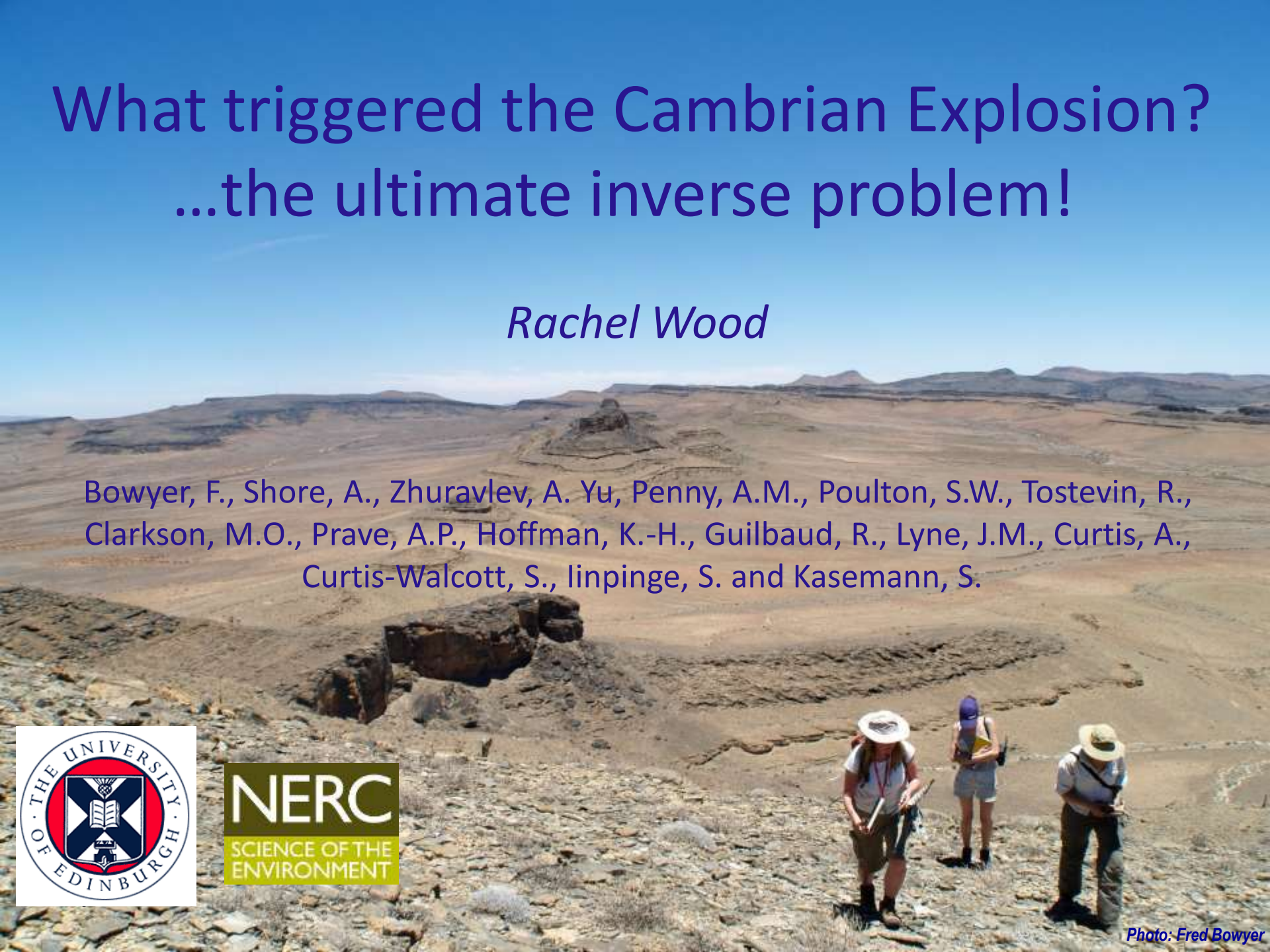
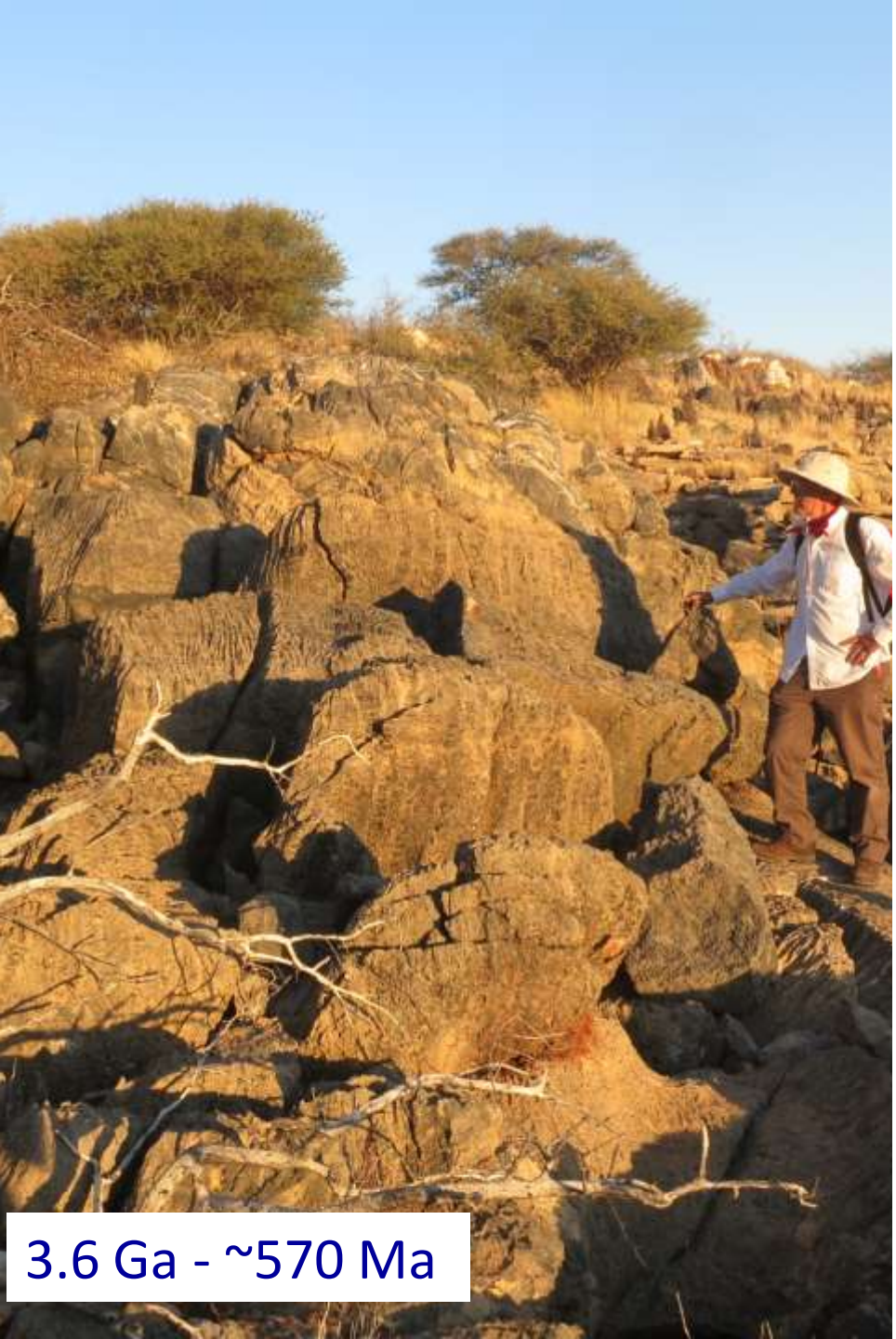

Source: Google

What triggered the Cambrian Explosion? …the ultimate inverse problem!

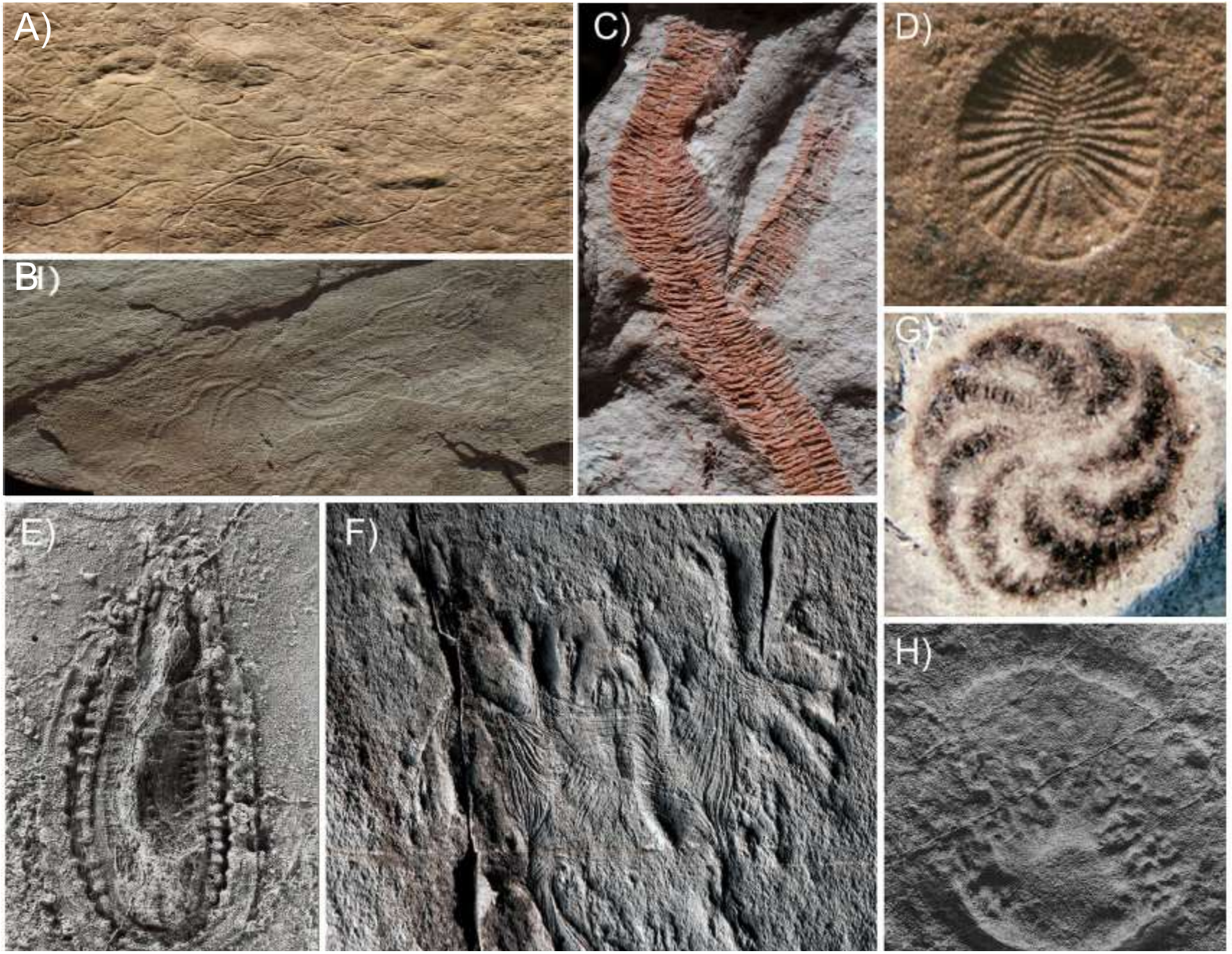
Rachel Wood

Bowyer, F., Shore, A., Zhuravlev, A. Yu, Penny, A.M., Poulton, S.W., Tostevin, R., Clarkson, M.O., Prave, A.P., Hoffman, K.-H., Guilbaud, R., Lyne, J.M., Curtis, A., Curtis-Walcott, S., Iinpinge, S. and Kasemann, S.

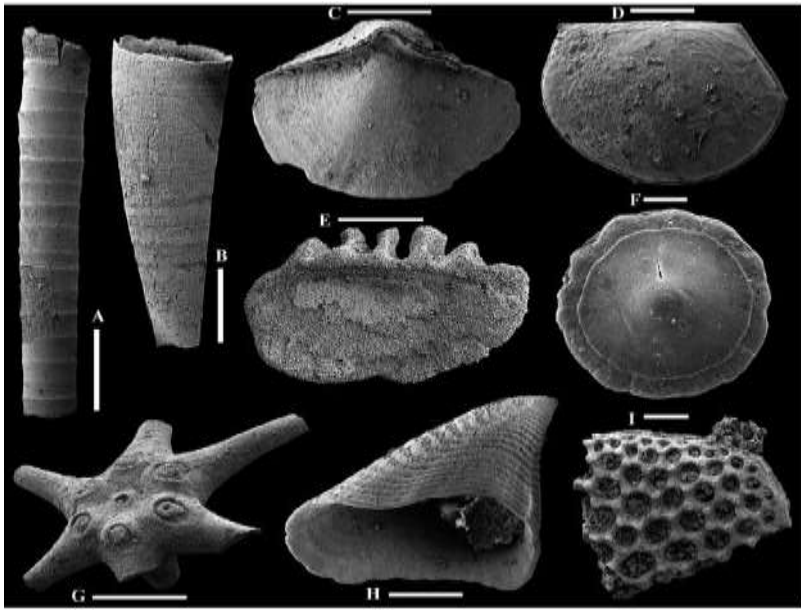


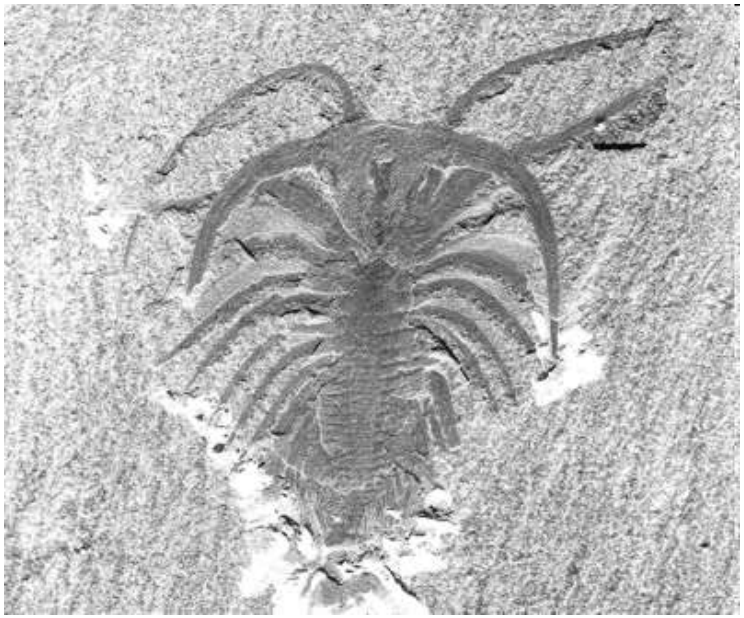


3.6 Ga - ~570 Ma



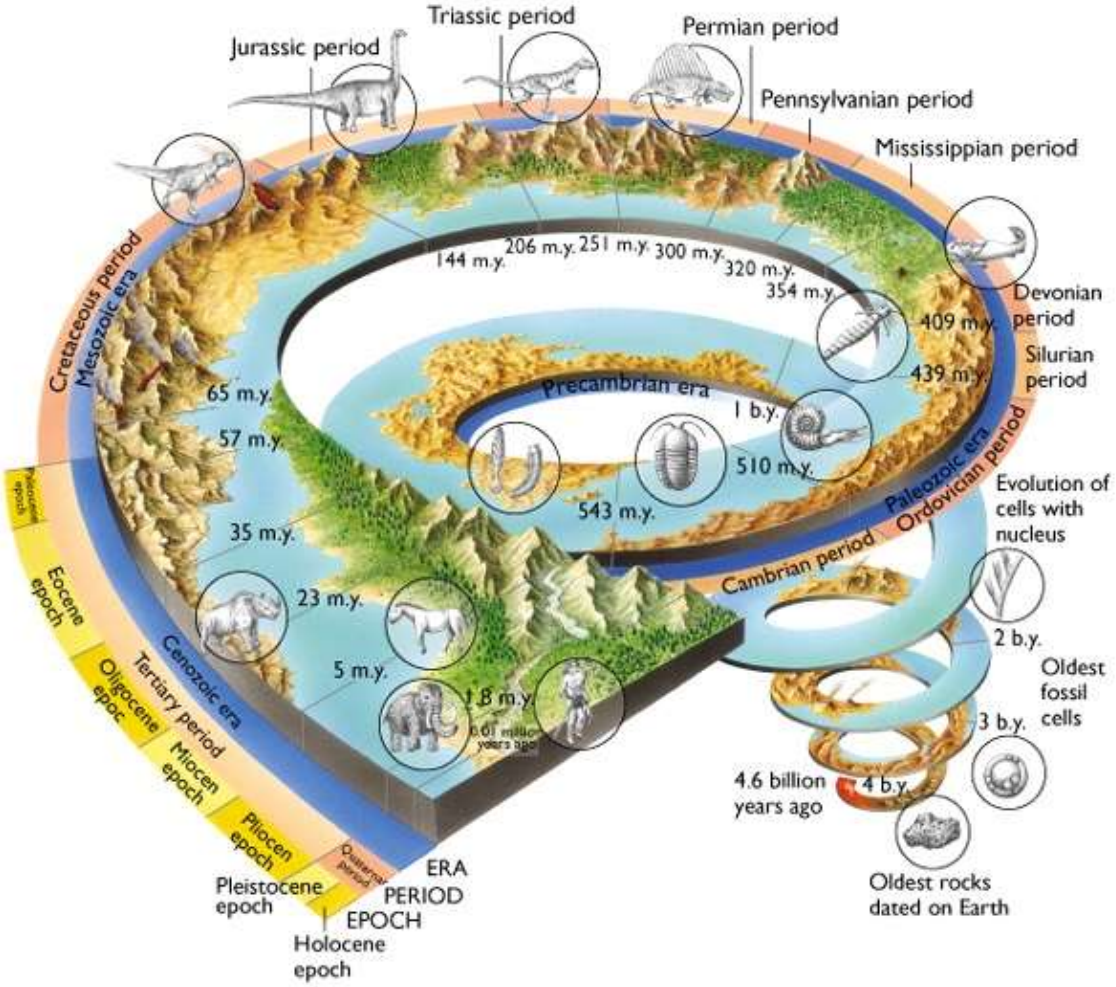
~570 - 541 Ma: the first probably animals (metazoans)



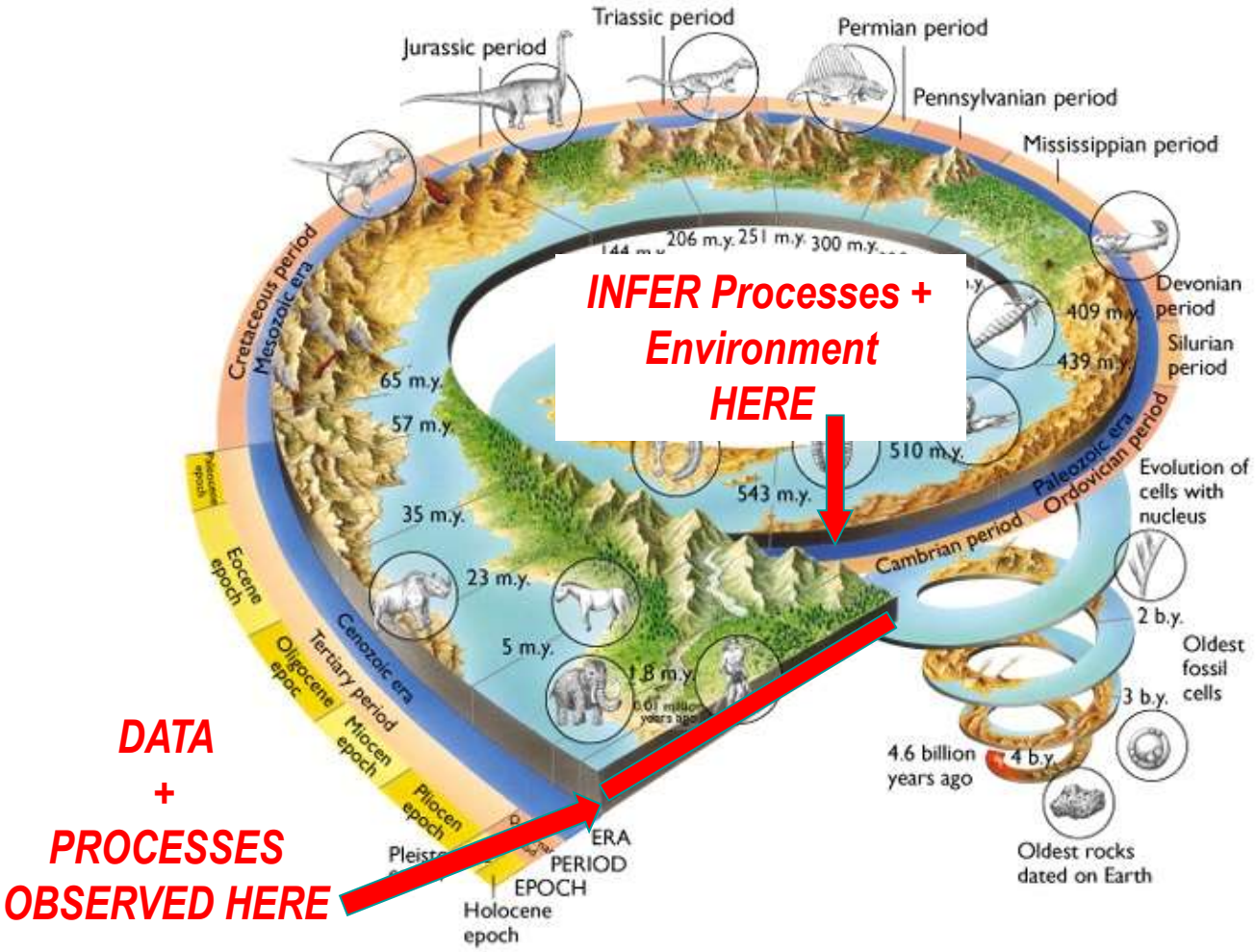


~541 Ma: The 'Cambrian Explosion'

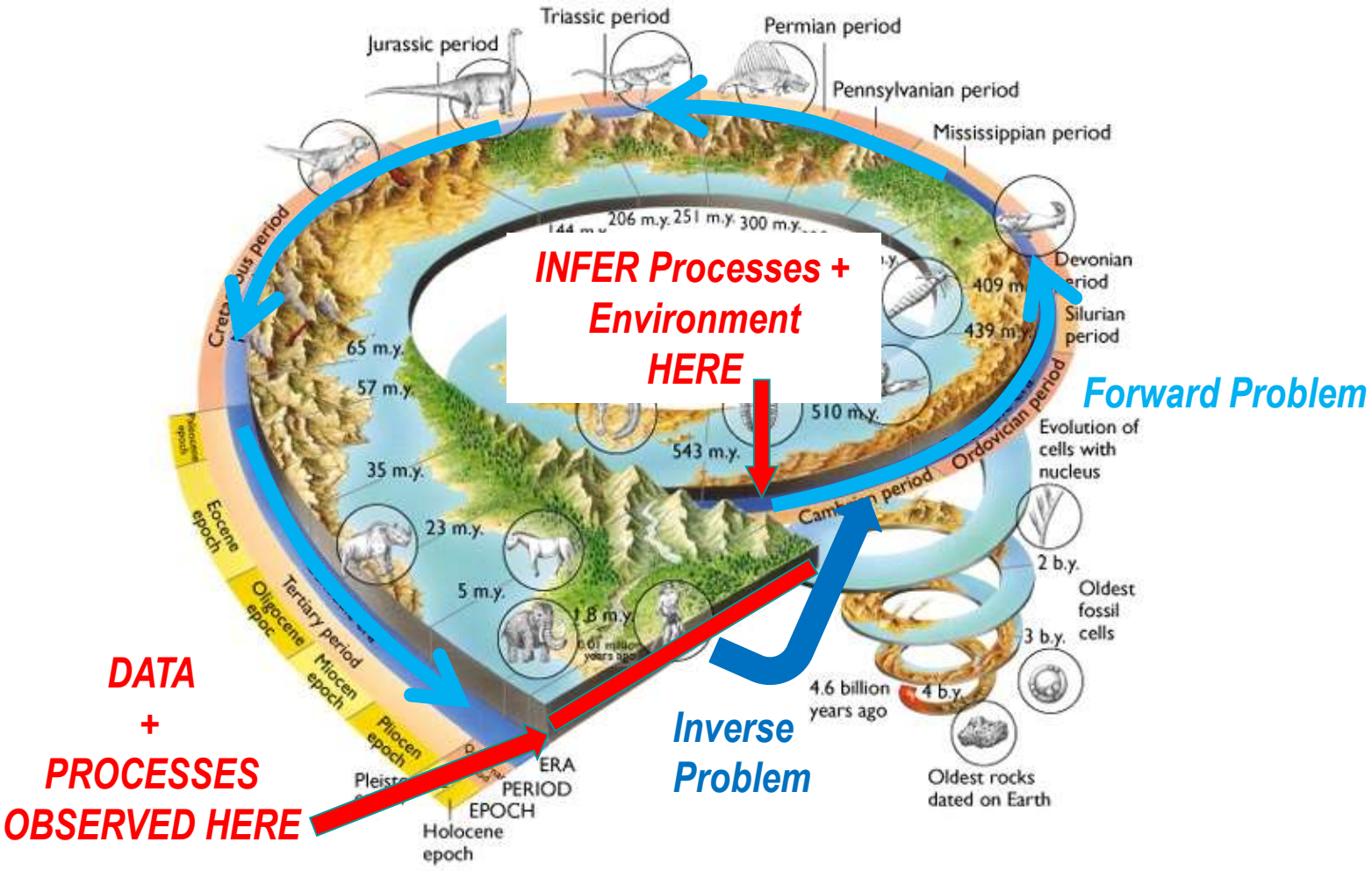
Environmental Opportunity vs Evolutionary Innovation

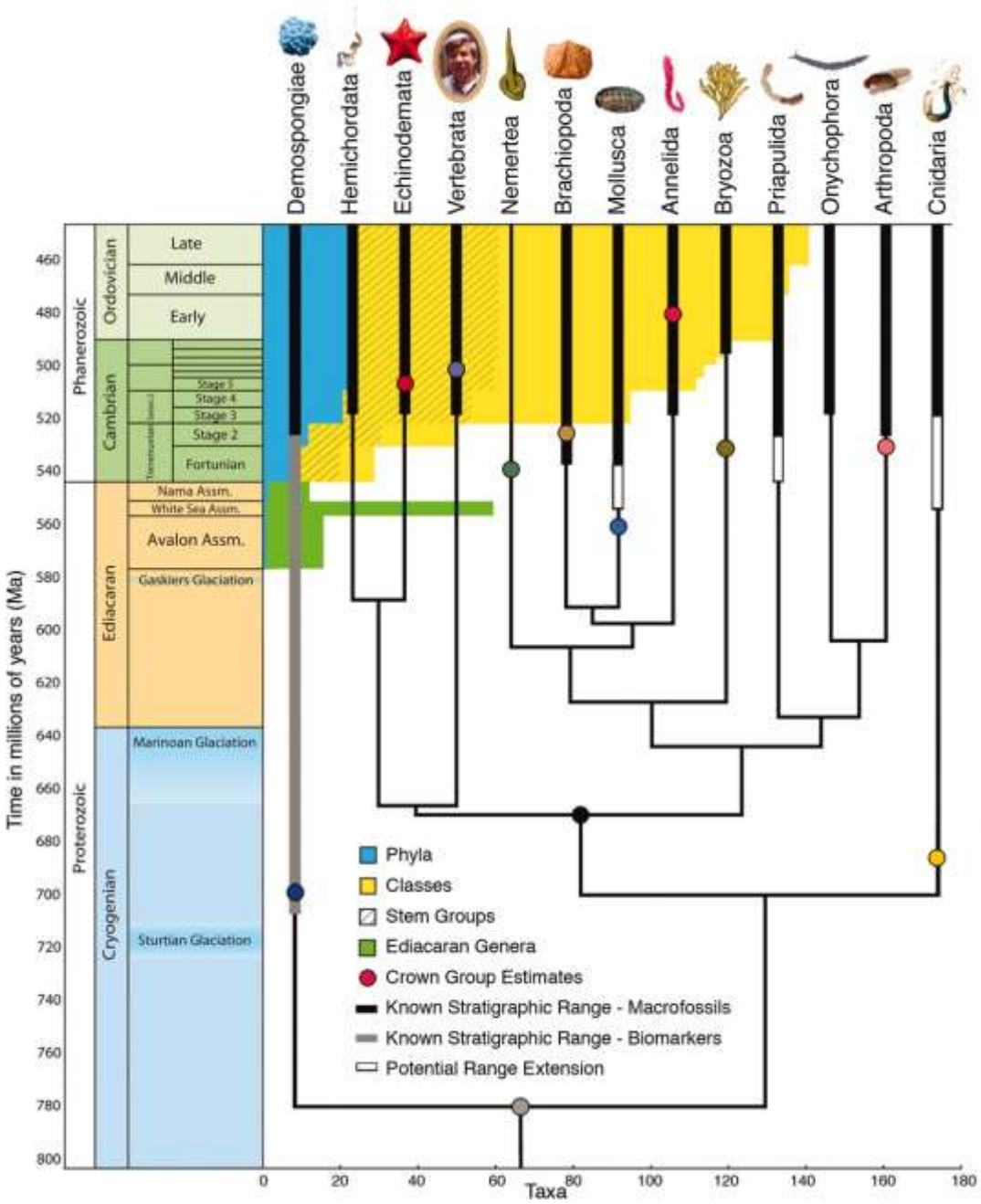


Environmental Opportunity vs Evolutionary Innovation



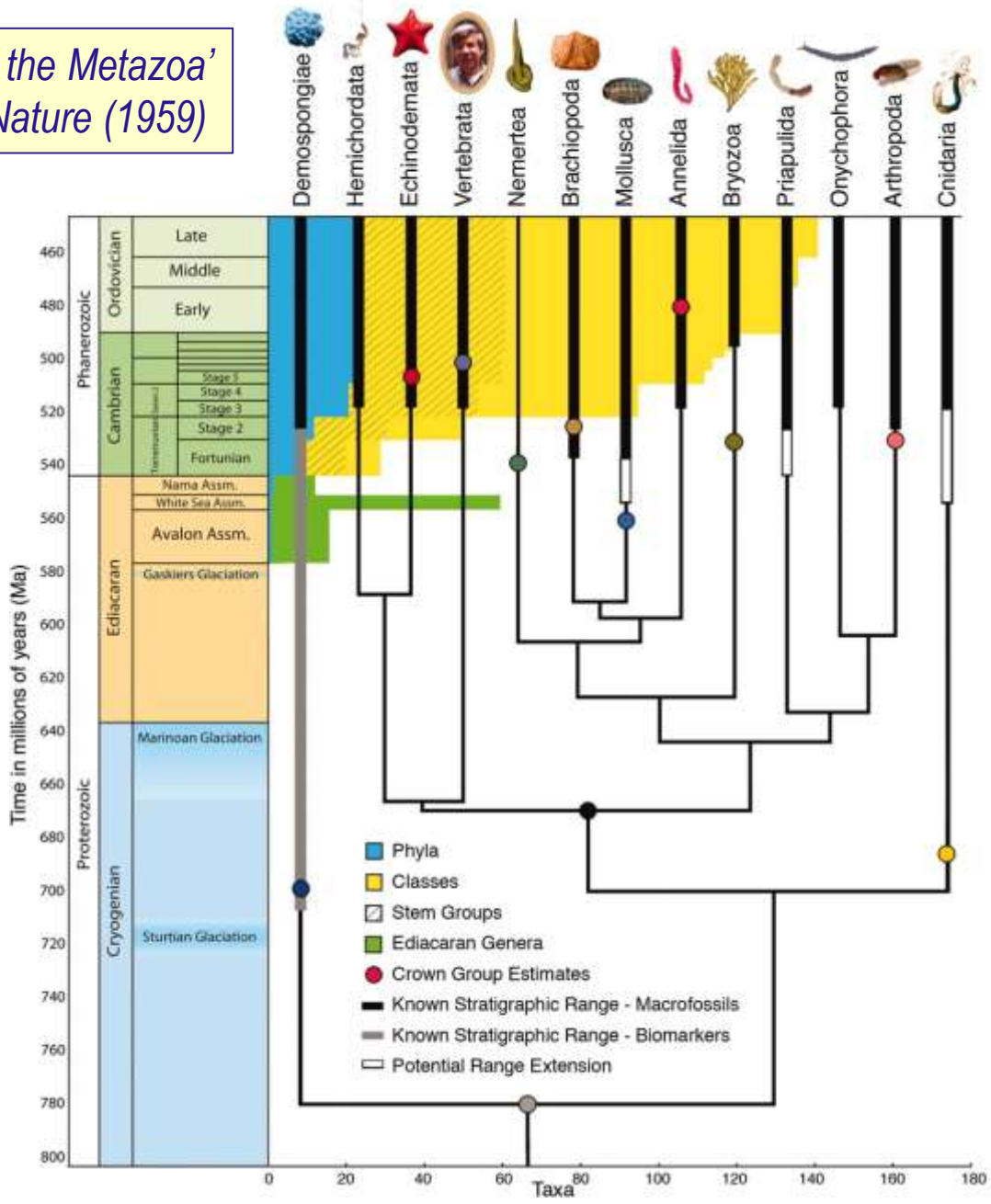
Environmental Opportunity vs Evolutionary Innovation





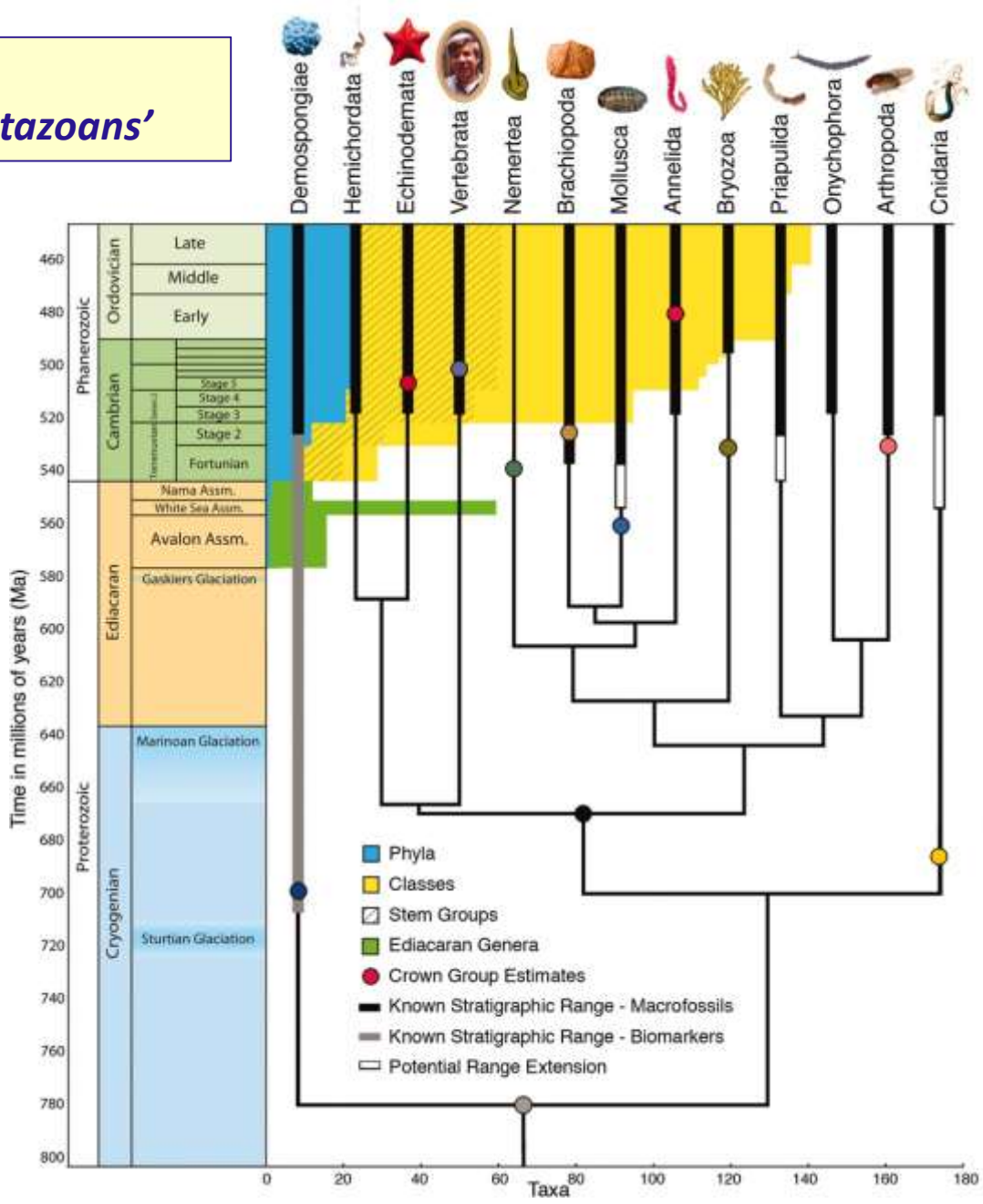
Erwin et al., 2011

'Oxygen as a Prerequisite to the Origin of the Metazoa'
J. R. Nursall, Nature (1959)



Erwin et al., 2011

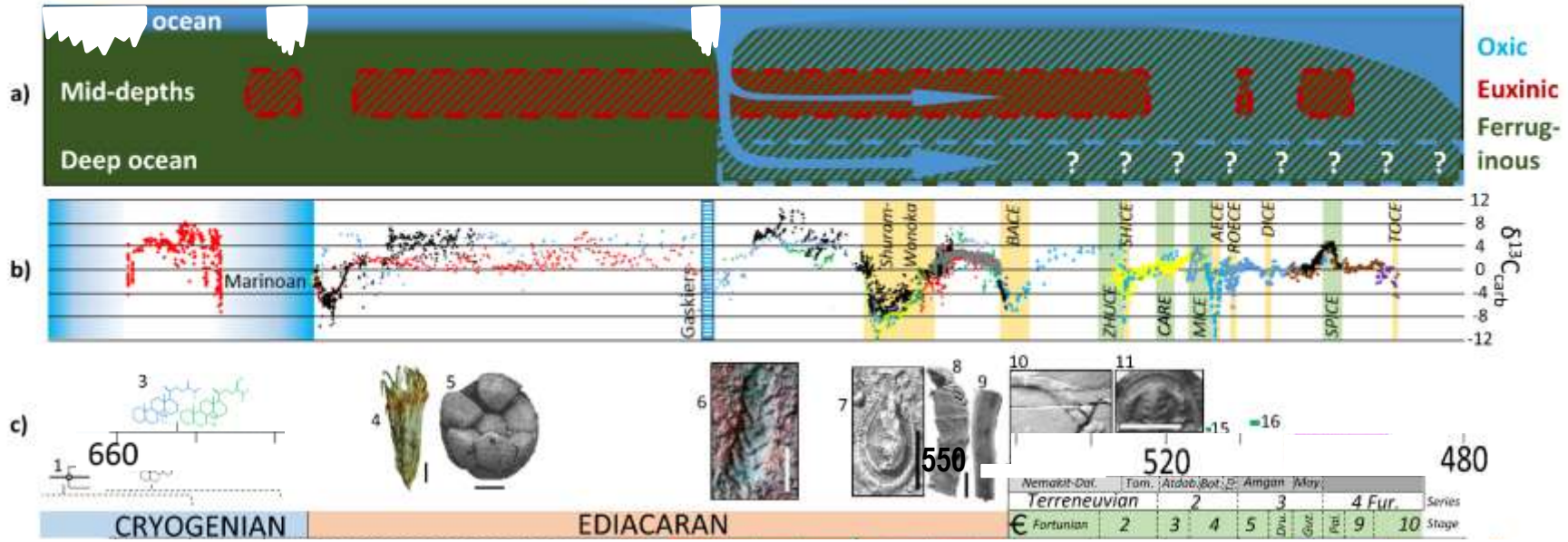
Hypothesis:
'Oxygen controlled the rise of metazoans'



Erwin et al., 2011

Oxygen & Evolution of Metazoans

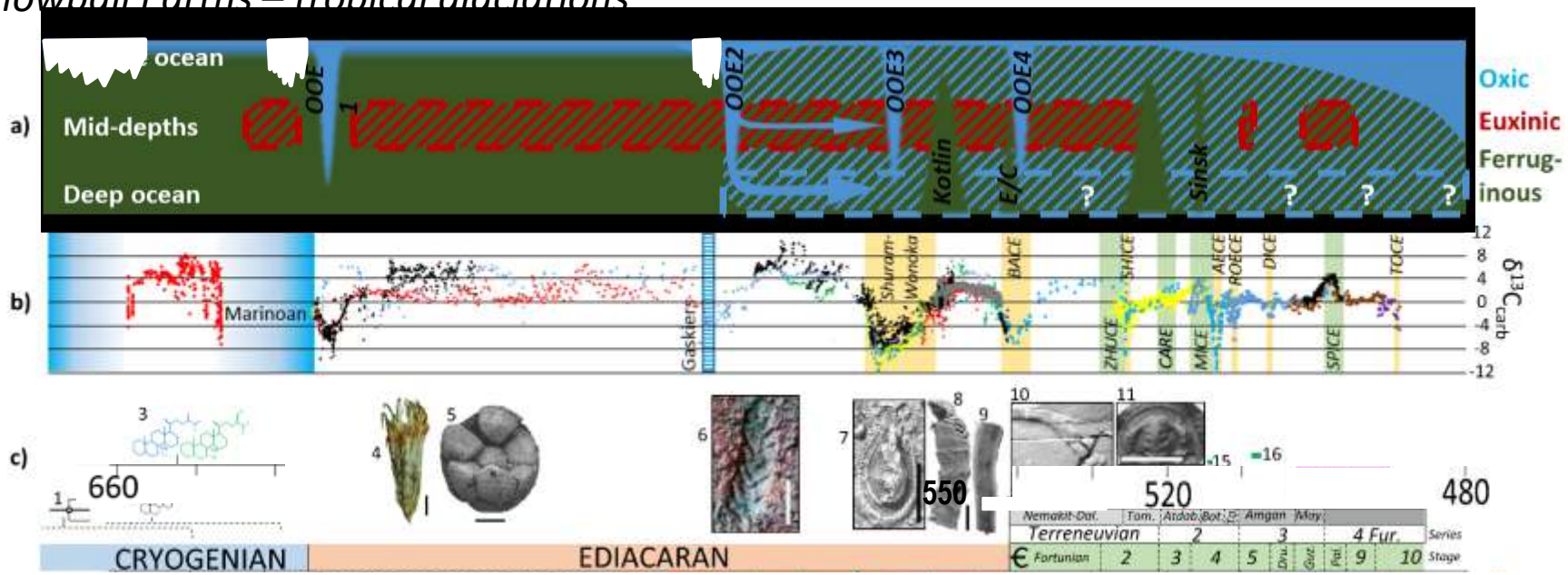
Snowball Earths – tropical glaciations



Modified from Wood et al., 2019

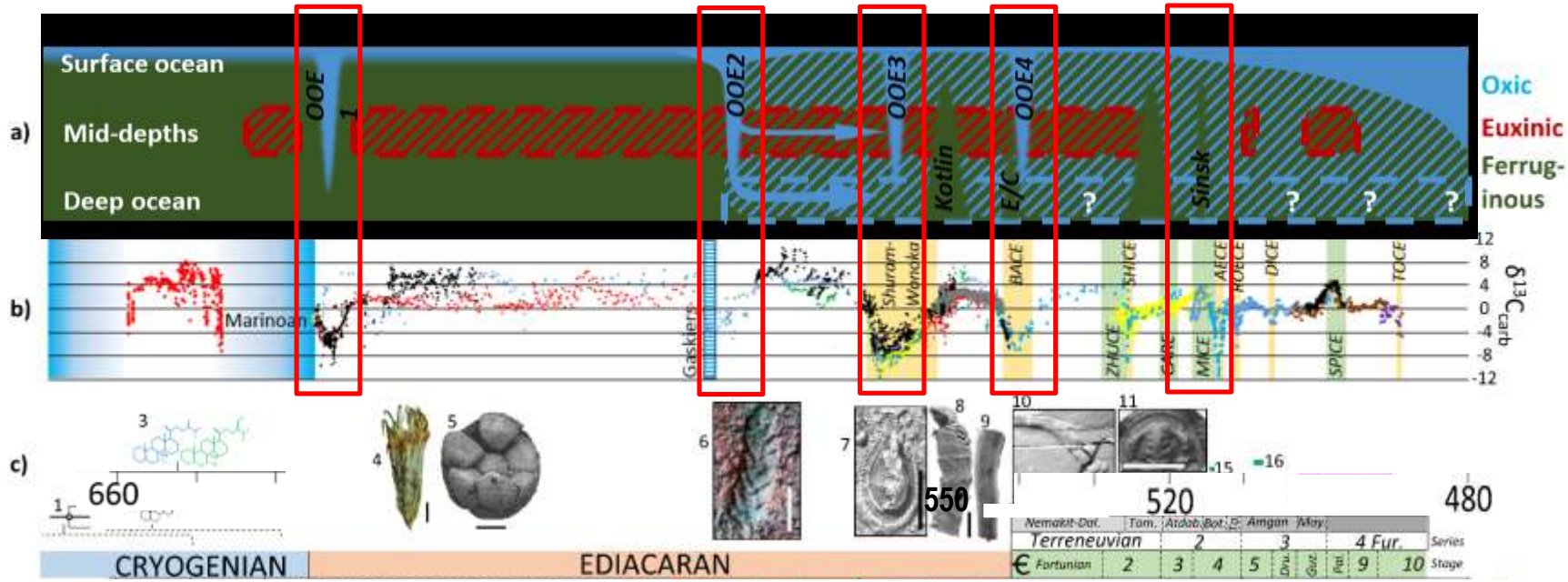
Oxygen & Evolution of Metazoans

Snowball Earths – tropical glaciations



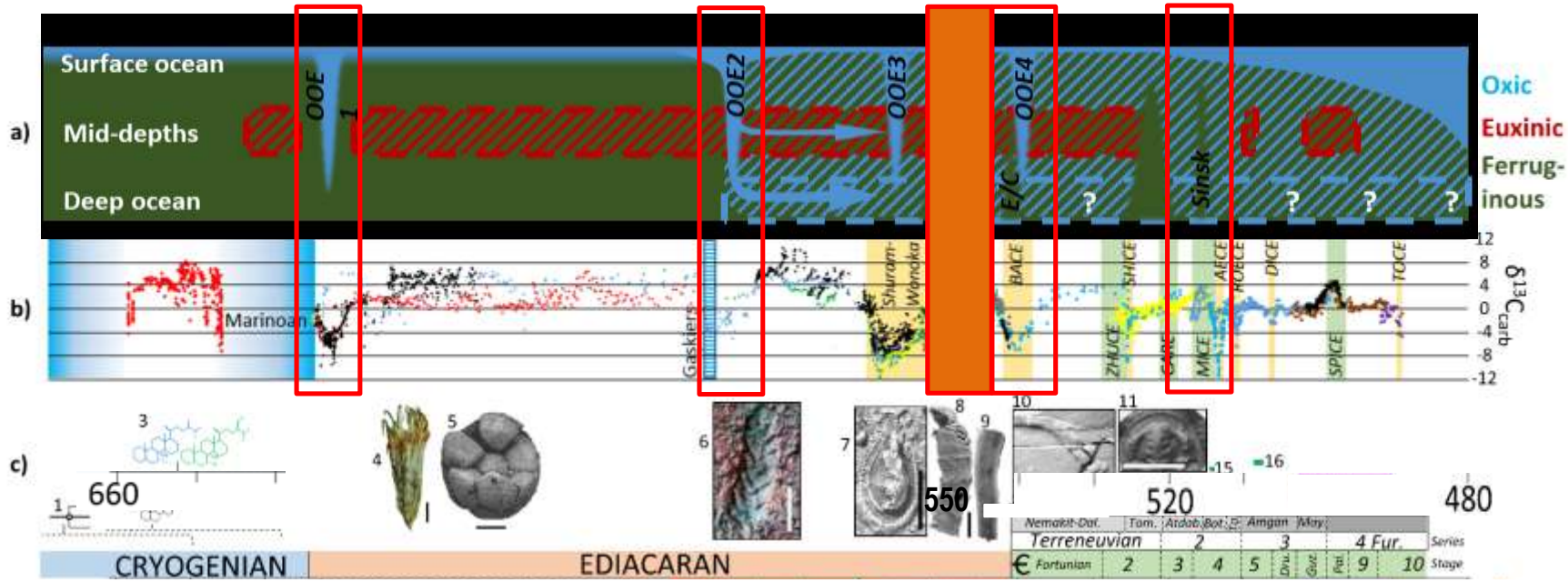
Modified from Wood et al., 2019

Oxygen & Evolution of Metazoans



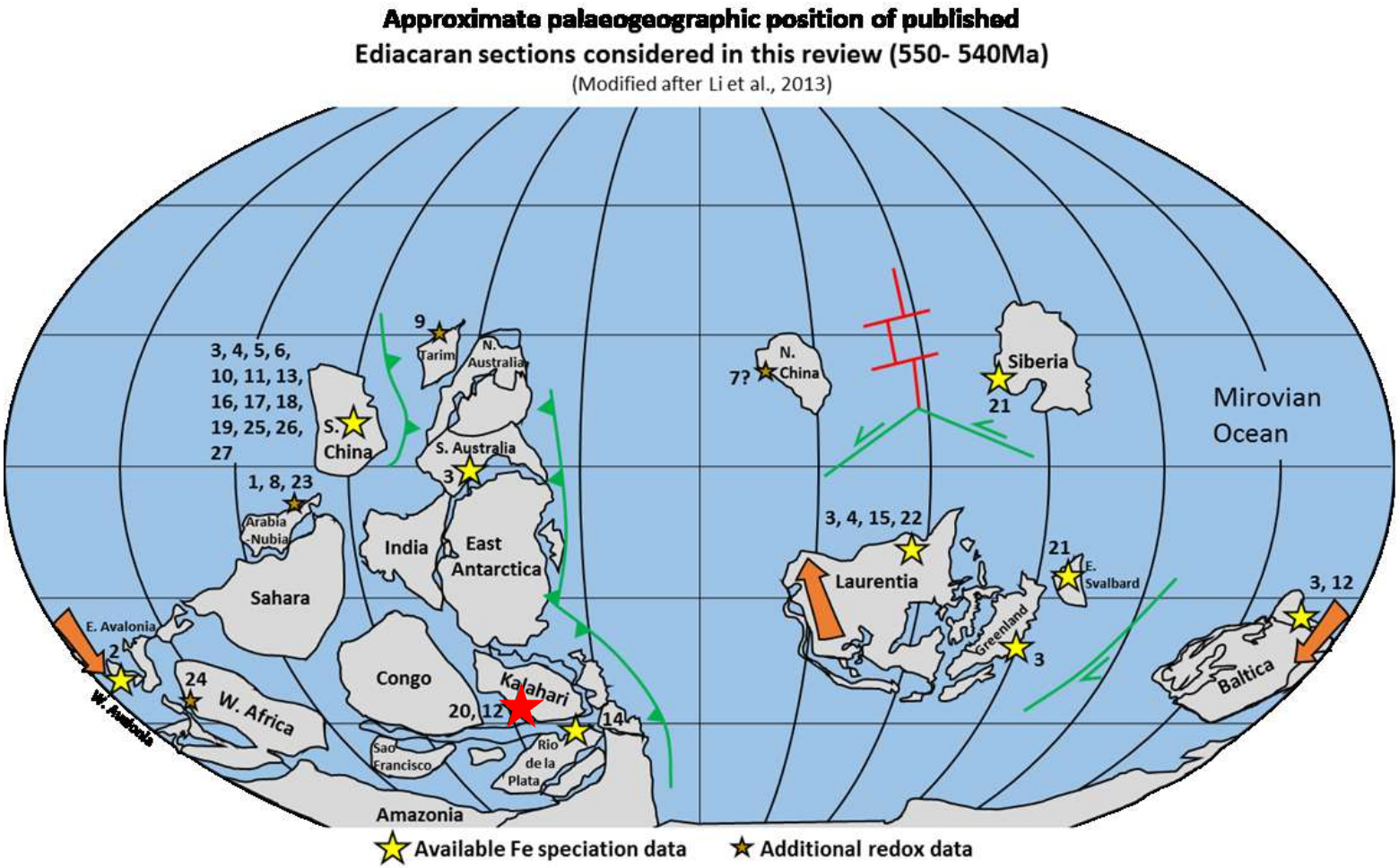
Modified from Wood et al., 2019

Oxygen & Evolution of Metazoans



Modified from Wood et al., 2019

The Earth 550 million years ago….

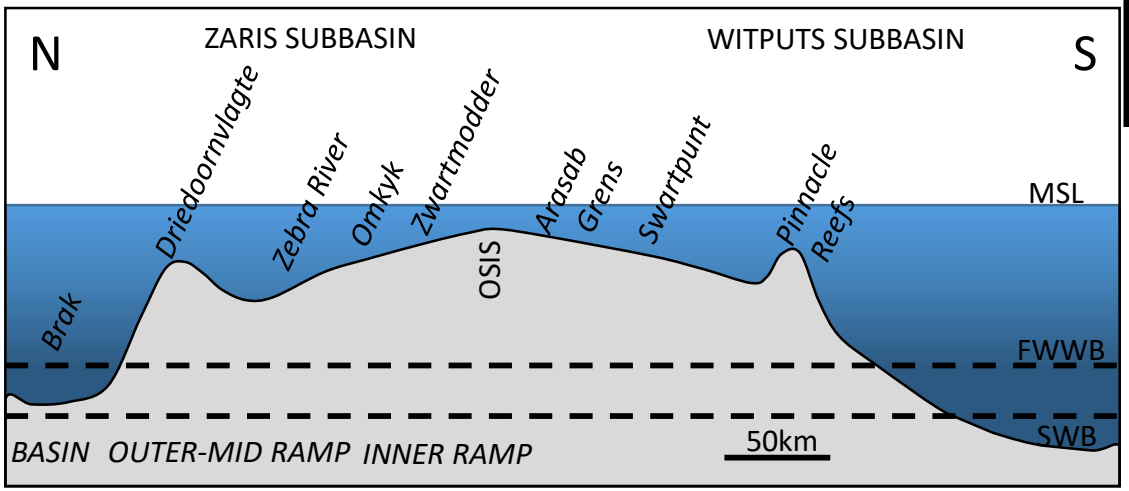


Bowyer et al., 2016

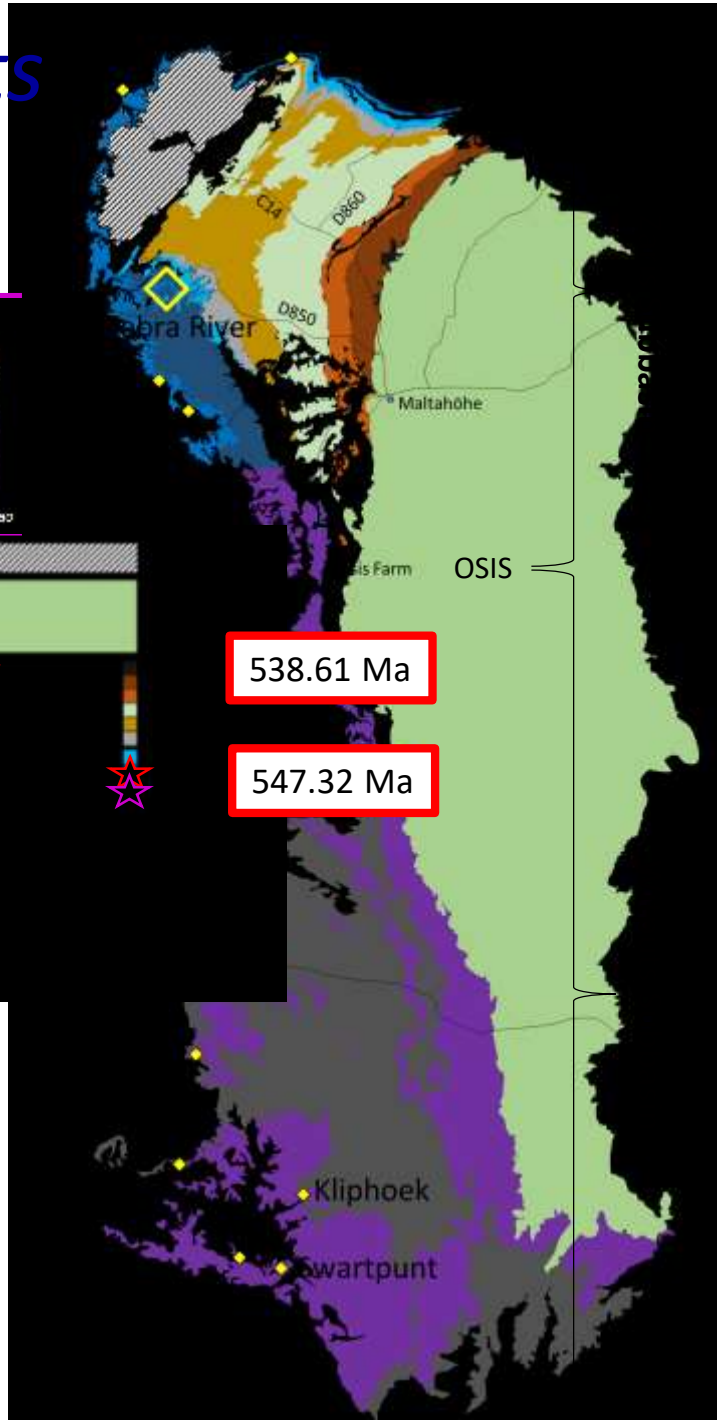
Nama Group, Namibia ~550-541 Ma

Photo: Fred Bowyer

4D Redox: Shelf-basin transects



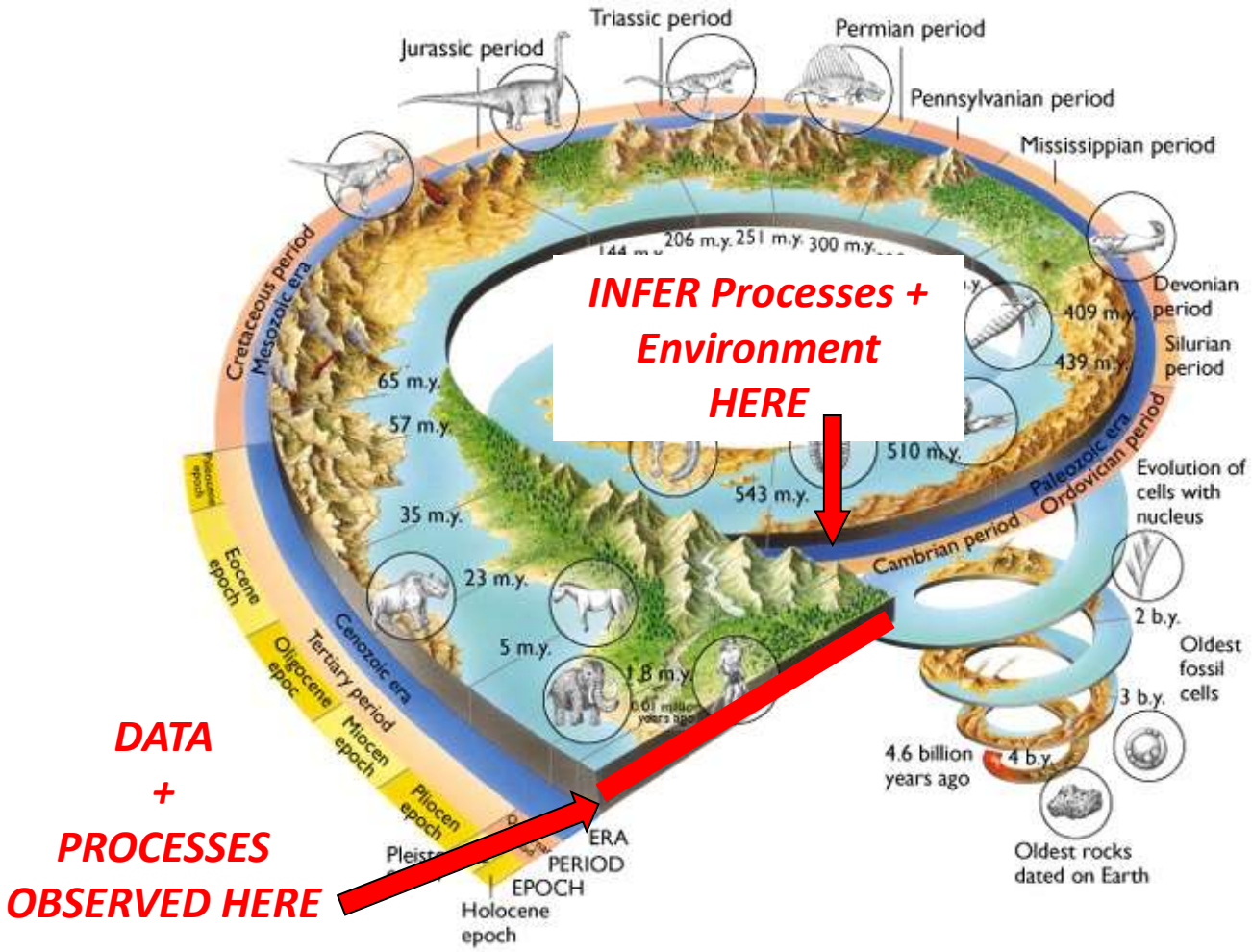
Wood et al., 2015




ANOXIA
Dirt Bag
Dirt Bag

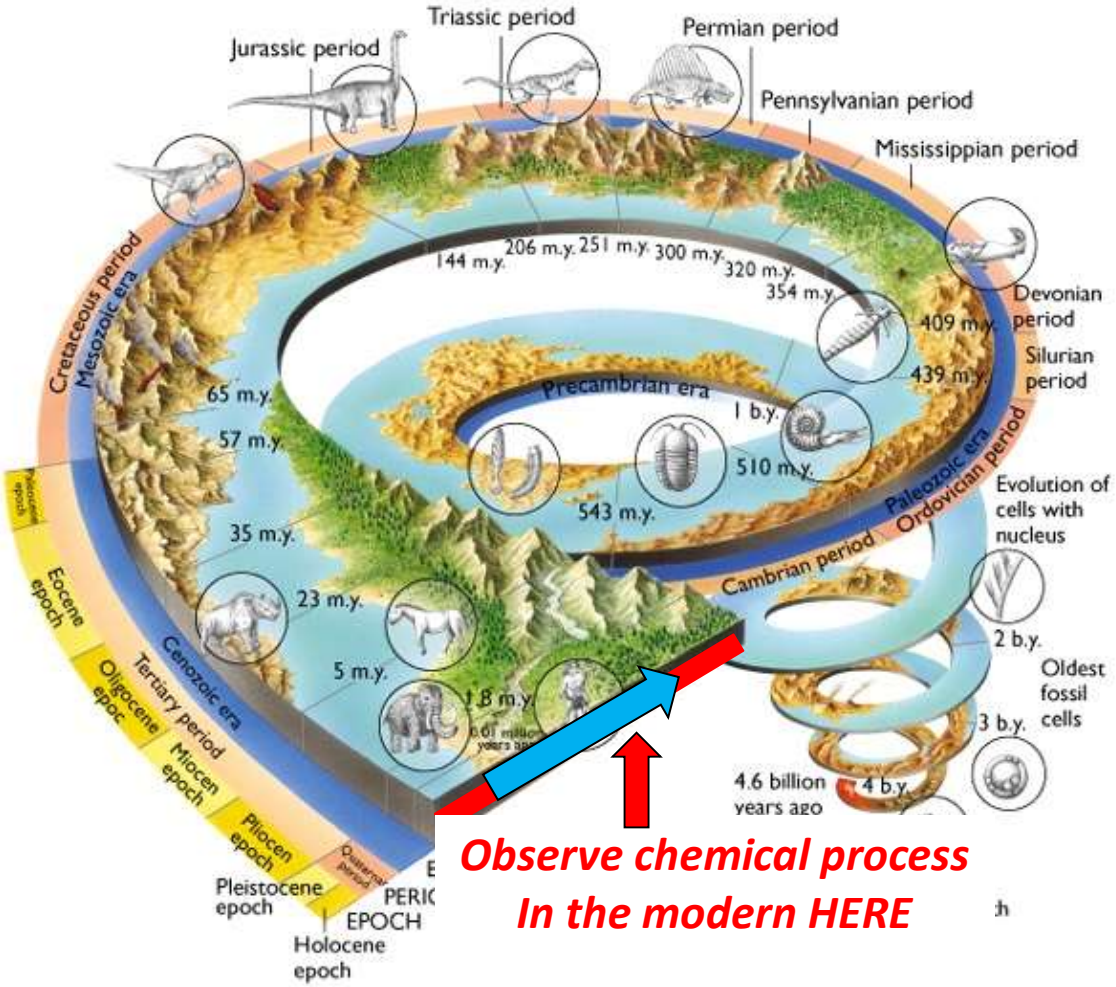
Environmental Opportunity vs Evolutionary Innovation

Hypothesis:
Oxygen controlled the rise of metazoans



Environmental Opportunity vs Evolutionary Innovation

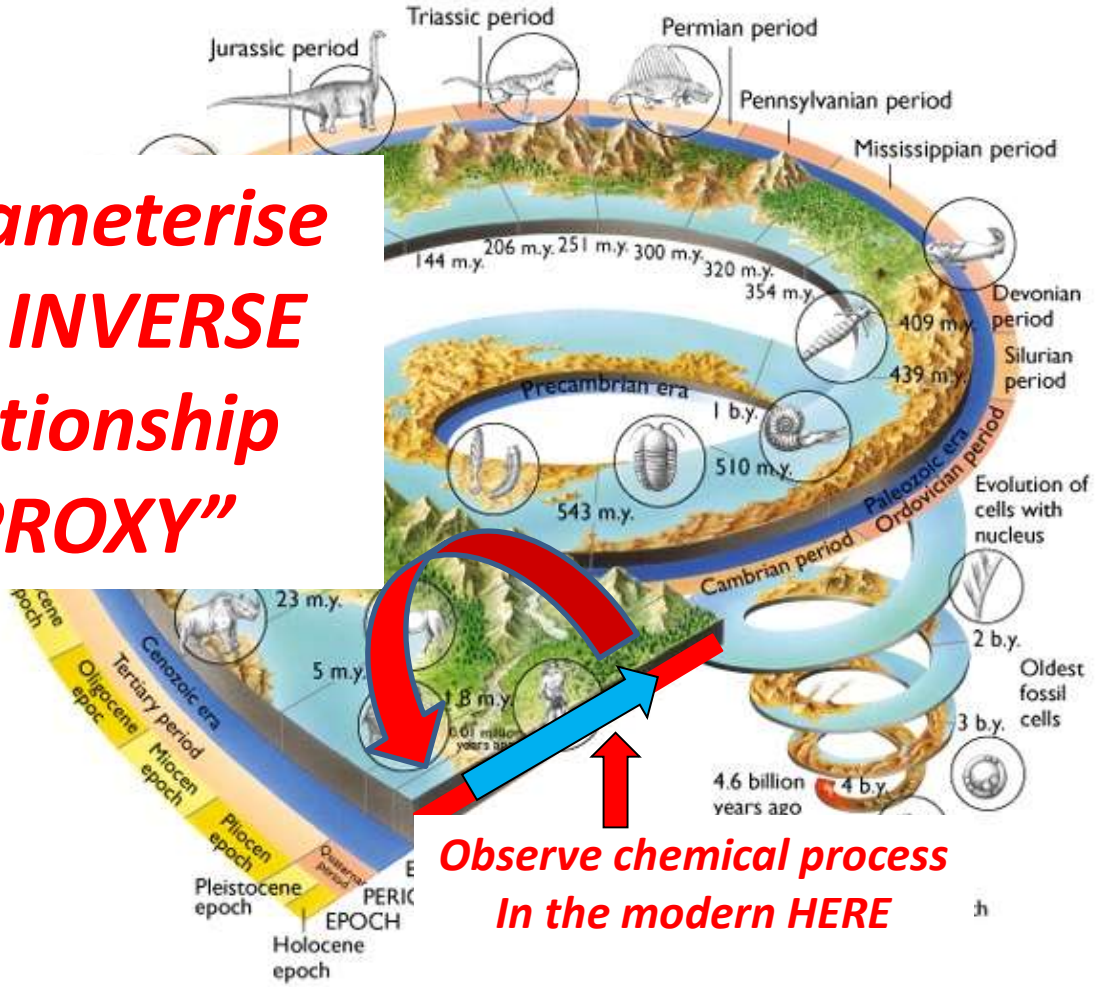
Hypothesis:
Oxygen controlled the rise of metazoans



Environmental Opportunity vs Evolutionary Innovation

Hypothesis:
Oxygen controlled the rise of metazoans

Parameterise
The INVERSE
relationship
= "PROXY"



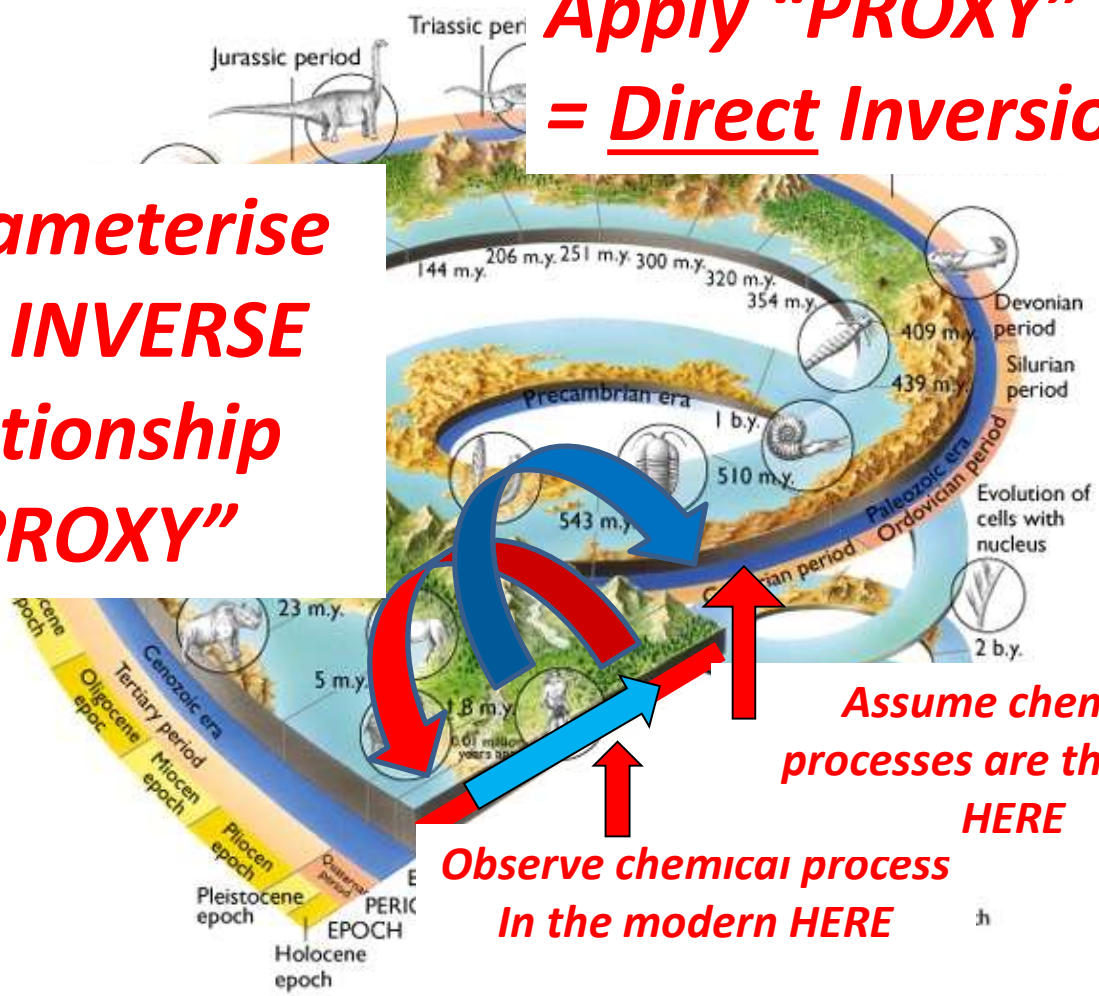
Observe chemical process
In the modern HERE

Environmental Opportunity vs Evolutionary Innovation

Hypothesis:
Oxygen controlled the rise of metazoans

Apply "PROXY"
= Direct Inversion

Parameterise
The INVERSE
relationship
= "PROXY"



Assume chemical processes are the same HERE

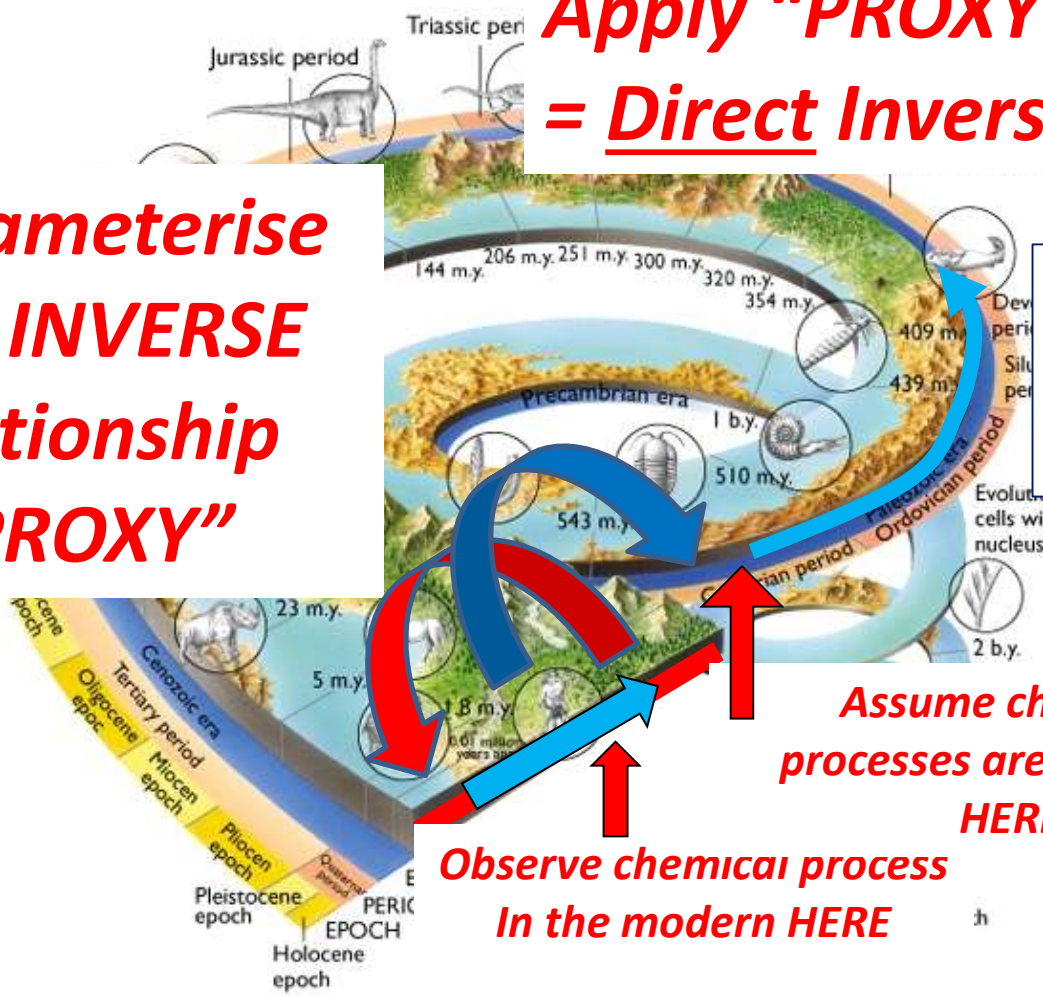
Observe chemical process In the modern HERE

Environmental Opportunity vs Evolutionary Innovation

Hypothesis:
Oxygen controlled the rise of metazoans

Apply "PROXY"
= Direct Inversion

Parameterise
The INVERSE
relationship
= "PROXY"

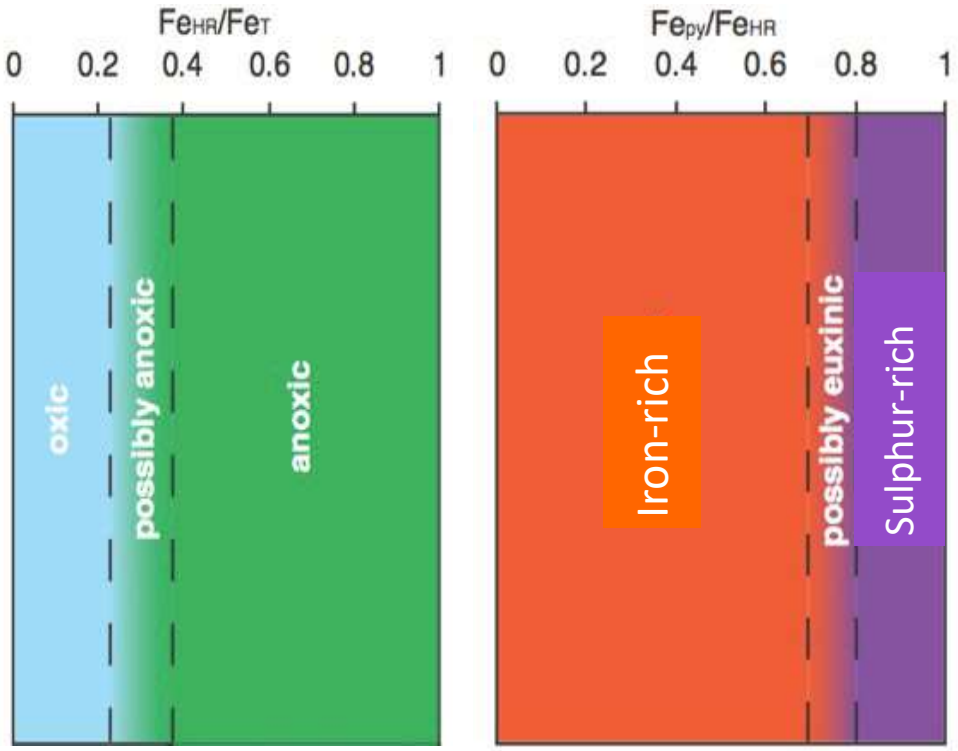


Estimate uncertainties due to variable preservation

Assume chemical processes are the same HERE

Observe chemical process In the modern HERE

Local Redox Proxy: Fe-speciation

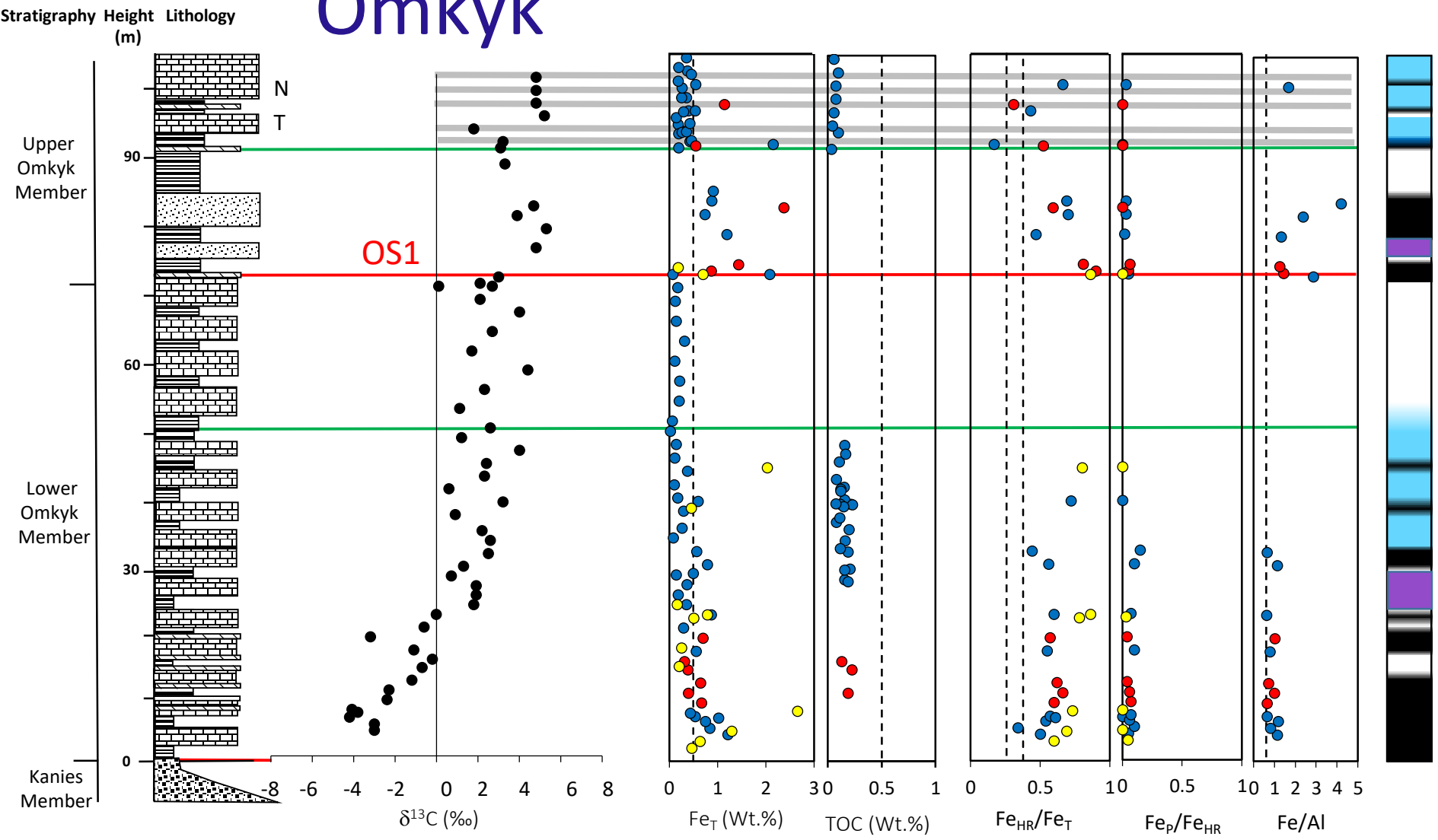


Poulton and Canfield, 2011

Highly Reactive Fe

FeHR = Fecarb + Feox + Femag + Fepy

Omkyk



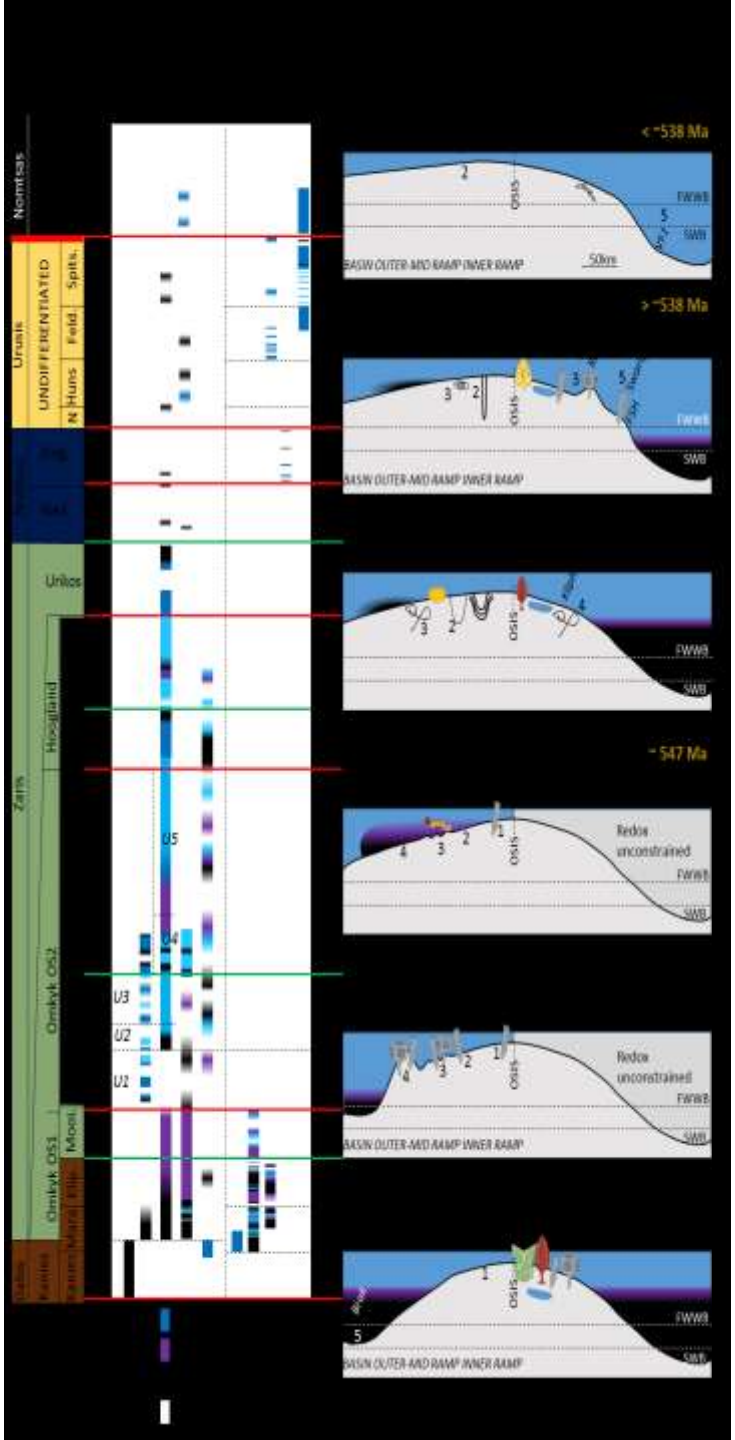
Conglomerate
Shale
Dolomite
Limestone (Grainstone)
Limestone (Laminite-Heterolithic)
Sandstone
Maximum Flooding Surface
Major Sequence Boundary

Sample
Desiccation cracks
Bird's Eye
Fenestrae
Slump structures
Symmetrical ripples
Normal graded bedding
Intraclasts
Ball and Pillow Structure
Samples with Bioclasts

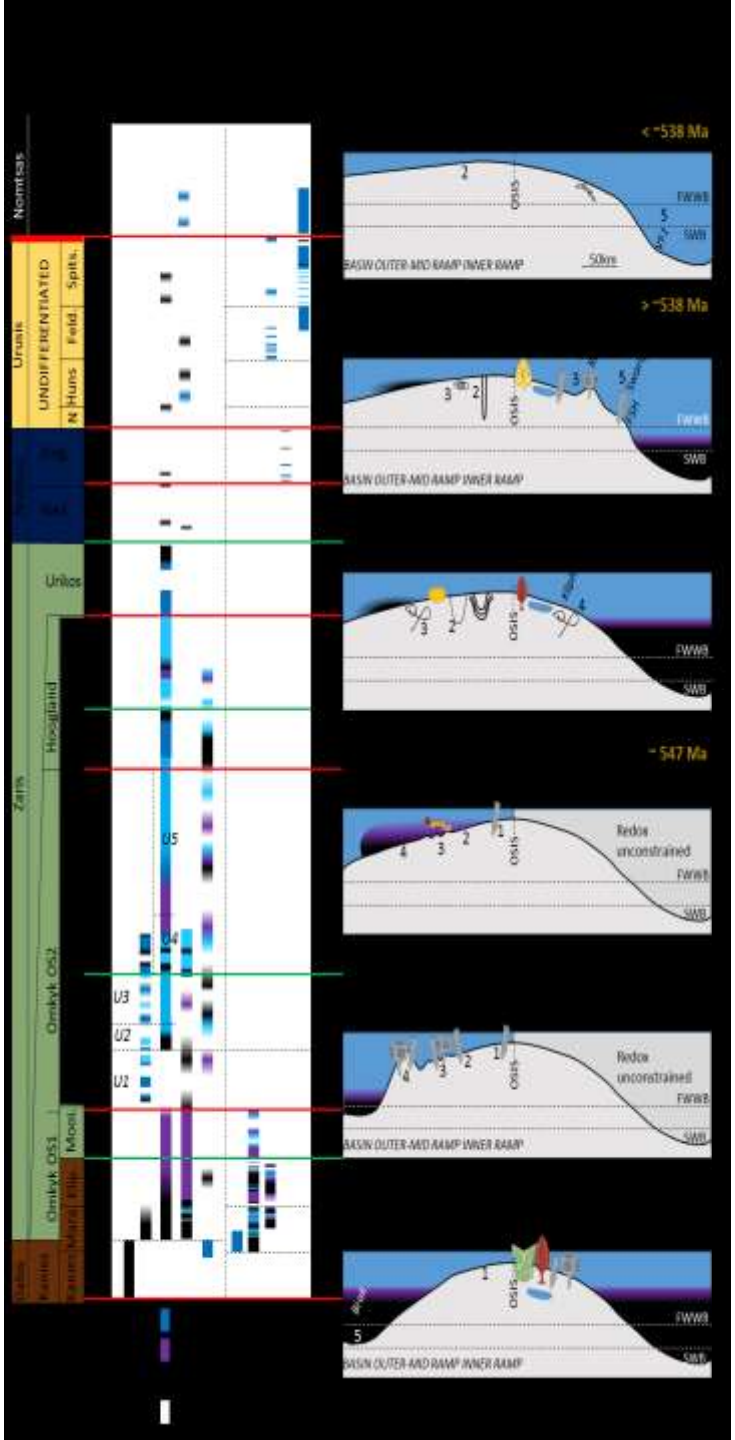
N *Namacalathus*
C *Cloudina*
NP *Namapoikia*
Skeletal Fossils (undifferentiated)
T Thrombolites
Bioturbation
Rhythmites
Flaser Bedding

Limestone
Dolomite
Clastic
$\delta^{13}C$

Wood et al., 2015



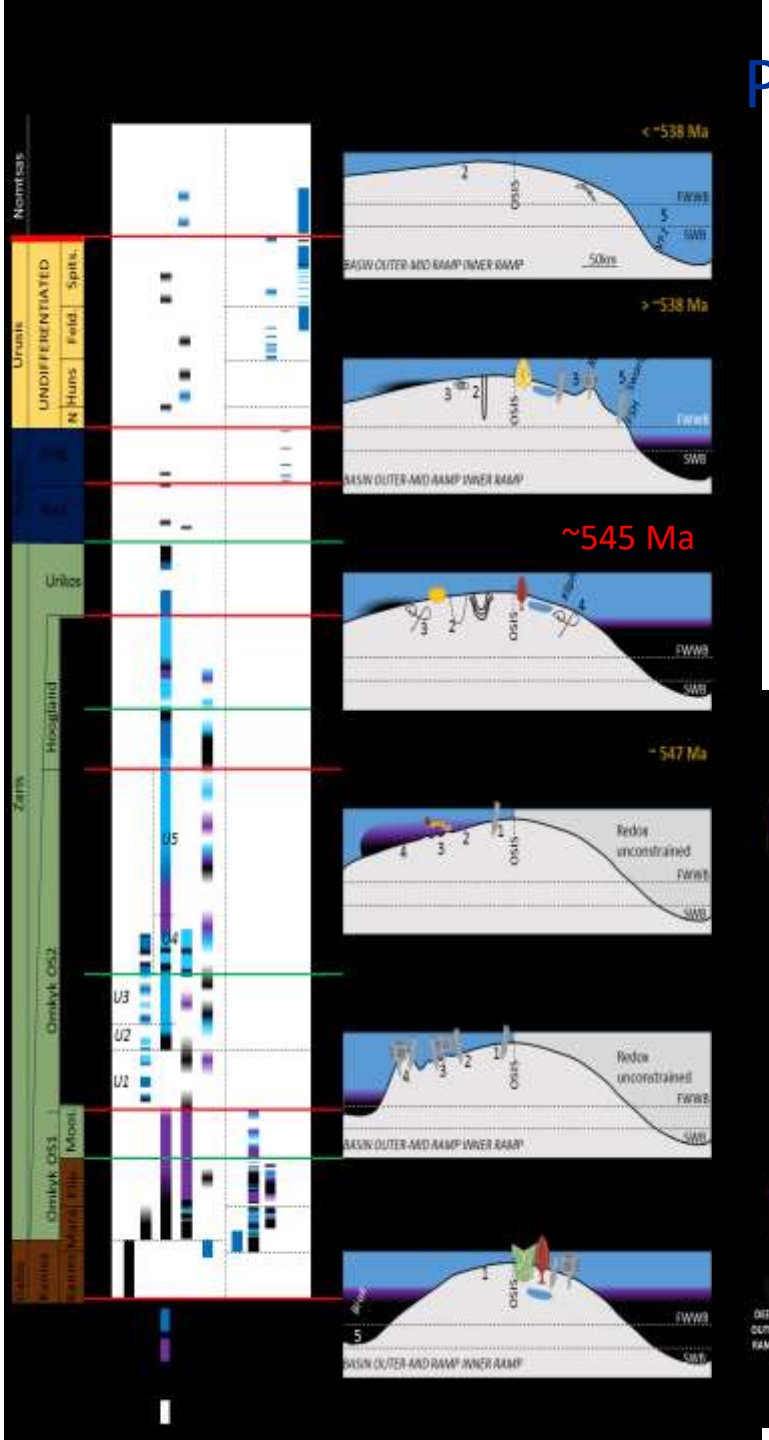
Bowyer et al., 2020

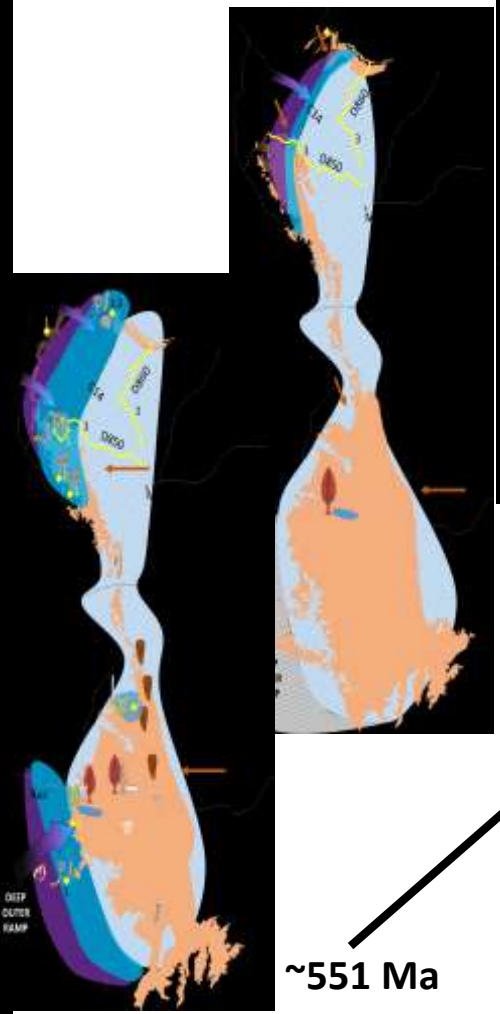


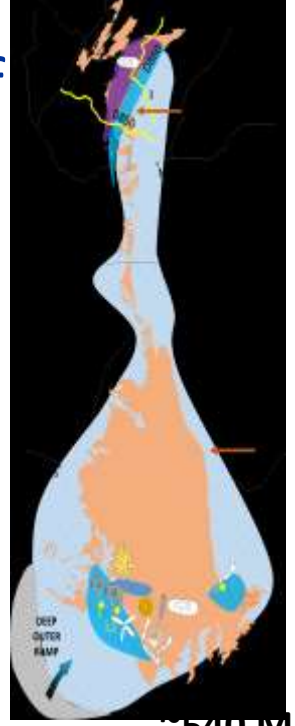
Low-oxygen waters limited habitable space for oldest animals

Bowyer et al., 2020

Progressive stabilisation of oxygen







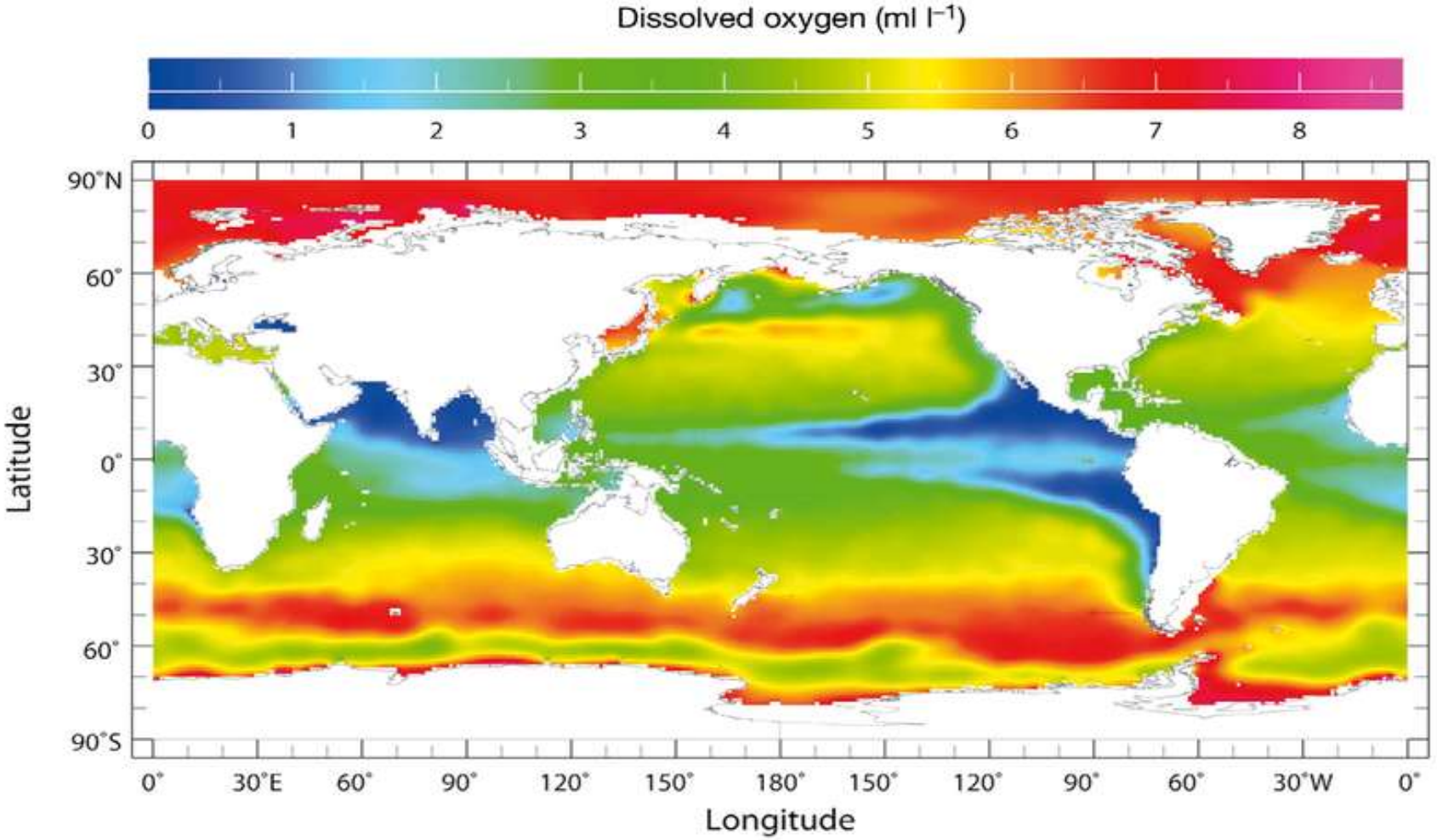
~551 Ma

~545 Ma

~540 Ma

Bowyer et al., 2020

What drove the stabilisation of oxygen?

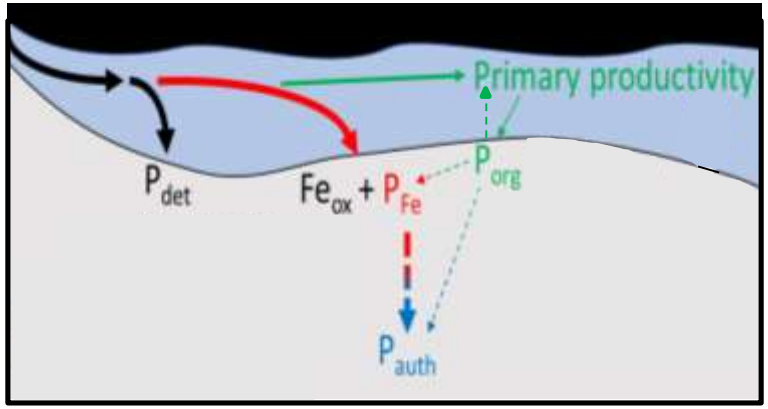


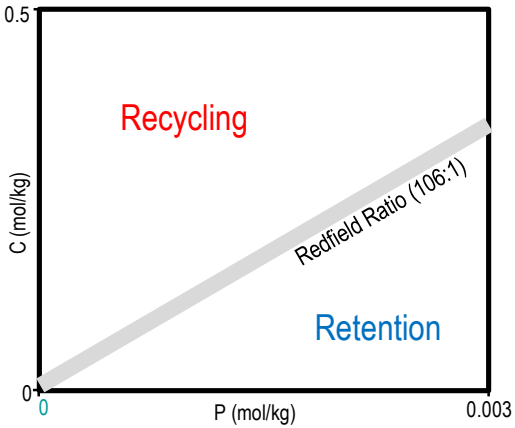
DEGRADATION TRAJECTORY more nutrients → more algal production → less O_2 → more N & P recycled

More denitrification & P burial ← more O_2 ← less algal production ← less nutrients **RESTORATION TRAJECTORY**

What drove the stabilisation of oxygen?

Phosphorous (P) Speciation





Reactive P = mobile and bioavailable

$P_{reac} = P_{Fe} + P_{org} + P_{auth}$

Chemical Index of Alteration (CIA)

Mobile

$$CIA\ (\%) = [Al_2O_3/(Al_2O_3 + CaO^* + Na_2O + K_2O)] \times 100$$

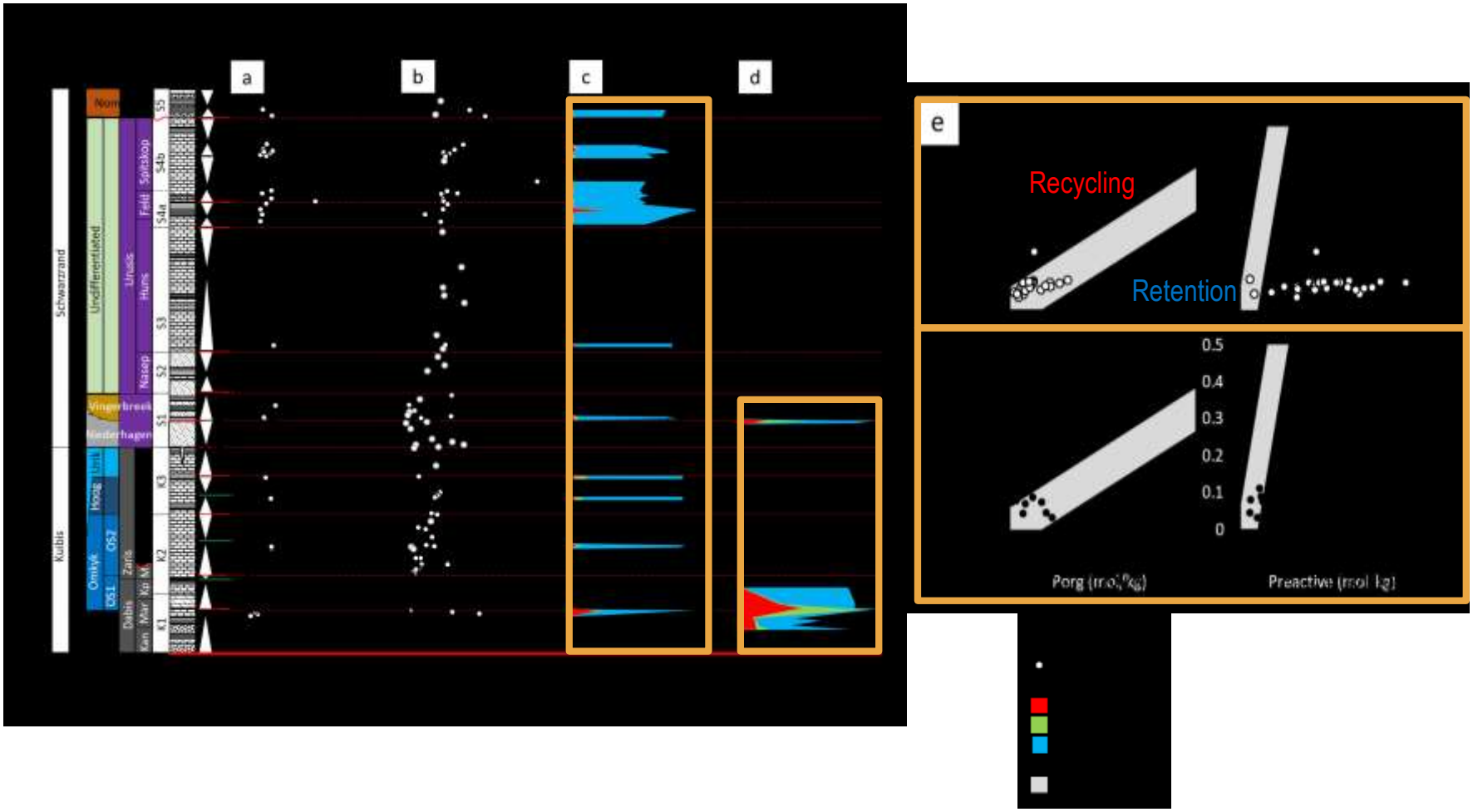
Immobile

Bowyer et al., 2020

Phosphorous speciation method

Poulton et al., 2019

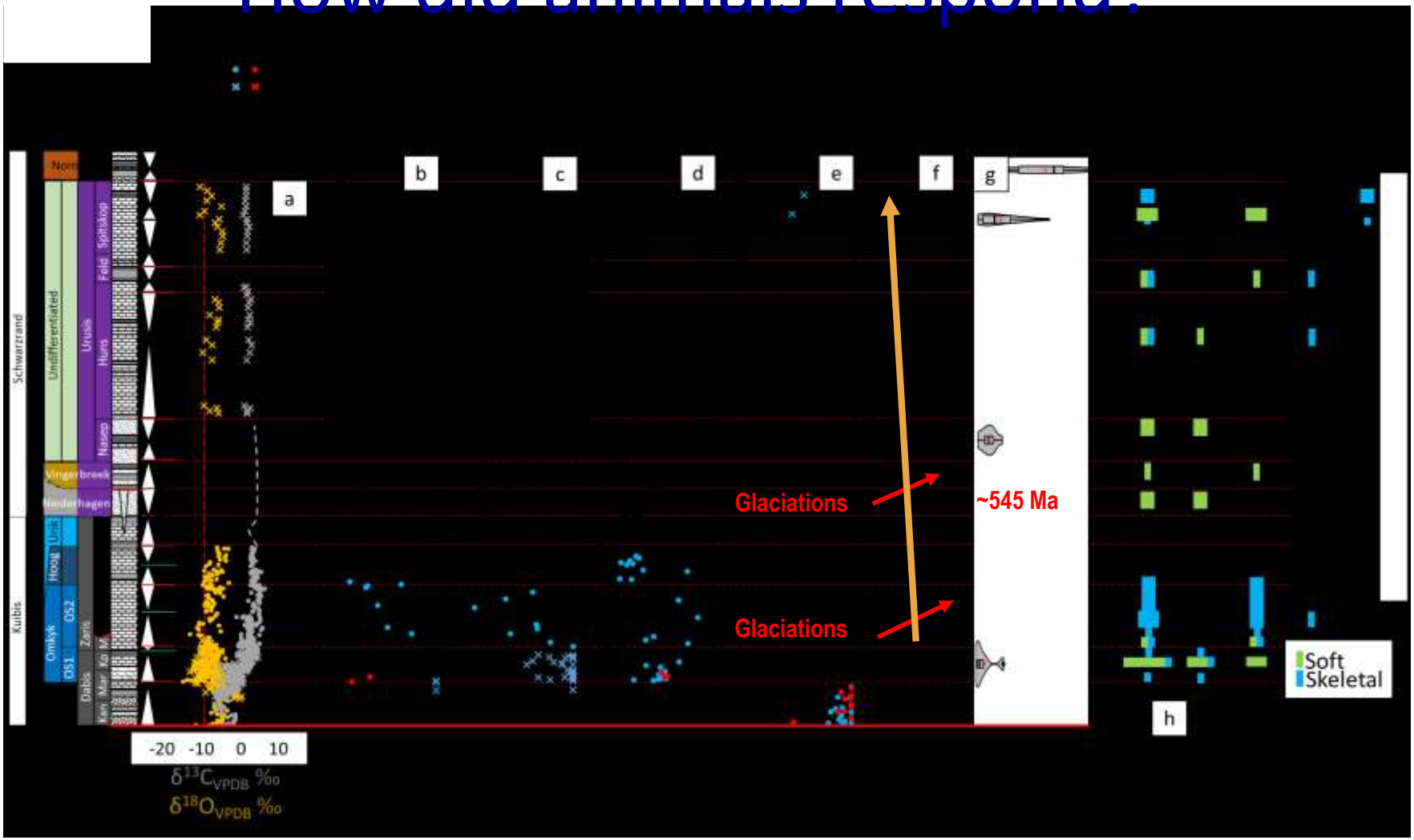
Redox-controlled Phosphorous cycling



Anoxia = phosphate drawdown = limited recycling = increase productivity
Oxia = phosphate burial = retention = reduced productivity

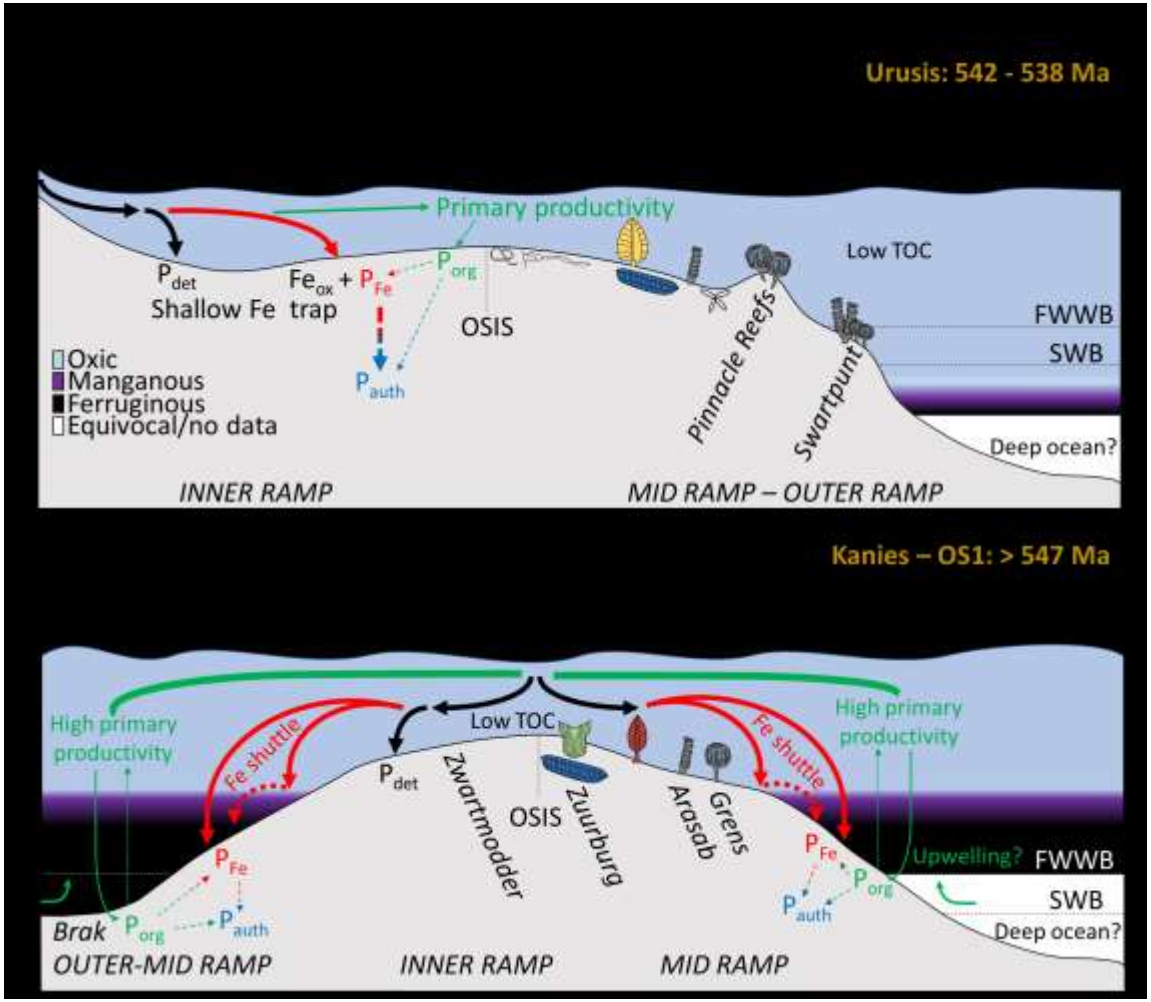
Bowyer et al., 2020

How did animals respond?



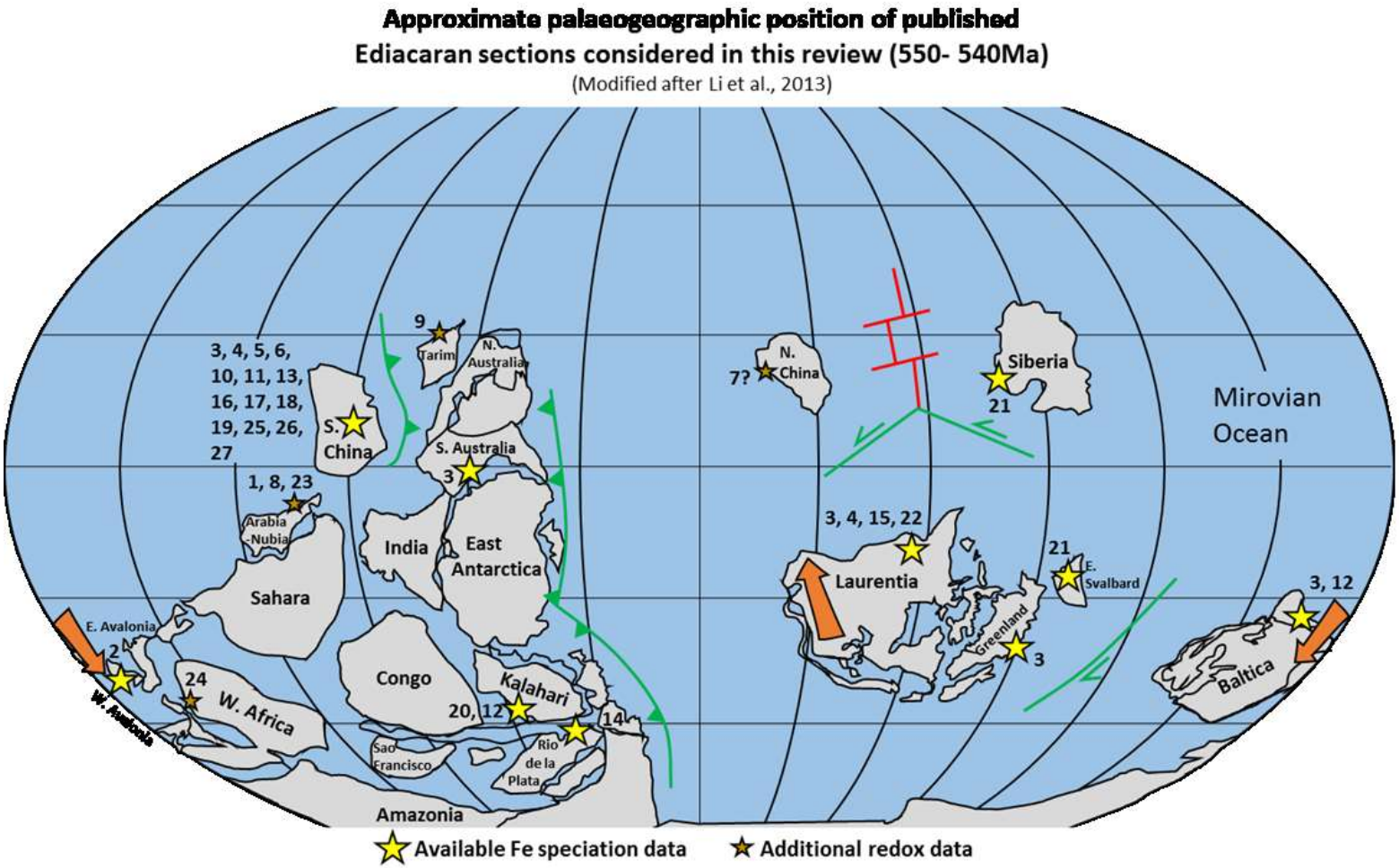
Bowyer et al., 2020

Co-evolution of oxygen and life



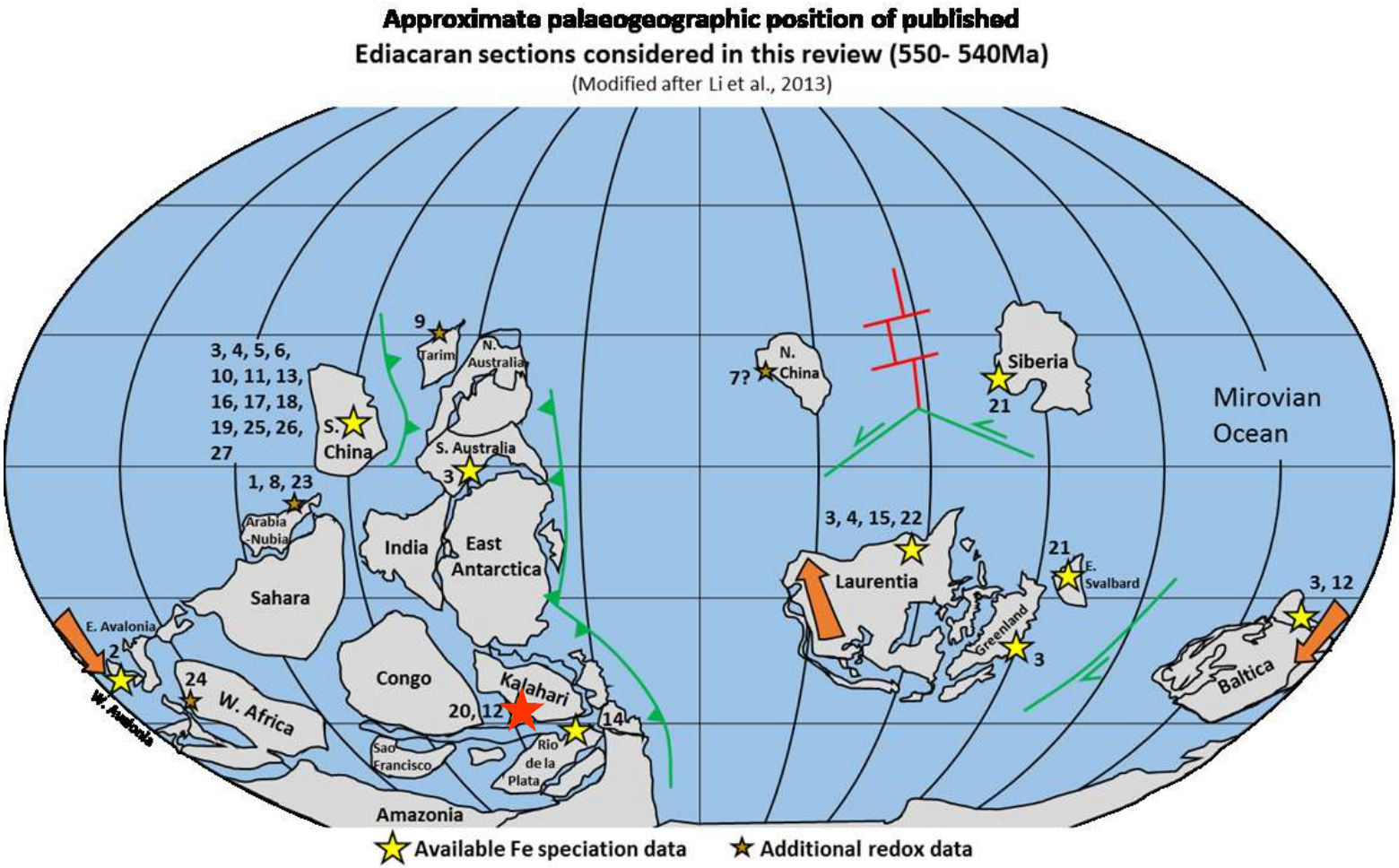
Bowyer et al., 2020

Co-evolution of oxygen and life and tectonics



Bowyer et al., 2016

A few parameters, one place, one narrative….



Bowyer et al., 2016

A few parameters, one place, one narrative….