Radiations and extinctions during the Devonian plant revolution and their role in anoxia-driven marine extinction crises

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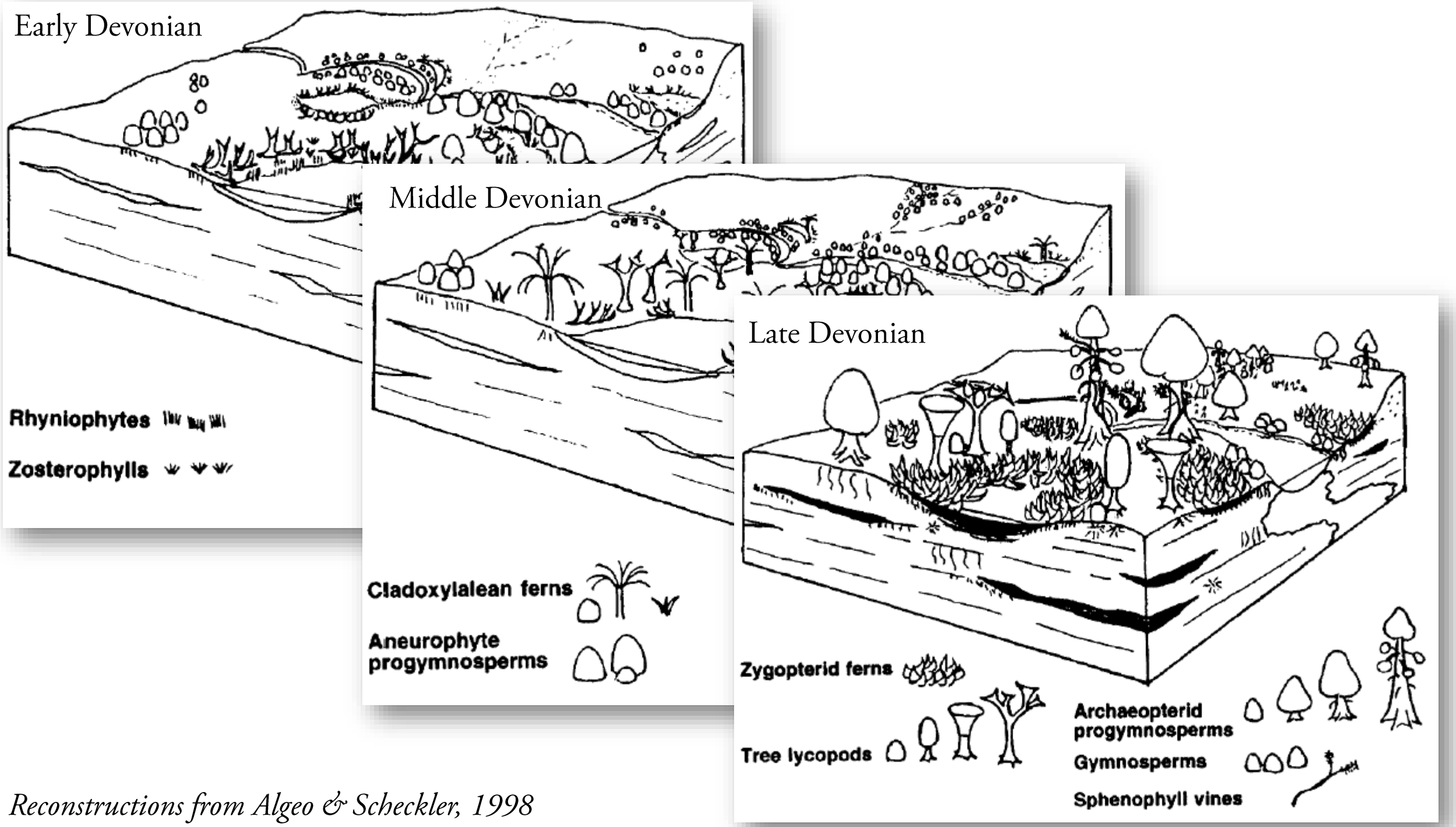
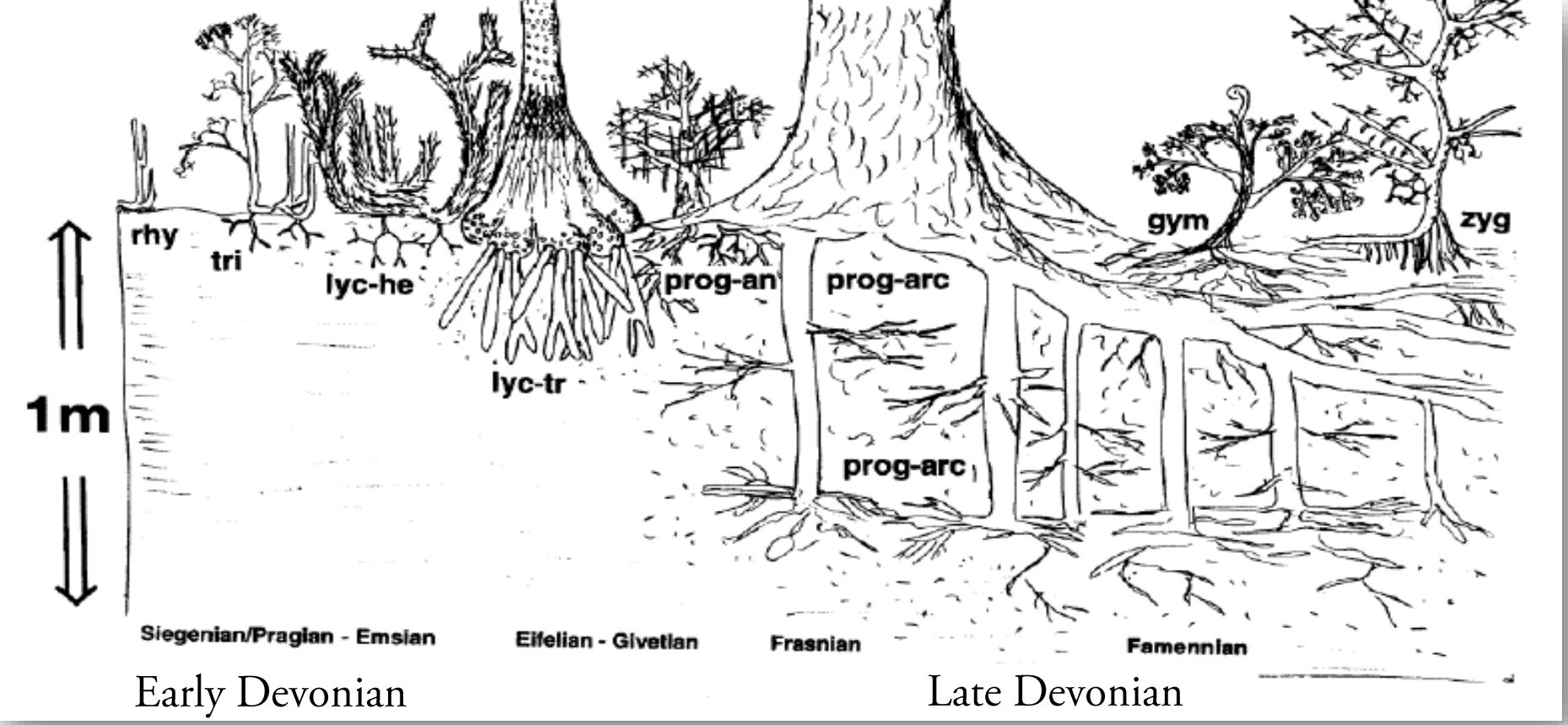


Reconstructions from Algeo & Scheckler, 1998

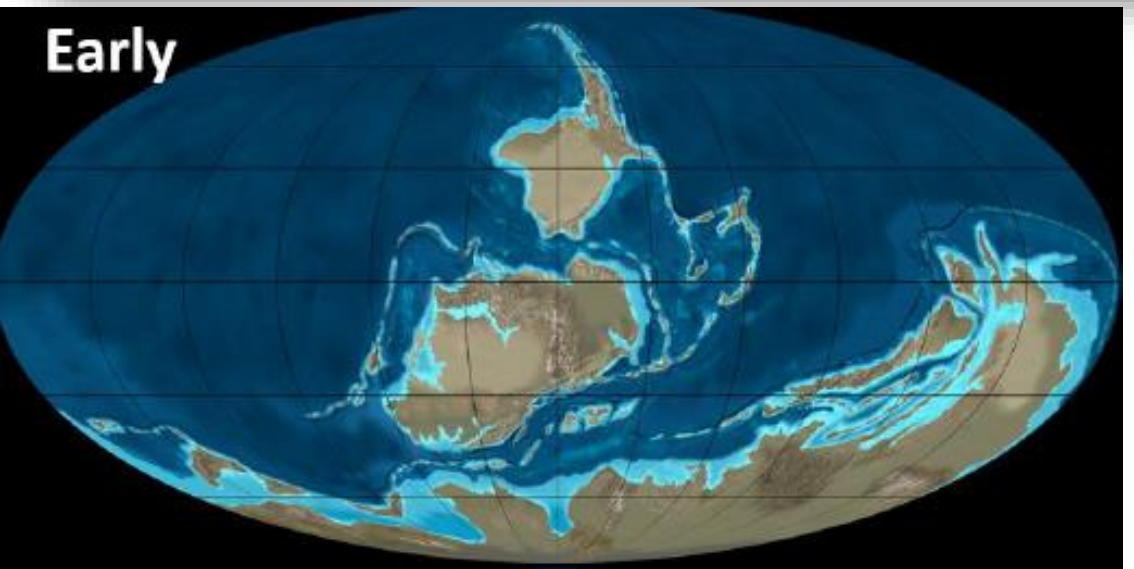


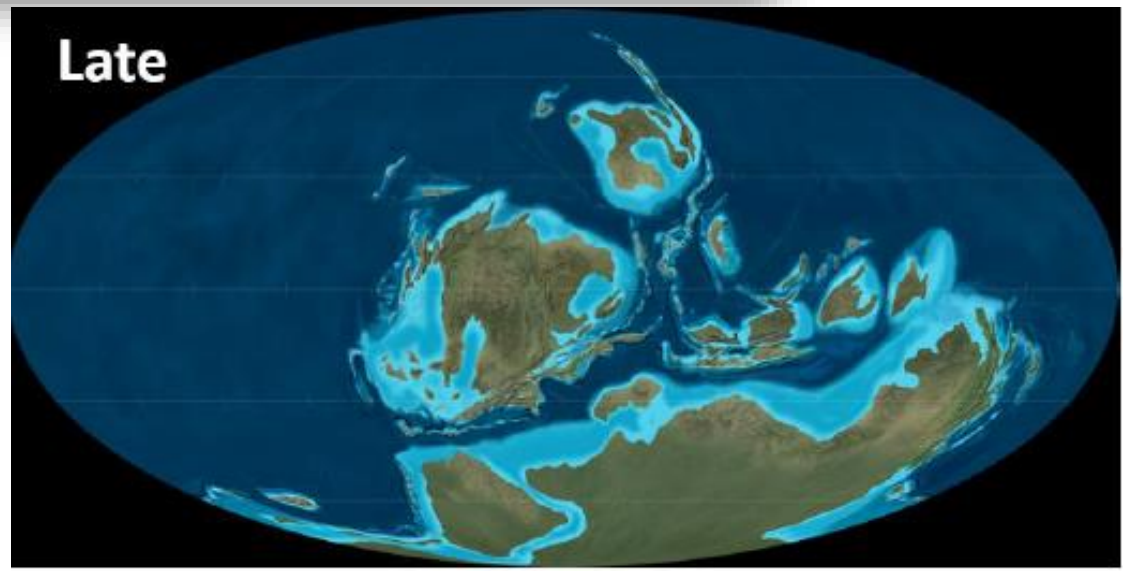
Early Devonian

Late Devonian

A time of colonisation, enhanced pedogenesis, and major global change

Land reconstructions from Algeo & Scheckler, 1998





A possible driver of Late Devonian (Frasnian-Famennian) anoxia and mass extinction?

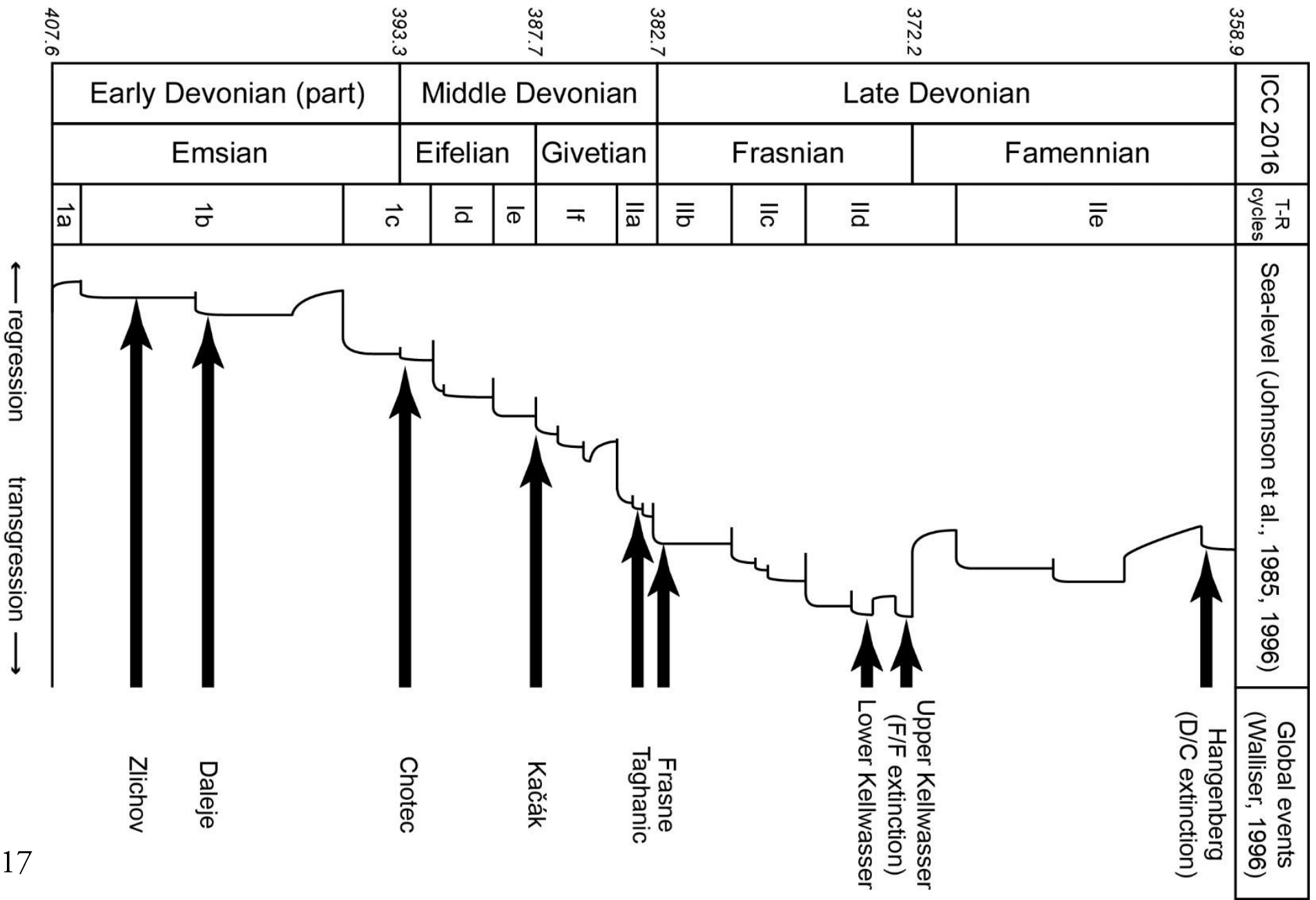
As proposed by Algeo et al., 1995

Look at all these other Devonian crises! There's loads of them!

#	Event	%[1]	Event	%[2]	Event	%[3]	Severity ranking[4]
1	End Permian	−58	End Permian	−57	End Permian	−83	End Permian
2	End Ordovician	−49	End Ordovician	−43	End Triassic	−73	End Cretaceous
3	Capitanian	−47	Capitanian	−36	End Ordovician	−52	End Triassic
4	End Triassic	−40	End Cretaceous	−34	End Devonian	−50	Frasnian-Famennian
5	End Cretaceous	−39	End Triassic	−33	End Cret., Fras-Fam.	−40	Capitanian
6	Frasnian-Famennian	−35	Frasnian-Famennian	−22	N.A.	NA	Serpukhov.
7	Givetian	−30	Serpukhovian	−13	Serpukhovian	−39	End Dev., End Ordovician
8	End Devonian	−28	Givetian	−10	Givetian	−36	NA
9	Eifelian	−24	End Dev., Ludford.	−7	Eifelian	−32	Givetian
10	Serpuk., Ludford.	−23	N.A.	NA	Capitanian	−25	Eifelian, Ludford.
11	N.A.	NA	Eifelian	−6	Ludfordian	−9	NA

% marine genera extinct: [1]Sepkoski (1996), [2]Bambach et al. (2004), [3]McGhee et al. (2013) and severity ranking [4]McGhee et al. (2013)

The Frasnian-Famennian crisis was just the culmination of numerous global anoxic events



Bond & Grasby, 2017

Did Devonian land colonisation drive these fundamental changes in the ocean?

Illustration by Zhenzhen Deng

We built the Devonian Plant Database to test this out…

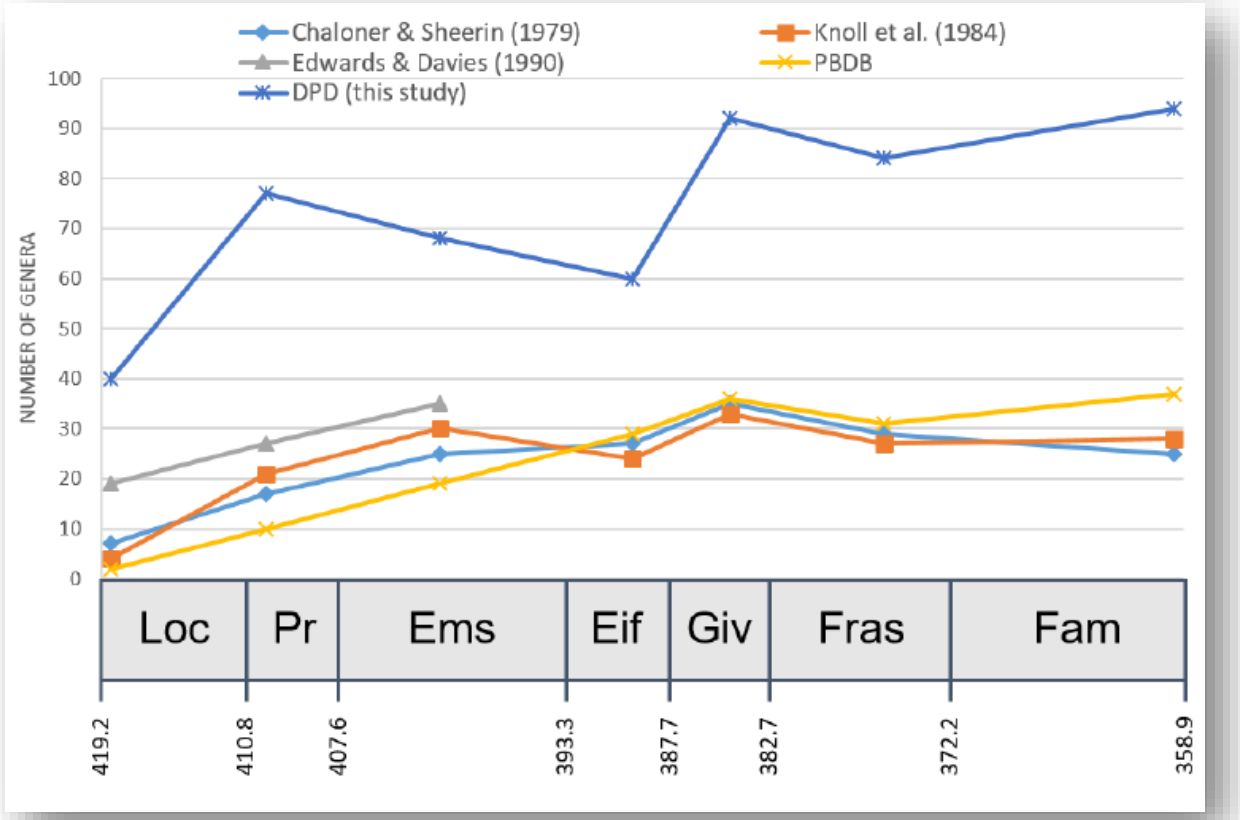
Plants constitute just 5% of records in the Paleobiology Database and Devonian plants are a tiny proportion of these

We analysed 1314 individual plant records in 294 genera from 389 publications using Excel

Presence/absence matrix created within stratigraphic bins (stages divided into three equal sub-stages, Early, Middle, Late)

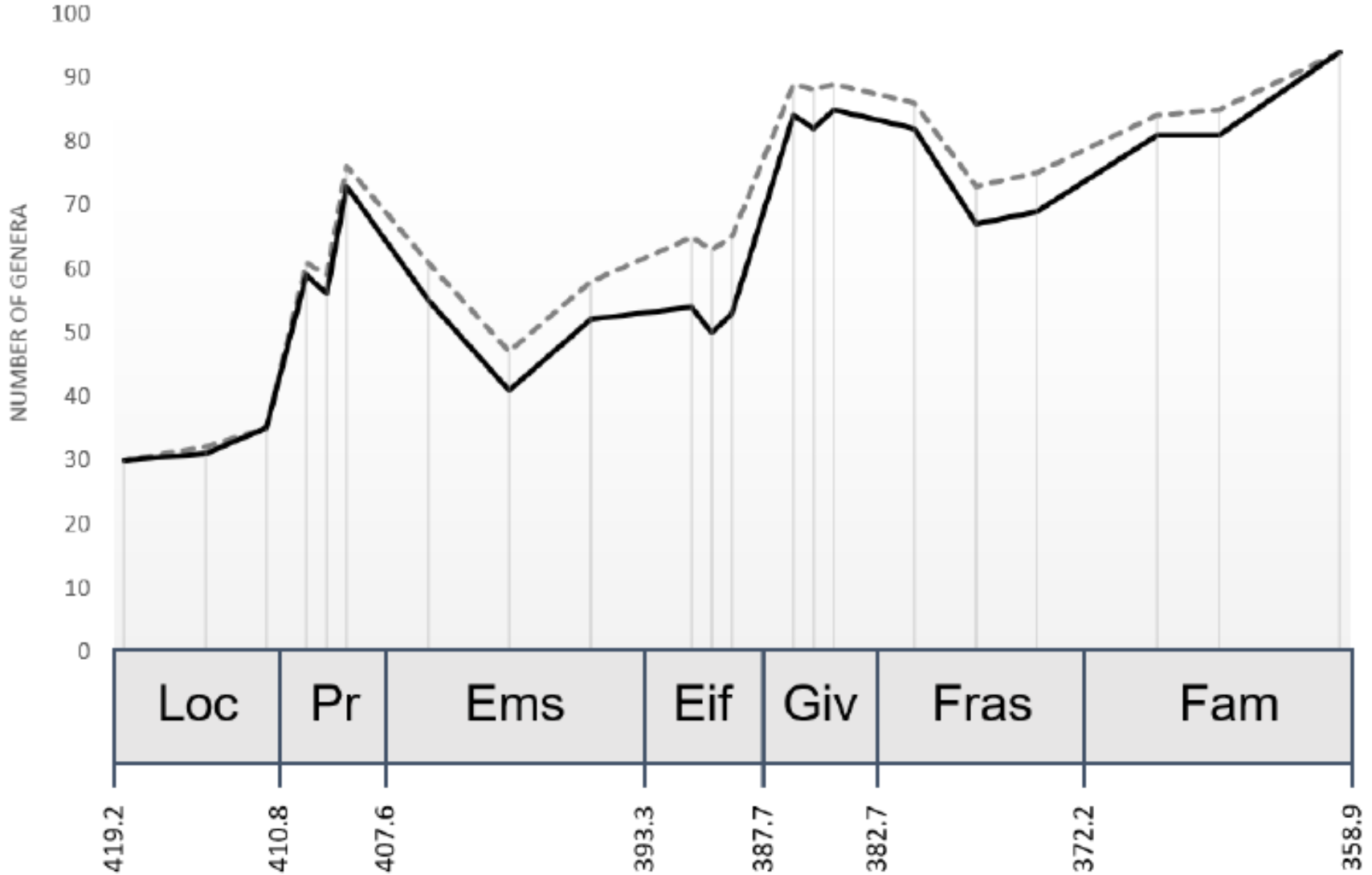
	B	C	D	E	F	G	H	I	J	K	L
1	**Genus**	Early Lochkovian	Middle Lochkovian	Late Lochkovian	Early Pragian	Middle Pragian	Late Pragian	Early Emsian	Middle Emsian	Late Emsian	Early Eifelian
2	Aarabia	0	0	0	0	0	0	1	0	0	0
3	Aberlemnia	1	1	1	0	0	0	0	0	0	0
4	Acanthophyton	0	0	0	0	0	0	0	0	0	1
5	Actinopodium	0	0	0	0	0	0	0	0	0	1
6	Actinoxylon	0	0	0	0	0	0	0	0	0	0
7	Adiantites	0	0	0	0	0	0	0	0	0	0
8	Adoketophyton	0	0	0	1	1	1	0	0	0	0
9	Aglaophyton	0	0	0	0	0	1	1	0	0	0
10	Alicornopteris	0	0	0	0	0	0	0	0	0	0
11	Amphidoxodendron	0	0	0	0	0	0	0	0	0	1
12	Anapaulia	0	0	0	0	0	0	0	0	0	0
13	Aneurophyton	0	0	0	0	0	0	0	0	0	1
14	Anisophyton	0	0	0	0	0	0	1	1	1	0
15	Aphlebiopteris	0	0	0	0	0	0	0	0	0	0
16	Aphyllopteris	0	0	0	1	1	1	1	0	0	1
17	Arachnoxylon	0	0	0	0	0	0	0	0	0	1
18	Archaeocalamites	0	0	0	0	0	0	0	0	0	0
19	Archaeopteris	0	0	0	0	0	0	0	0	0	0
20	Artschaliphyton	0	0	0	0	0	0	0	0	0	0
21	Askisiella	0	0	0	0	0	0	0	0	0	1
22	Asteropteris	0	0	0	0	0	0	0	0	0	0
23	Asteroxylon	0	0	0	1	1	1	0	0	0	0
24	Astralocaulis	0	0	0	0	0	0	0	0	0	1
25	Atasudendron	0	0	0	0	0	0	0	0	0	0
26	Bachasupteris	0	0	0	0	0	0	0	0	0	0
27	Baragwanathia	0	0	0	1	1	1	1	1	1	0
28	Barinophyton	0	0	0	0	0	1	1	1	1	0

Presence/absence matrix in Excel



Comparison of new database with previous collations (replotted)

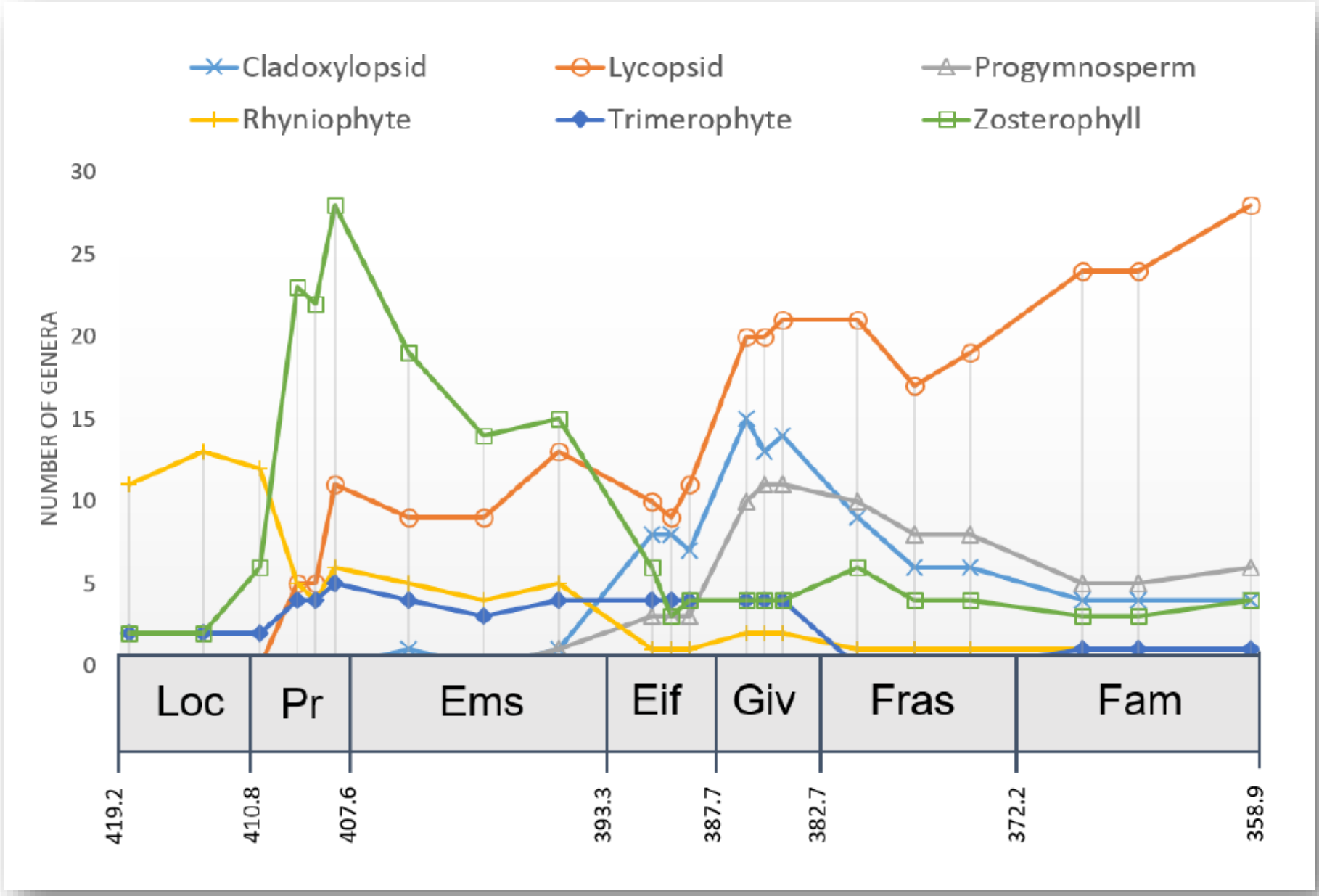
Results: generic diversity through the Devonian



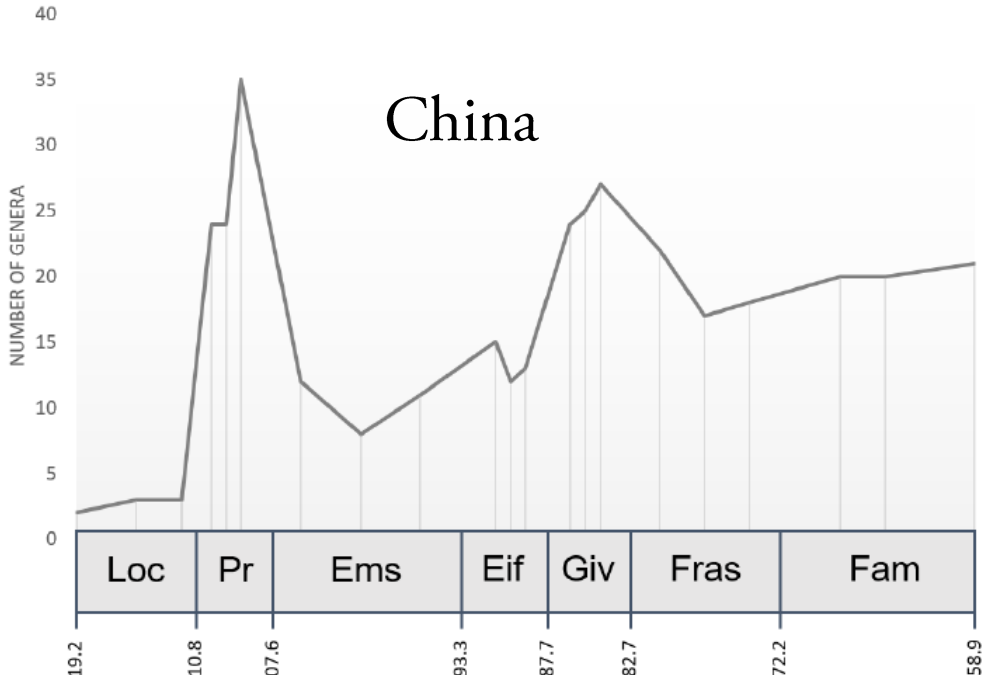
Solid line = standing diversity; dashed line = including range through genera

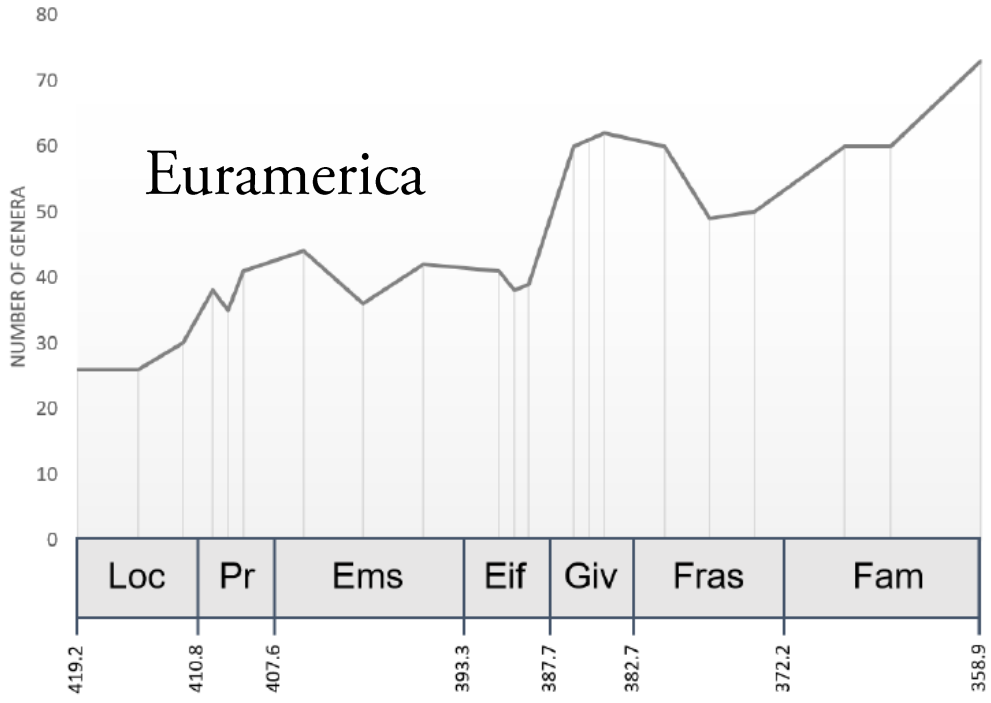
Generic diversity in different plant groups

Zosterophylls & rhyniophytes: important early



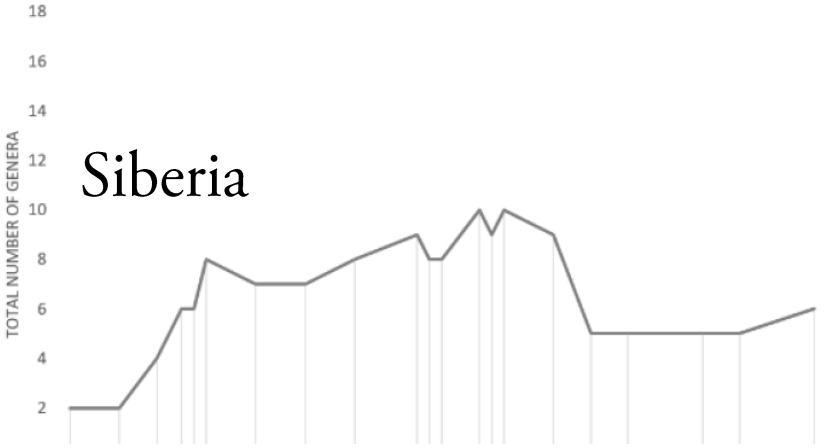
Later replaced by lycopsids

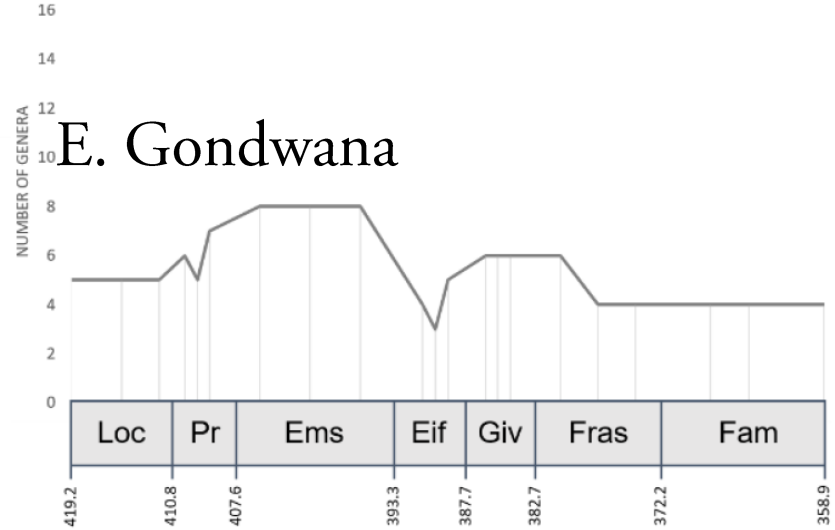




Regional variations:

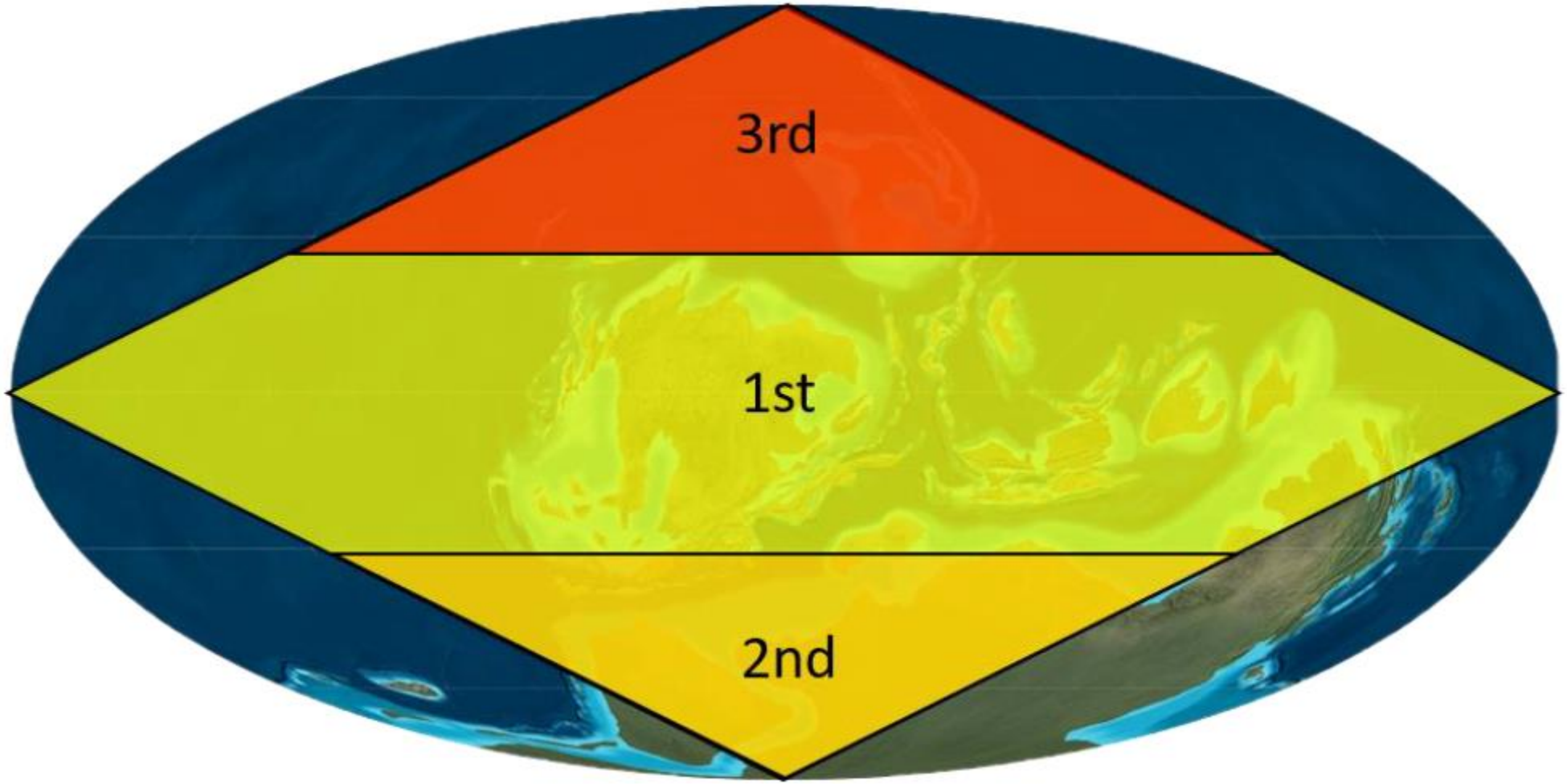
China's Pragian spike and a Late Givetian – Middle Frasnian event





Where did each group originate?

	Order of Palaeo-Regional Appearance			
	1st	2nd	3rd	4th
Cladoxylopsid	Euramerica	Kazakhstan China W Gondwana	E Gondwana	
Lycopsid	China Euramerica E Gondwana	W Gondwana	Siberia Kazakhstan	
Progymnosperm	Euramerica W Gondwana	Siberia China	Kazakhstan	E Gondwana
Rhyniophyte	***Euramerica*** ***W Gondwana*** ***E Gondwana***			
Trimerophyte	***Euramerica*** ***W Gondwana***	China		
Zosterophyll	***Siberia*** ***China*** ***Euramerica*** ***E Gondwana***	W Gondwana		



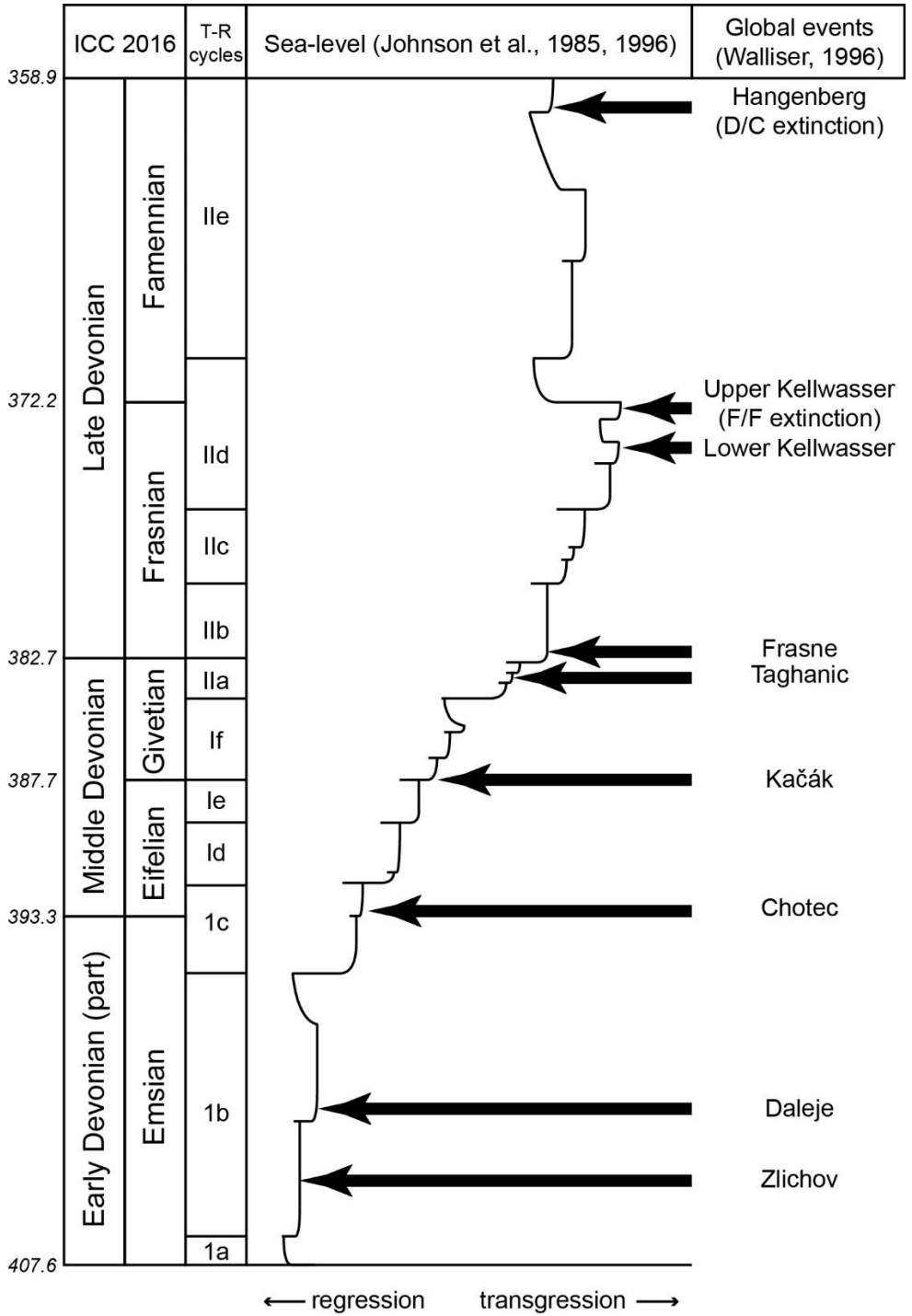
Many groups, including the important lycopsids, originated in equatorial regions

A little-known Late Givetian to Middle Frasnian terrestrial extinction event

	Late Givetian – Middle Frasnian Change
Cladoxylopsid	- 57 %
Lycopsid	- 19 %
Progymnosperm	- 27 %
Rhyniophyte	- 50 %
Trimerophyte	- 100 %
Zosterophyll	- 100 %

	Late Givetian – Middle Frasnian Change
Siberia	- 50 %
Kazakhstan	- 43 %
China	- 37 %
Euramerica	- 21 %
W Gondwana	- 44 %
E Gondwana	- 33 %

Affecting all plant groups in all locations



Hangenberg Event (DC extinction): further lycopsid diversification

Upper KW Event (FF extinction): major diversification in lycopsids

Lower Kellwasser Event: minor diversification in lycopsids

Frasne Event: extinctions amongst all plant groups

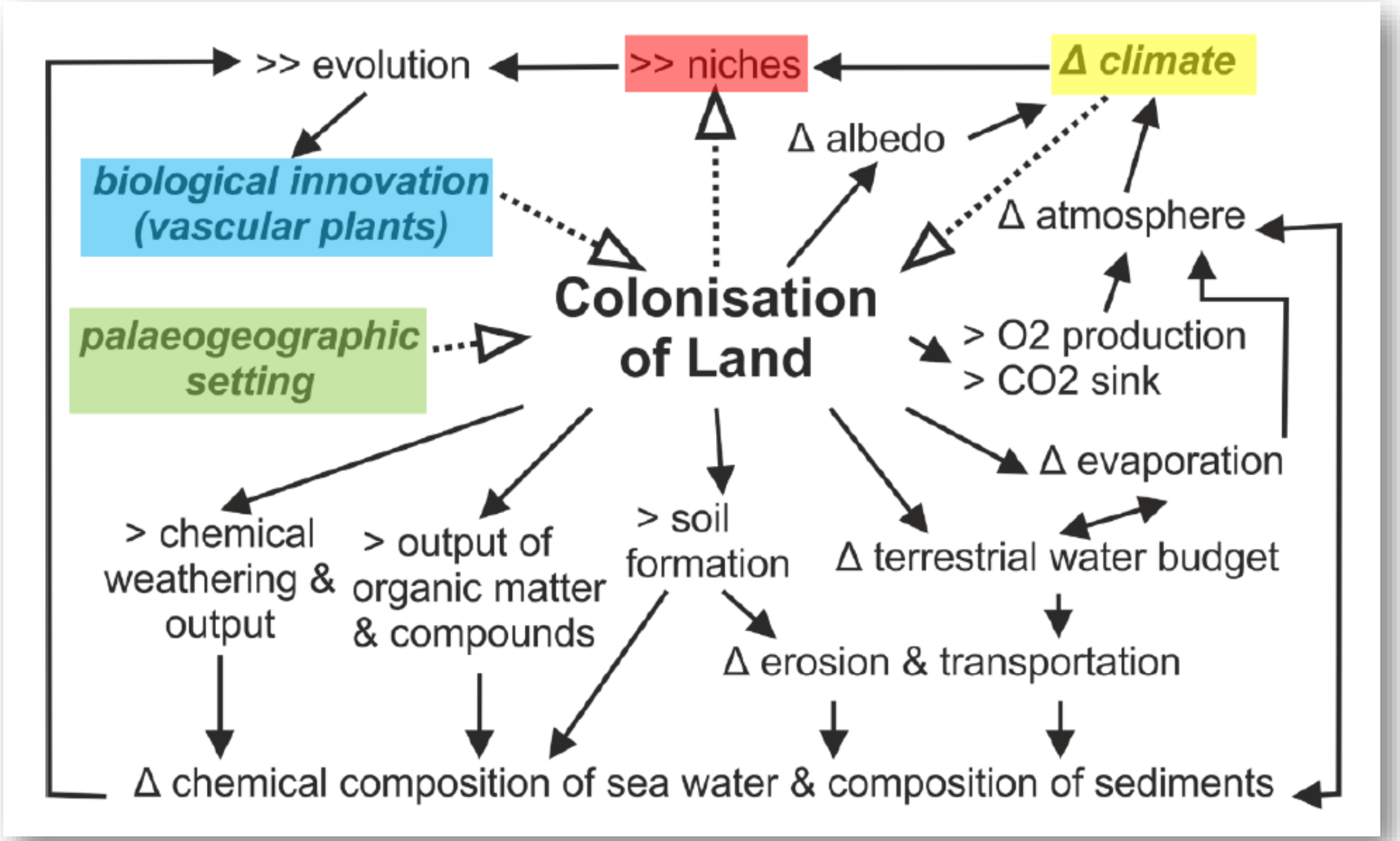
Taghanic Event: minor diversification in lycopsids and cladoxylopsids

Kacak Event: major diversification in lycopsids

Chotec Event: diversification in cladoxylopsids and progymnosperms; lycopsids become dominant group

Daleje Event: decline in diversity in all extant groups

Zlichov Event: arrival of Cladoxylopsids



Stephenson, C.A., 2017. Flora, Fires & Phytoliths: An Integrated Approach to Devonian Terrestrialisation. Univ. Hull PhD thesis.

Our plant database analysis reveals:

1) all groups have early Euramerican presence - the likely site of origination for several higher taxa

2) plants experienced a Late Givetian to Middle Frasnian turnover possibly coincident with the Taghanic & Frasne marine crises

3) Devonian black shale events coincide with major steps in terrestrialisation, suggesting plant evolution – of lycopsids in particular - played a role in the Frasnian/Famennian extinction

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