

Is There Life Beyond Twenty-One (ka)?

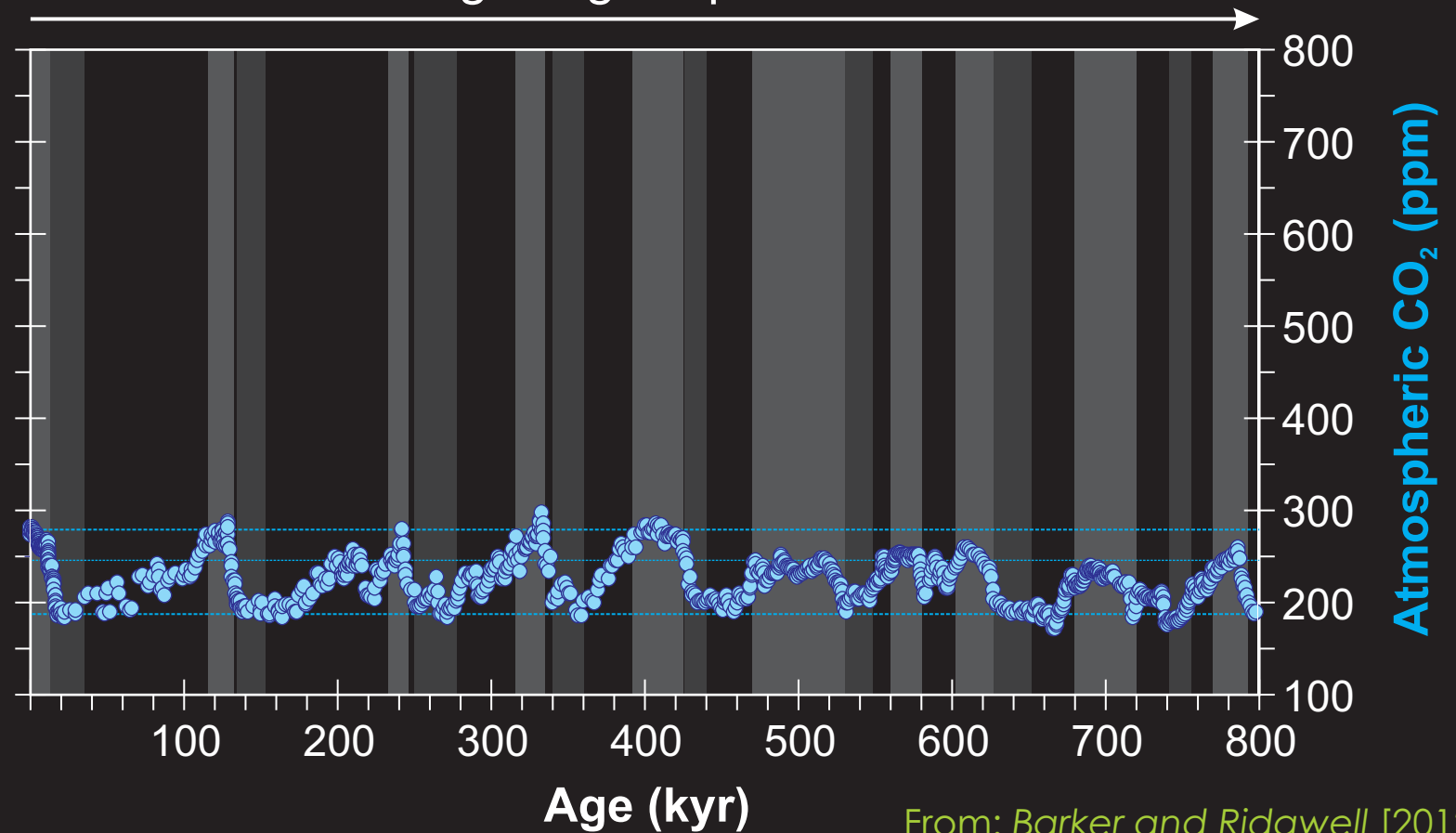
(proxies and models and the 'other' 99.999533% of Earth history)

Andy Ridgwell

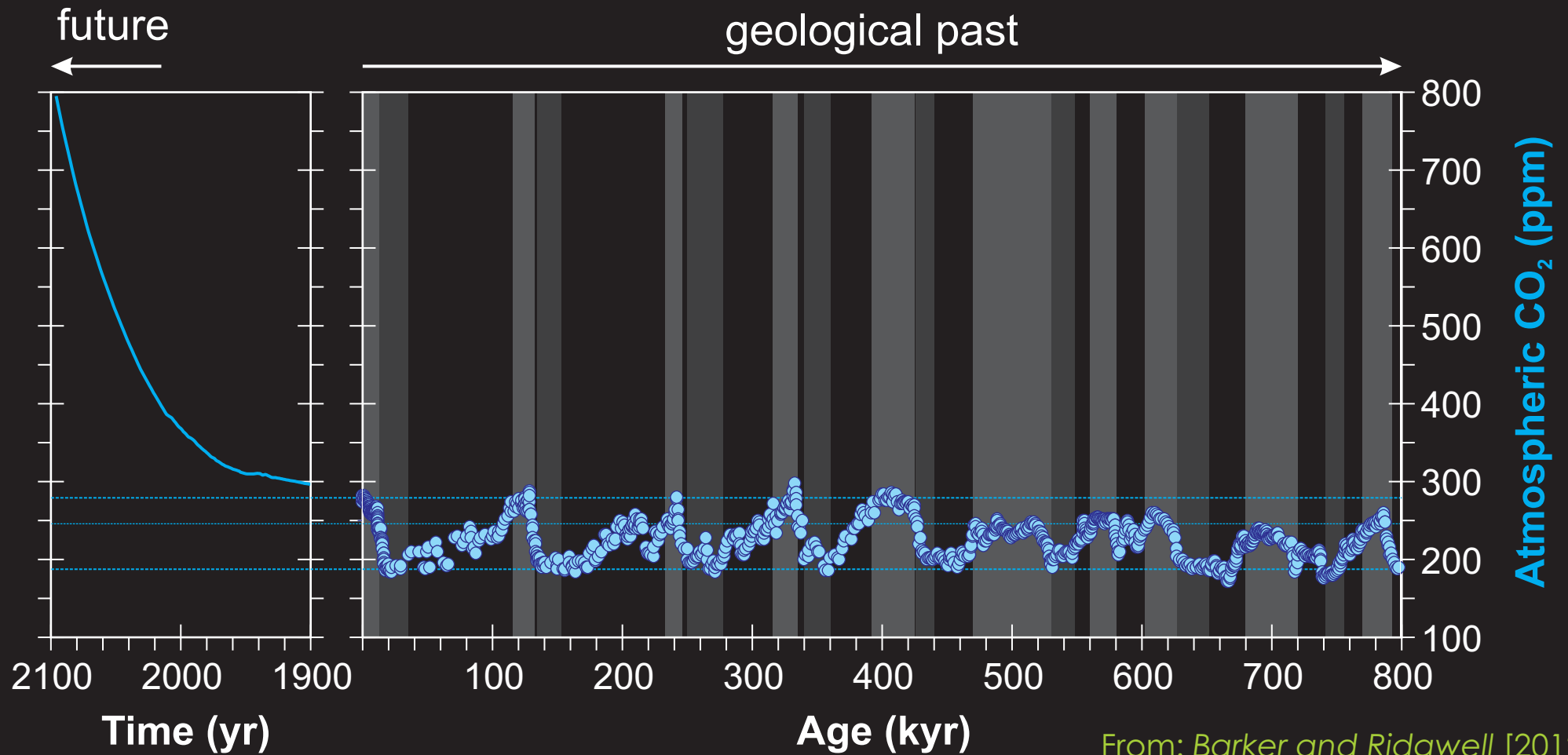




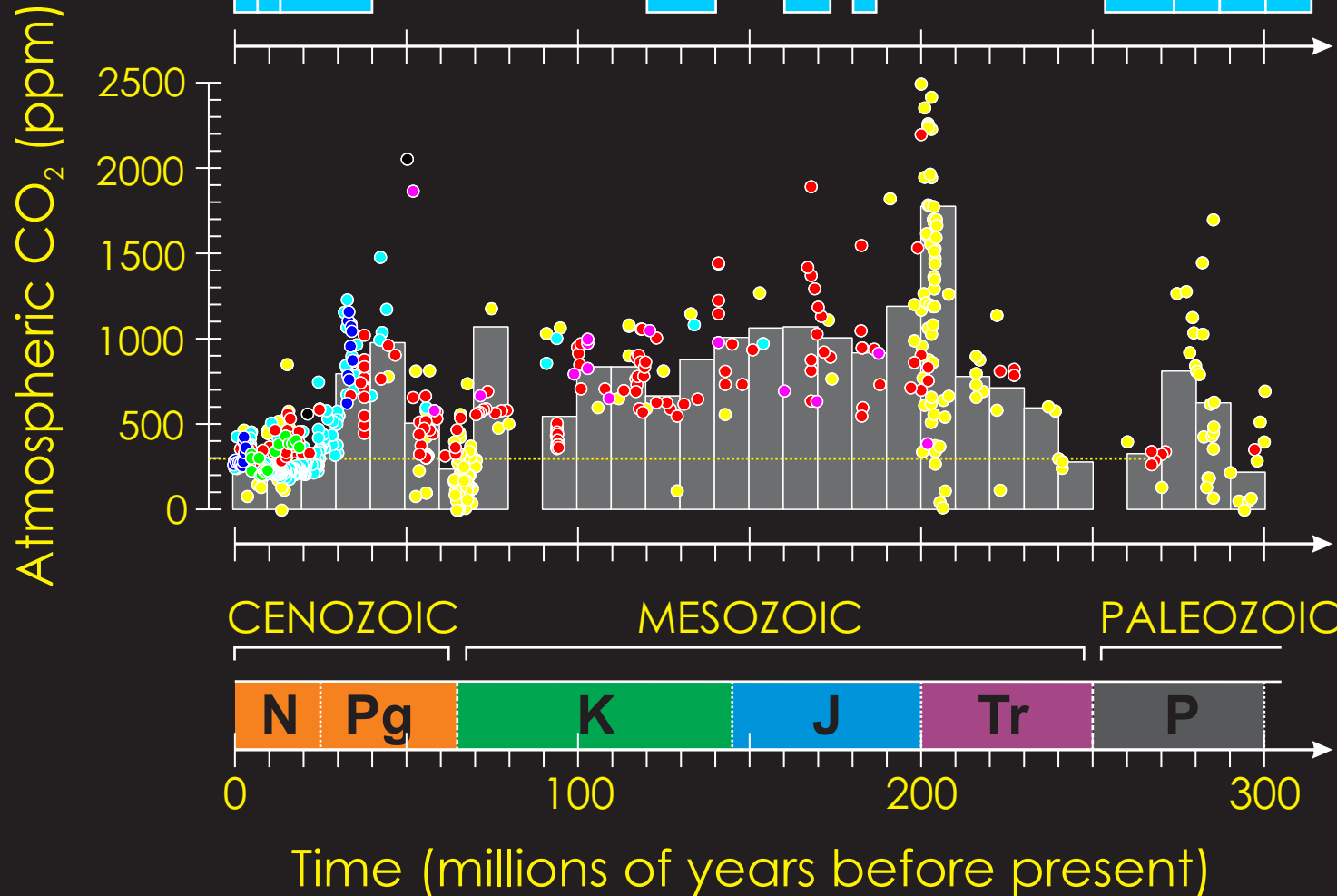
geological past



From: *Barker and Ridgwell [2012]*



From: *Barker and Ridgwell [2012]*





Introduction



ASTON MARTIN OWNERS CLUB



AMOC ART



AMOC



ACADÉMIE MÉDICALE D'OSTÉOPATHIE CRÂNIENNE

A multitude of COUNSELORS UNSCRIPTED + HONEST

Association of Maine Outing Clubs



A MAP OF CHANGES

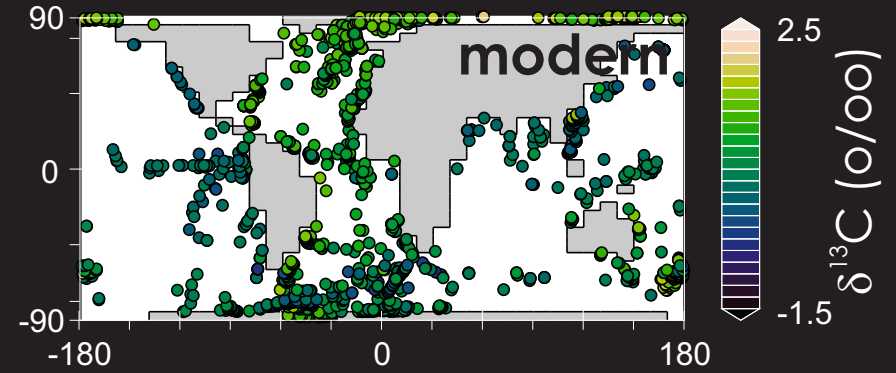
--- ENDING THE AIDS EPIDEMIC ---



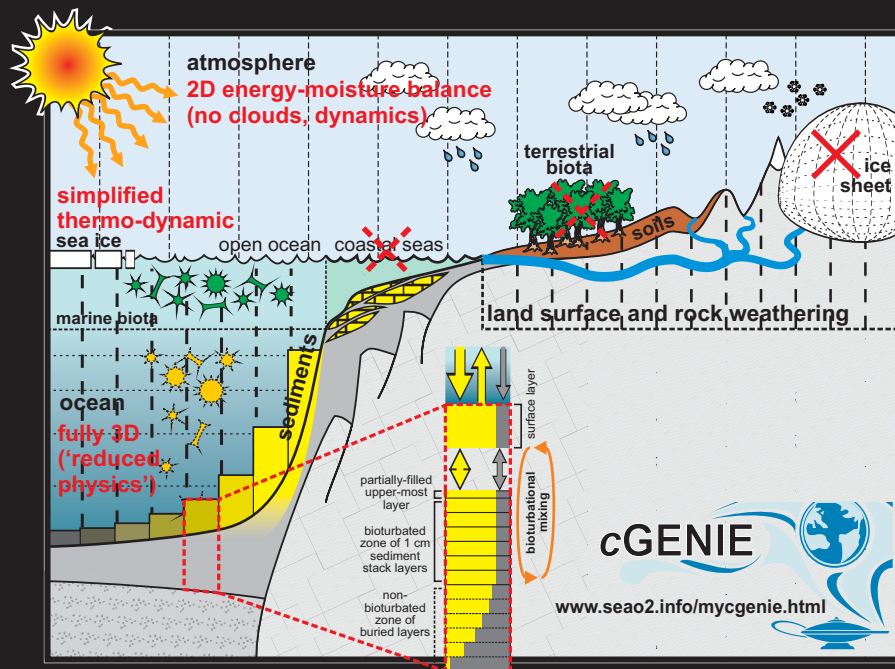
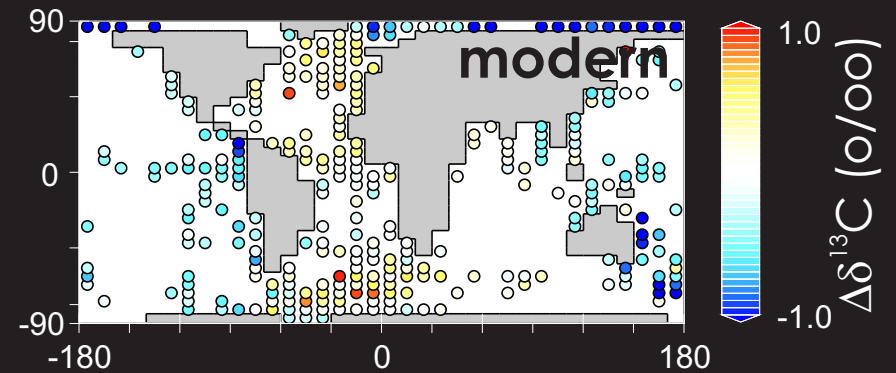
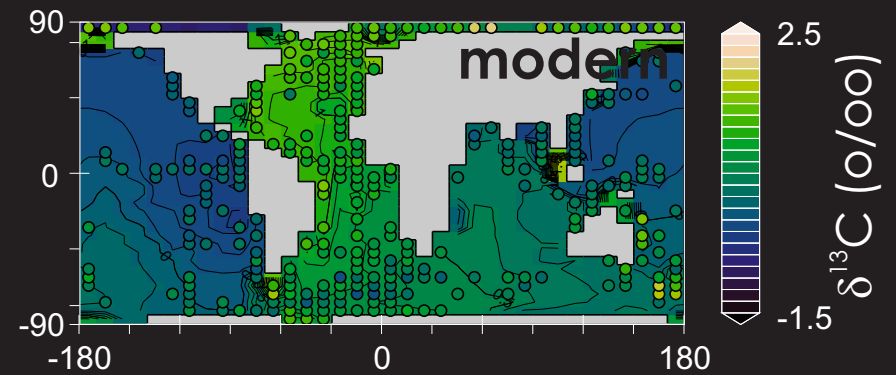
ARTS MISSION OAK CLIFF



amoc
a matter of choice



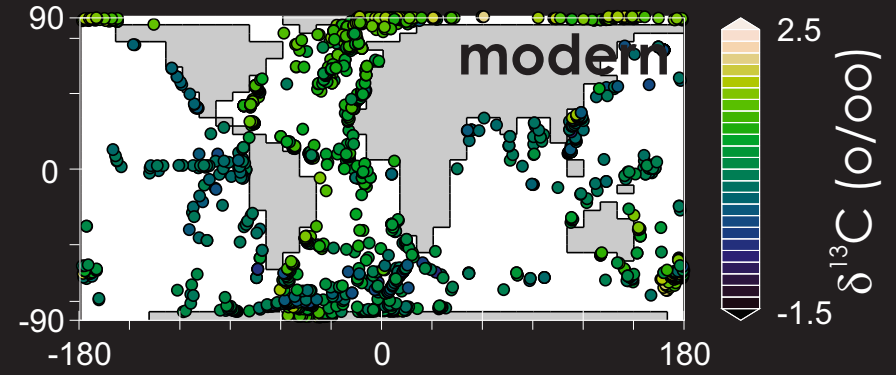
Schmittner et al. [2016] 10.1002/2016PA003072



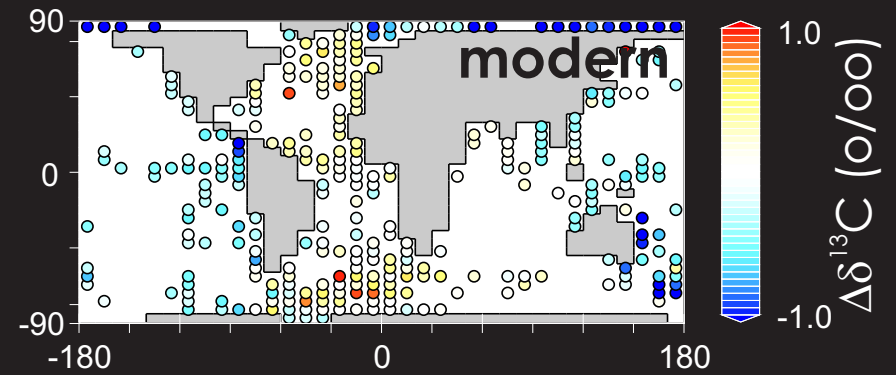
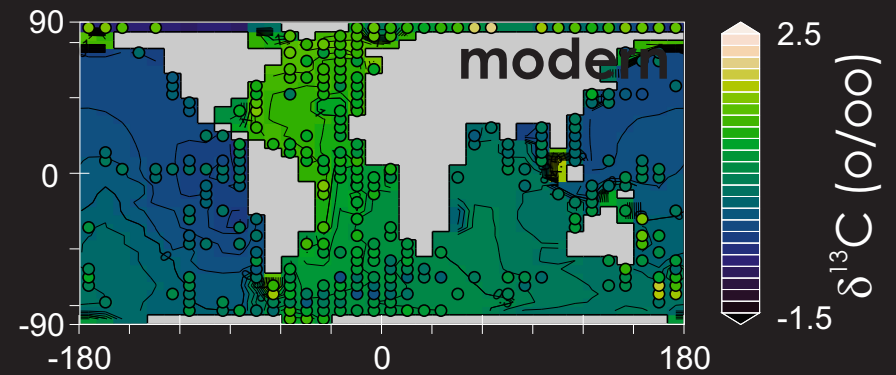
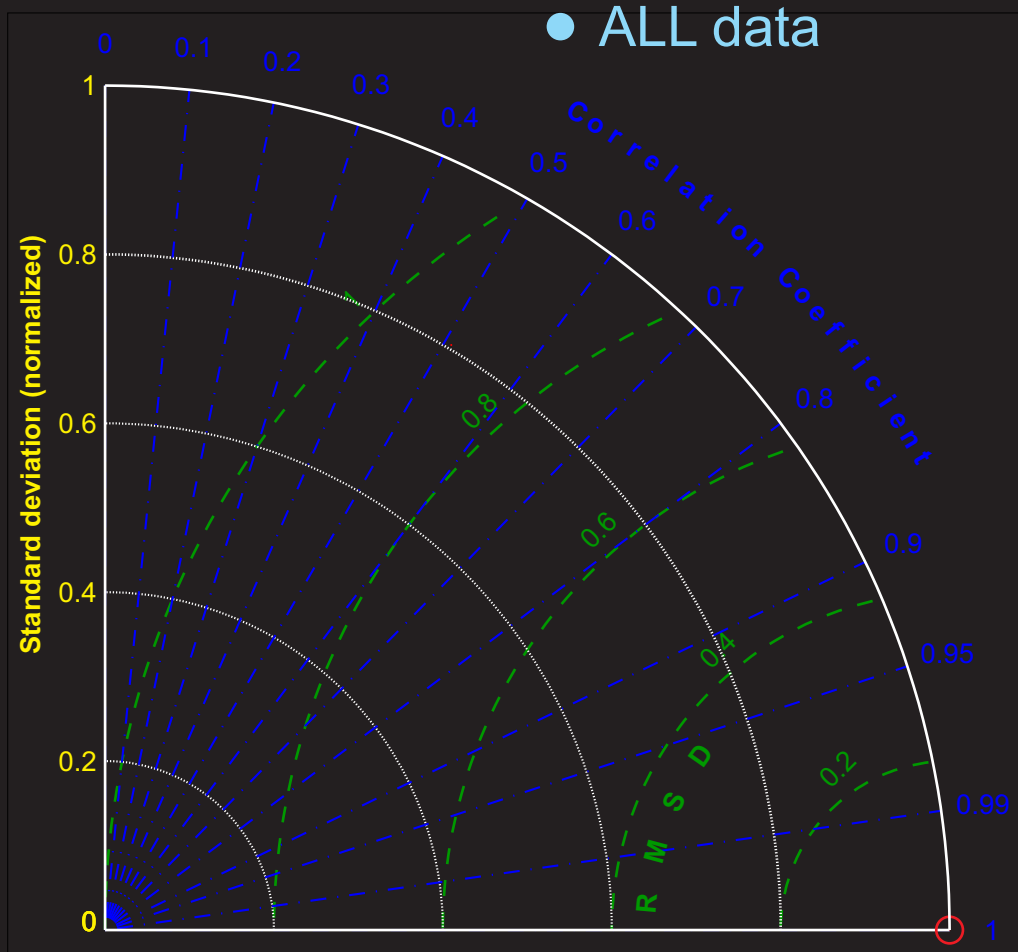
cGENIE 'muffin' Earth system model
(of Intermediate Complexity')

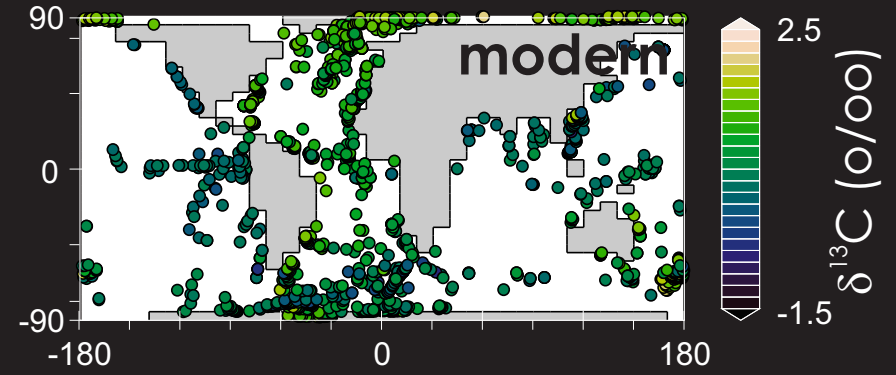
<https://github.com/derpycode/cgenie.muffin>

Introduction

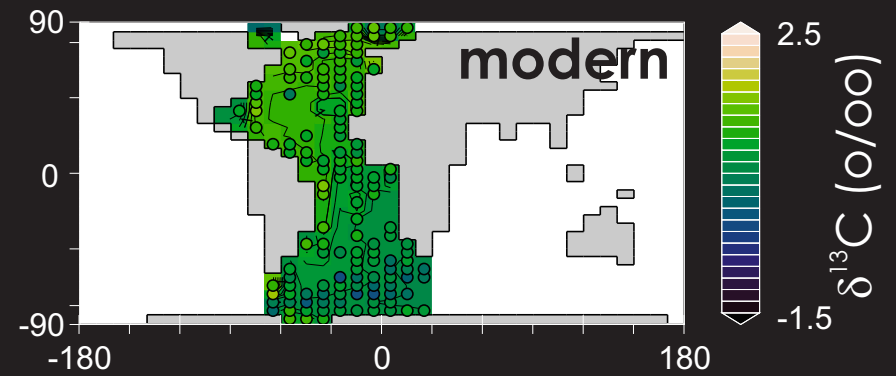
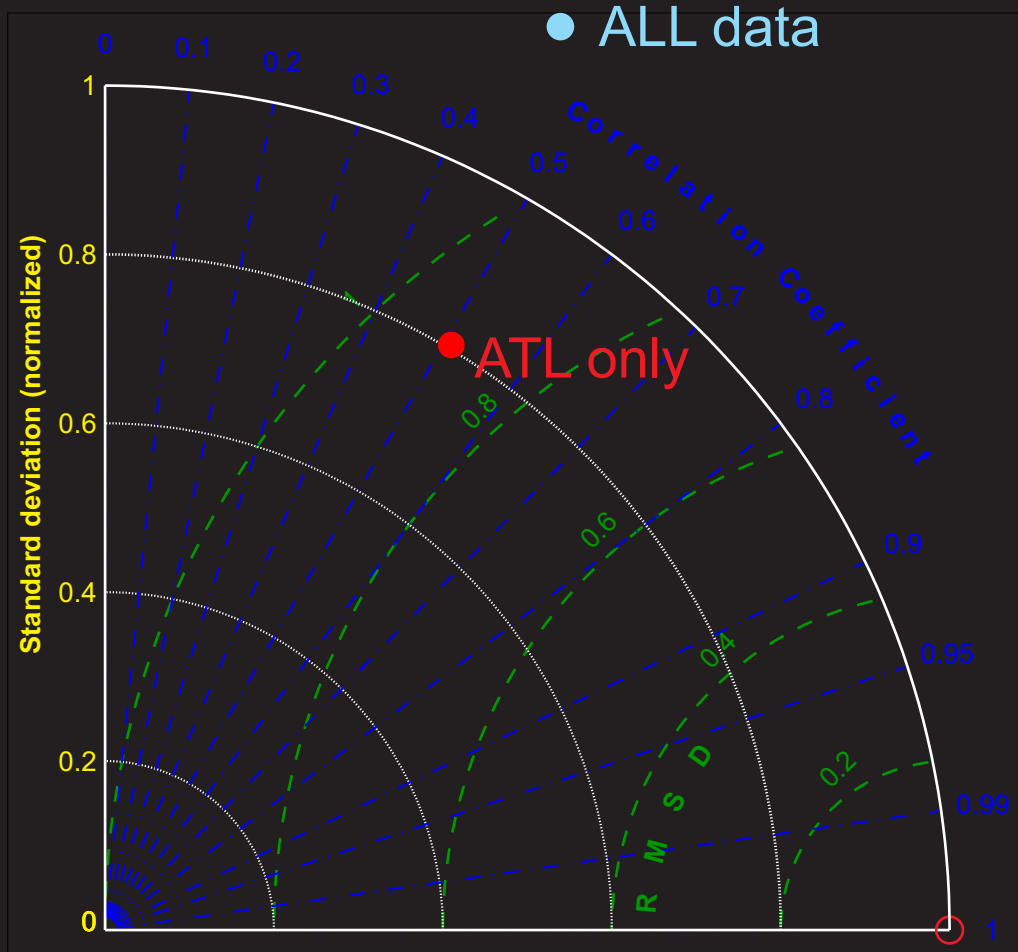


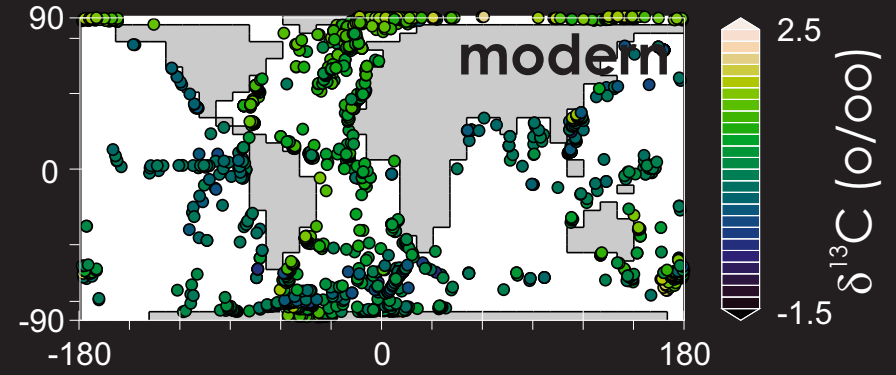
Schmittner et al. [2016] 10.1002/2016PA003072



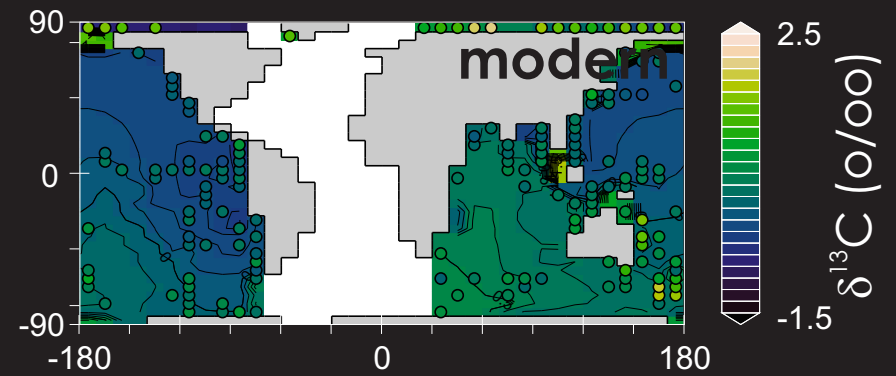
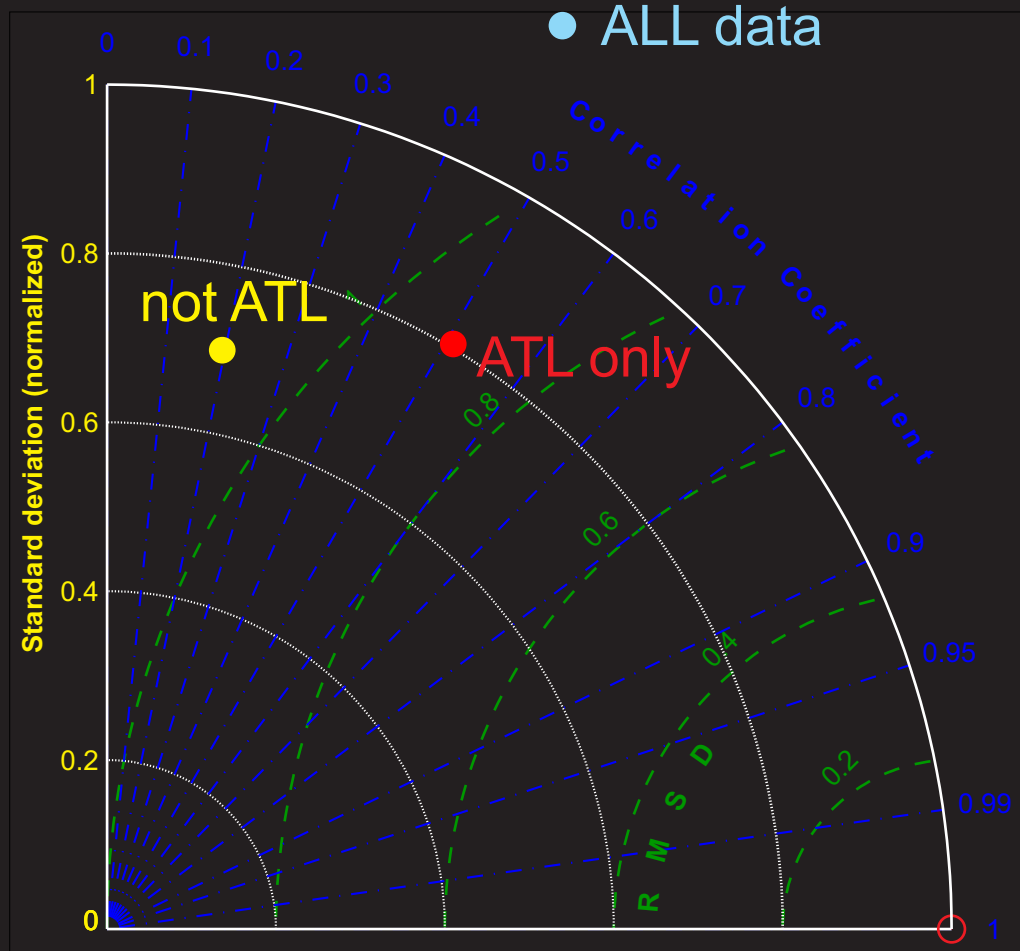


Schmittner et al. [2016] 10.1002/2016PA003072





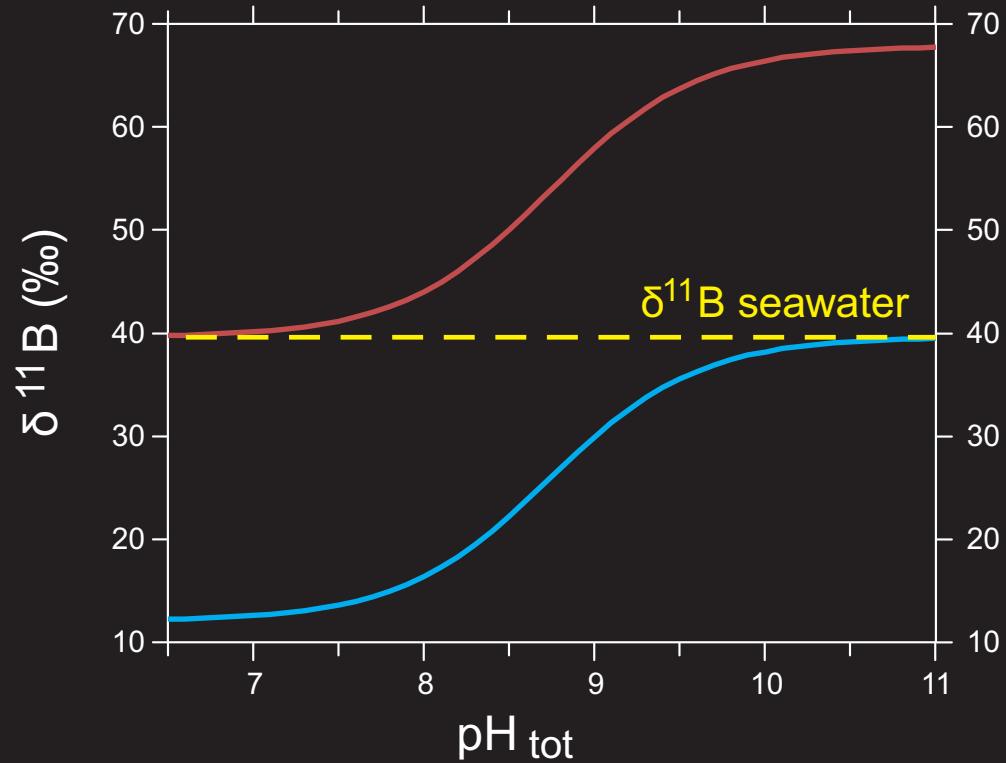
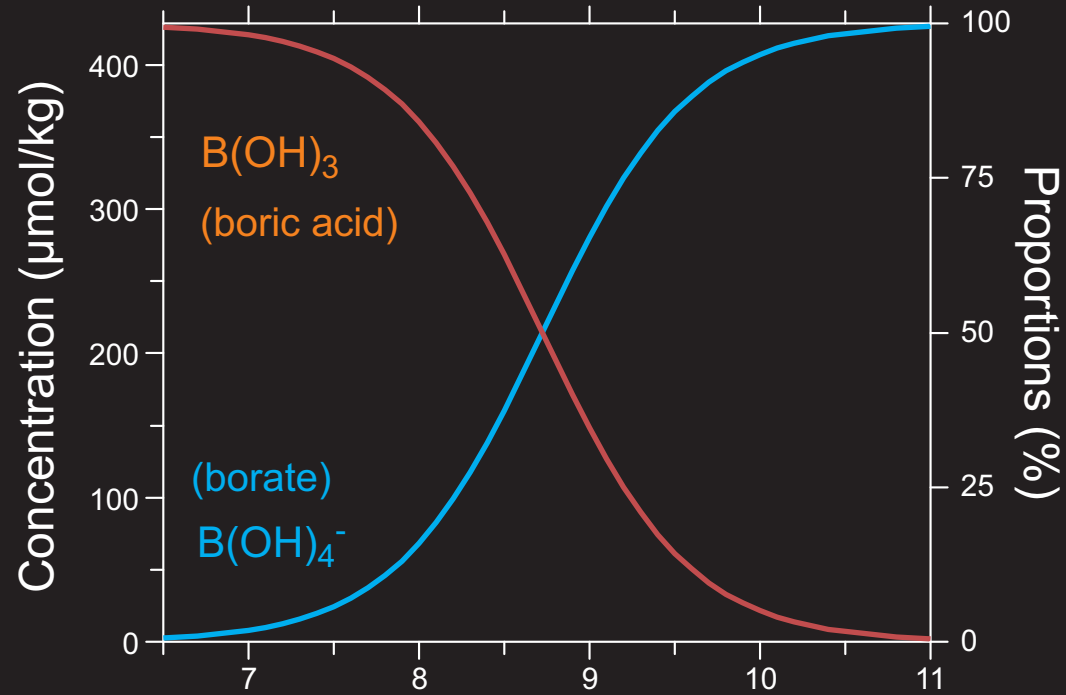
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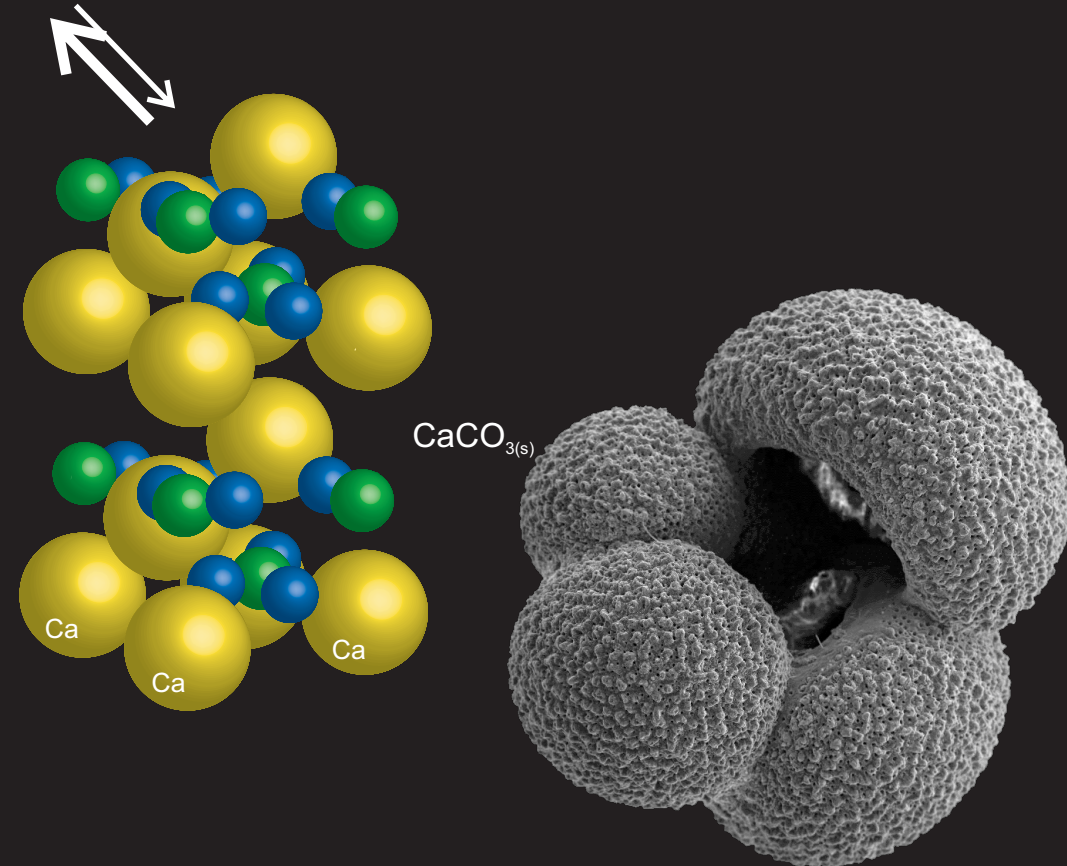
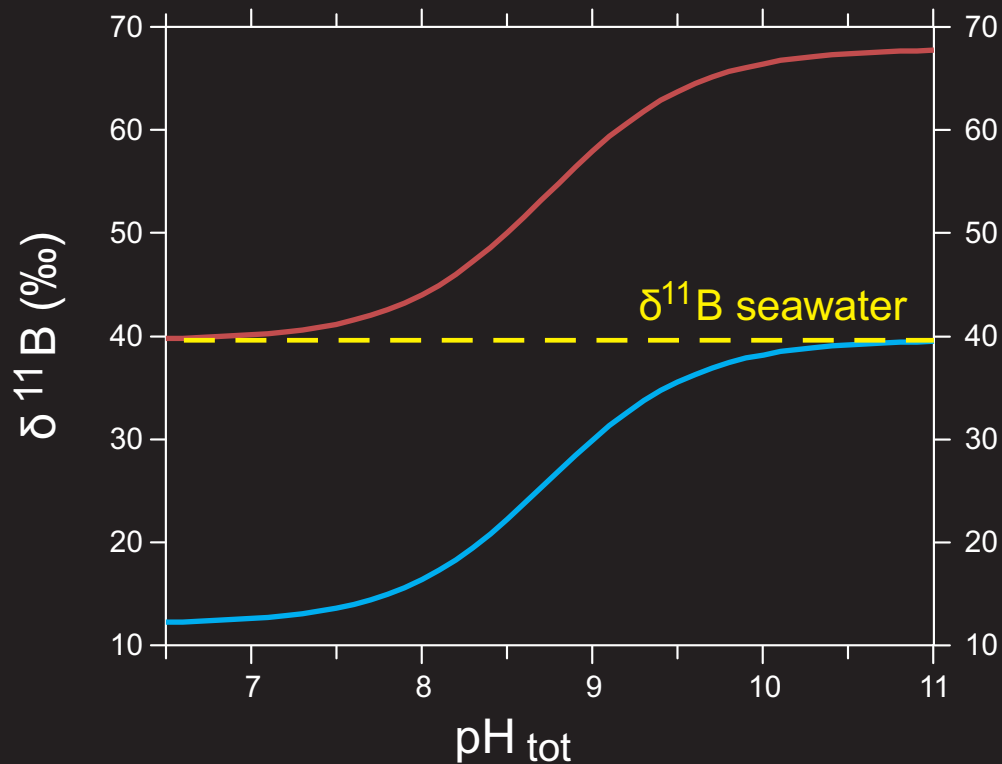
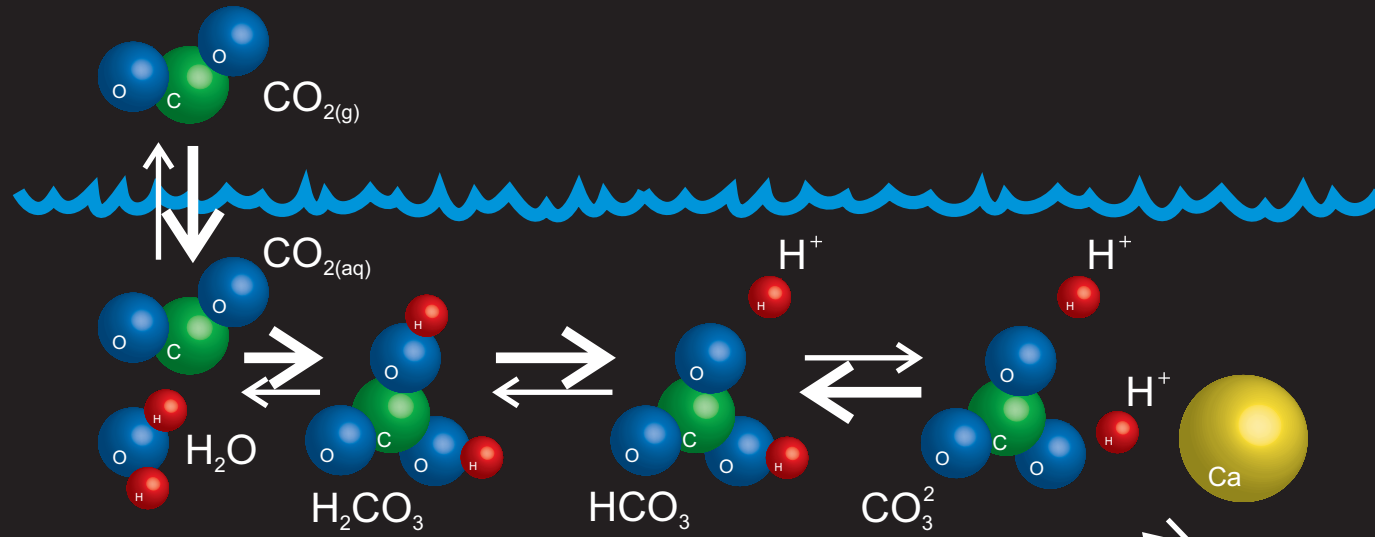


Introduction – proxies in deeper time



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hydrogen																beryllium		boron										carbon										nitrogen										oxygen										fluorine										helium	
1.008																9.012		10.81										12.01										14.01										16.00										19.00										4.003	
3																12		13										14										15										16										17										18	
Li																Mg		Al										Si										P										S										Cl										Ar	
lithium																magnesium		aluminum										silicon										phosphorus										sulfur										chlorine										argon	
6.941																24.31		26.98										28.09										30.97										32.07										35.45										39.95	
11																20		19										21										22										23										24										25	
Na																Ca		K										Sc										Ti										V										Cr										Mn	
sodium																calcium		potassium										scandium										titanium										vanadium										chromium										manganese	
22.99																40.08		39.10										44.96										47.88										50.94										52.00										54.94	
37																56		37										39										40										41										42										43	
Rb																Ba		Rb										Y										Zr										Nb										Mo										Tc	
rubidium																barium		85.47										88.91										91.22										92.91										95.94										101.1	
85.47																137.3		85.47										88.91										91.22										92.91										95.94										101.1	
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Cs																Hf		Cs										La*										Ta										W										Re										Os	
cesium																hafnium		132.9										138.9										173.05										183.84										186.21										190.23	
132.9																178.5		132.9										138.9										173.05										183.84										186.21										190.23	
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Fr																Sg		Fr										Ra										Ac~										Rf										Db										Sg	
francium																seaborgium		223										226										227										261										262										263	
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58.85																263		58.85										58.93										58.69										63.55										65.39										69.72	
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44																108		44										45										46										47										48										49	
Ru																Hs		Ru										Rh										Pd										Ag										Cd										In	
101.1																277		101.1										102.9										106.4										107.9										112.4										114.8	
101.1																277		101.1										102.9										106.4										107.9										112.4										114.8	
76																109		76										77										78										79										80										81	
Os																Mt		Os										Ir										Pt										Au										Hg										Tl	
190.2																268		190.2										192.22										195.08										197.0										200.59										204.4	
190.2																268		190.2										192.22										195.08										197.0										200.59										204.4	
108																110		108										109										110										111										112										113	
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263																271		263										268										271										272										277										284	
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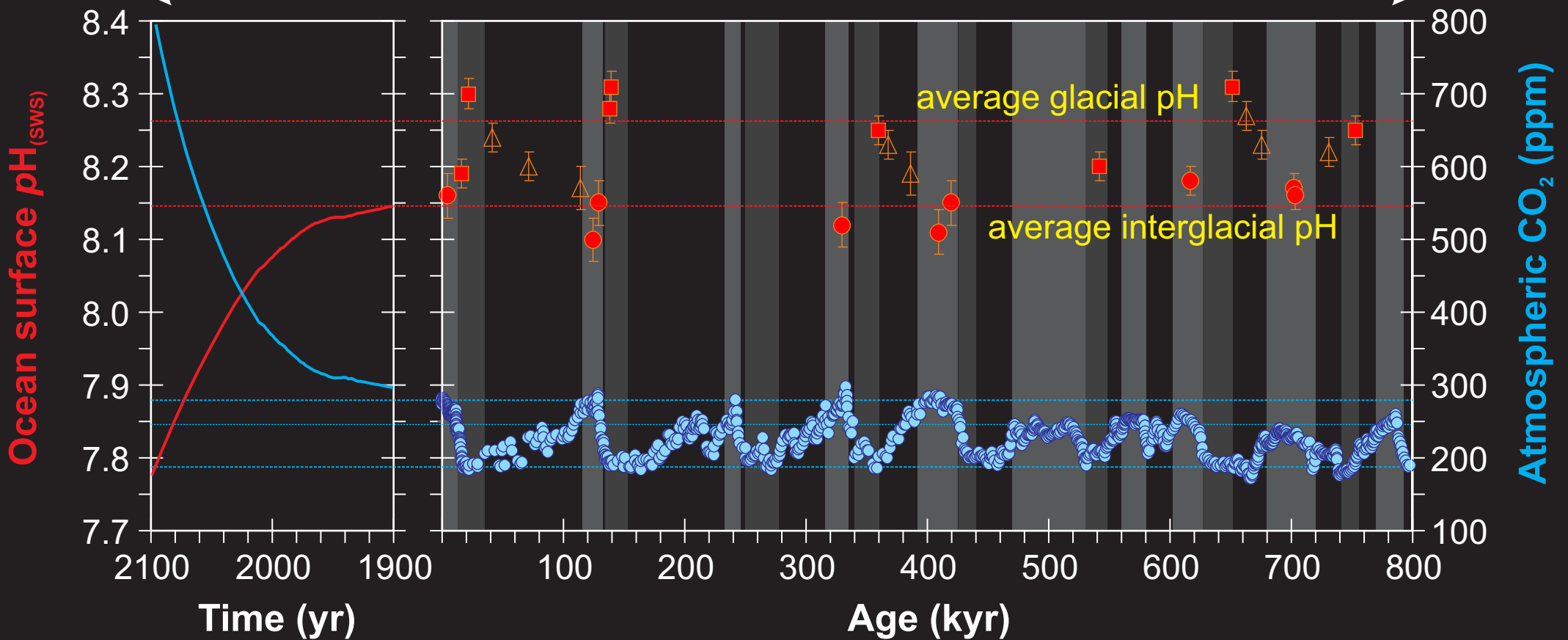


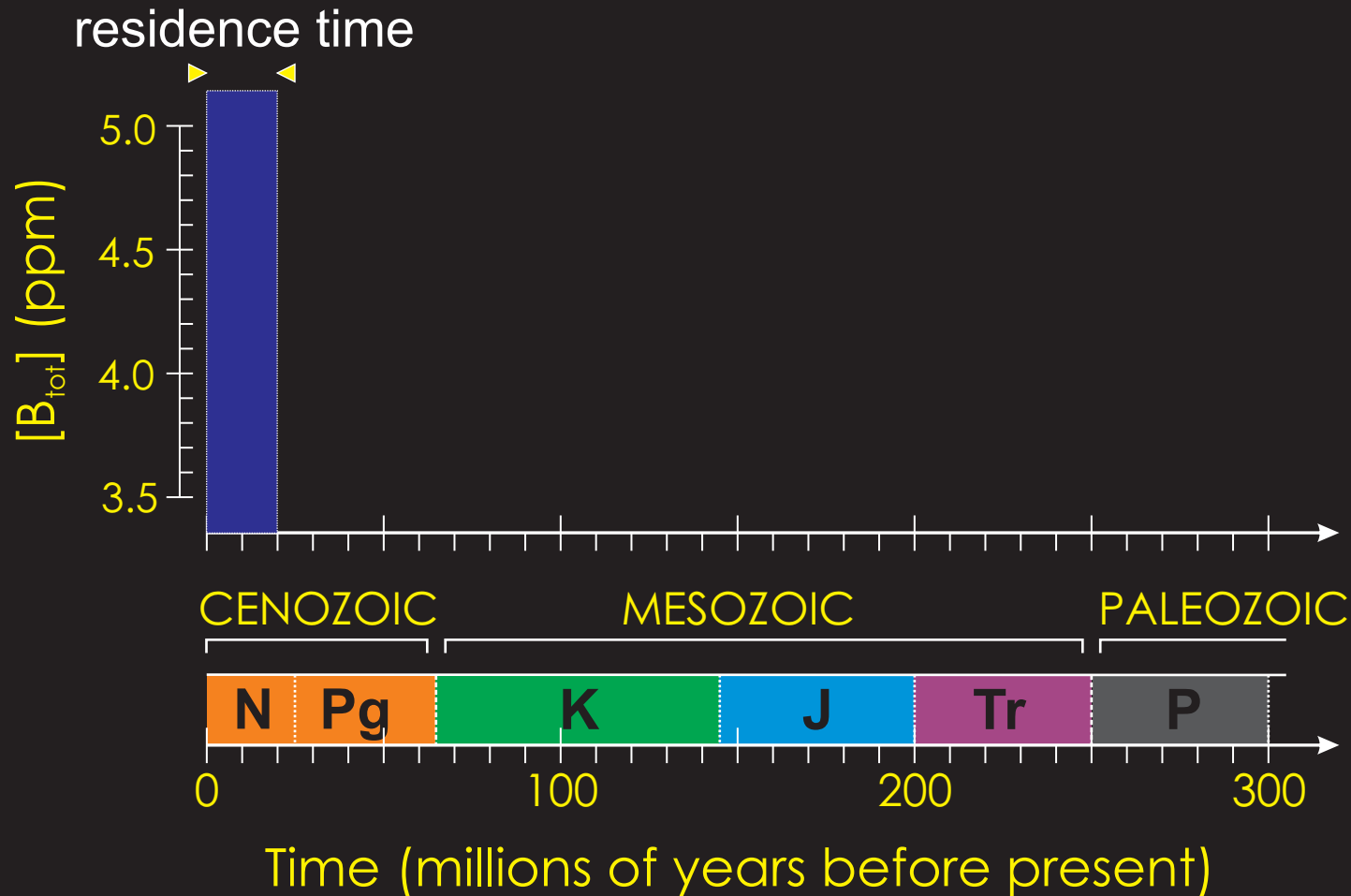


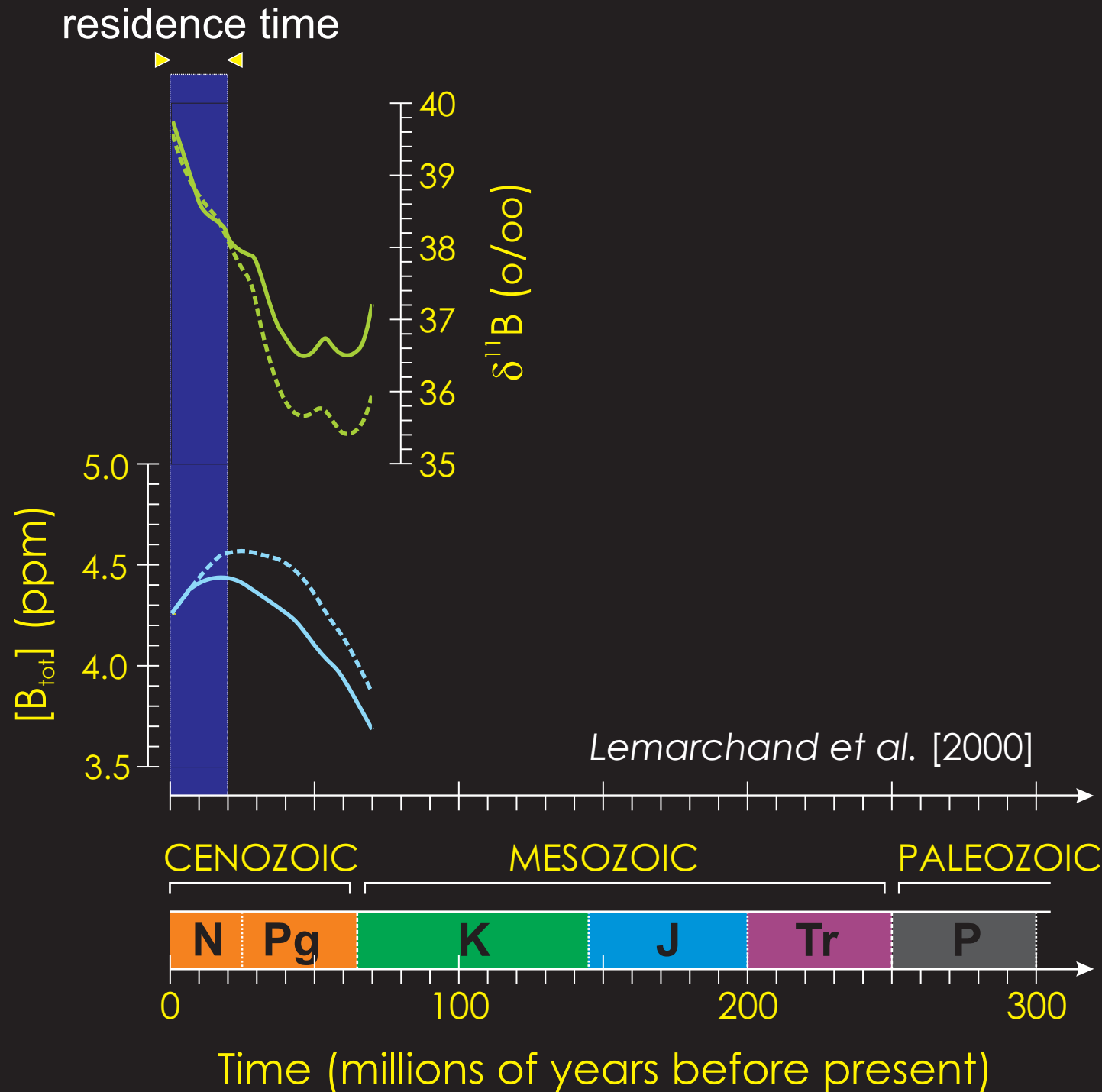


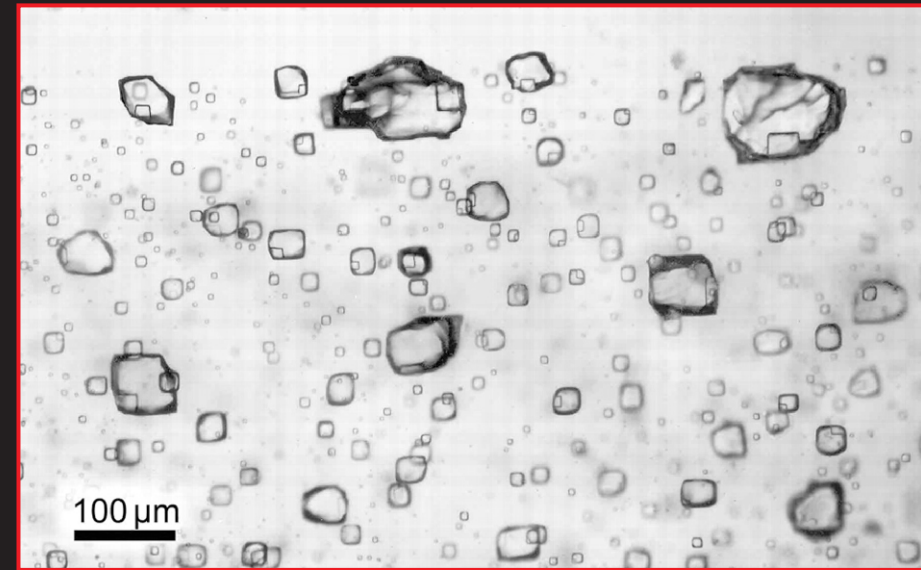
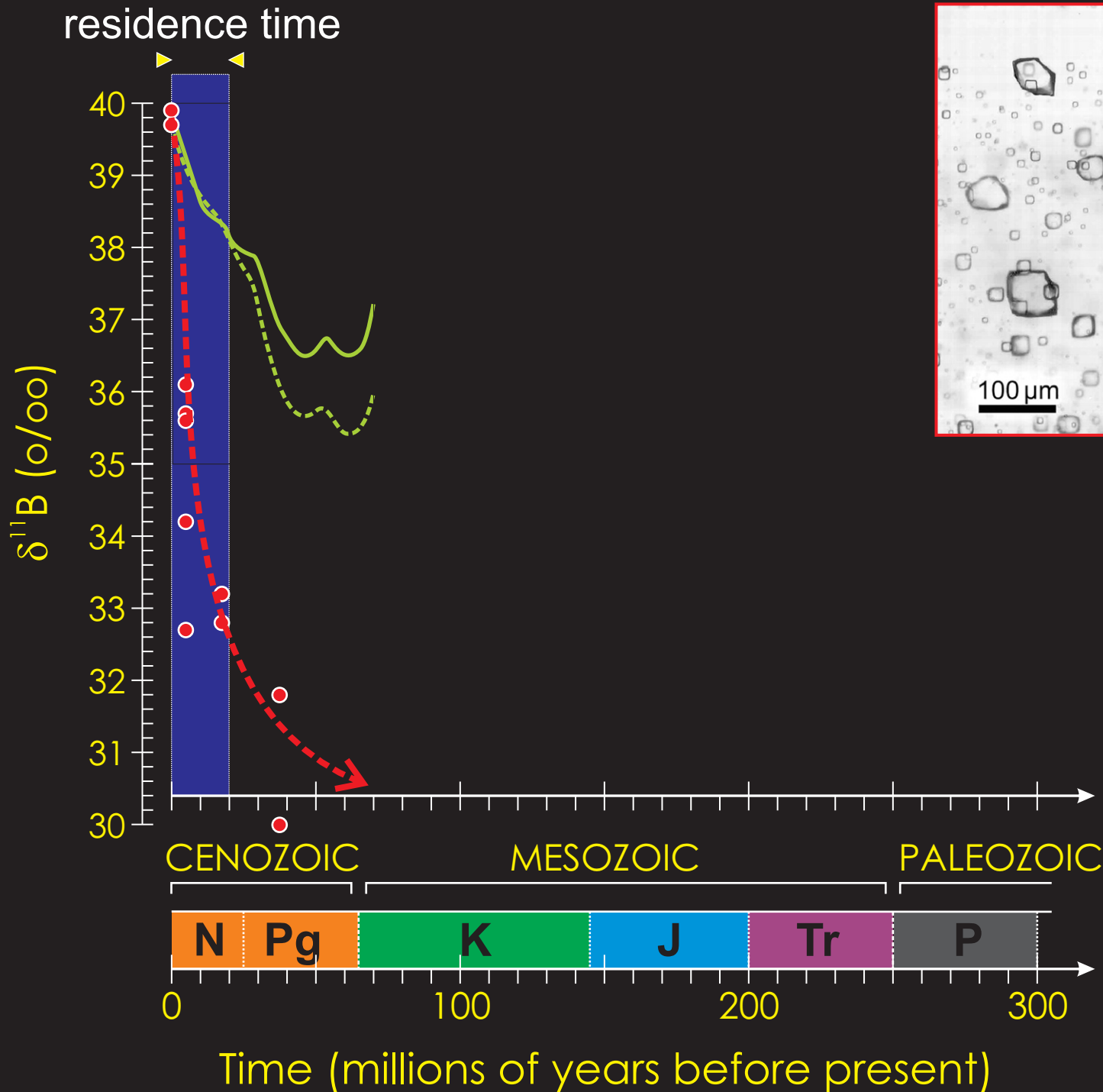
future

geological past

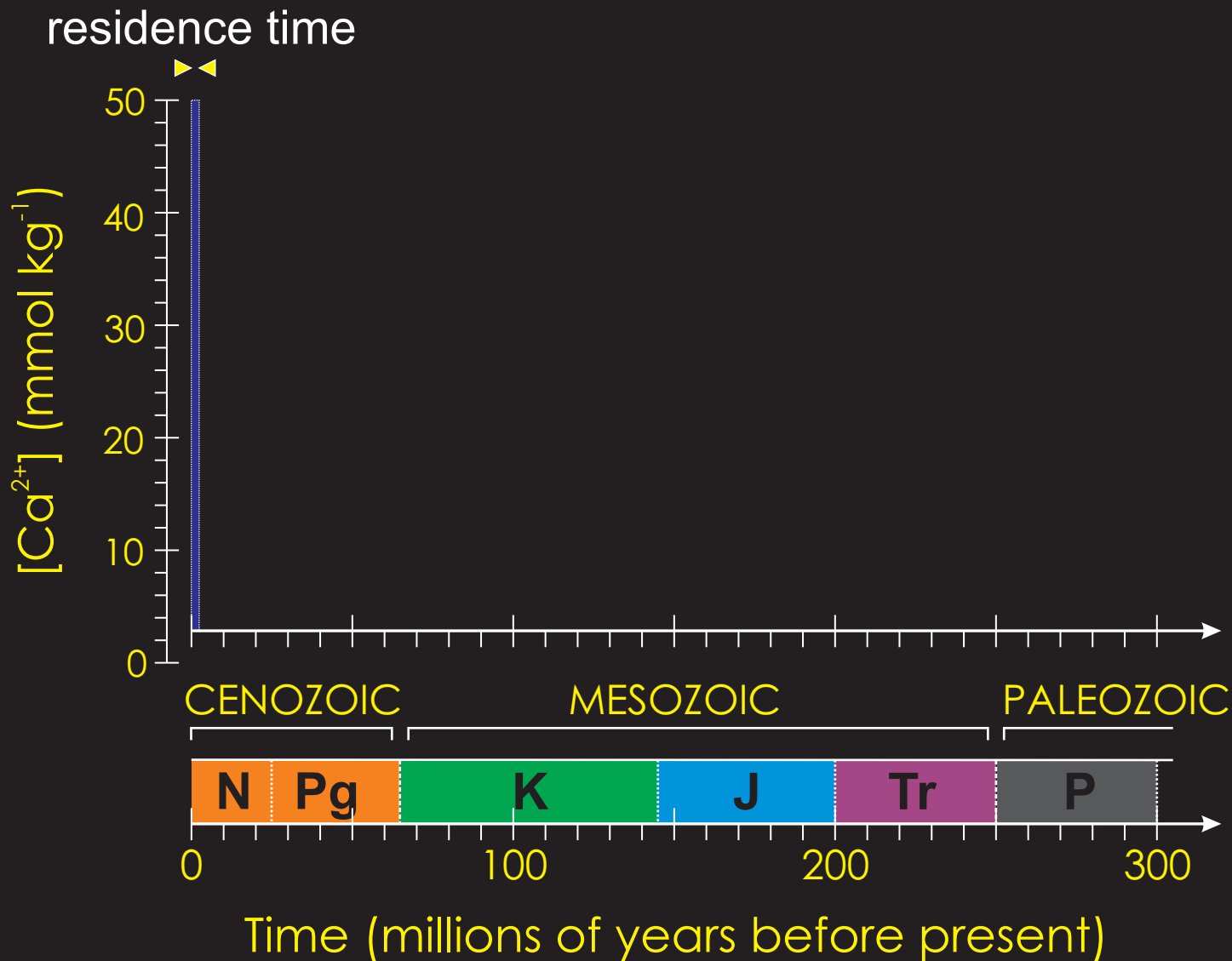


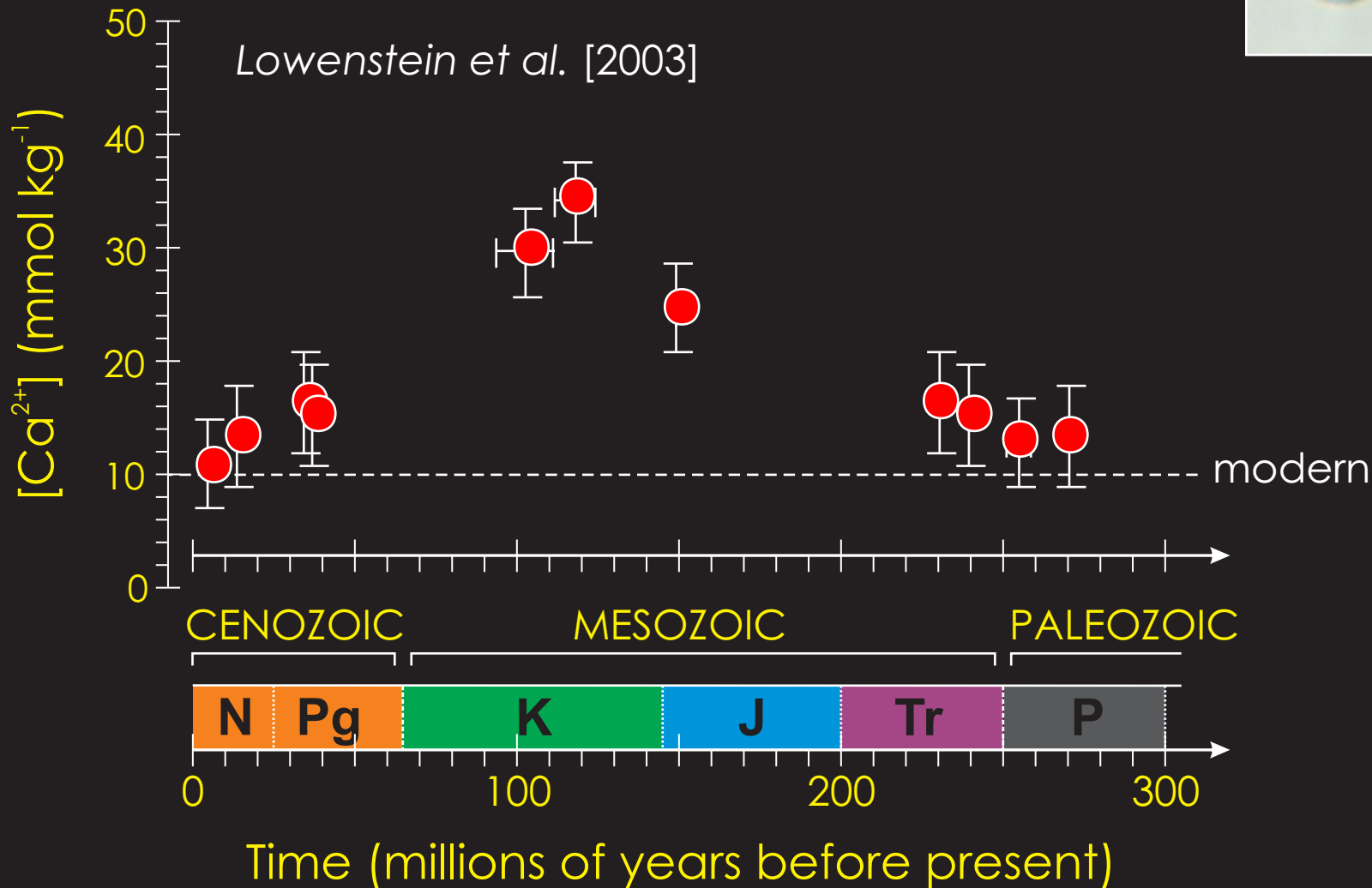
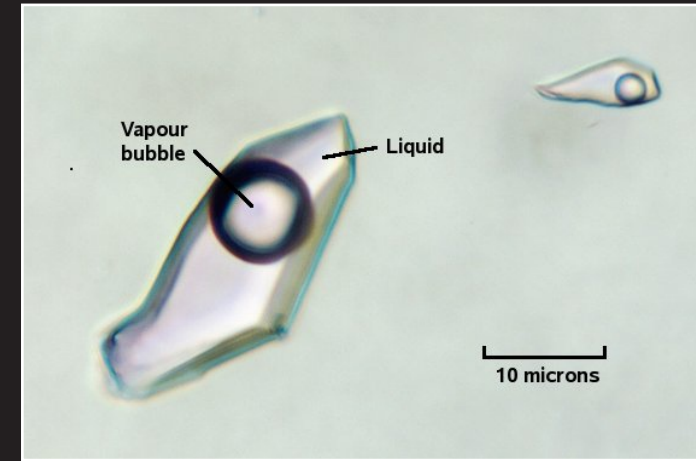






Paris et al. [2010]



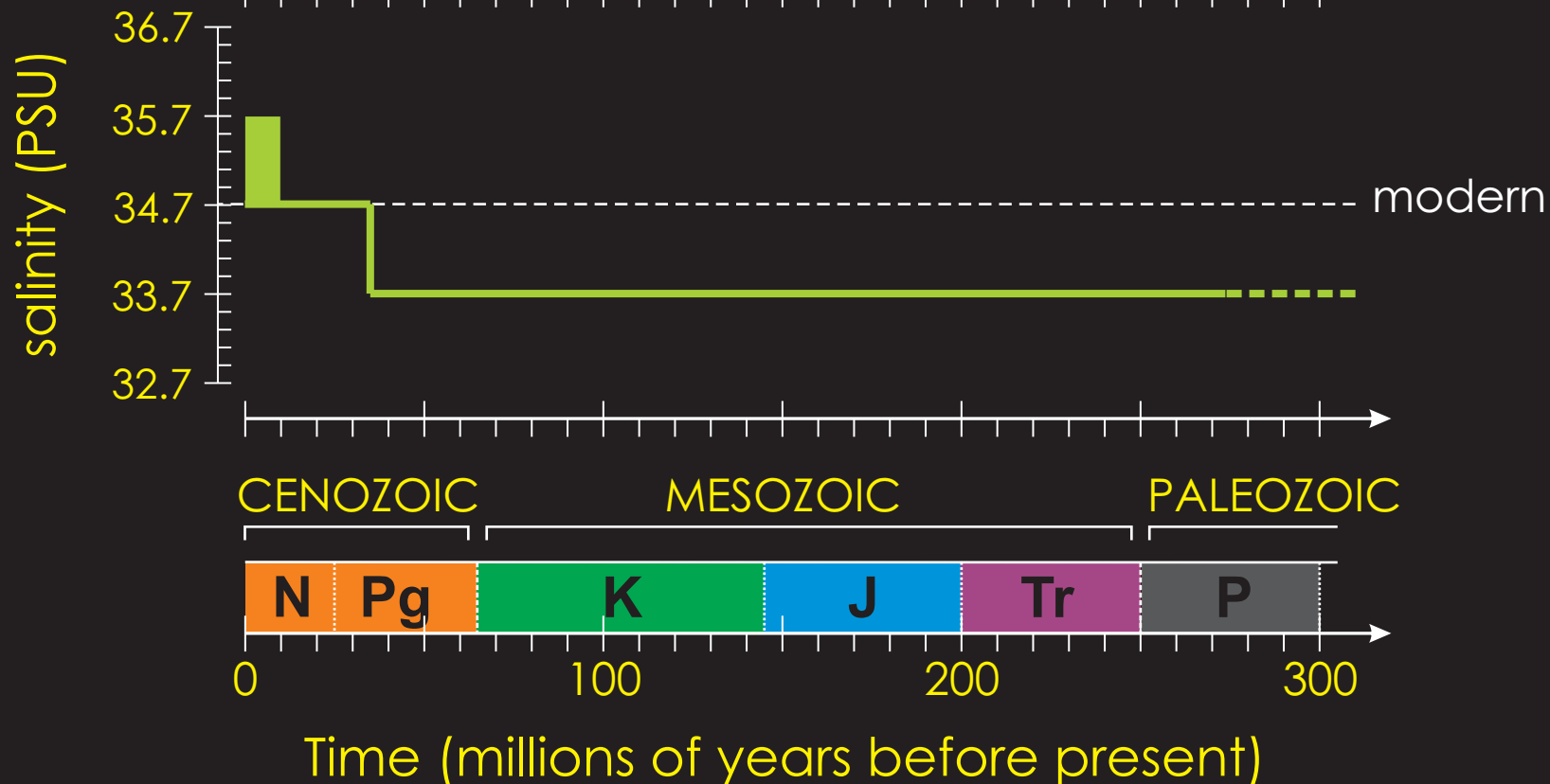




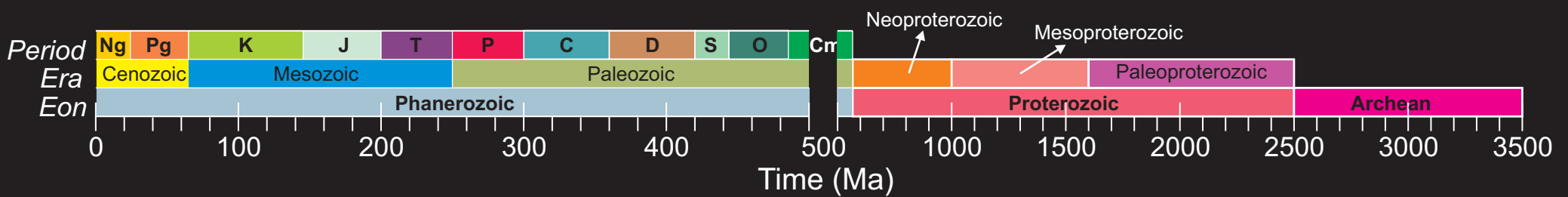
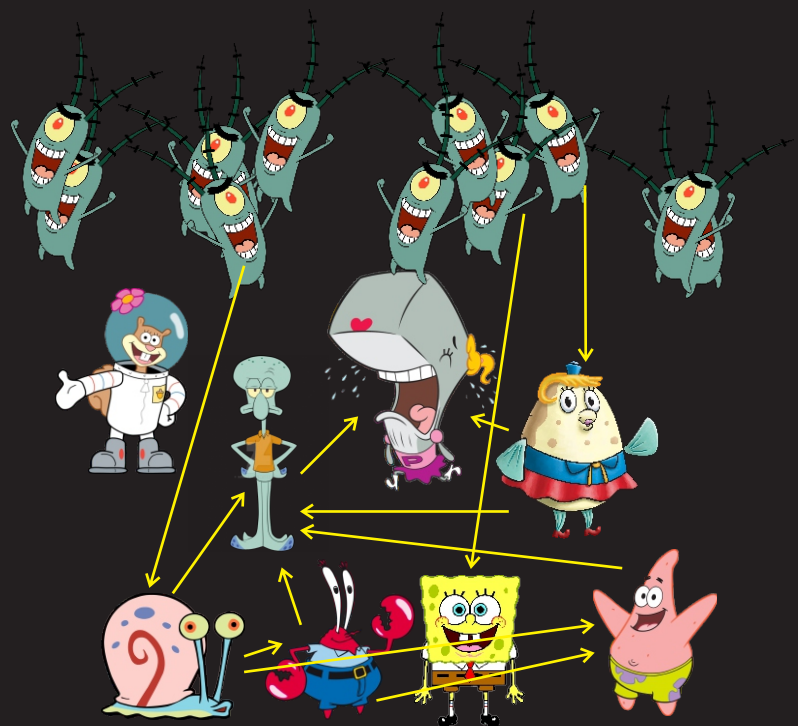
“How has salinity varied in the past ... ?”

[Anon, Chemical Oceanography GRC]

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1 H hydrogen 1.008										3 Li lithium 6.941										4 Be beryllium 9.012										11 Na sodium 22.99										12 Mg magnesium 24.31										19 K potassium 39.10										20 Ca calcium 40.08										21 Sc scandium 44.96										22 Ti titanium 47.88										23 V vanadium 50.94										24 Cr chromium 52.00										25 Mn manganese 54.94										26 Fe iron 55.85										27 Co cobalt 58.93										28 Ni nickel 58.69										29 Cu copper 63.55										30 Zn zinc 65.39										31 Ga gallium 69.72										32 Ge germanium 72.58										33 As arsenic 74.92										34 Se selenium 78.96										35 Br bromine 79.90										36 Kr krypton 83.80										7 N nitrogen 14.01										8 O oxygen 16.00										16 S sulfur 32.07										17 Cl chlorine 35.45										18 Ar argon 39.95										9 F fluorine 19.00										10 Ne neon 20.18										13 Al aluminum 26.98										14 Si silicon 28.09										15 P phosphorus 30.97										19 K potassium 39.10										20 Ca calcium 40.08										21 Sc scandium 44.96										22 Ti titanium 47.88										23 V vanadium 50.94										24 Cr chromium 52.00										25 Mn manganese 54.94										26 Fe iron 55.85										27 Co cobalt 58.93										28 Ni nickel 58.69										29 Cu copper 63.55										30 Zn zinc 65.39										31 Ga gallium 69.72										32 Ge germanium 72.58										33 As arsenic 74.92										34 Se selenium 78.96										35 Br bromine 79.90										36 Kr krypton 83.80										13 Al aluminum 26.98										14 Si silicon 28.09										15 P phosphorus 30.97										16 S sulfur 32.07										17 Cl chlorine 35.45										18 Ar argon 39.95										49 In indium 114.8										50 Sn tin 118.7										51 Sb antimony 121.8										52 Te tellurium 127.6										53 I iodine 126.9										54 Xe xenon 131.3										81 Tl thallium 204.4										82 Pb lead 207.2										83 Bi bismuth 208.9										84 Po polonium (209)										85 At astatine (210)										86 Rn radon (222)										55 Cs cesium 132.9										56 Ba barium 137.3										57 La* lanthanum 138.9										72 Hf hafnium 178.5										73 Ta tantalum 180.9										74 W tungsten 183.9										75 Re rhenium 186.2										76 Os osmium 190.2										77 Ir iridium 192.2										78 Pt platinum 195.1										79 Au gold 197.0										80 Hg mercury 200.5										87 Fr francium (223)										88 Ra radium (226)										89 Ac~ actinium (227)										104 Rf rutherfordium (261)										105 Db dubnium (262)										106 Sg seaborgium (263)										107 Bh bohrium (264)										108 Hs hassium (265)										109 Mt meitnerium (266)										110 Ds darmstadtium (271)										111 Uuu (272)										112 Uub (277)										60 Nd neodymium									

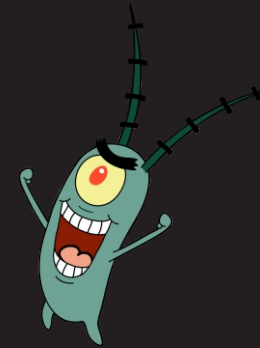
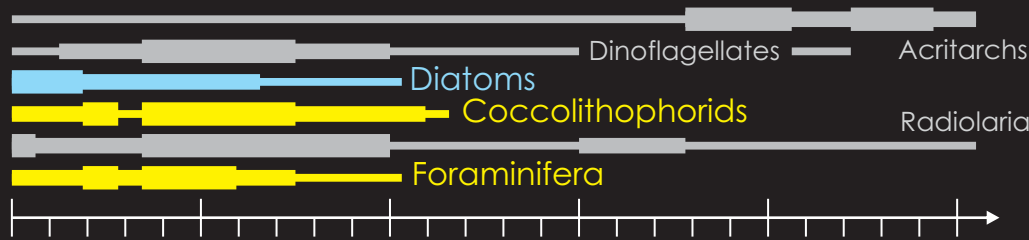


Introduction – ecological (proxy host) evolution





Martin [1995]

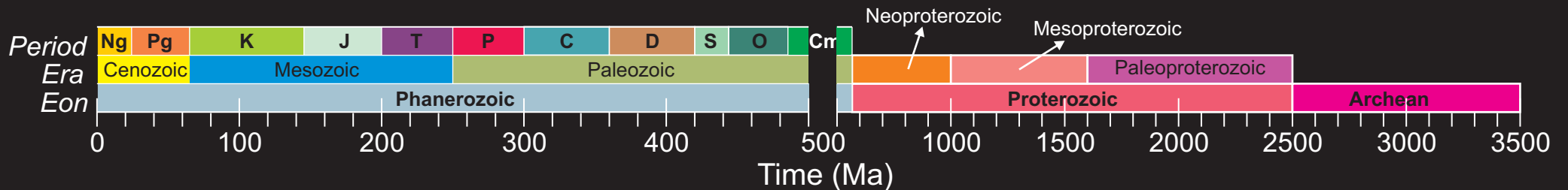


Animals! (metzoans)

Eukaryotes [Knoll, 2014]

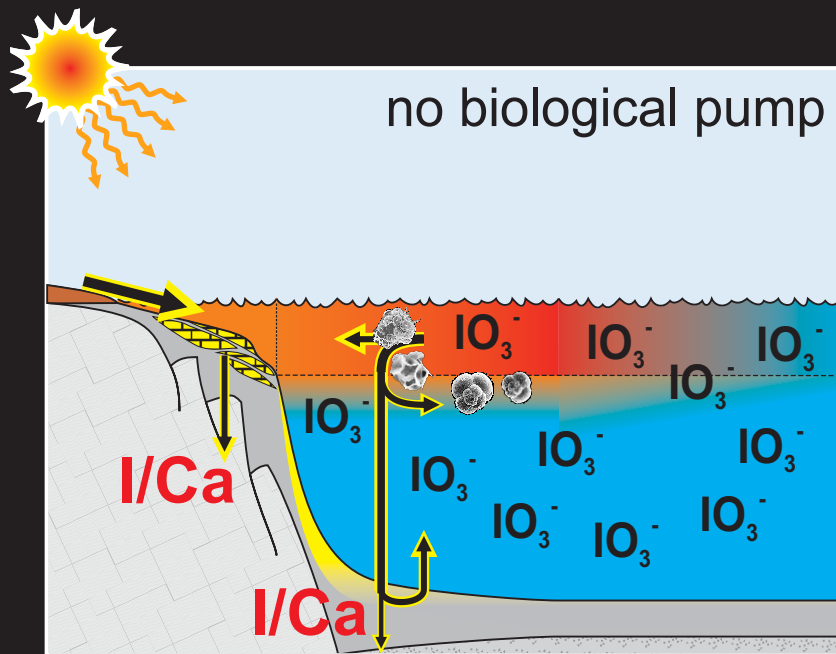
Cyanobacteria (planktonic) [Sánchez-Baracaldo, 2015]

Cyanobacteria (benthic) [Sánchez-Baracaldo, 2015]



proxies (and models) in esp. 'deep time'

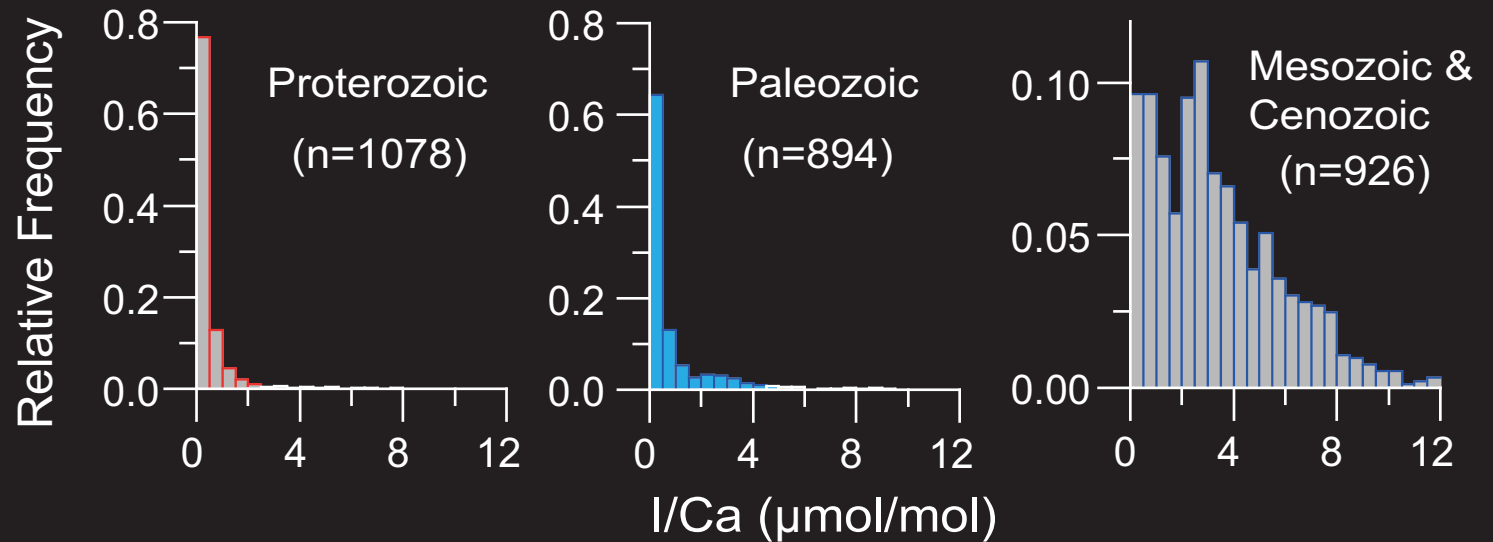
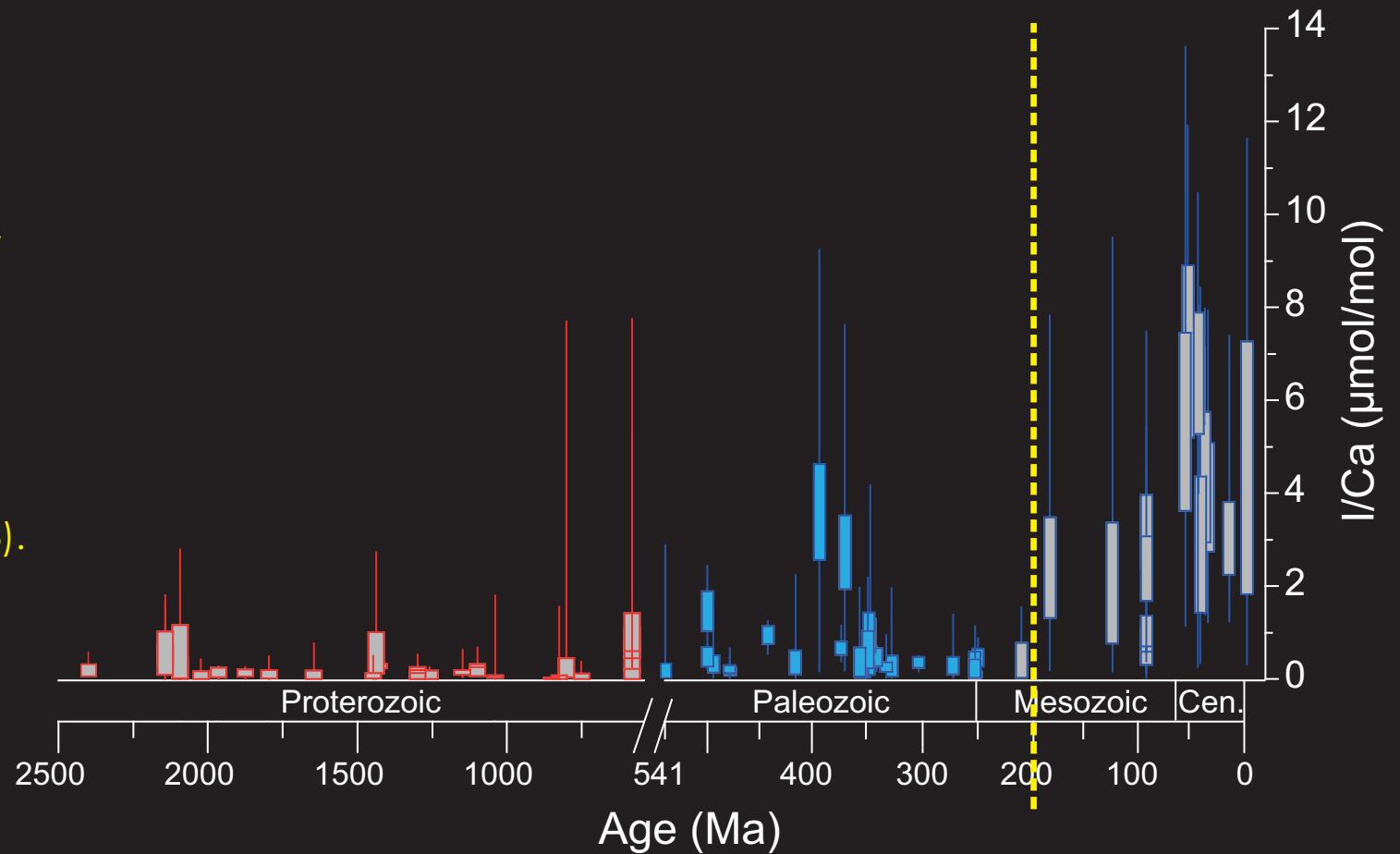
- ★ Need for a 'complete' mechanistic/physiological understanding that can be forward-modelled (simple is good!)
- ★ Independent of specific species and associated metabolic pathways (or the above to be true).
- ★ Hosting in bulk shallow water carbonates and/or shells (in addition to open ocean pelagic sediments) extends applicability before ca. 183 Ma.
- ★ Independent of long-term ocean geochemical evolution OR based on geochemical/isotopic changes that can be reconstructed.
- ★ Sensitive to 'small' differences in water mass origin ... BUT ... specific to large-scale / mean water mass properties that models might hope to model ...
- ★ Multi-proxy approaches ... but are they truly ever useful (beyond one underlying part of a 2nd (proxy forward model))?

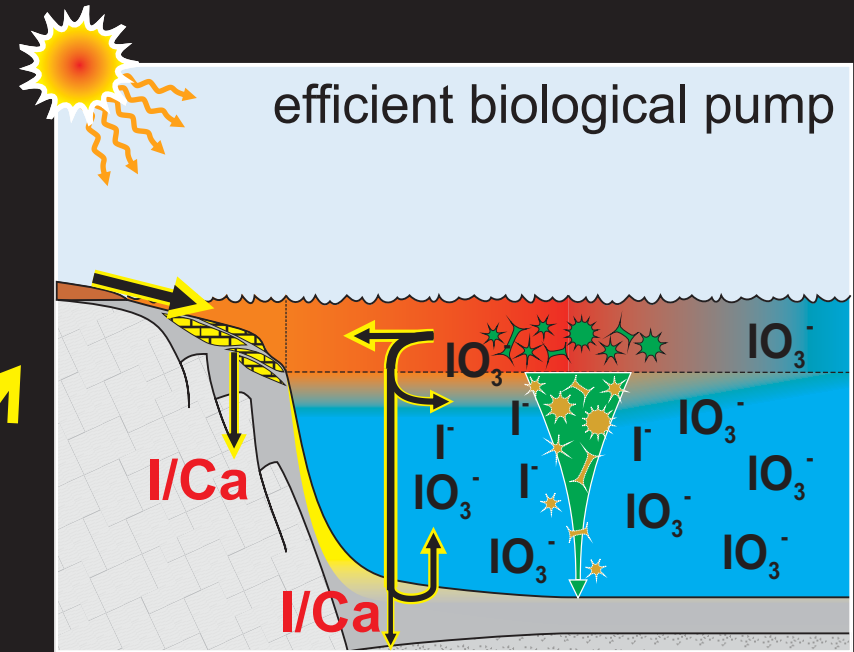
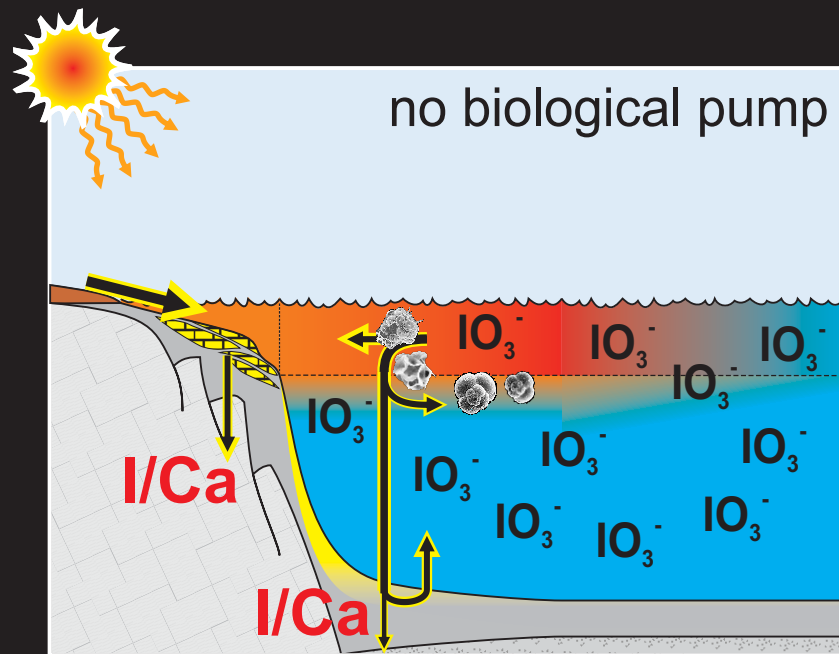


IO_3^- is incorporated into carbonates

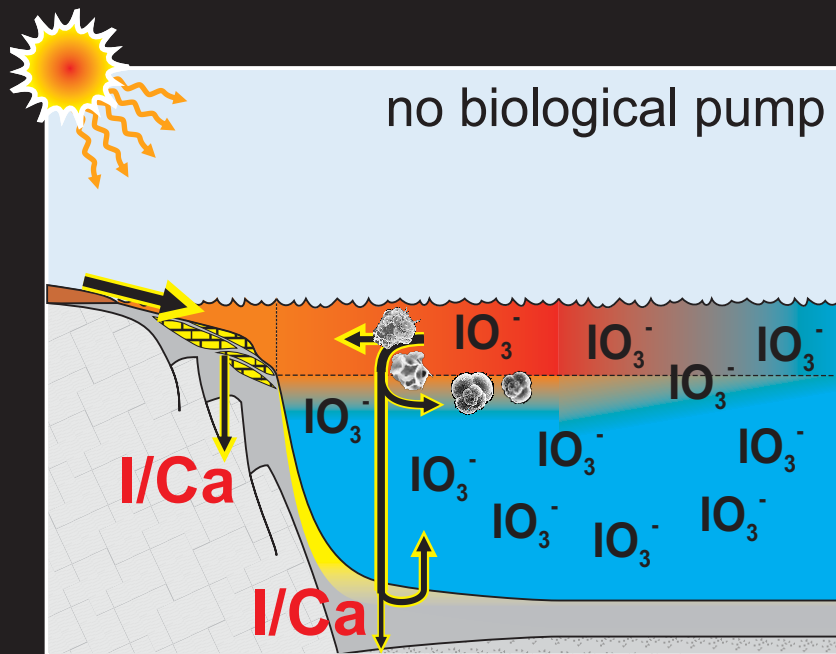
Introduction – Conclusions!

Wanyi, L., A. Ridgwell, E. Thomas, D.S. Hardisty, G. Luo, T.J. Algeo, M.R. Saltzman, B.C. Gill, Y. Shen, H-F. Ling, C.T. Edwards, M.T. Whalen, X. Zhou, K.M. Gutchess, L. Jin, R.E.M. Rickaby, H.C. Jenkyns, T.W. Lyons, T.M. Lenton, L.R. Kump, and Z. Lu¹, Late inception of a resiliently oxygenated upper ocean, *Science* DOI: 10.1126/science.aar5372 (2018).

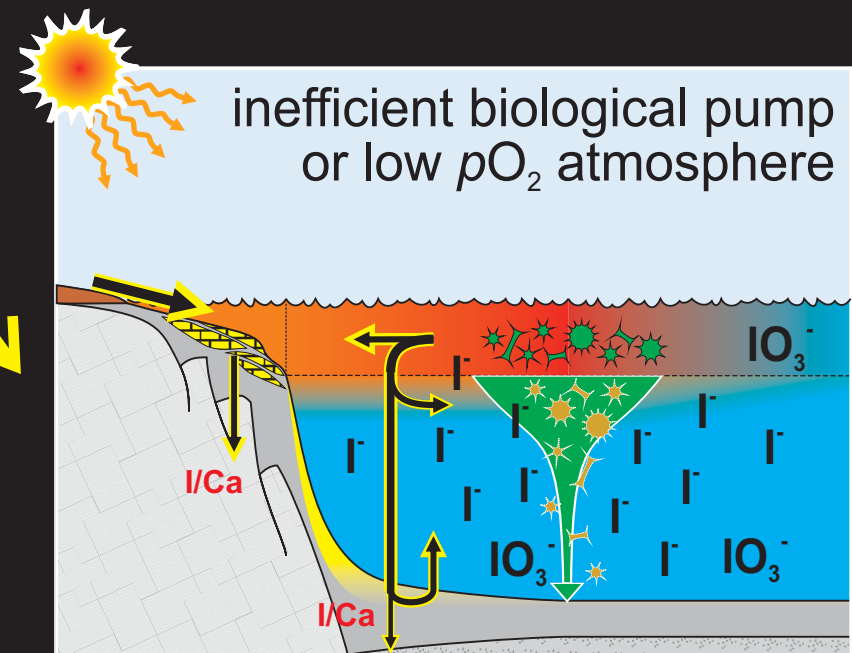


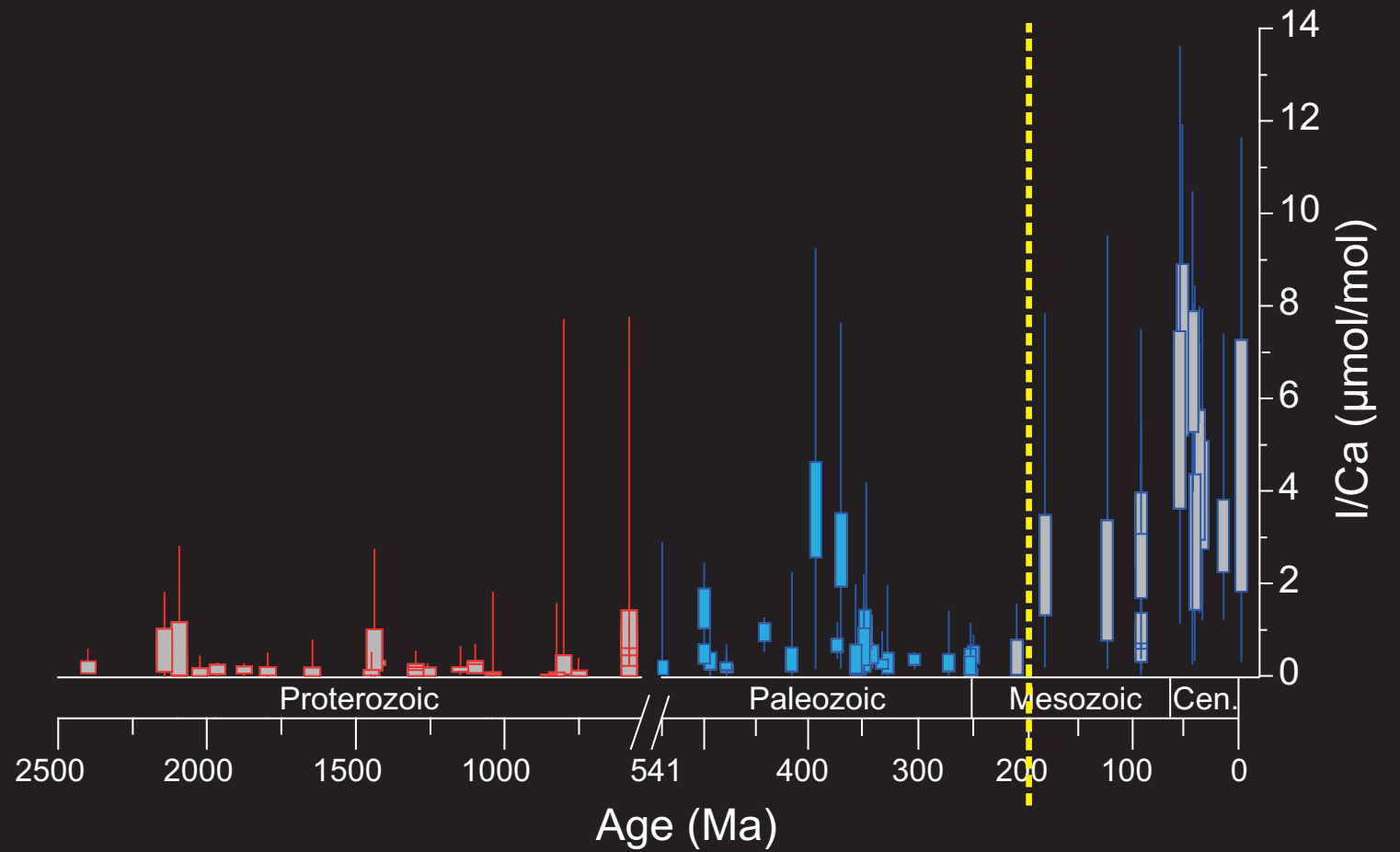


IO_3^- is incorporated into carbonates

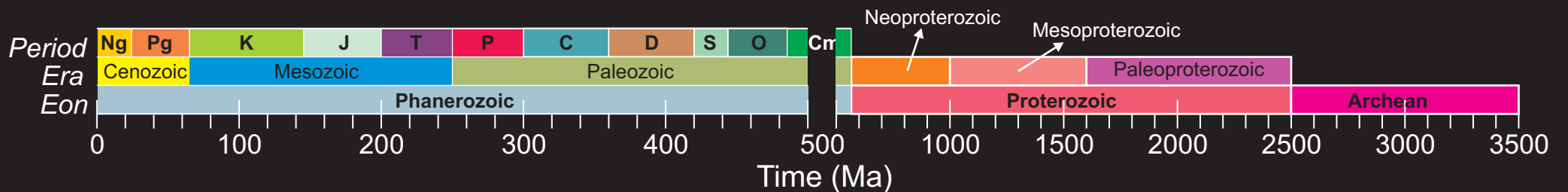
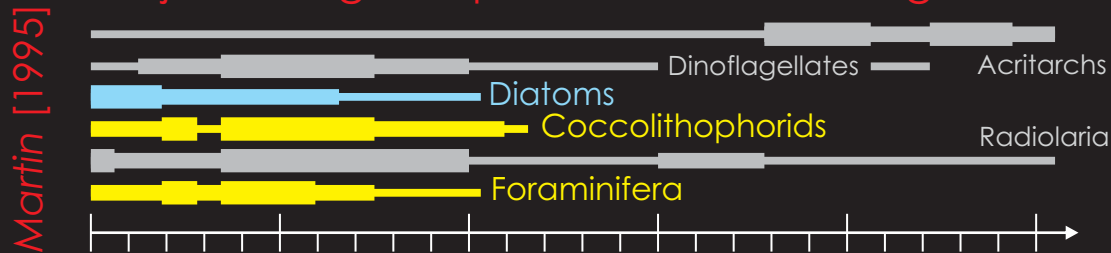


IO_3^- is incorporated into carbonates





Major changes in plankton assemblage



proxies (and models) in esp. 'deep time'

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- ★ Independent of specific species and associated metabolic pathways (or the above to be true).
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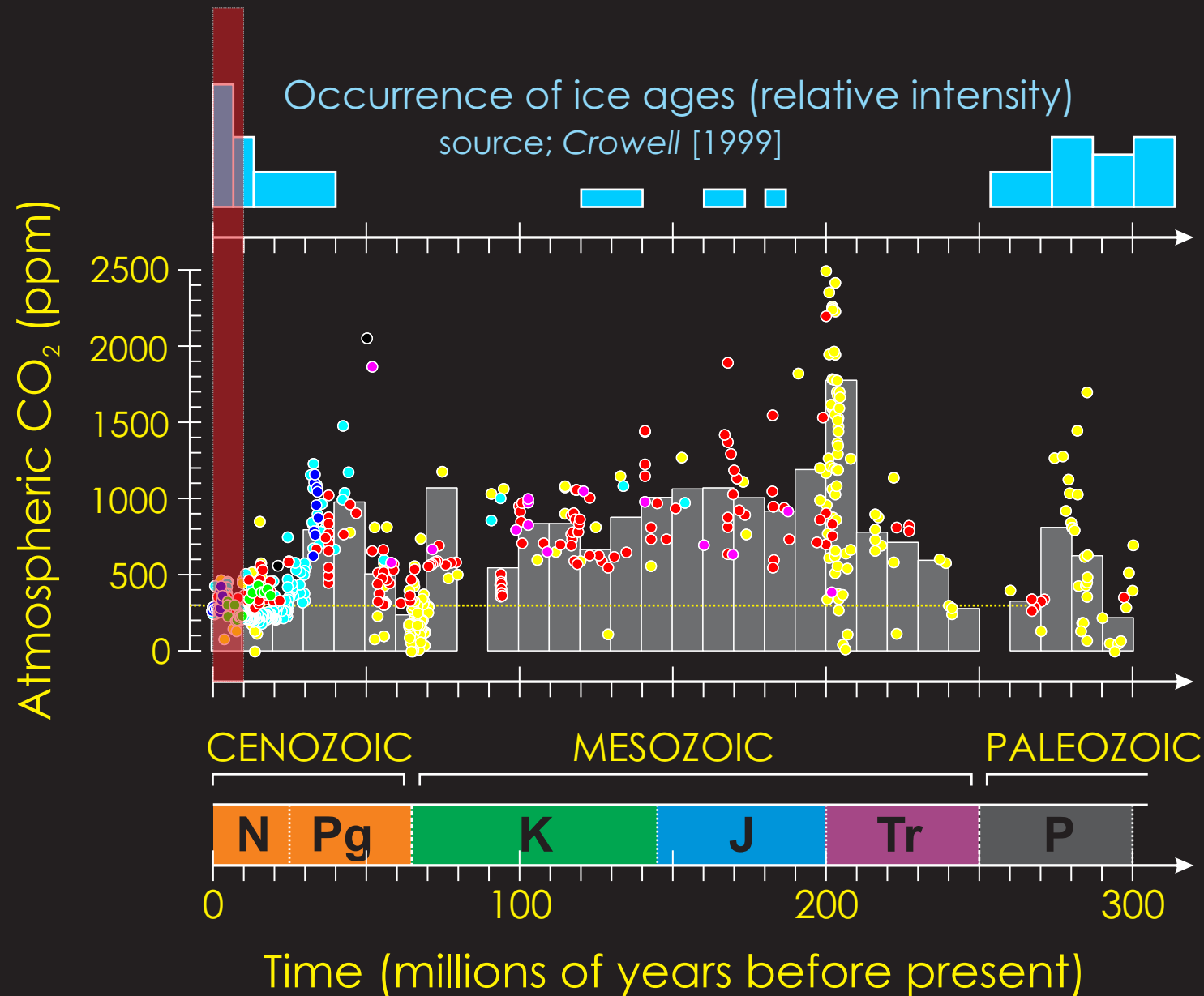
Introduction – Conclusions!



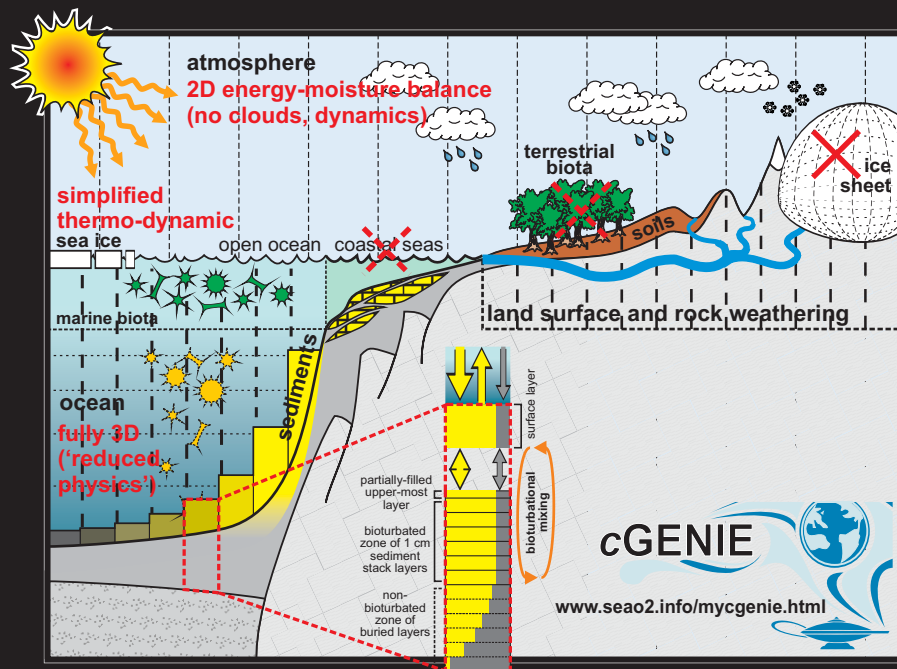
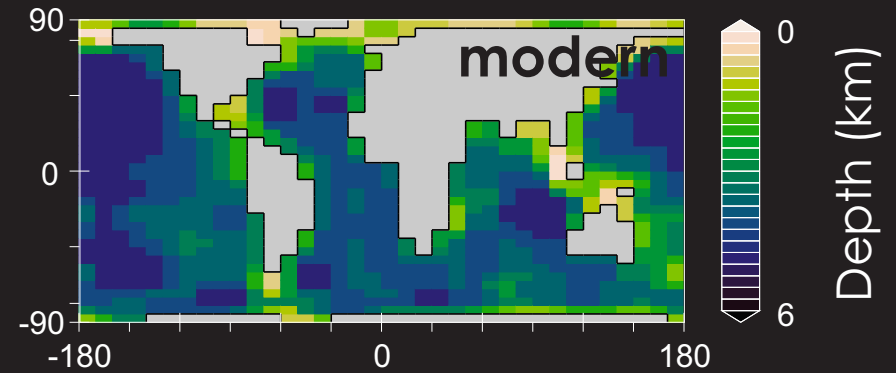
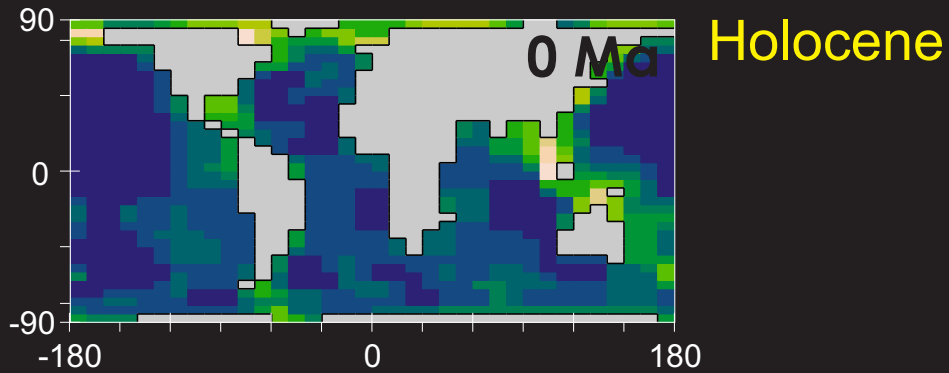
1A											2A											3A	4A	5A	6A	7A	8A												
1 H hydrogen 1.008											2 He helium 4.003											3 Li lithium 6.941	4 Be beryllium 9.012											5 B boron 10.81	6 C carbon 12.01	7 N nitrogen 14.01	8 O oxygen 16.00	9 F fluorine 19.00	10 Ne neon 20.18
11 Na sodium 22.99	12 Mg magnesium 24.31											13 Al aluminum 26.98	14 Si silicon 28.09	15 P phosphorus 30.97	16 S sulfur 32.07	17 Cl chlorine 35.45	18 Ar argon 39.95																						
19 K potassium 39.10	20 Ca calcium 40.08	21 Sc scandium 44.96	22 Ti titanium 47.88	23 V vanadium 50.94	24 Cr chromium 52.00	25 Mn manganese 54.94	26 Fe iron 55.85	27 Co cobalt 58.93	28 Ni nickel 58.69	29 Cu copper 63.55	30 Zn zinc 65.39	31 Ga gallium 69.72	32 Ge germanium 72.58	33 As arsenic 74.92	34 Se selenium 78.96	35 Br bromine 79.90	36 Kr krypton 83.80																						
37 Rb rubidium 85.47	38 Sr strontium 87.62	39 Y yttrium 88.91	40 Zr zirconium 91.22	41 Nb niobium 92.91	42 Mo molybdenum 95.94	43 Tc technetium (98)	44 Ru ruthenium 101.1	45 Rh rhodium 102.9	46 Pd palladium 106.4	47 Ag silver 107.9	48 Cd cadmium 112.4	49 In indium 114.8	50 Sn tin 118.7	51 Sb antimony 121.8	52 Te tellurium 127.6	53 I iodine 126.9	54 Xe xenon 131.3																						
55 Cs cesium 132.9	56 Ba barium 137.3	57 La* lanthanum 138.9	72 Hf hafnium 178.5	73 Ta tantalum 180.9	74 W tungsten 183.9	75 Re rhenium 186.2	76 Os osmium 190.2	77 Ir iridium 190.2	78 Pt platinum 195.1	79 Au gold 197.0	80 Hg mercury 200.5	81 Tl thallium 204.4	82 Pb lead 207.2	83 Bi bismuth 208.9	84 Po polonium (209)	85 At astatine (210)	86 Rn radon (222)																						
87 Fr francium (223)	88 Ra radium (226)	89 Ac~ actinium (227)	104 Rf rutherfordium (261)	105 Db dubnium (260)	106 Sg seaborgium (263)	107 Bh bohrium (262)	108 Hs hassium (265)	109 Mt meitnerium (266)	110 Ds darmstadtium (271)	111 Uuu (272)	112 Uub (277)																												

60
Nd
neodymium

Miocene (23-5 Ma) to present

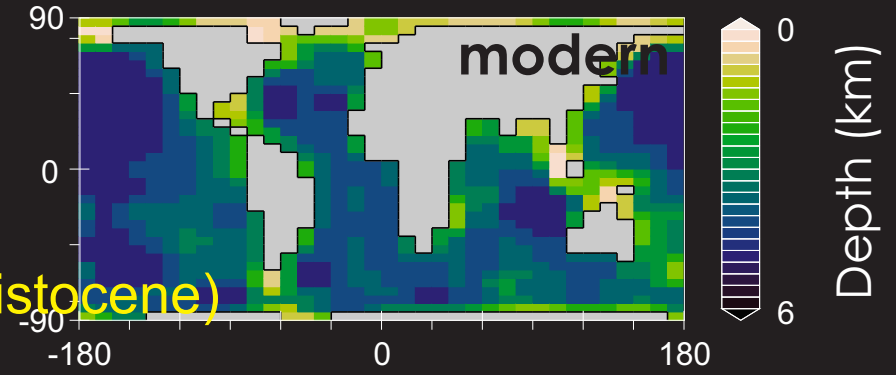
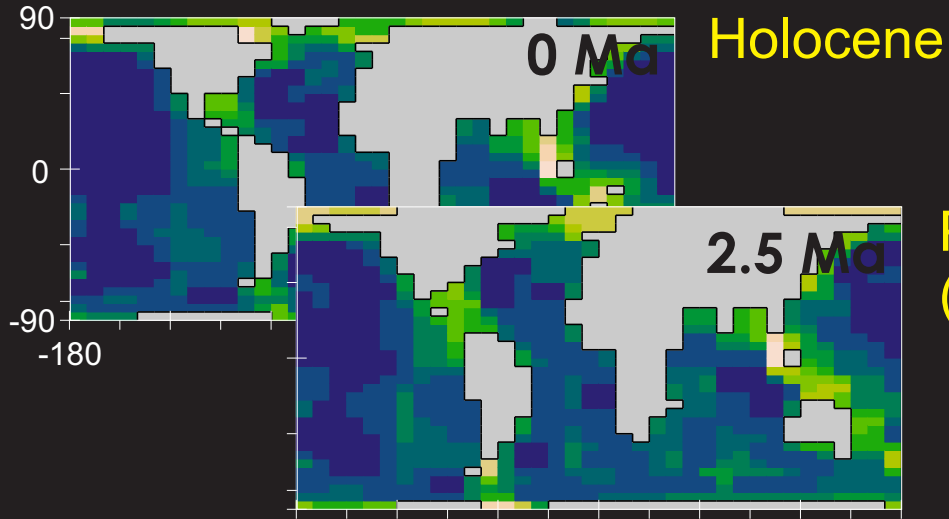


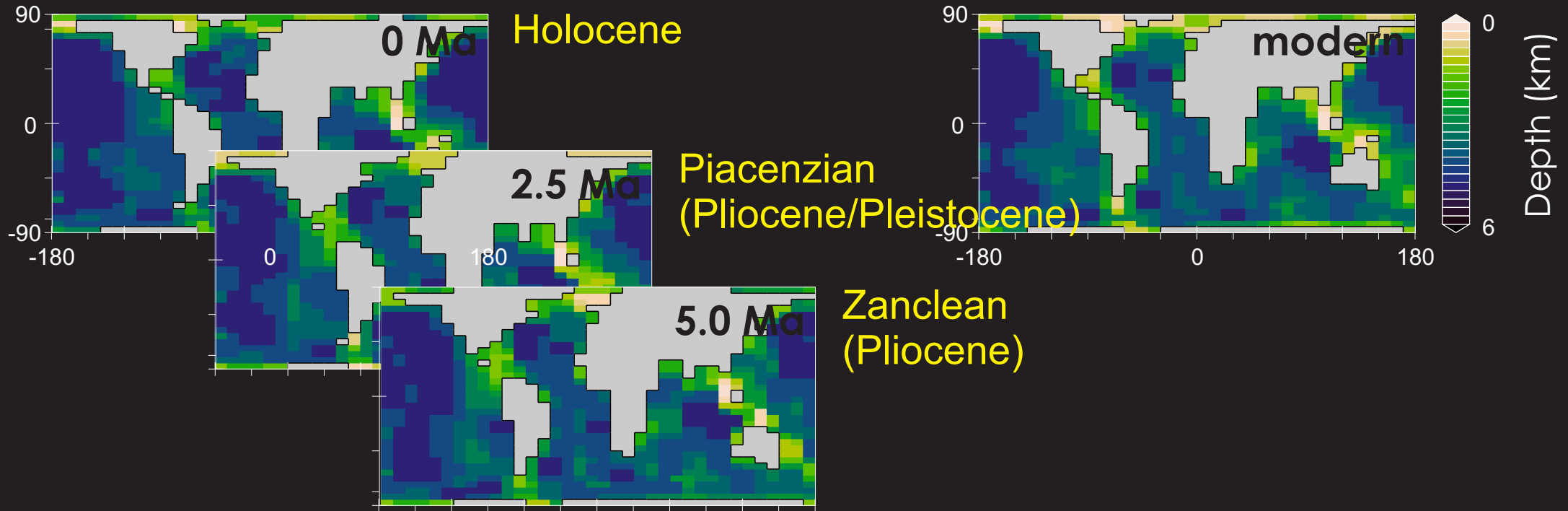
Past circulation (and carbon-cycling)

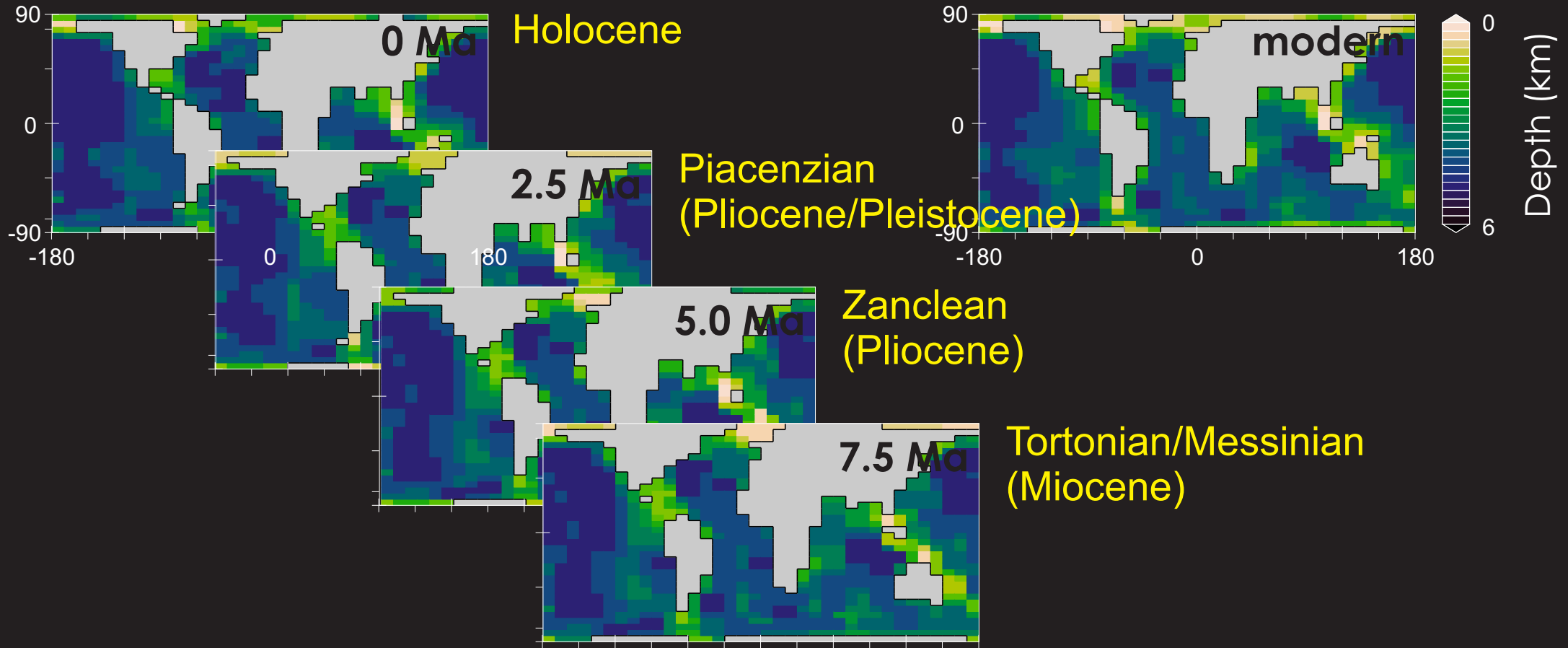


cGENIE 'muffin' Earth system model
(of Intermediate Complexity')

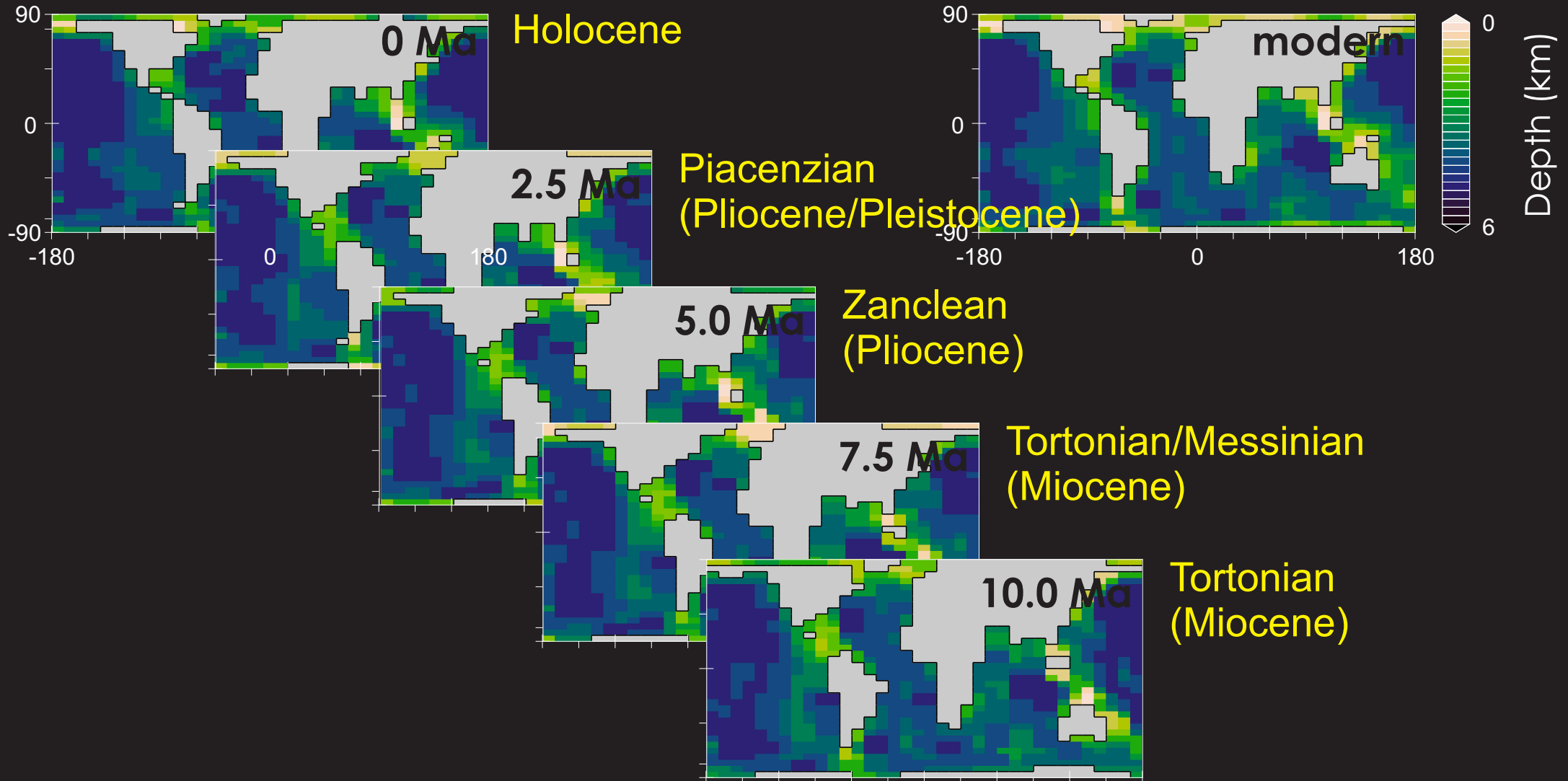
<https://github.com/derpycode/cgenie.muffin>



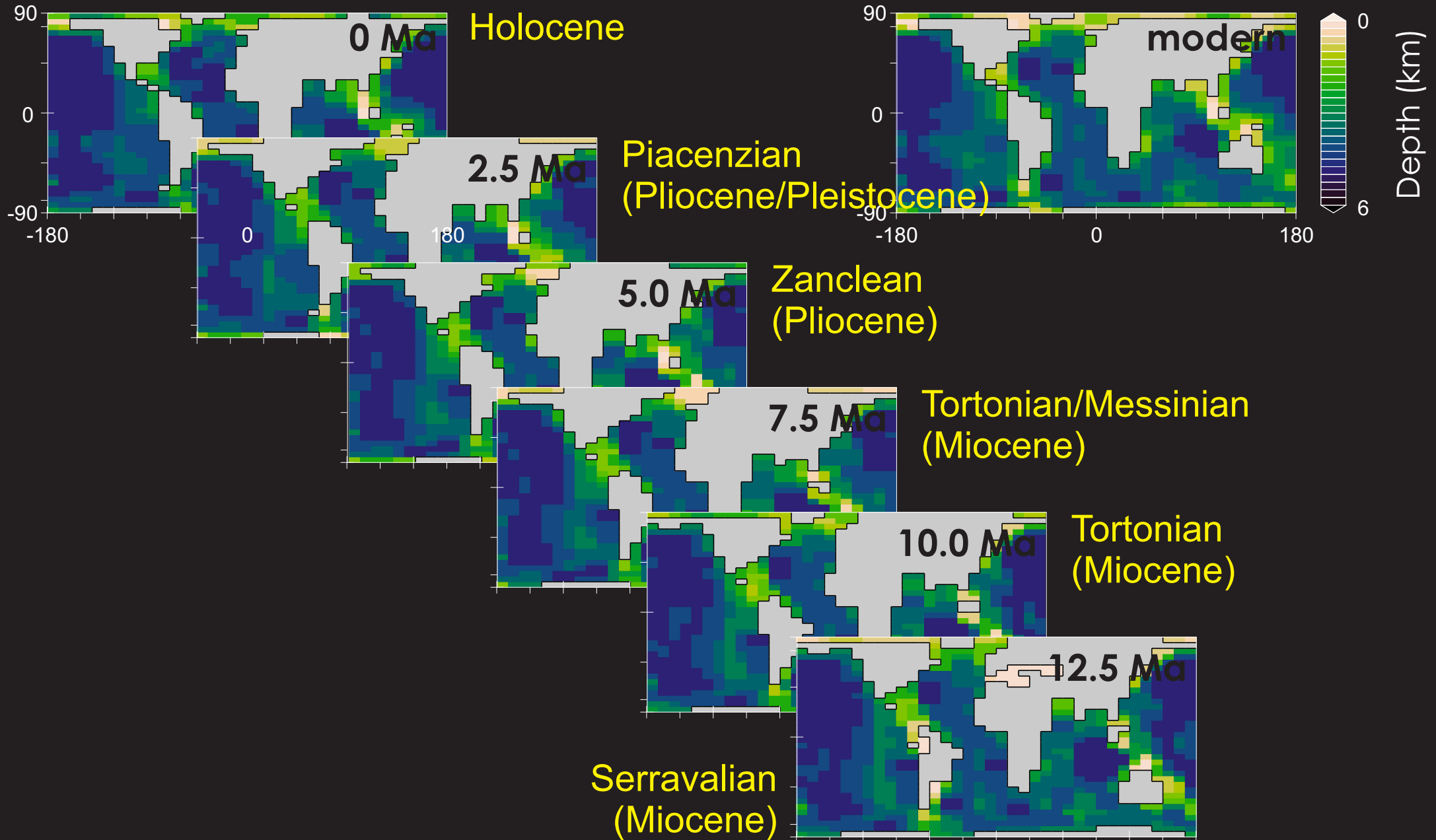




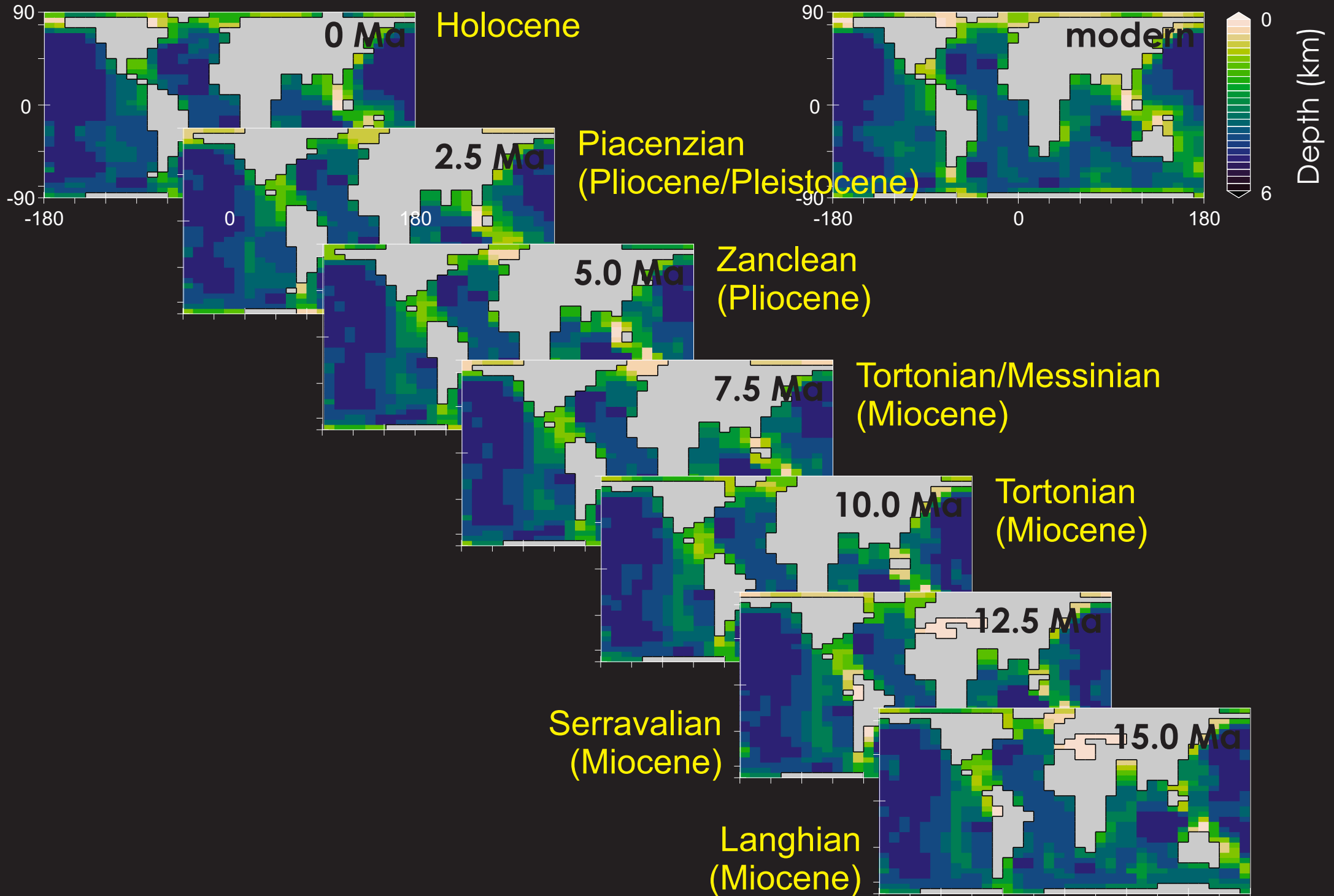
Past circulation (and carbon-cycling)



Past circulation (and carbon-cycling)



Past circulation (and carbon-cycling)

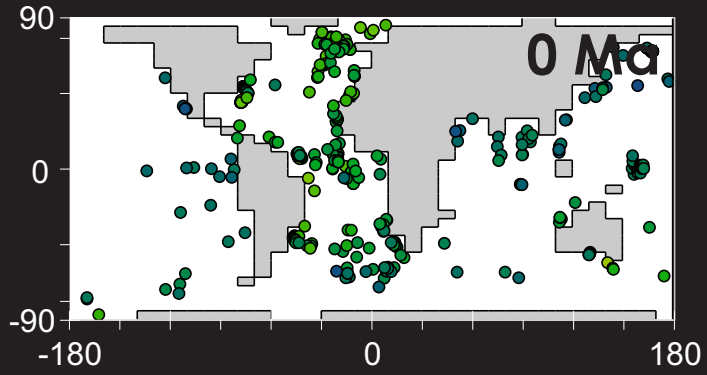


Past circulation (and carbon-cycling)

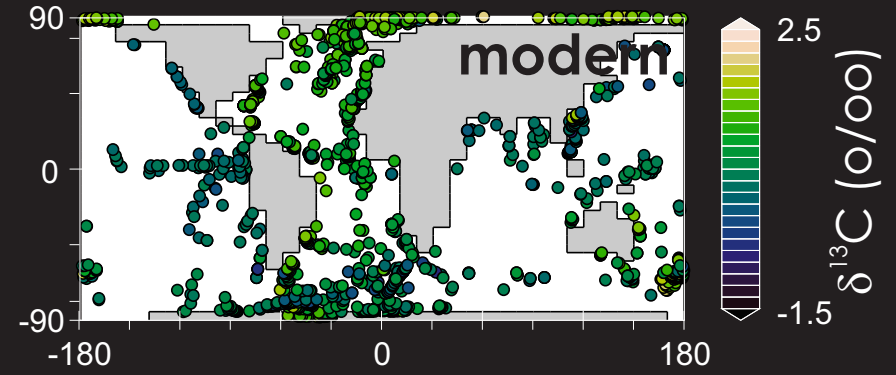


Caution: 1970s isotope tracer technology at work!

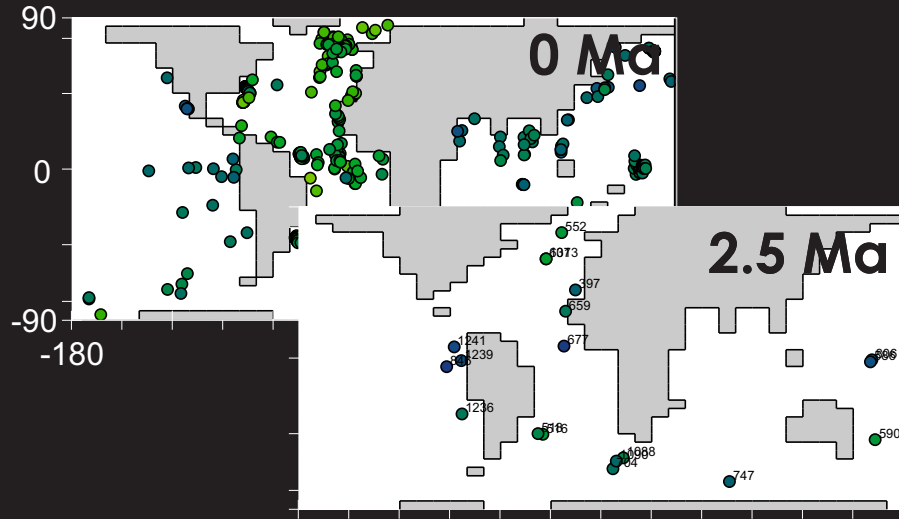
1A																2A																3A																4A																5A																6A																7A																8B																9A																10A																11B																12B																13A																14A																15A																16A																17A																18A																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
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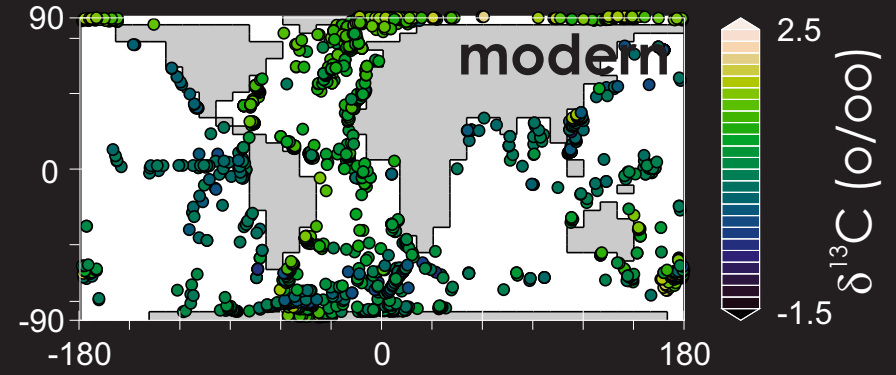
Peterson et al. [2014] 10.1002/2013PA002552



Schmittner et al. [2016] 10.1002/2016PA003072

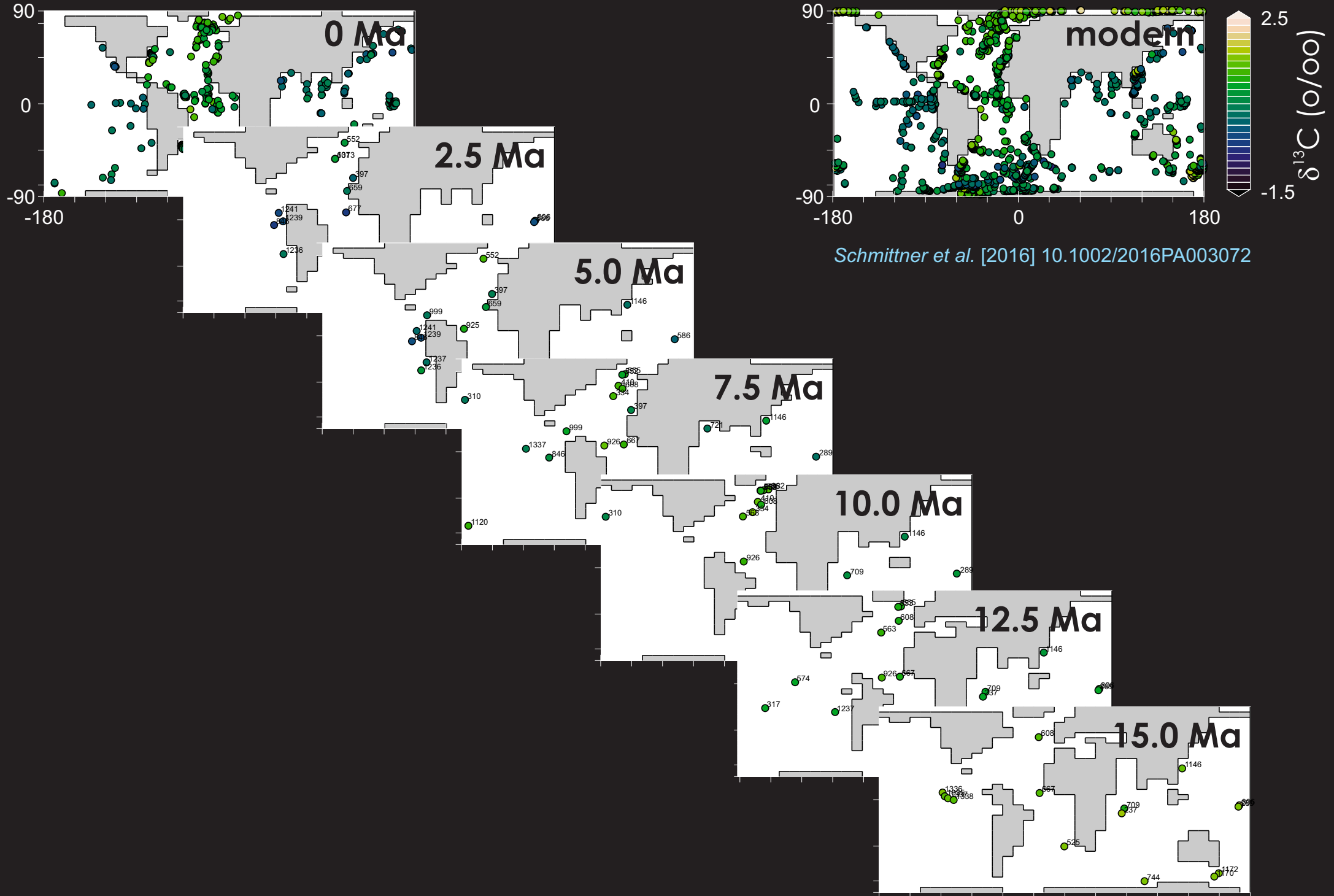


Crichton et al. [in prep]

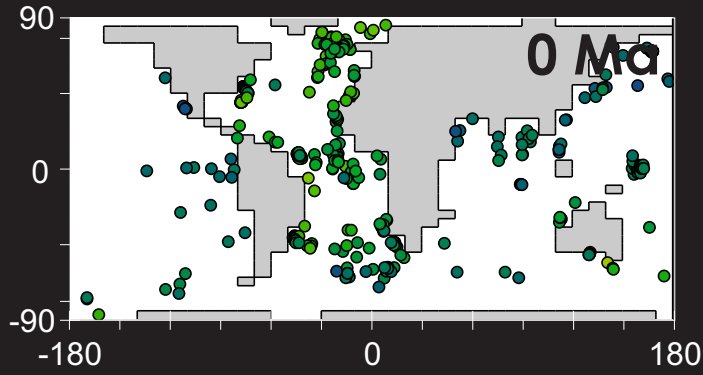


Schmittner et al. [2016] 10.1002/2016PA003072

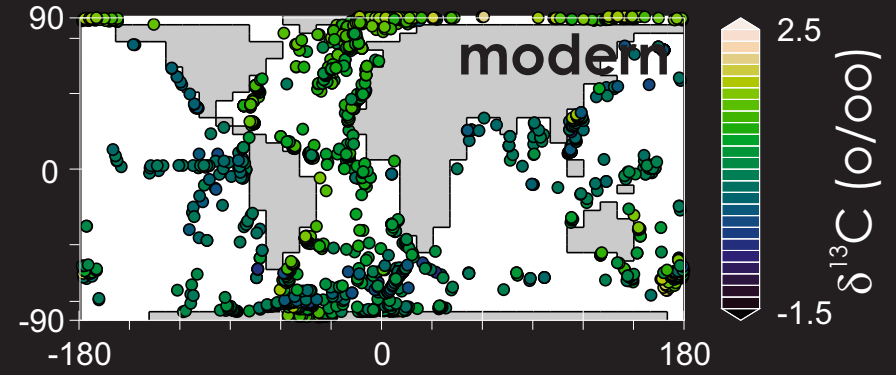
Past circulation (and carbon-cycling)



Past circulation (and carbon-cycling)

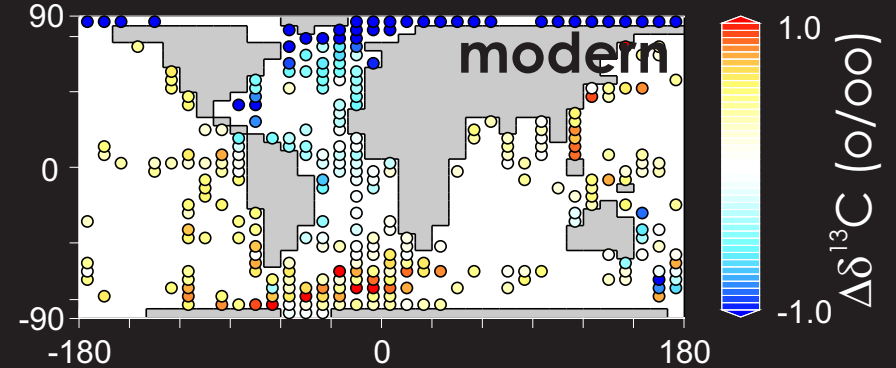
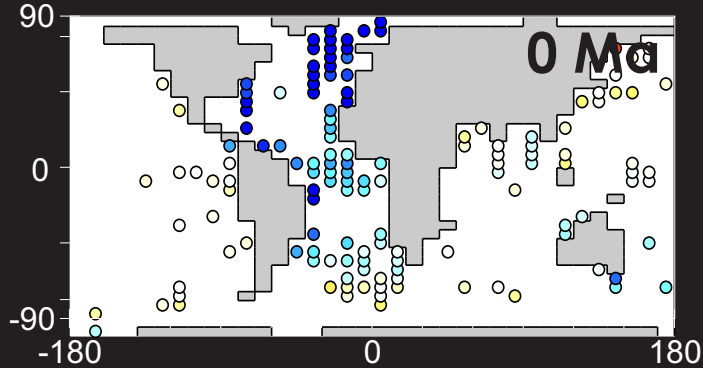
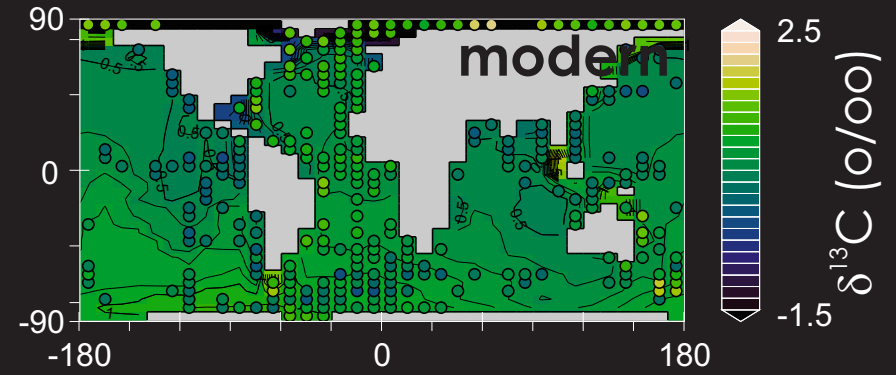
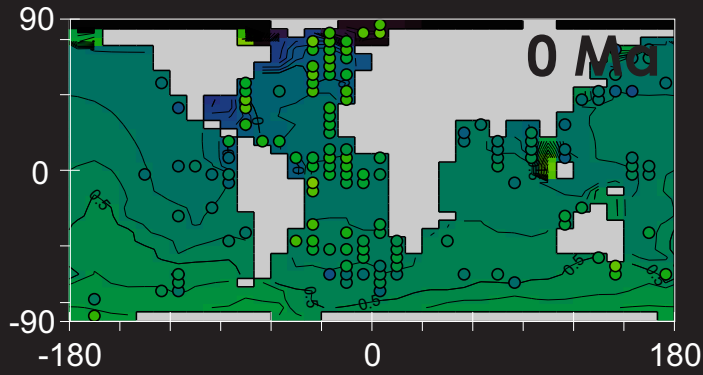


Peterson et al. [2014] 10.1002/2013PA002552

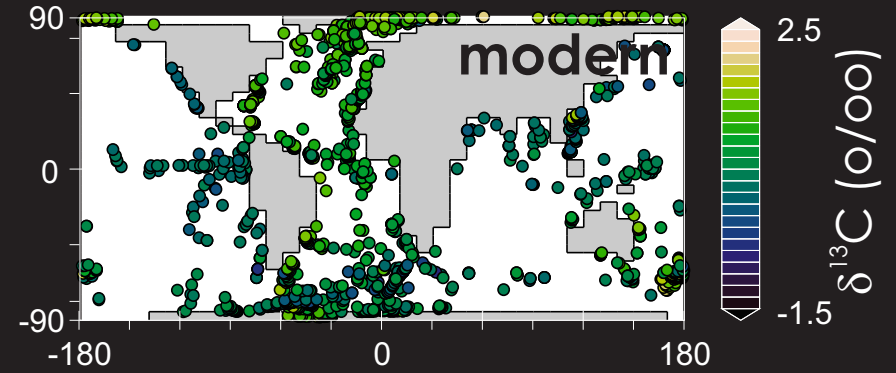
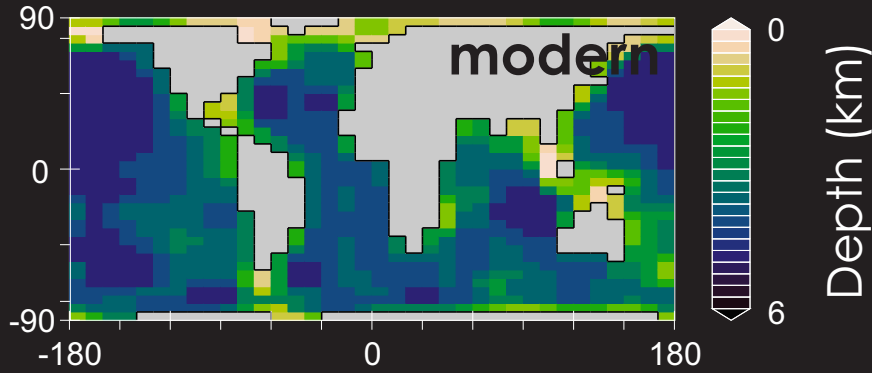


Schmittner et al. [2016] 10.1002/2016PA003072

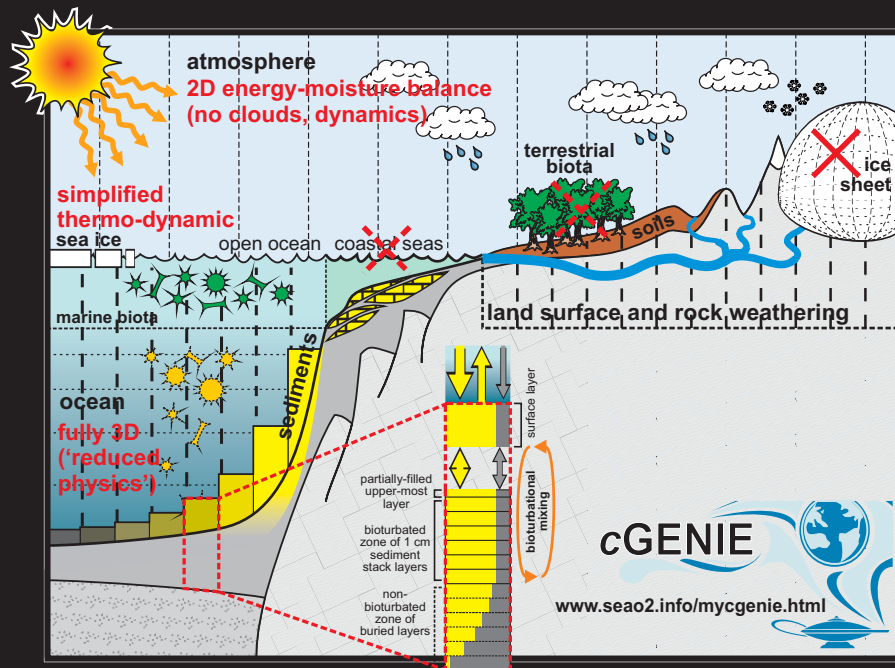
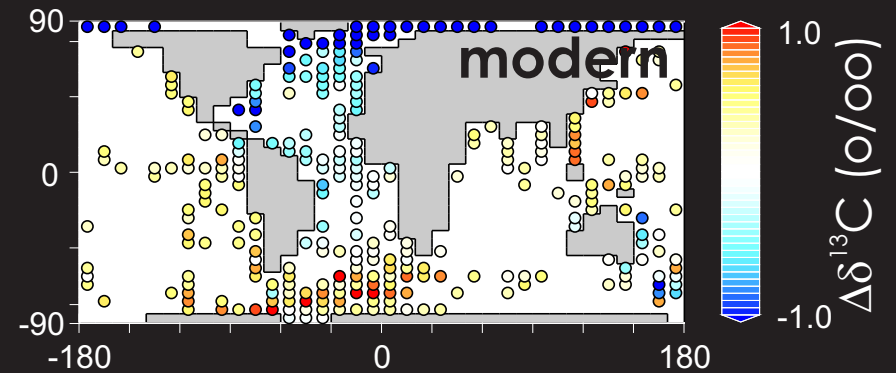
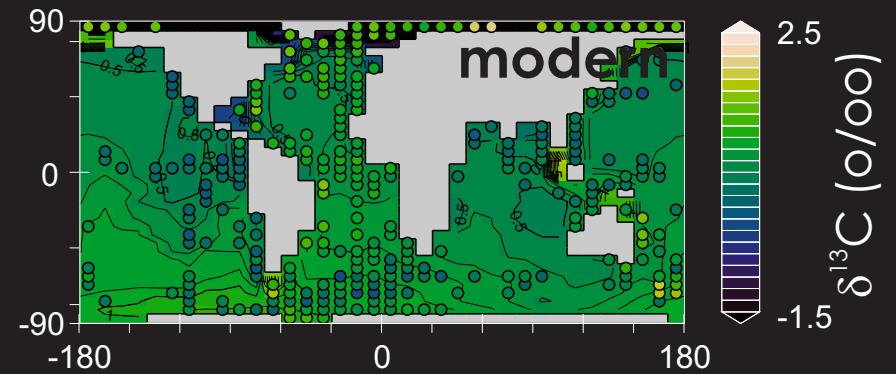
↓
regrid data
& compare



Past circulation (and carbon-cycling)



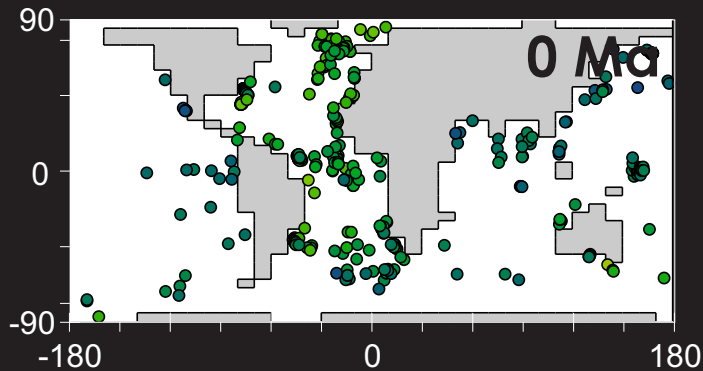
Schmittner et al. [2016] 10.1002/2016PA003072



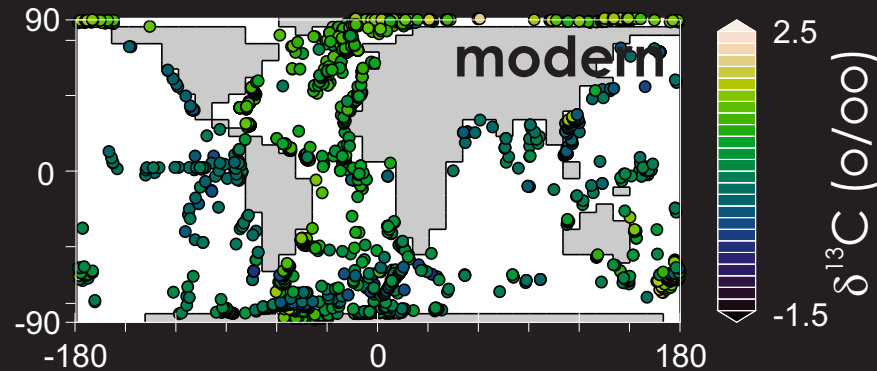
cGENIE 'muffin' Earth system model ('of Intermediate Complexity')

<https://github.com/derpycode/cgenie.muffin>

Past circulation (and carbon-cycling)



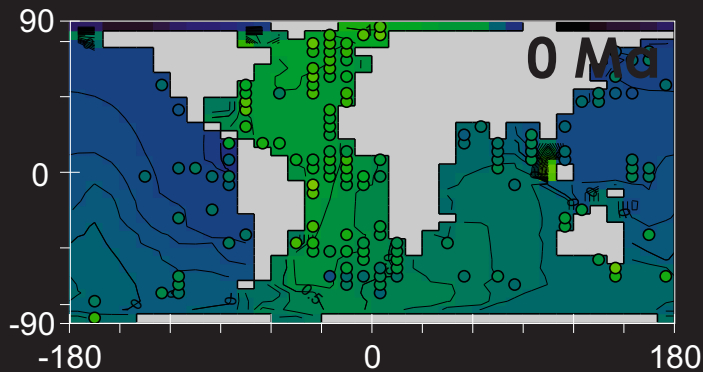
Peterson et al. [2014] 10.1002/2013PA002552



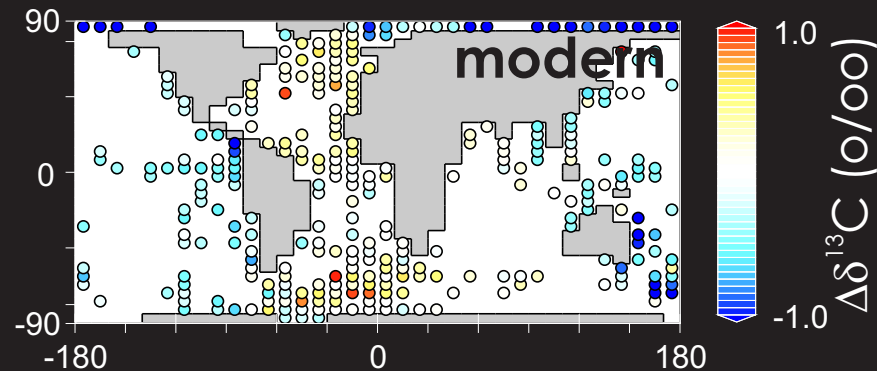
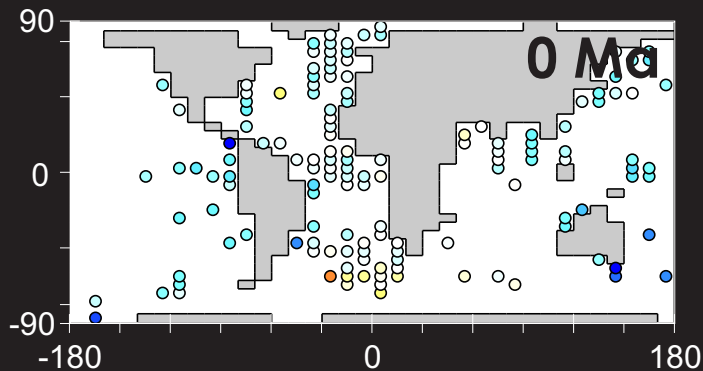
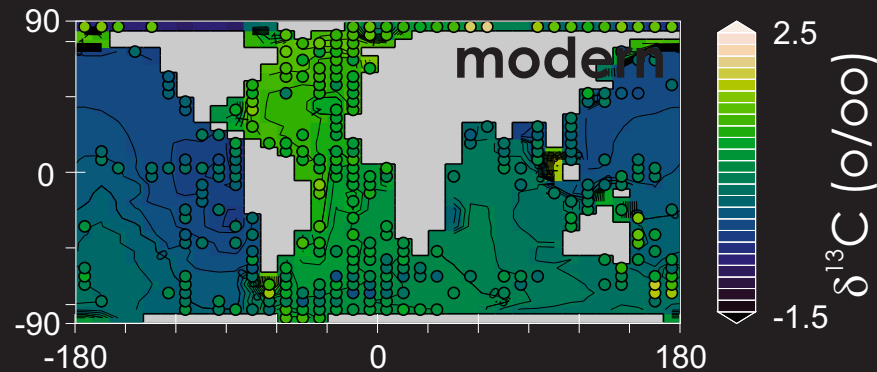
Schmittner et al. [2016] 10.1002/2016PA003072

↓
regrid data
& compare
+ FWflux

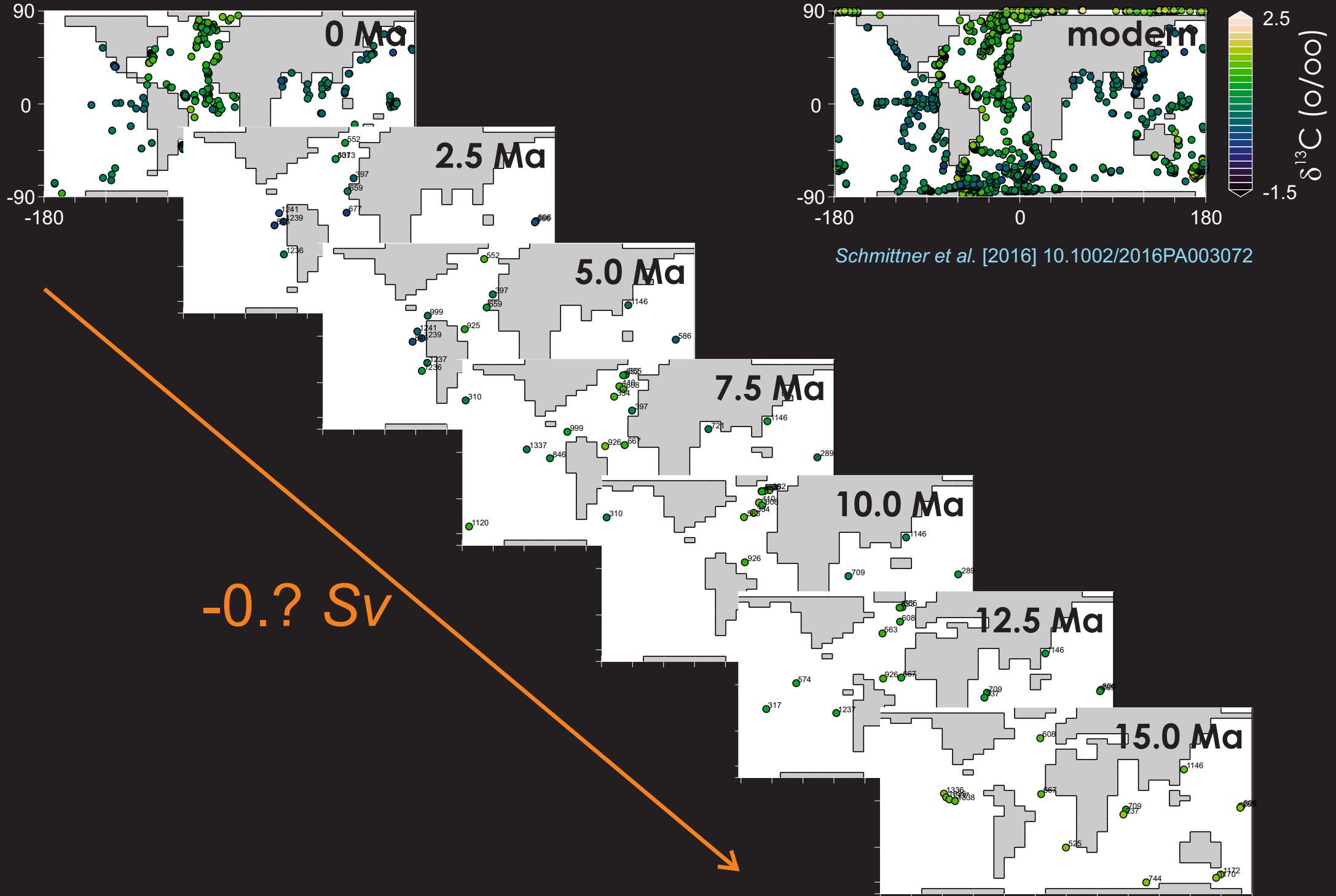
-0.3 Sv



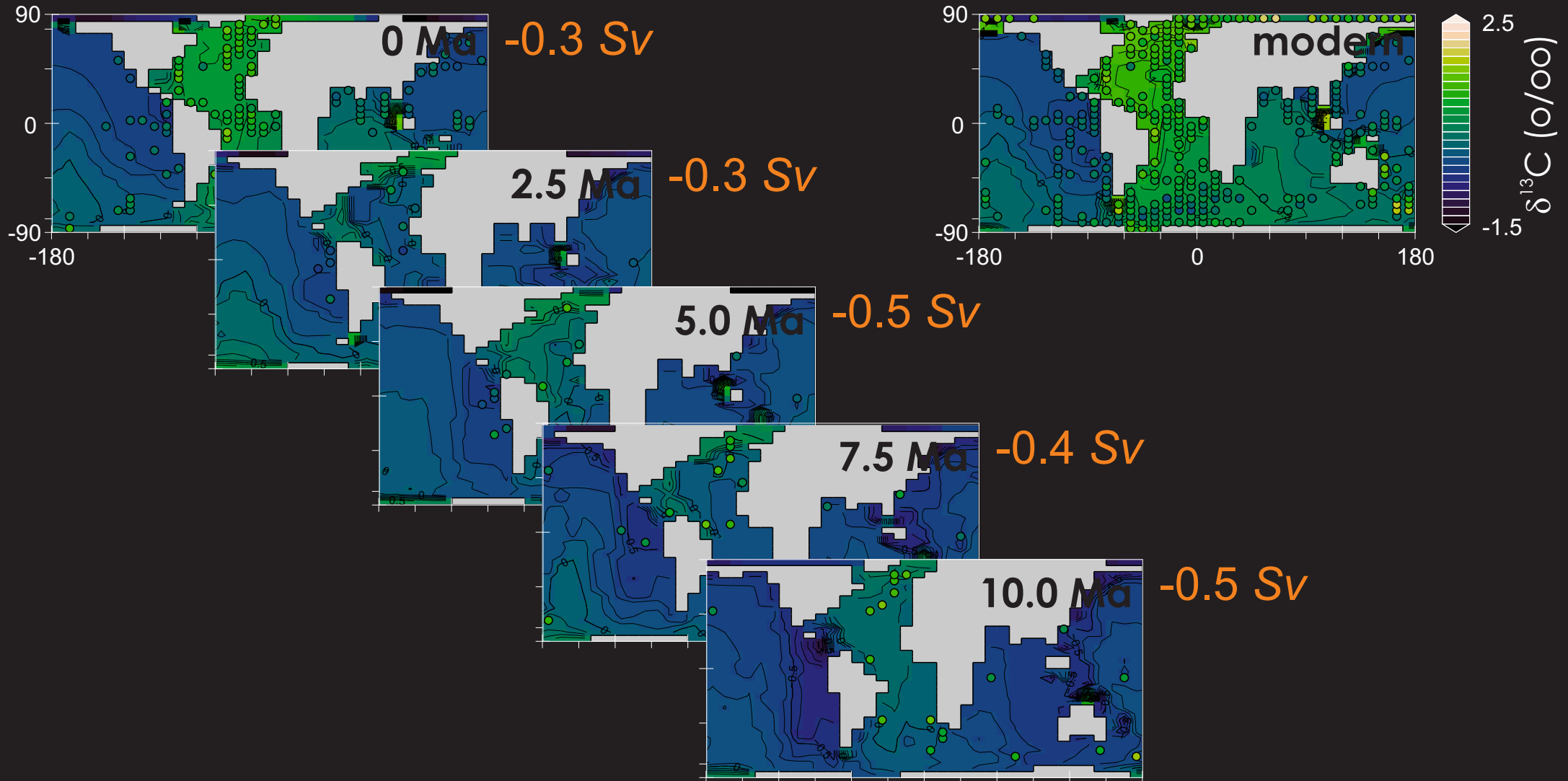
-0.2 Sv



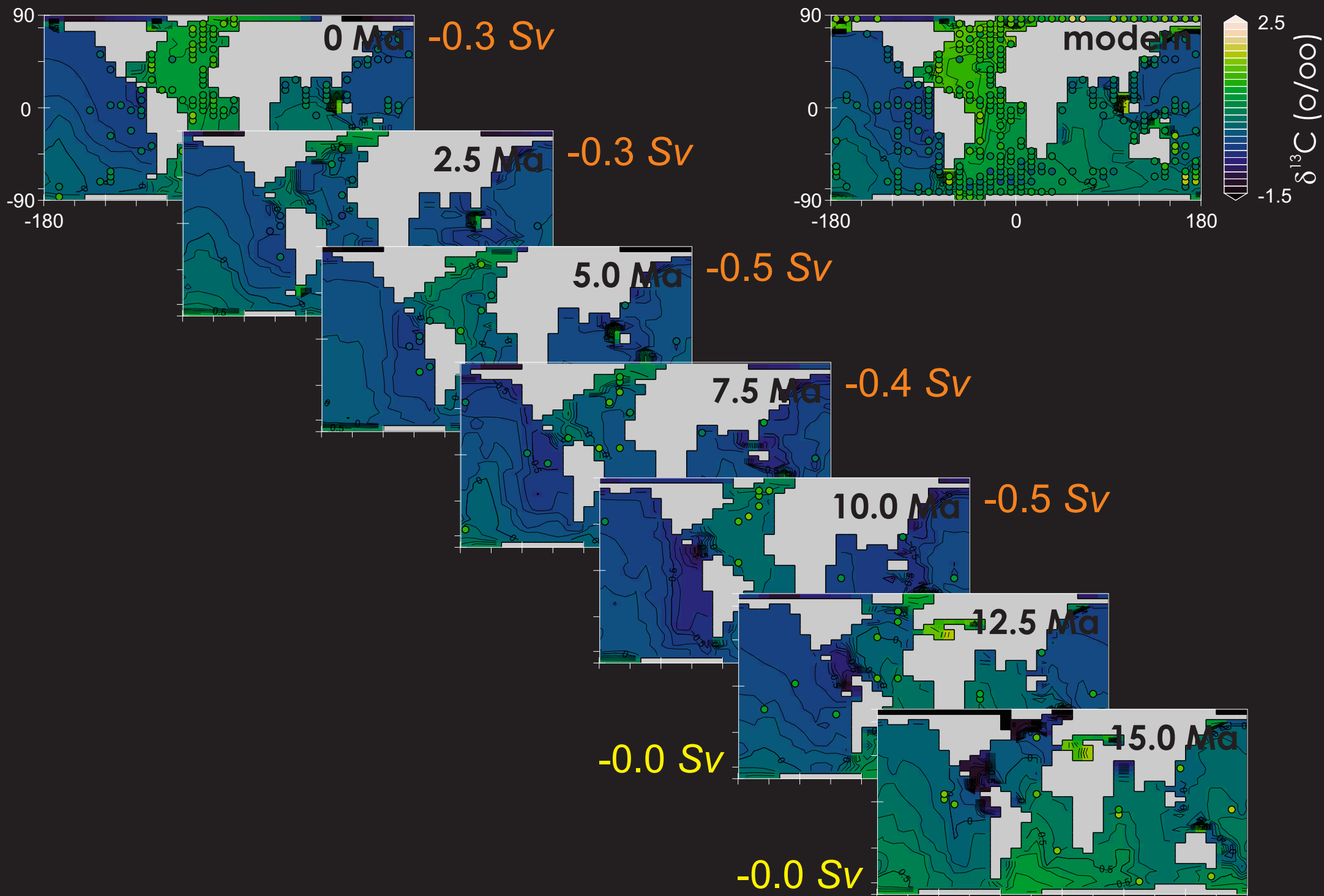
Past circulation (and carbon-cycling)



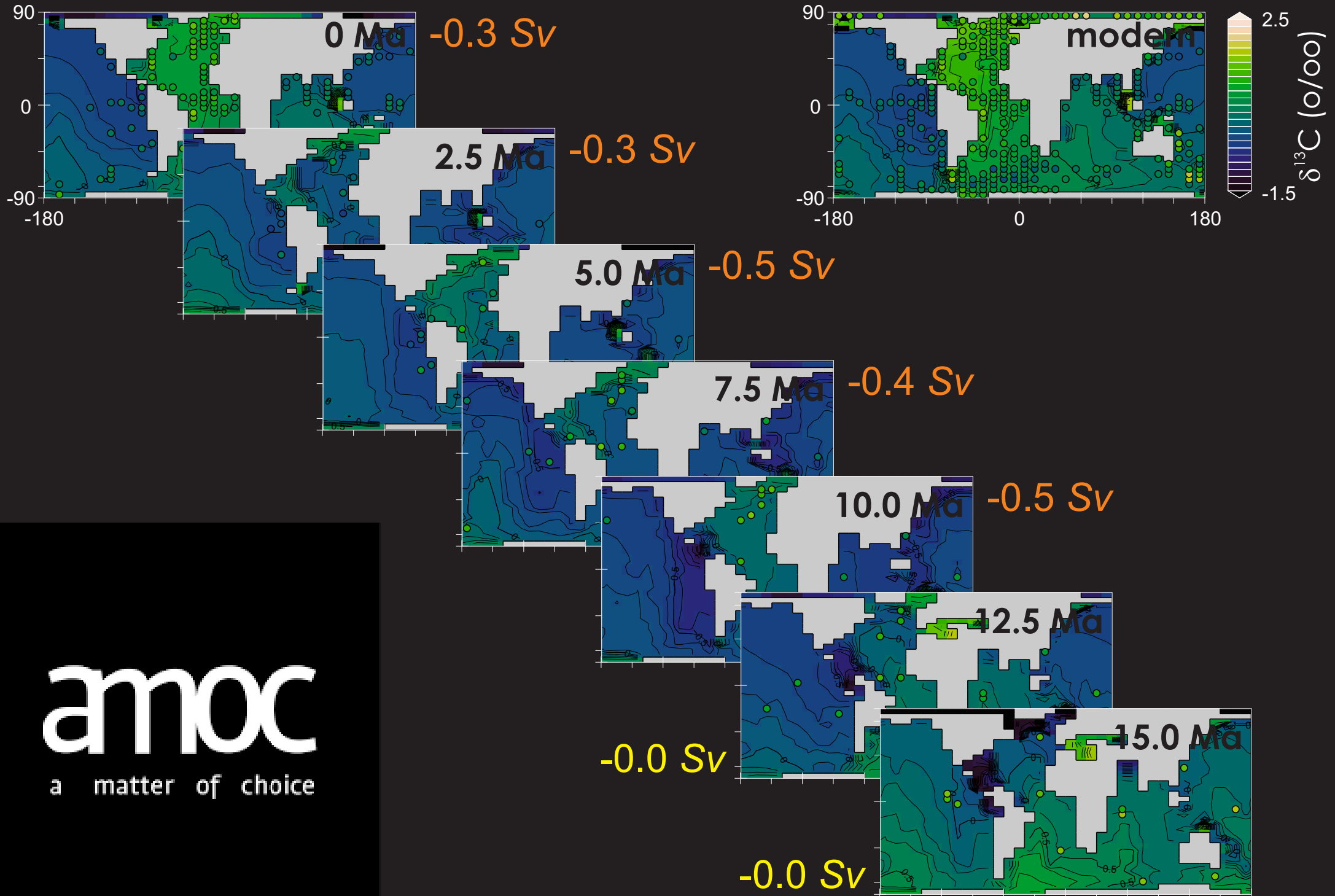
Past circulation (and carbon-cycling)



Past circulation (and carbon-cycling)



Past circulation (and carbon-cycling)



amoc
a matter of choice

proxies (and models) in esp. 'deep time'

- ★ Need for a 'complete' mechanistic/physiological understanding that can be forward-modelled (simple is good!)
- ★ Independent of specific species and associated metabolic pathways (or the above to be true).
- ★ Hosting in bulk shallow water carbonates and/or shells (in addition to open ocean pelagic sediments) extends applicability before ca. 183 Ma.
- ★ Independent of long-term ocean geochemical evolution OR based on geochemical/isotopic changes that can be reconstructed.
- ★ Sensitive to 'small' differences in water mass origin ... BUT ... specific to large-scale / mean water mass properties that models might hope to model ...
- ★ Multi-proxy approaches ... but are they truly ever useful (beyond one underlying part of a 2nd (proxy forward model))?



Thanks to:

Carlye Peterson [UCR]

Katherine Crichton, Paul Pearson [Cardiff]

Sandy Kirtland Turner [UCR]

The European Research Council

Heising-Simons Foundation

NERC