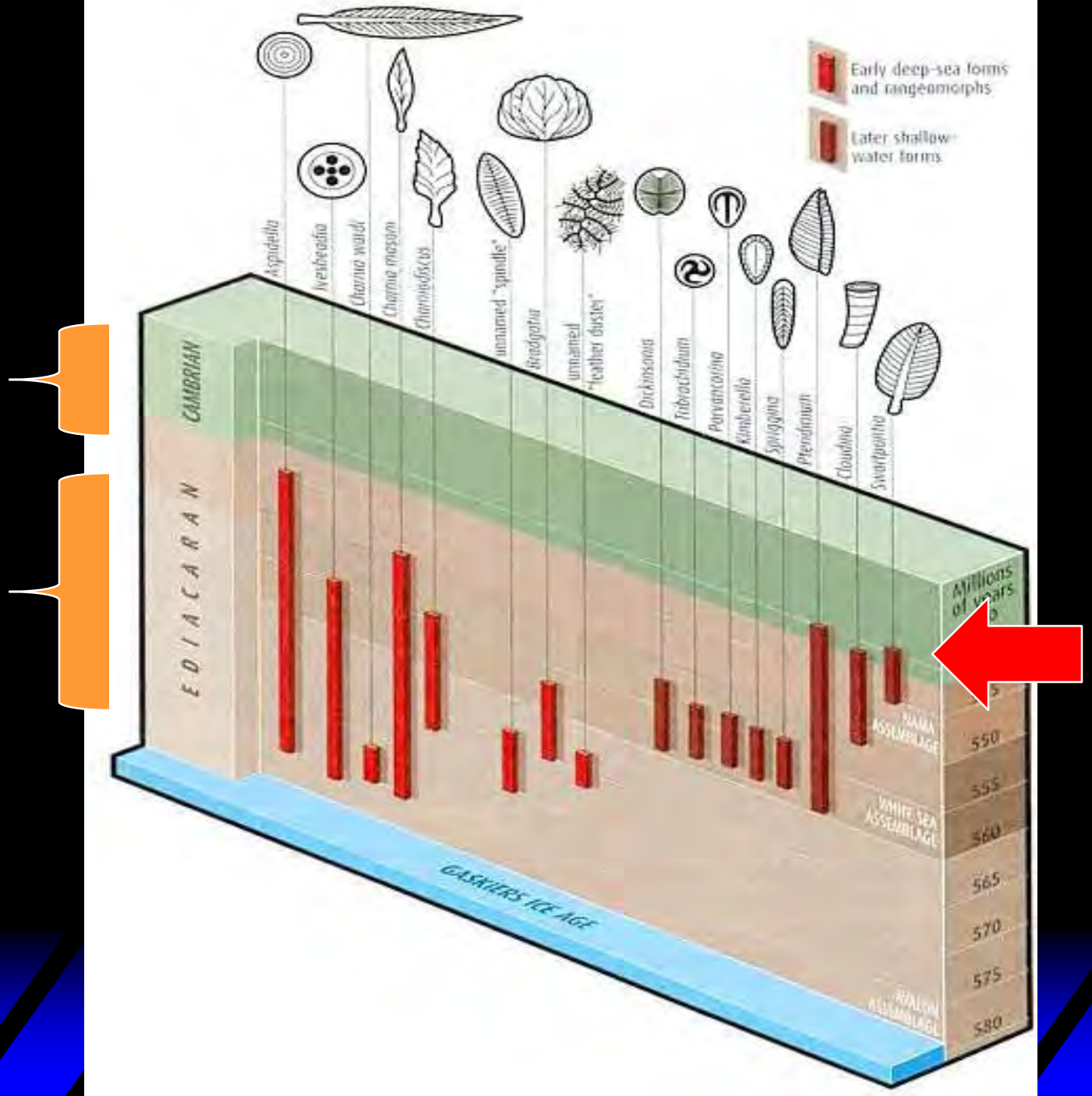
Animal Groups among Ediacara

5. Segmented arthropod-like [Spriggina; Parvacorina]

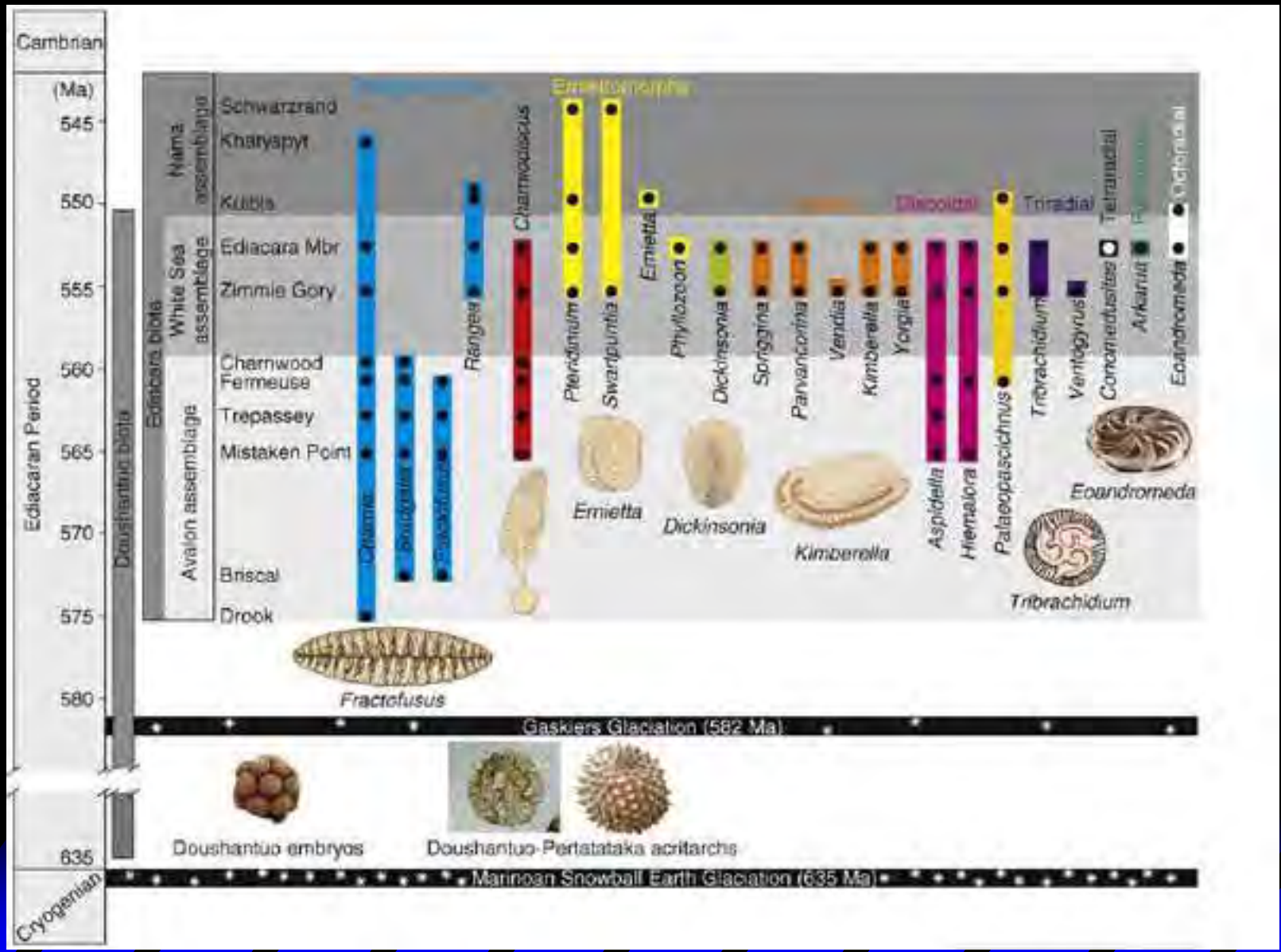
6. Mollusc [Kimberella]

7. Sea Star-like [Arkarua]

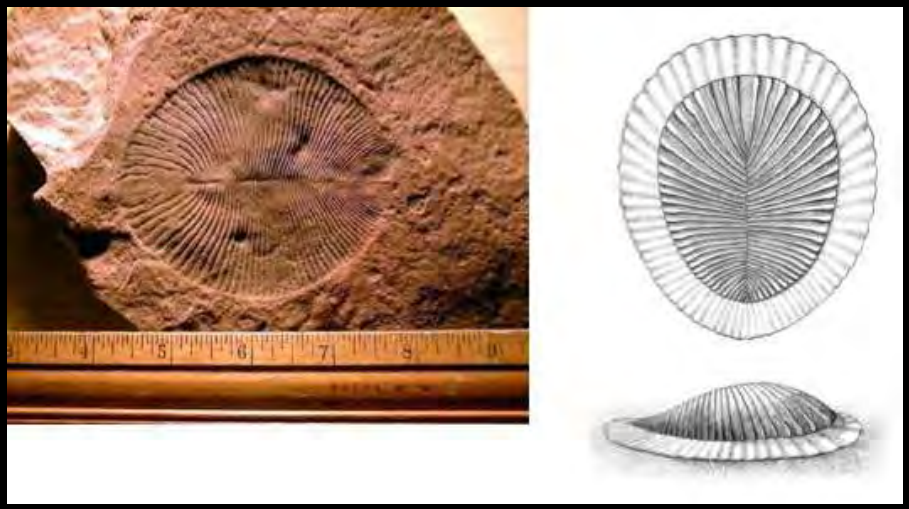
Source: Fedonkin et al. 2007 Rise of Animals

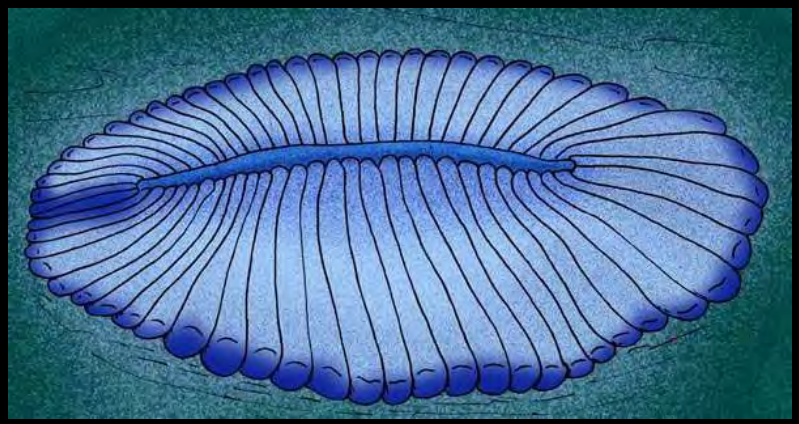

Early deep-sea forms and rangeomorphs
Later shallow-water forms
Aspidella
Ivesheadia
Charnia wardi
Charnia masoni
Charnidiscus
unnamed "spindle"
Beothukis
unnamed "feather duster"
Dickinsonia
Tribrachidium
Parvancorina
Kimberella
Spriggina
Pteridinium
Cloudina
Swartpuntia
EDIACARAN
CAMBRIAN
GASKIERS ICE AGE
NAMA ASSEMBLAGE
WHITE SEA ASSEMBLAGE
NAMA ASSEMBLAGE
Millions of years
550
555
560
565
570
575
580

Vendian Faunal Diversity in Time



Dickinsonia





Best Publically Known of Vendian; considered to be a worm; size varied up to 1 meter

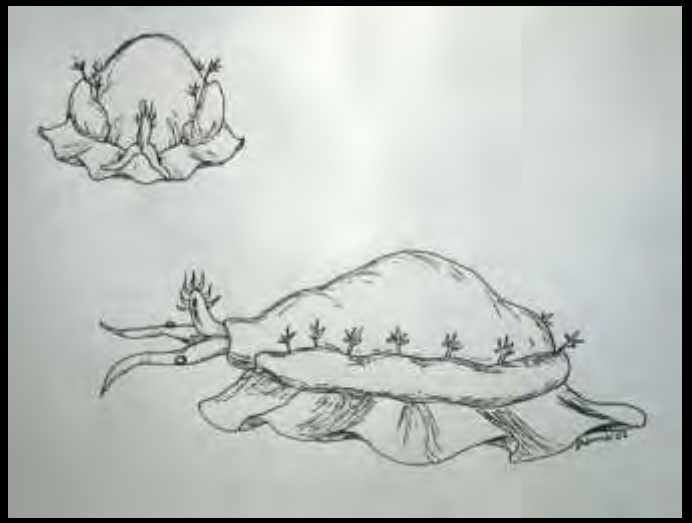
Ref. http://www.ucmp.berkeley.edu/vendian/dickinsonia.html

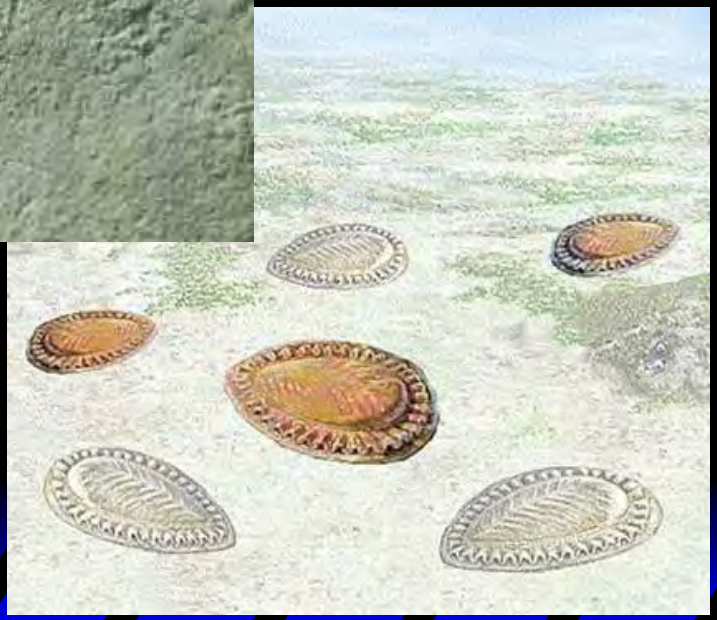
Kimberella

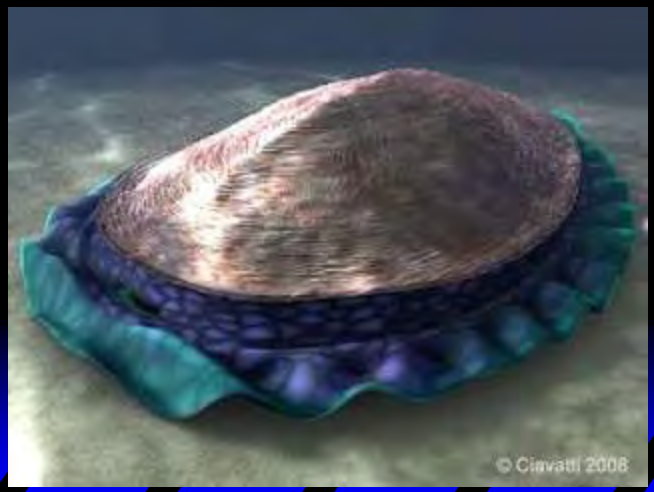
Early proto-mollusc; common from White Sea Russia

Ref. http://www.ucmp.berkeley.edu/vendian/kimberella.html

Kimberella







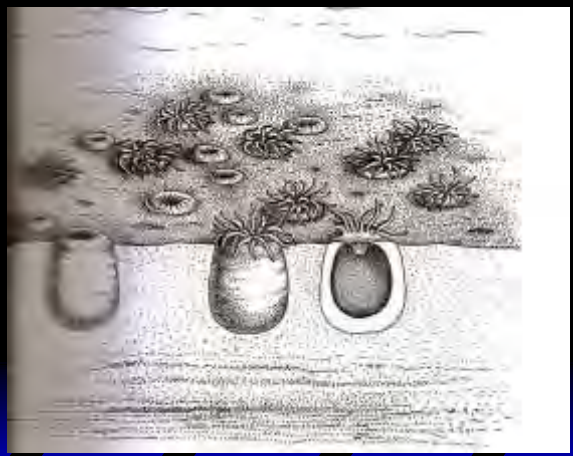
Cyclomedusa

Most common & widespread of Vendian fossils; size range from a few mm to 1 m in dia.; think was benthic, bottom-dwelling sea anemone-like

Ref. http://www.ucmp.berkeley.edu/vendian/cyclomedusa.html

Nemiana

Simplest of all Vendian fossils; always gregarious; often interpreted as jellyfish masses; thought now anemone polyps; tentacles are absent



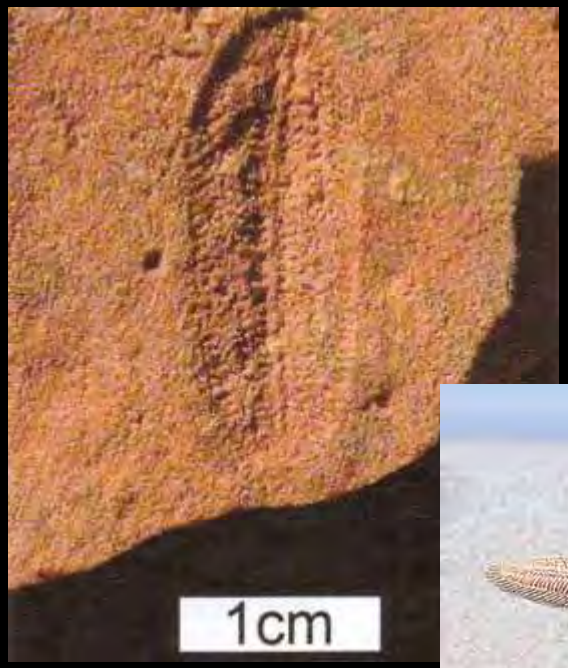
Ref. http://www.ucmp.berkeley.edu/vendian/nemiana.html

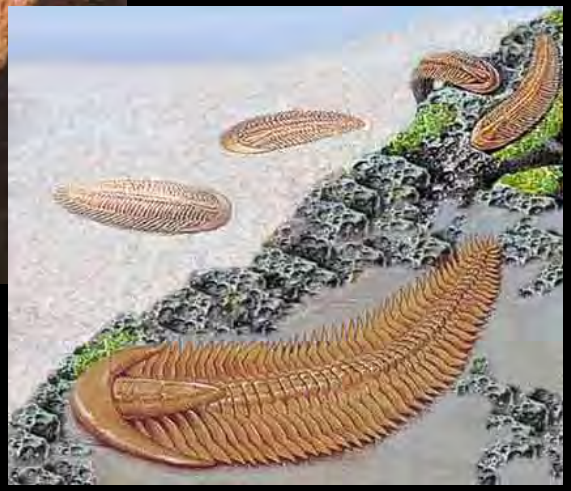
Tribrachidium

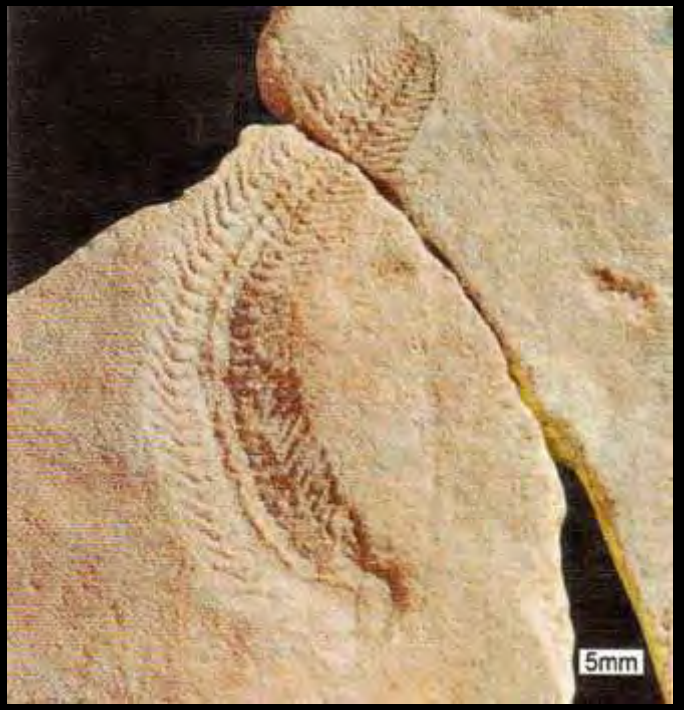
Mysterious, bizarre disc-shaped form with tri-radial symmetry; affinities to Echinoderms

Ref. http://www.ucmp.berkeley.edu/vendian/tribrach.html

Spriggina







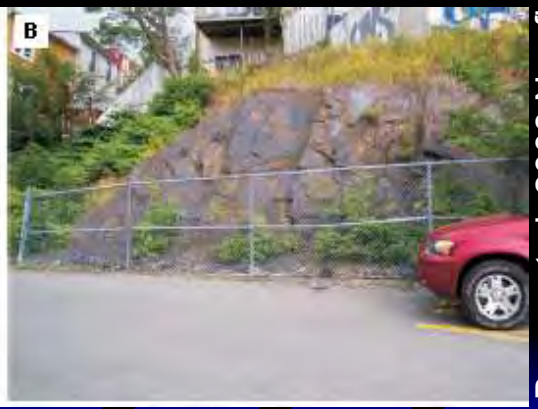
Soft-bodied arthropod-like
known mostly from Australia

Ref. http://www.ucmp.berkeley.edu/vendian/spriggina.html

Newfoundland Aspidella Ediacaran

First described Ediacaran body fossil – attachment disc for frond

Locality at street parking lot St. John



Type Locality St. John

Ref. W. Boyce et al. 2008 Newfld Dept Nat Res Geol Survey

Pteridinium

Squashed, flat, ribbed body animal like leaves; maybe like a cnidarian

Ref. http://www.ucmp.berkeley.edu/vendian/pteridinium.html

Swartpuntia

Namibia vendian of 3 vertical sheets attached to a central stalk off sea floor; thought that inflated chambers may have held photosynthetic algae or bacteria

Eoporpita

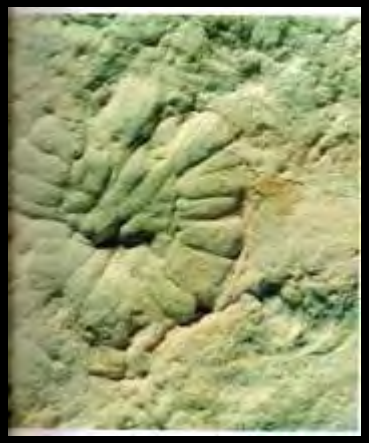
One of most striking Vendian of tentacles surrounded by a central body; thought is more like a sea anemone than jellyfish

Ref. http://www.ucmp.berkeley.edu/vendian/eoporpita.html

Namibian Edicaran

Other Ediacaran Fossils

Archaeaspinus



Inaria

Medusinites

Protodipleurosoma

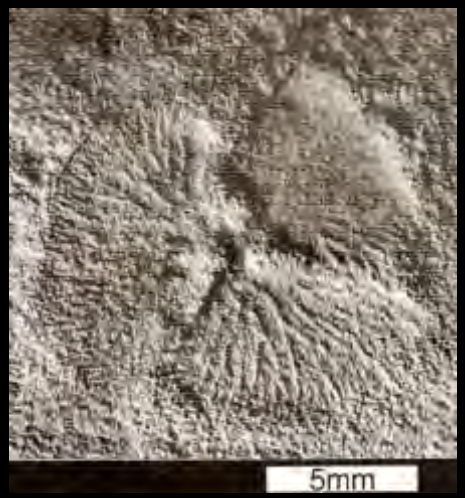
Kharakhtia

Zimni

Suzmities

Pomoria

Other Ediacaran Fossils



Albumares

Anfesta

Paravendia

Mialsemia

Ivovicia

Solza

Extinction of Ediacaran

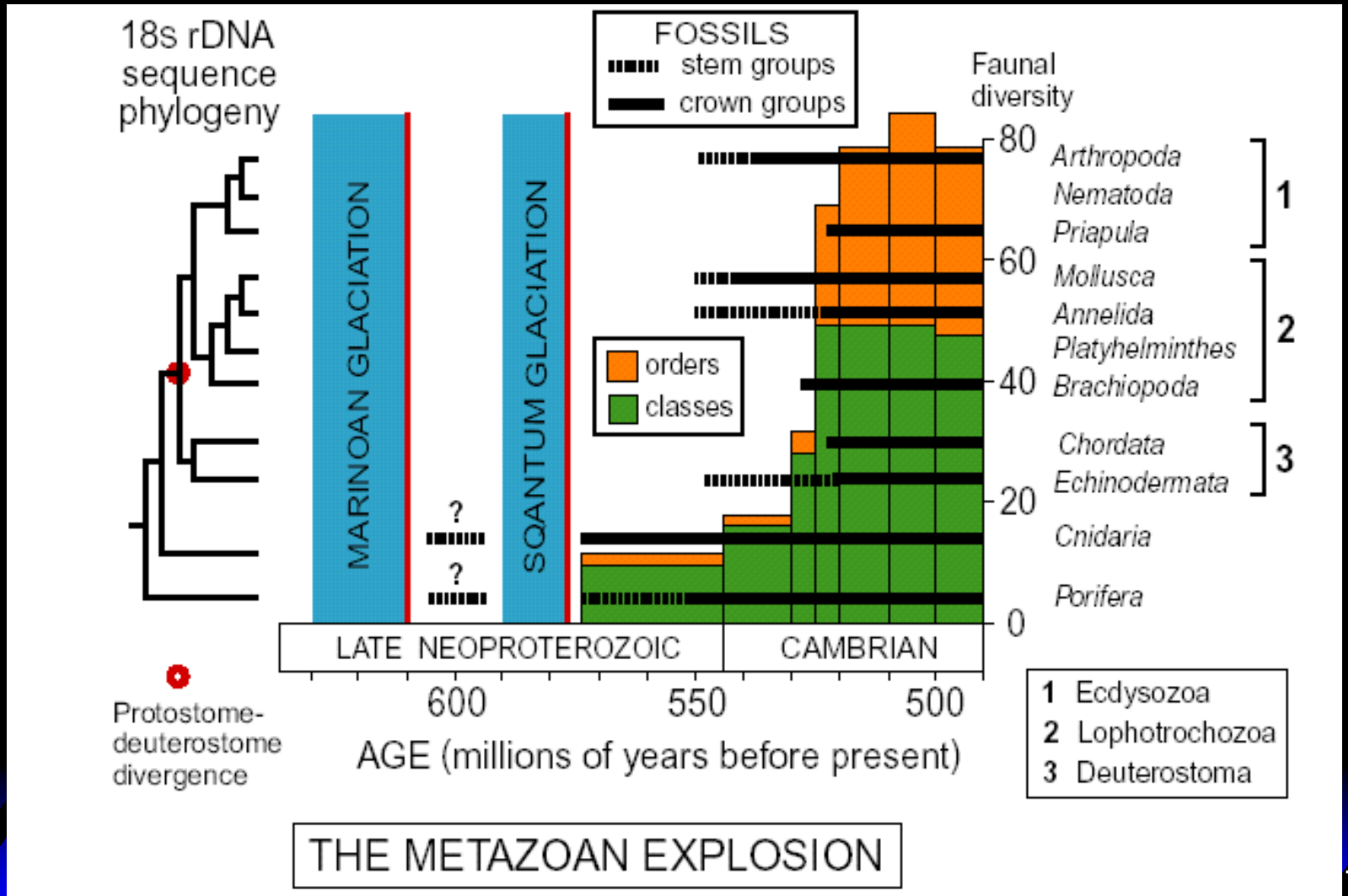
- There appears to have been a major extinction event at the boundary between the Precambrian and the Cambrian Explosion (around 545 mya). No Ediacaran representatives survived to Cambrian Explosion & all went extinct.

Extinction of the Ediacara- Why?

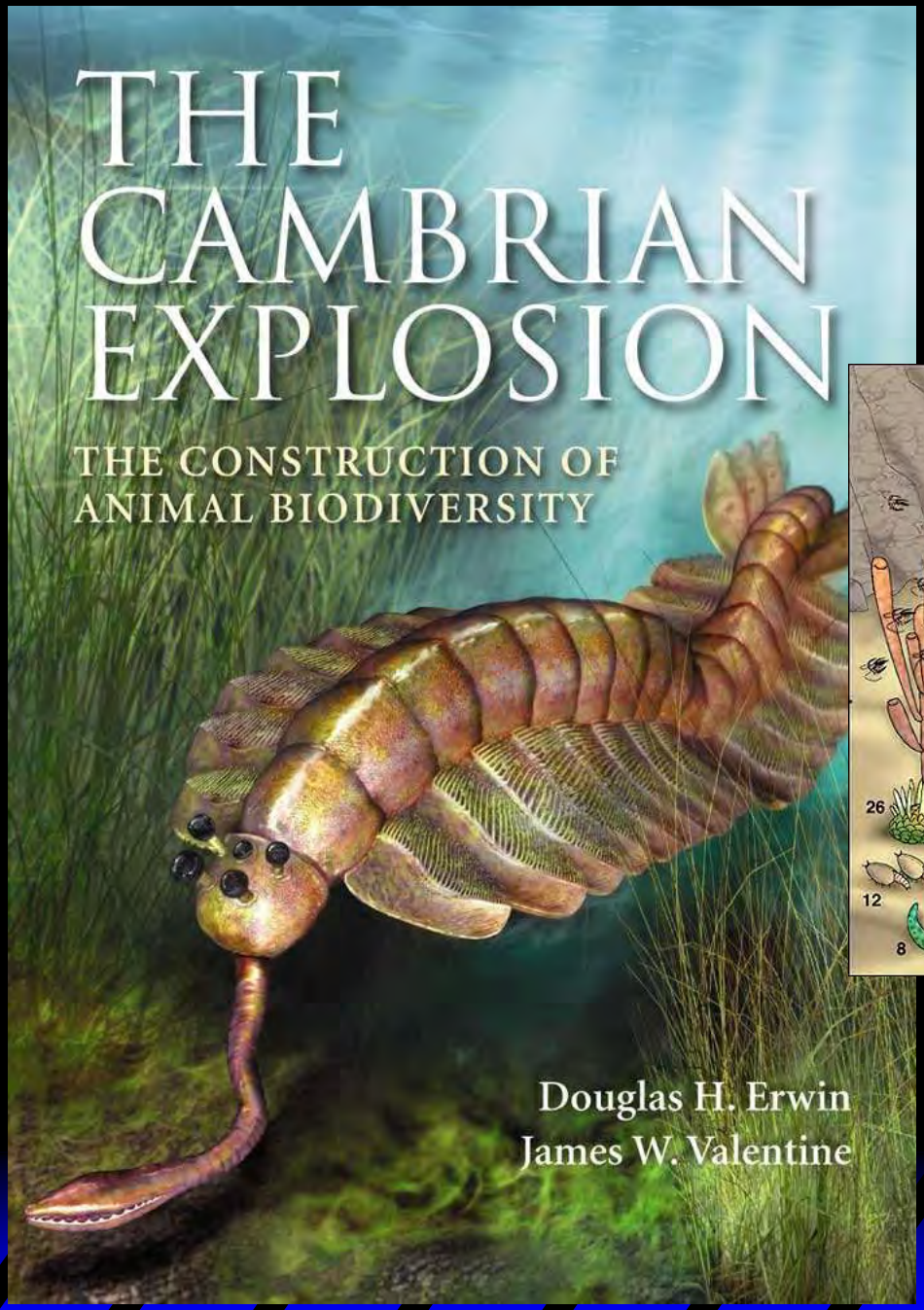
- Higher O2 levels favor shelled animal competitors for resources?
- Abrupt change in ocean chemistry?
- Global anoxic event (widespread methane release?)
- Rise of Cambrian Explosion predators?

Vendian Animals Ruled the Earth's Seas 635-541 m.y. ago [90 m.y.] but most vanished leaving no decendants. However, now thought some were early ancestors to Cambrian arthropods (Paravancornia) and echinoderms (Arkarua) , so Precambrian boom (Ediacaran) paved path to Cambrian Explosion

Extension of Vendian Biota into Cambrian?



Hoffman and Shrag (1998)


THE CAMBRIAN EXPLOSION
THE CONSTRUCTION OF ANIMAL BIODIVERSITY
Douglas H. Erwin
James W. Valentine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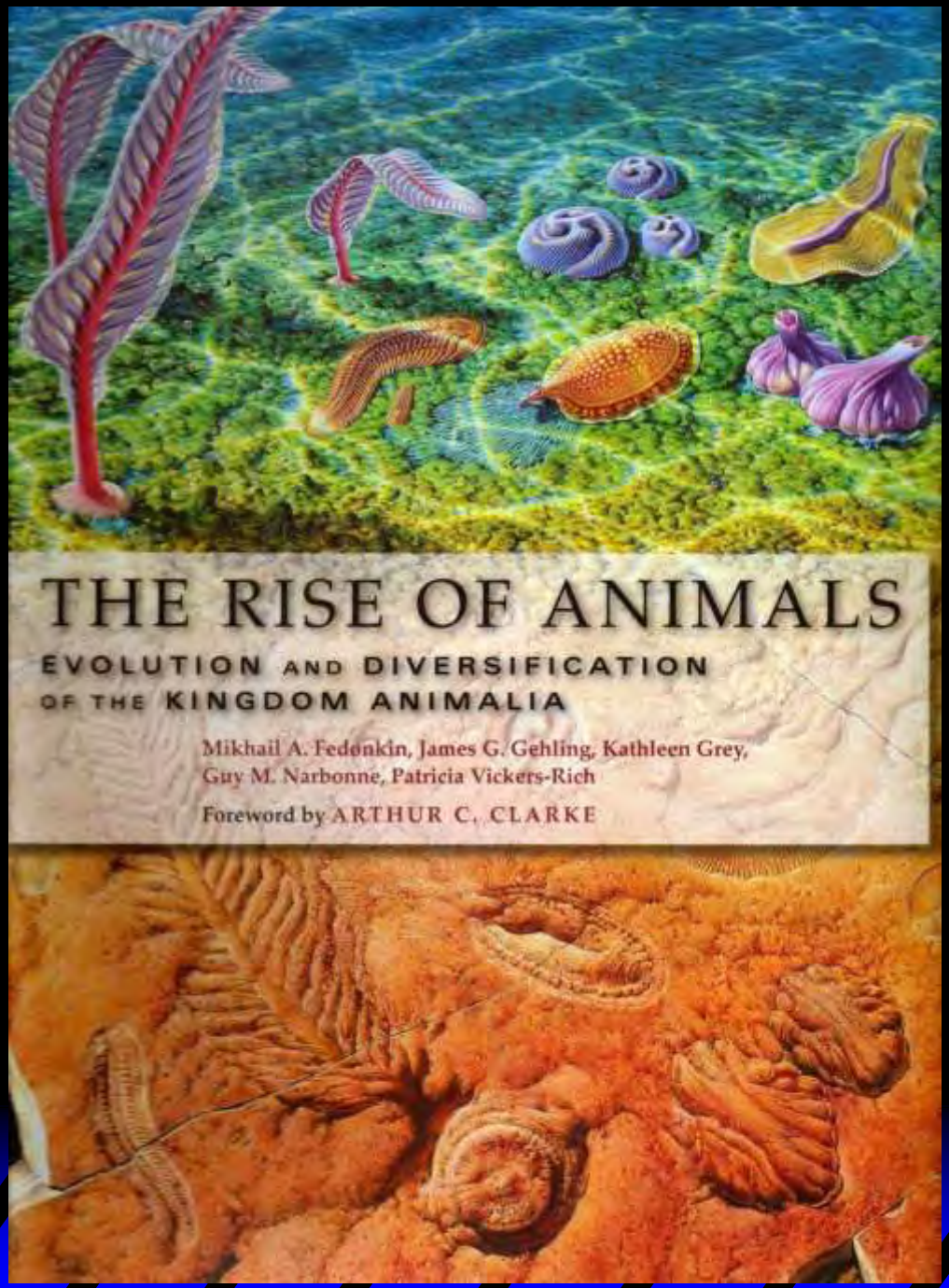
Rise of Animals by M. Fedonkin et al. 2007



The Early Animals (Ediacaran) of Earth – Nature's Experiments

Donald Baumgartner

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