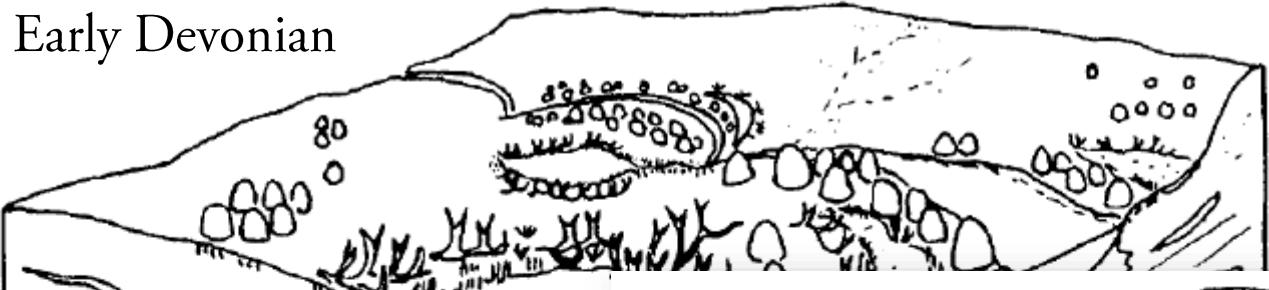


# Radiations and extinctions during the Devonian plant revolution and their role in anoxia-driven marine extinction crises

David Bond & Charlotte Stephenson  
University of Hull, United Kingdom



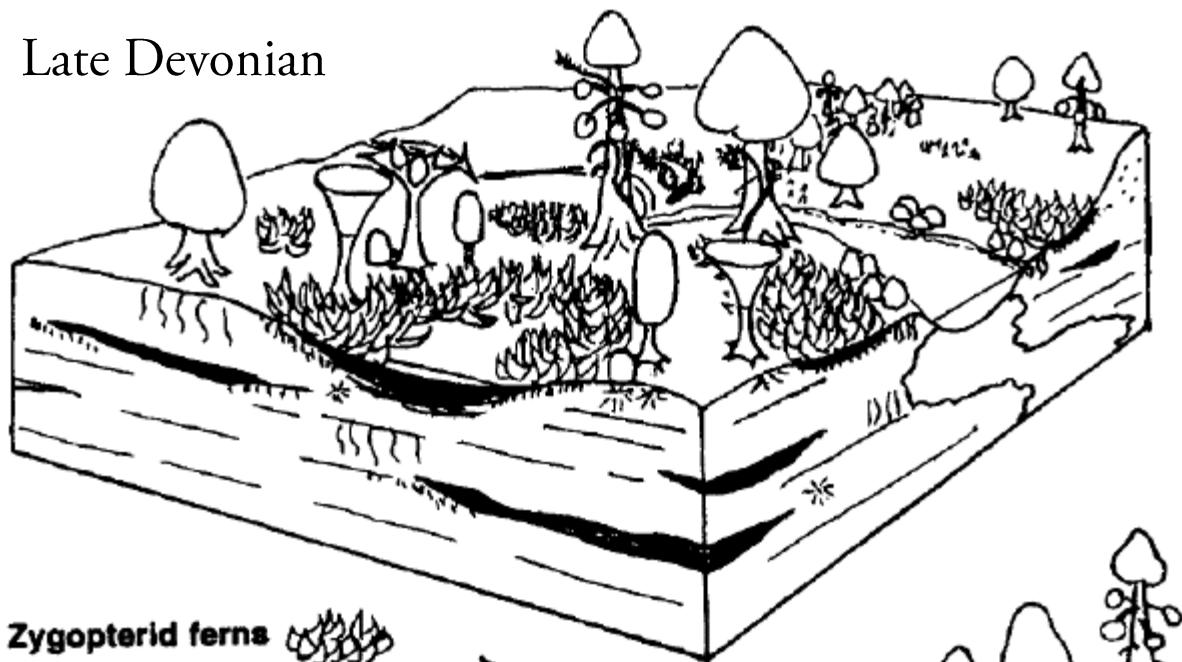
Early Devonian



Middle Devonian



Late Devonian



Rhyniophytes



Zosterophylls



Cladoxylolean ferns



Aneurophyte  
progymnosperms



Zygopterid ferns



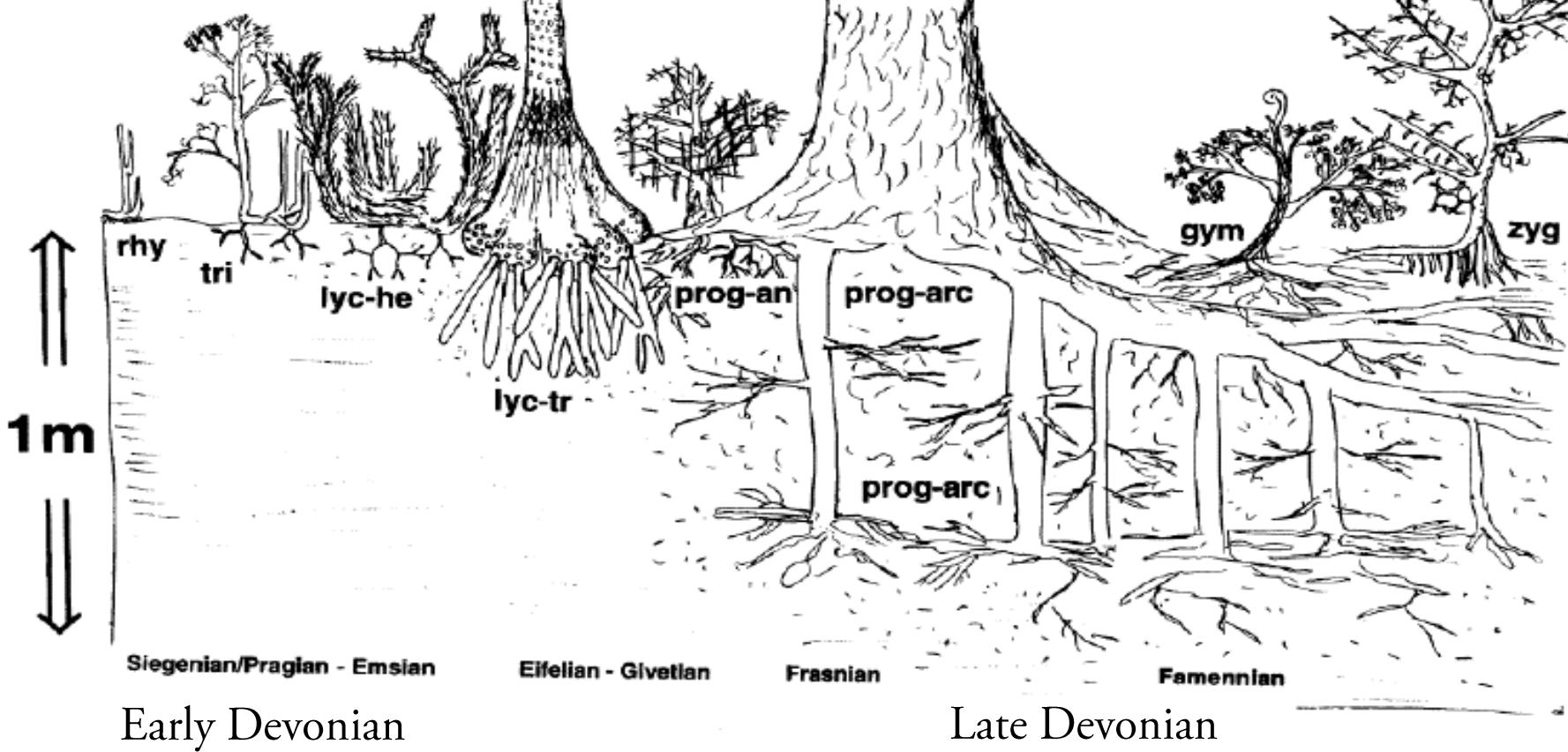
Tree lycopods



Archaeopterid  
progymnosperms  
Gymnosperms



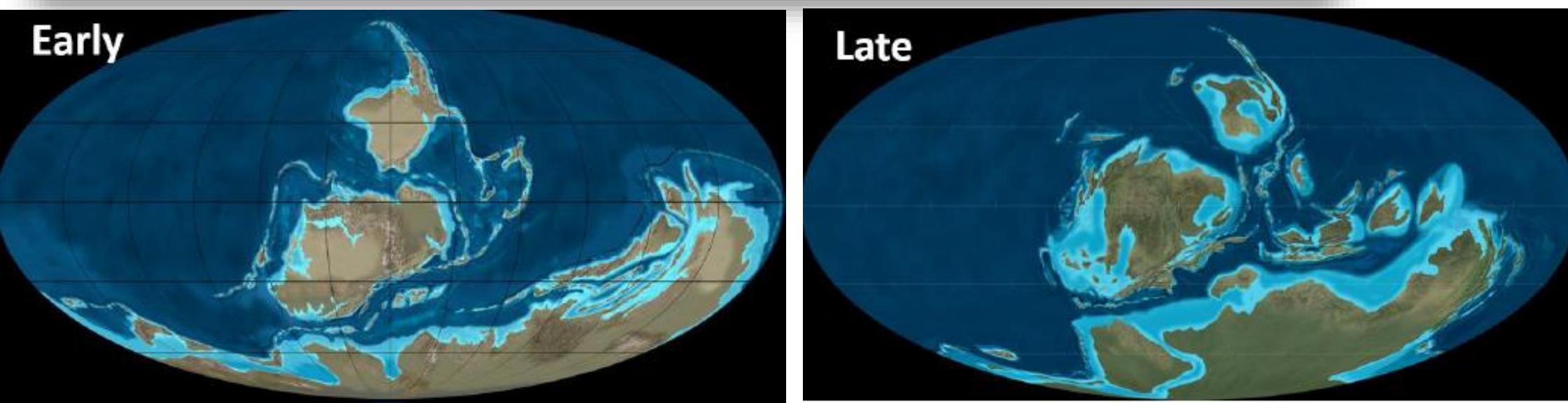
Sphenophyll vines



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

Land reconstructions from  
Algeo & Scheckler, 1998

Maps © Colorado Plateau  
Geosystems, used with permission



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

## Devonian Times

17 SEP 2019

### Catastrophe on par with dinosaur death hits Devonian oceans

By MARINA NOXIA

Bloody plants, colonising our land, making our oceans go all stinky, wiping out those atrypid brachiopods and buggering up my reefs. I wish they'd all just sod off.



### International Moose Count

United States, with the developing moose ecology to make gains. The large increase in moose come from China", said The Chinese government heavily in moose infestation in the past decade, and investment to macrofauna pay dividends". Since expanded moose production of arable land to 1 moose numbers are up to 60,000 making China an exporter for the good news for Ningxia, a barren moorland inhabitants non-negotiable desire for increase in Beijing anticipated to be relatively stable but increase trade with it.

Historically, exports to China in markets has been a tiny island nation is set to report net loss, expecting a decrease of more than five percent on last year's 50,000 moose counted. The head of Singapore's Agency for Agriculture, Jing-

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**BREAKING NEWS**

**CRISIS IN DEVONIAN OCEANS**

16:59 REEFS SET FOR BIGGEST CRISIS SINCE LAST TIME. PLANTS AND BREXIT TO BLAME

According to John... of the NASA Moon Sizing Experiment the first delivery of moose into low moon orbit could be achieved as

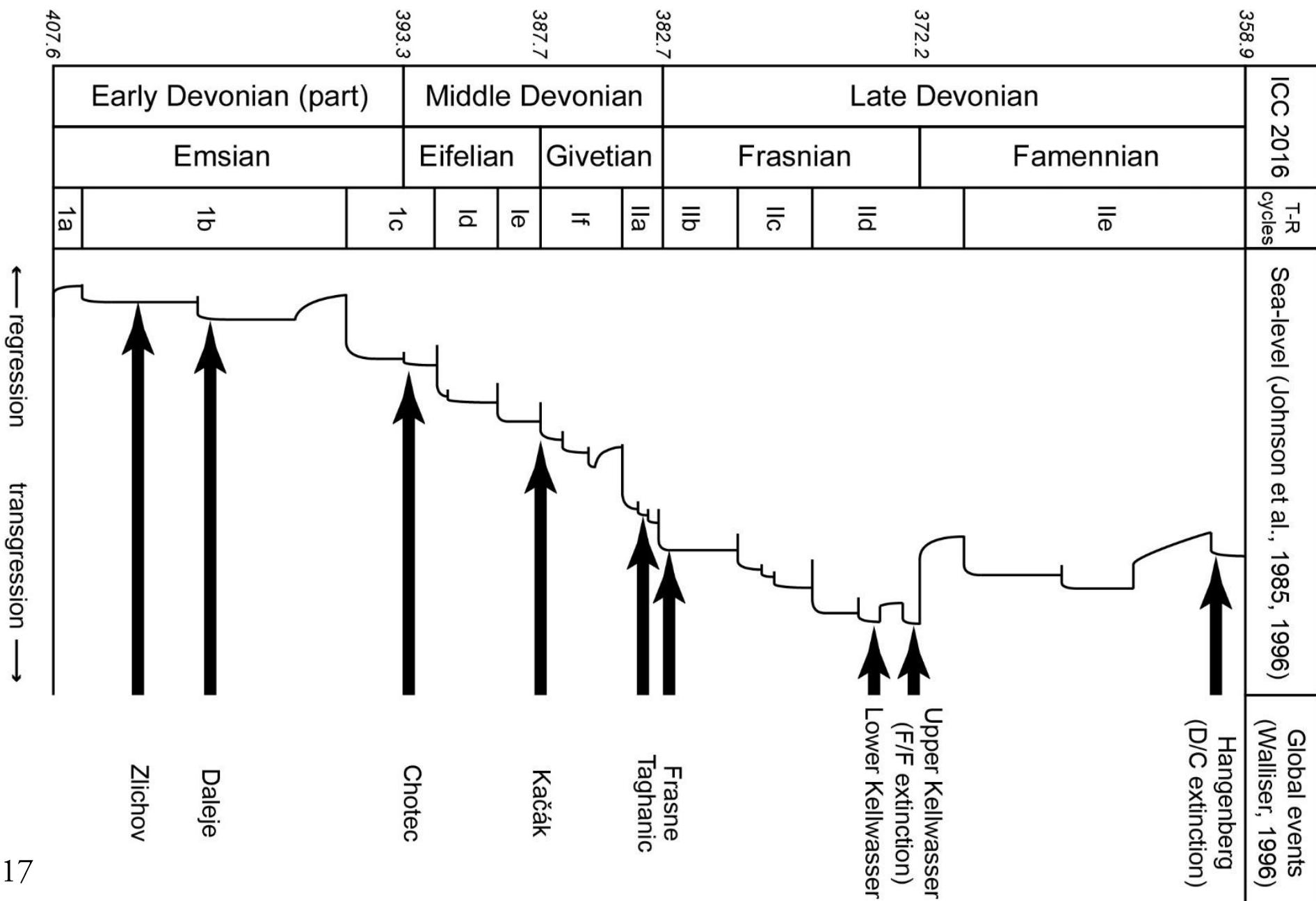
*As proposed by Algeo et al., 1995*

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

#	Event	% <sup>1</sup>	Event	% <sup>2</sup>	Event	% <sup>3</sup>	Severity ranking <sup>4</sup>
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: <sup>1</sup>Sepkoski (1996), <sup>2</sup>Bambach et al. (2004), <sup>3</sup>McGhee et al. (2013) and severity ranking <sup>4</sup>McGhee et al. (2013)

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



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...

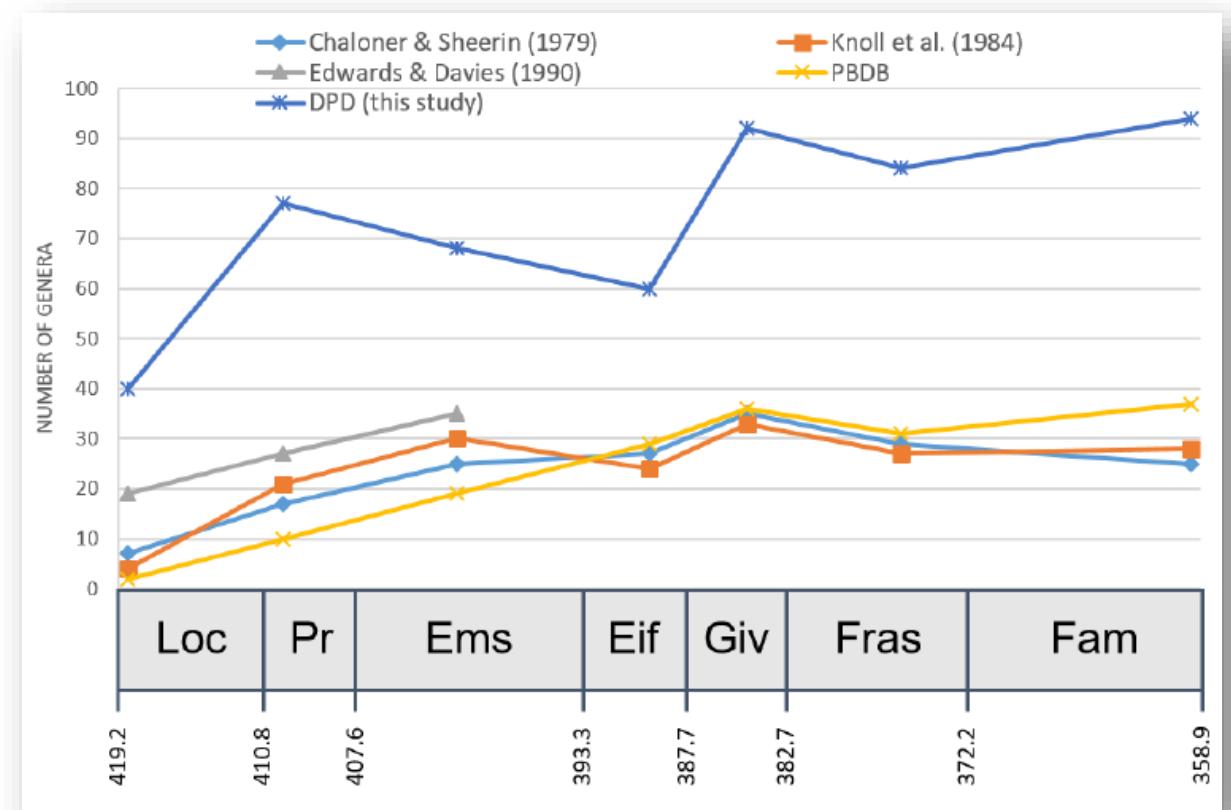
Plants constitute just 5% of records in the Paleobiology Database and Devonian plants are a tiny proportion of these

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)

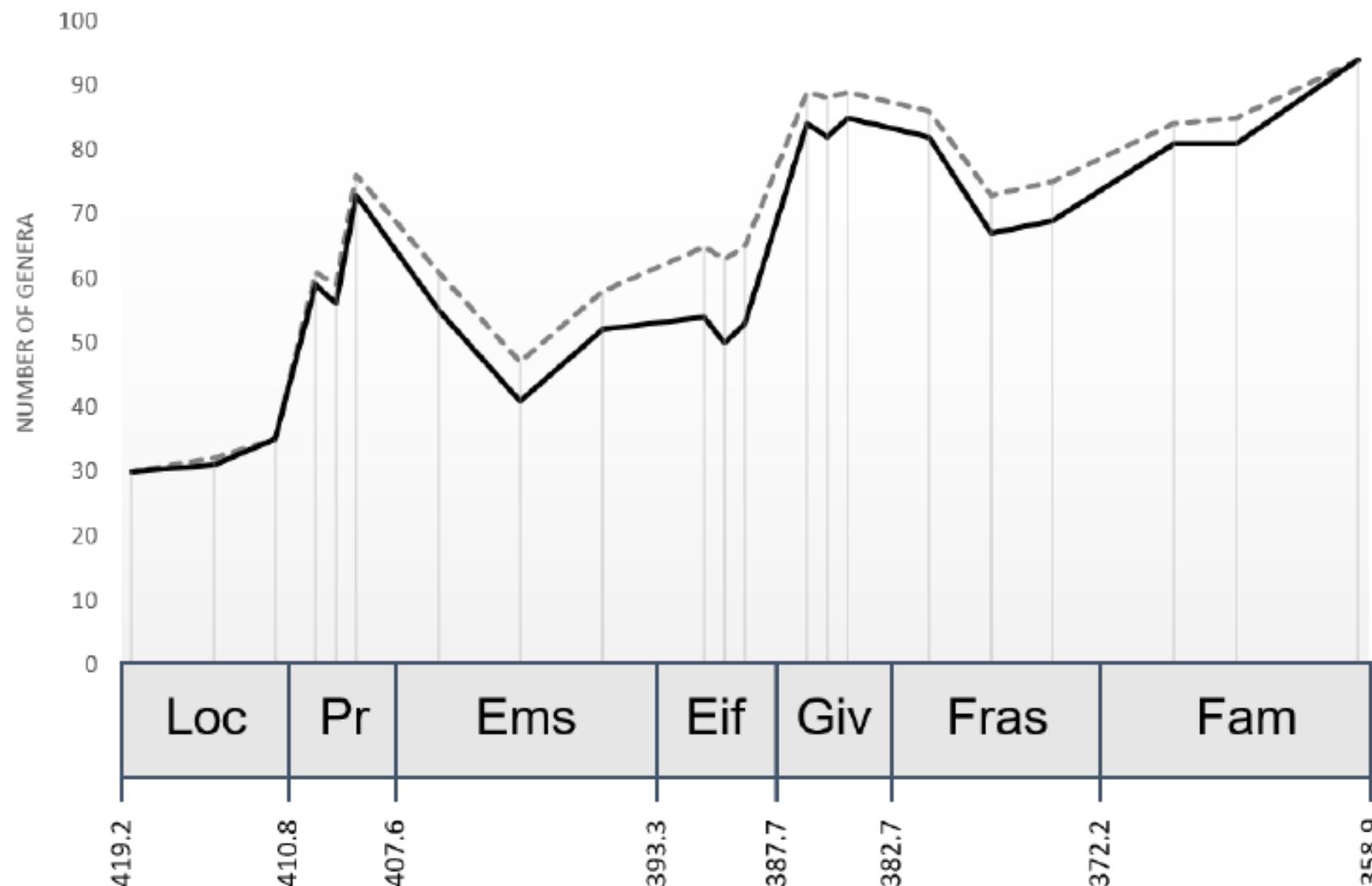
B	C	D	E	F	G	H	I	J	K	L
Genus	Early Lochkovian	Middle Lochkovian	Late Lochkovian	Early Pragian	Middle Pragian	Late Pragian	Early Emsian	Middle Emsian	Late Emsian	Early Eifelian
1	0	0	0	0	0	0	1	0	0	0
2	Aaribia	0	0	0	0	0	0	0	0	0
3	Aberlemnia	1	1	1	0	0	0	0	0	0
4	Acanthophyton	0	0	0	0	0	0	0	0	1
5	Actinopodium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

Presence/absence matrix in Excel



Comparison of new database with previous collations (replotted)

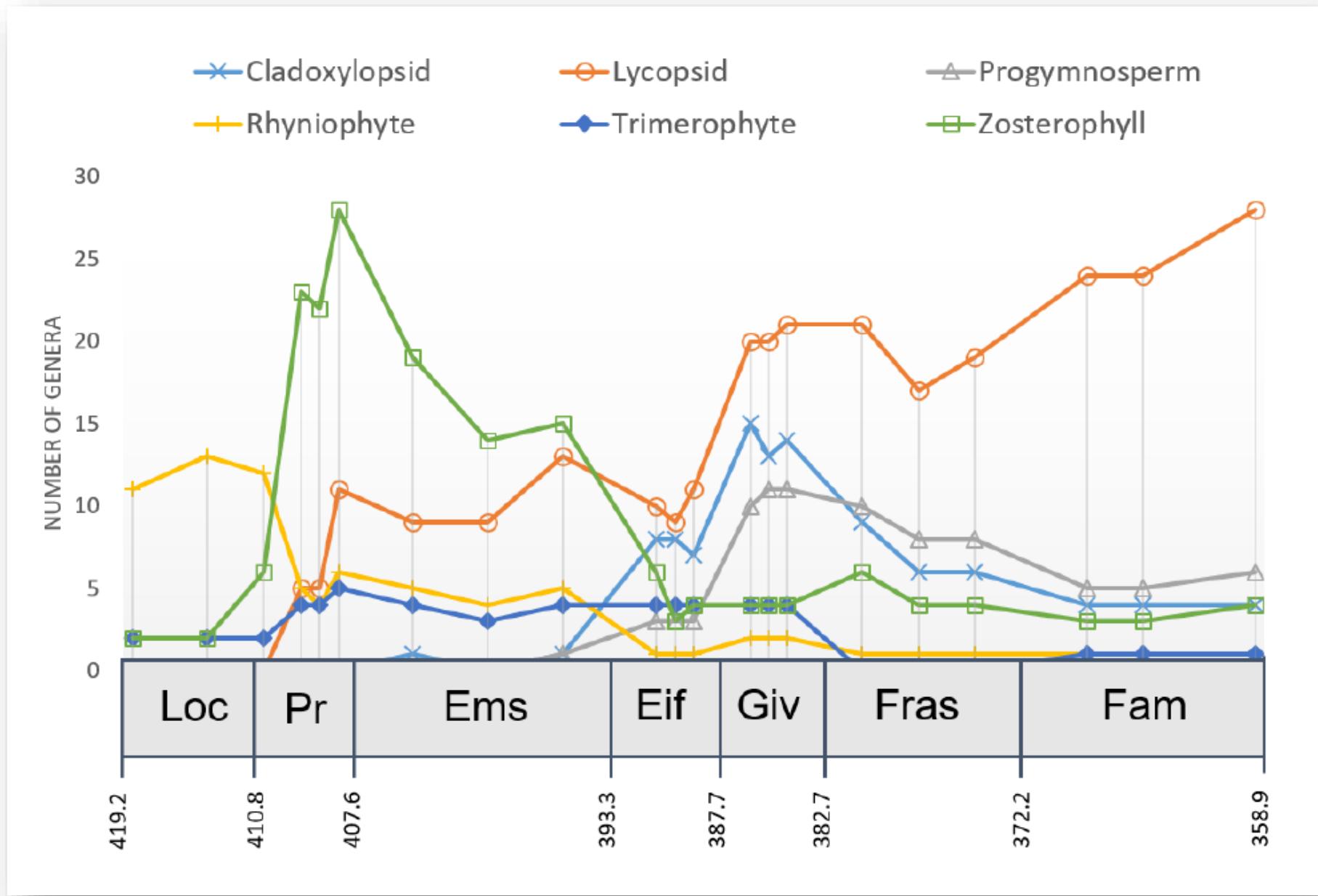
# Results: generic diversity through the Devonian



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

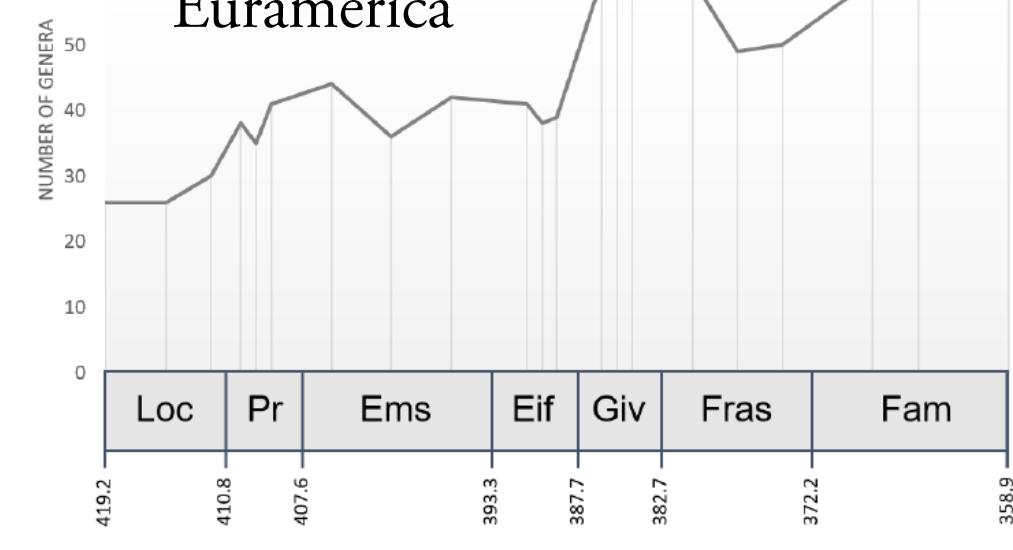
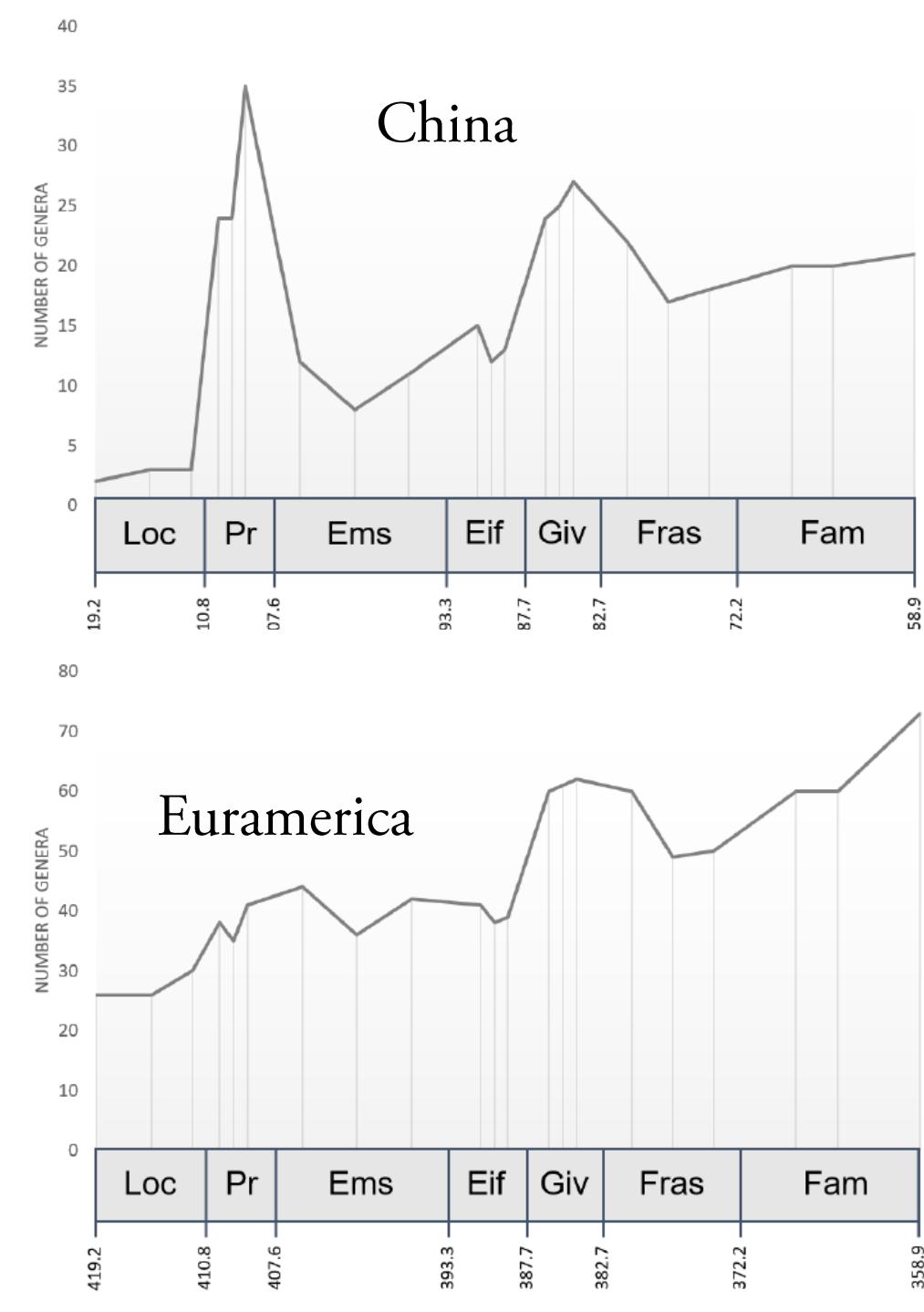
# Generic diversity in different plant groups

Zosterophylls  
& rhyniophytes:  
important early



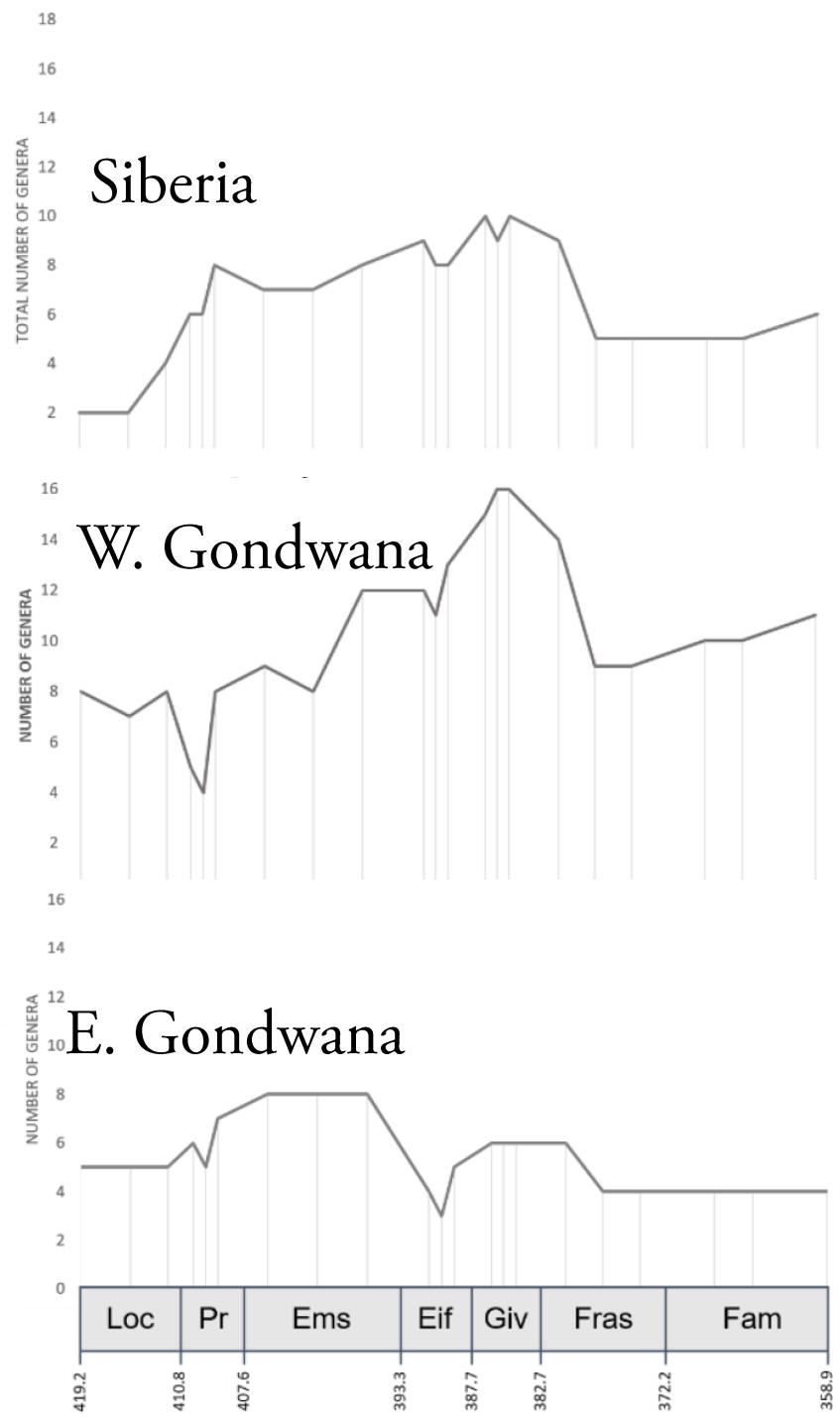
Later replaced  
by lycopsids





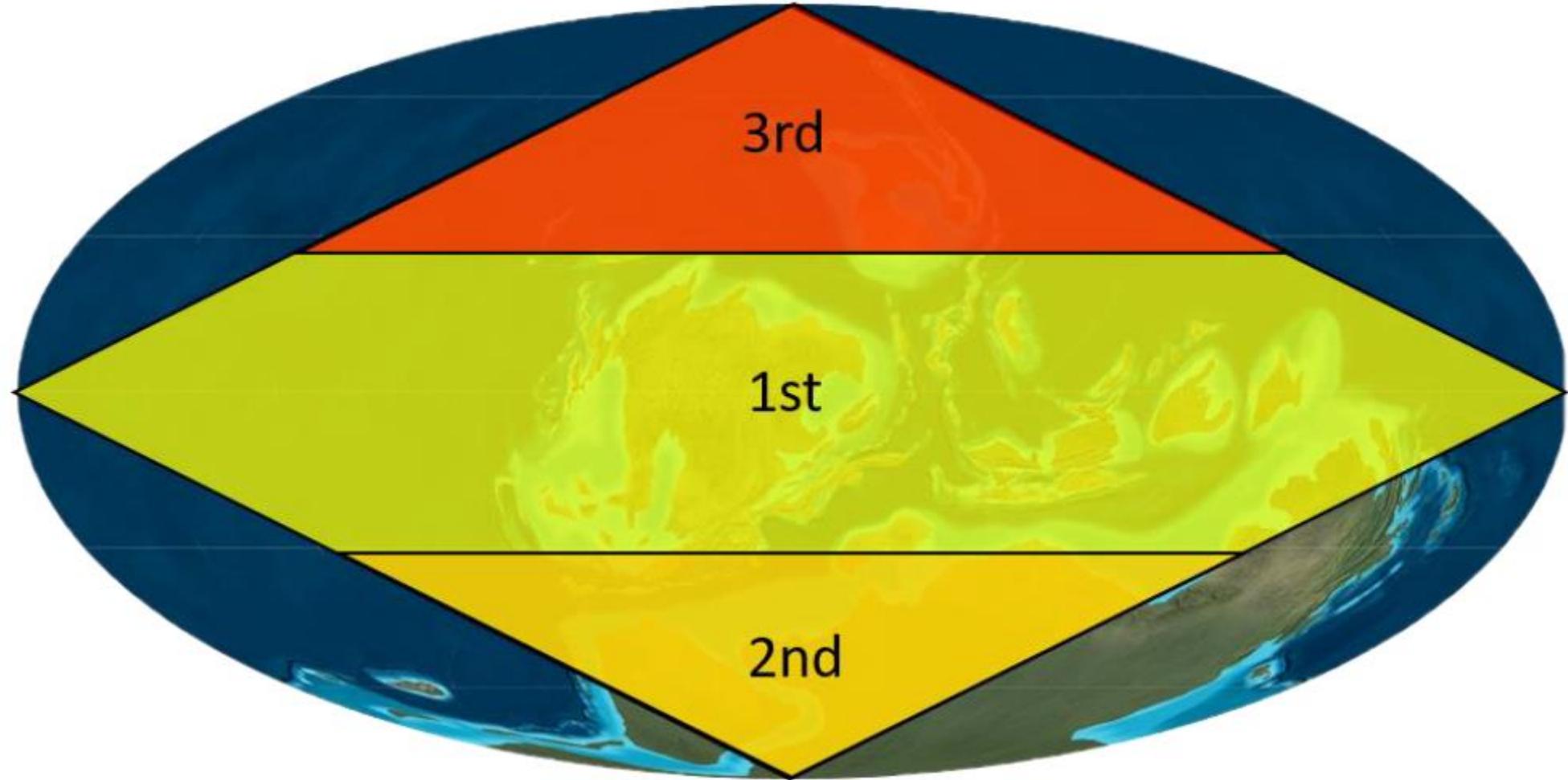
Regional variations:

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



# Where did each group originate?

	Order of Palaeo-Regional Appearance			
	1 <sup>st</sup>	2 <sup>nd</sup>	3 <sup>rd</sup>	4 <sup>th</sup>
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	<b>Euramerica</b> <b>W Gondwana</b> <b>E Gondwana</b>			
Trimerophyte	<b>Euramerica</b> <b>W Gondwana</b>	China		
Zosterophyll	<b>Siberia</b> <b>China</b> <b>Euramerica</b> <b>E Gondwana</b>	W Gondwana		



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

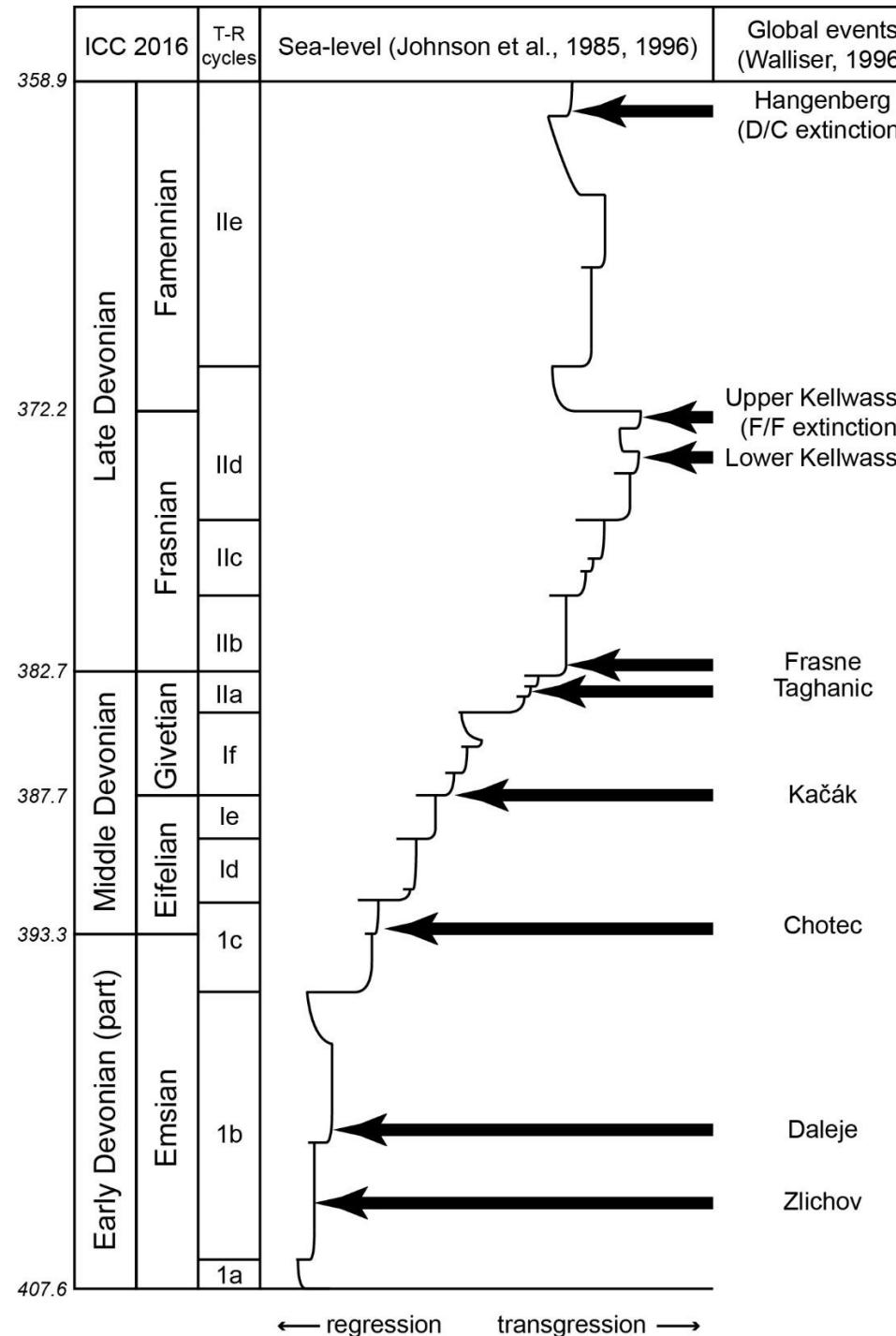
# A little-known Late Givetian to Middle Frasnian terrestrial extinction event

Late Givetian – Middle Frasnian Change	
	- 57 %

<b>Cladoxylopsid</b>	- 57 %
<b>Lycopsid</b>	- 19 %
<b>Progymnosperm</b>	- 27 %
<b>Rhyniophyte</b>	- 50 %
<b>Trimerophyte</b>	- 100 %
<b>Zosterophyll</b>	- 100 %

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

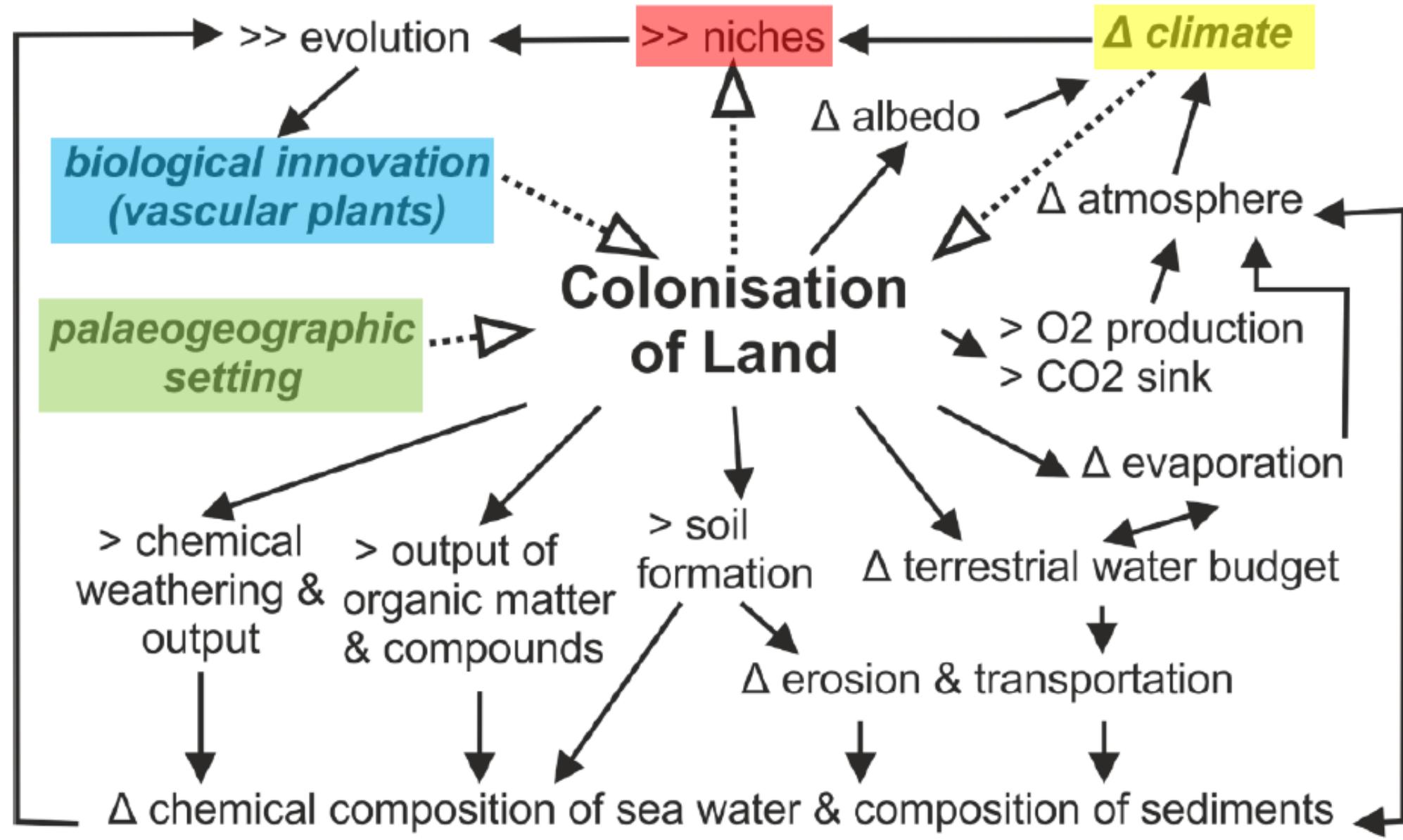
Taghanic Event: minor diversification in lycopsids and cladoxylopsids

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



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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