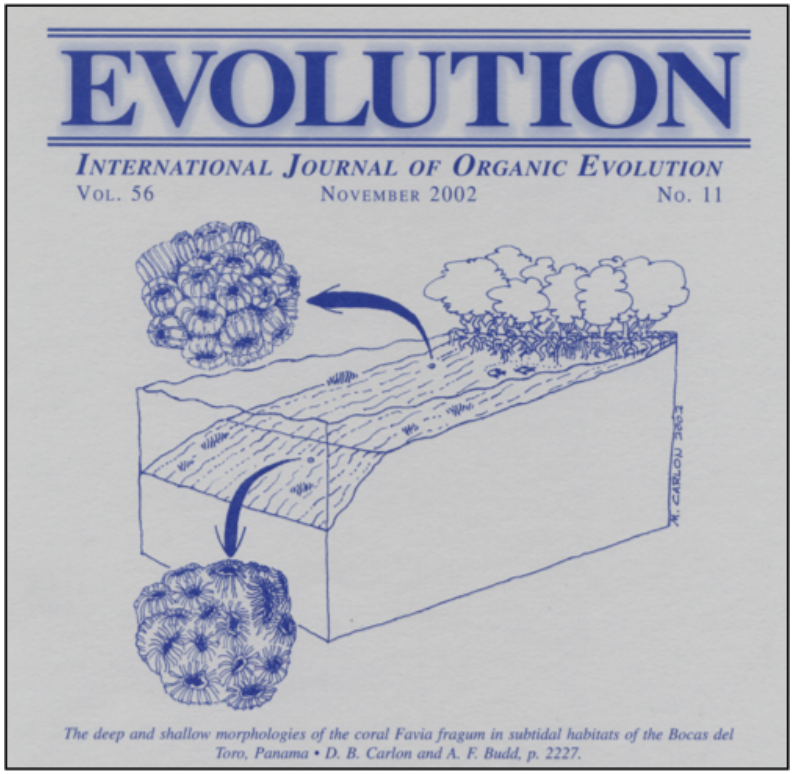
Is the tropical Atlantic an evolutionary hotspot for coral evolution?

Timing and diversification of the coral subfamilies Mussinae and Faviinae in the tropical Atlantic

David B. Carlon[1], Ann F. Budd[2], and Bob Thomson[3]

1. Coastal Studies Center, Bowdoin College
2. Department of Earth & Environmental Sciences, University of Iowa
3. Department of Biology, University of Hawaii at Manoa

My collaboration with Nancy…

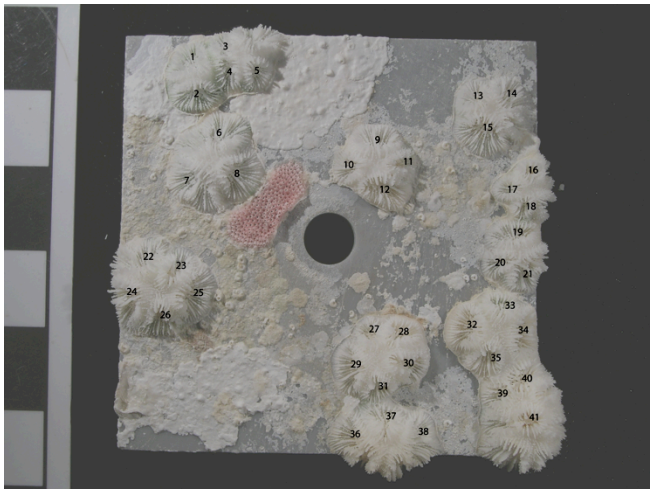


Evolution, 56(11), 2002, pp. 2227–2242

INCIPIENT SPECIATION ACROSS A DEPTH GRADIENT IN A SCLERACTINIAN CORAL?

DAVID B. CARLON[1,2] AND ANN F. BUDD[3]
[1]*Wrigley Institute for Environmental Studies, University of Southern California, P. O. Box 5069, Avalon, California 90704*
[3]*Department of Geoscience, University of Iowa, Iowa City, Iowa 52242*
E-mail: ann-budd@uiowa.edu

Quantitative Genetics…



THE QUANTITATIVE GENETICS OF INCIPIENT SPECIATION: HERITABILITY AND GENETIC CORRELATIONS OF SKELETAL TRAITS IN POPULATIONS OF DIVERGING *FAVIA FRAGUM* ECOMORPHS

David B. Carlon,[1,2] Ann F. Budd,[3] Catherine Lippé,[1,5] and Rose L. Andrew[4]

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Diversification…

Schwartz *et al. BMC Evolutionary Biology* 2012, **12**:123
http://www.biomedcentral.com/1471-2148/12/123

BMC
Evolutionary Biology

RESEARCH ARTICLE Open Access

Molecules and fossils reveal punctuated diversification in Caribbean "faviid" corals

Sonja A Schwartz[1*], Ann F Budd[2] and David B Carlon[3]

Mussinae

Faviianae

Fukami, H., A. F. Budd, G. Paulay, A. Sole-Cava, et al. 2004. Conventional taxonomy obscures deep divergence between Pacific and Atlantic corals. Nature **427:** 832-835.

Major systematic revision

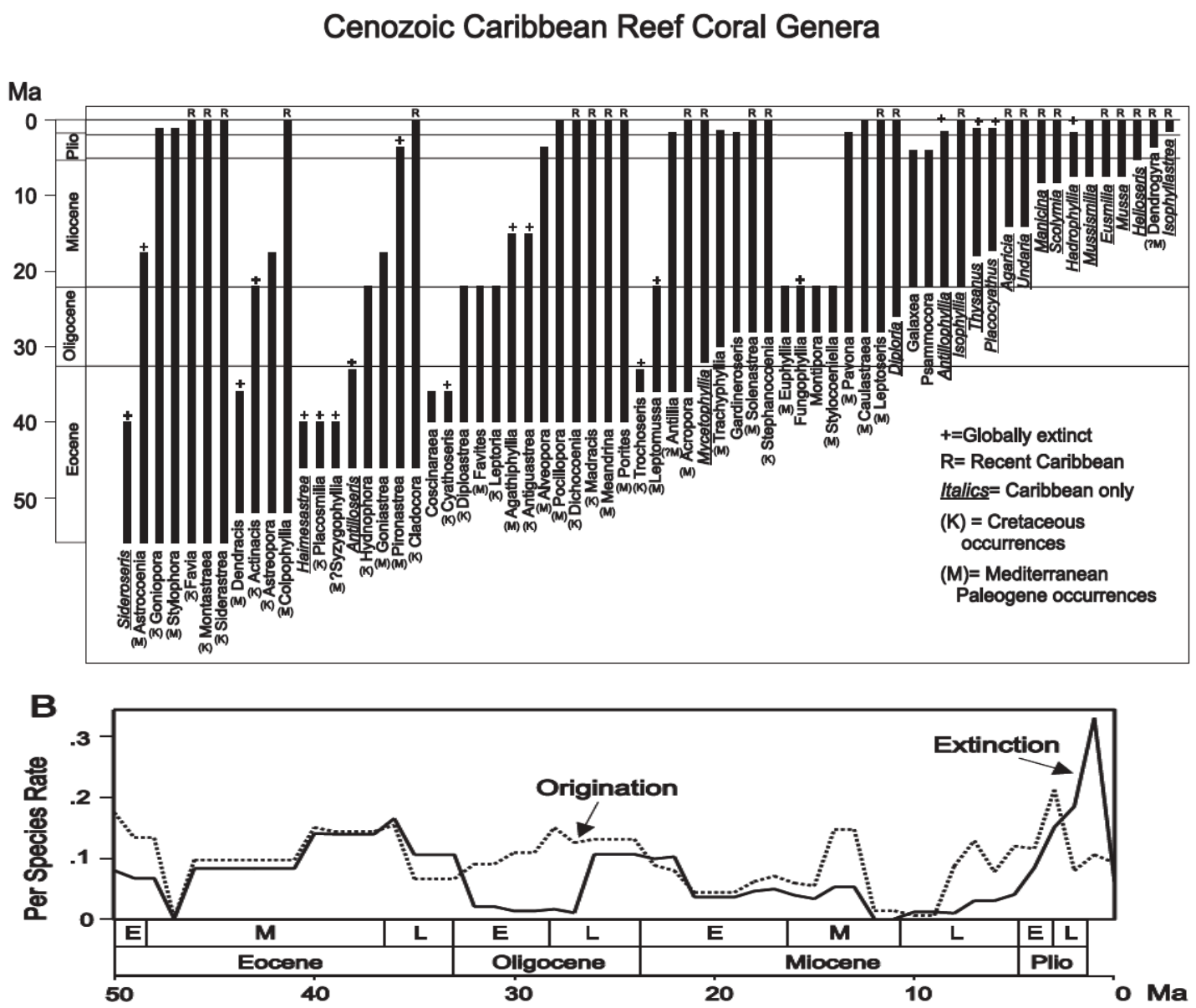
Wells (1956)	Veron (2000)	This Study
Family Mussidae	**Family Mussidae**	**Family Mussidae (clade XXI)**
Genus *Mussa* [=*Scolymia*]	Genus *Mussa*	**Subfamily Mussinae**
Genus *Isophyllia*	Genus *Isophyllia* [=*Isophyllastrea*]	Genus *Mussa*
Genus *Isophyllastrea*	Genus *Mycetophyllia*	Genus *Isophyllia* [=*Isophyllastrea*]
Genus *Mycetophyllia*	Genus *Mussismilia*	Genus *Mycetophyllia*
Genus *Mussismilia*	Genus *Lobophyllia*	Genus *Scolymia* (Atlantic only)
Genus *Lobophyllia*	Genus *Acanthastrea*	**Subfamily Faviinae**
Genus *Acanthastrea*	Genus *Symphyllia*	Genus *Favia* (Atlantic only)
Genus *Symphyllia*	Genus *Australomussa*	Genus *Colpophyllia*
?Genus *Cynarina*	Genus *Micromussa*	Genus *Diploria*
Genus *Homophyllia*	Genus *Cynarina*	Genus *Pseudodiploria*, new
Genus *Parascolymia*	Genus *Scolymia* [=*Homophyllia*, *Parascolymia*]	Genus *Manicina*
Genus *Blastomussa*	Genus *Blastomussa*	Genus *Mussismilia*
Family Faviidae	Genus *Indophyllia*	**Family Lobophylliidae, new (clade XIX)**
Subfamily Faviinae	**Family Faviidae**	Genus *Lobophyllia*
Genus *Favia*	Genus *Favia*	Genus *Acanthastrea*
Genus *Colpophyllia*	Genus *Colpophyllia*	Genus *Symphyllia*
Genus *Diploria*	Genus *Diploria*	?Genus *Australomussa*
Genus *Manicina*	Genus *Manicina*	Genus *Micromussa*
Genus *Barabattoia*		Genus *Cynarina*
Genus *Bikiniastrea*		Genus *Homophyllia* (part Indo-Pacific *Scolymia*)

Budd, A. F., H. Fukami, N. D. Smith, and N. Knowlton. 2012. Taxonomic classification of the reef coral family Mussidae (Cnidaria: Anthozoa: Scleractinia). Zoological Journal of the Linnean Society **166:** 465-529.

Trait diversification within the Mussidae – Adaptive radiation in corals?

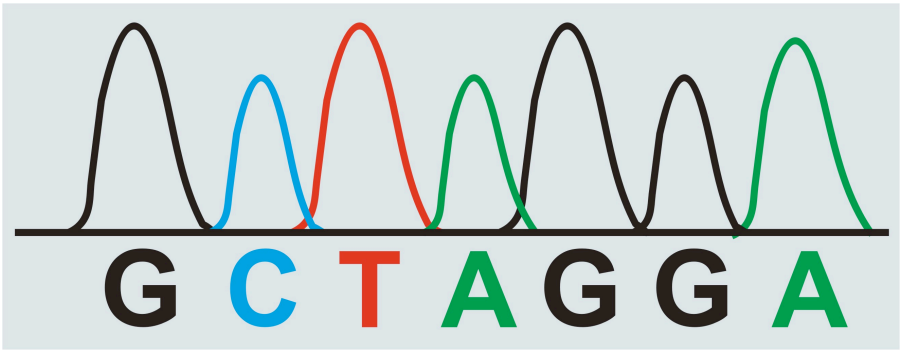
Trait	Variation	
Colony size	cms	meters
Poly size	mms	cms
Colony structure	Solitary	Colonial
Mobility	Free living	Attached
Development	Brood	Broadcast
Build reefs?	Yes	No

Rich fossil record

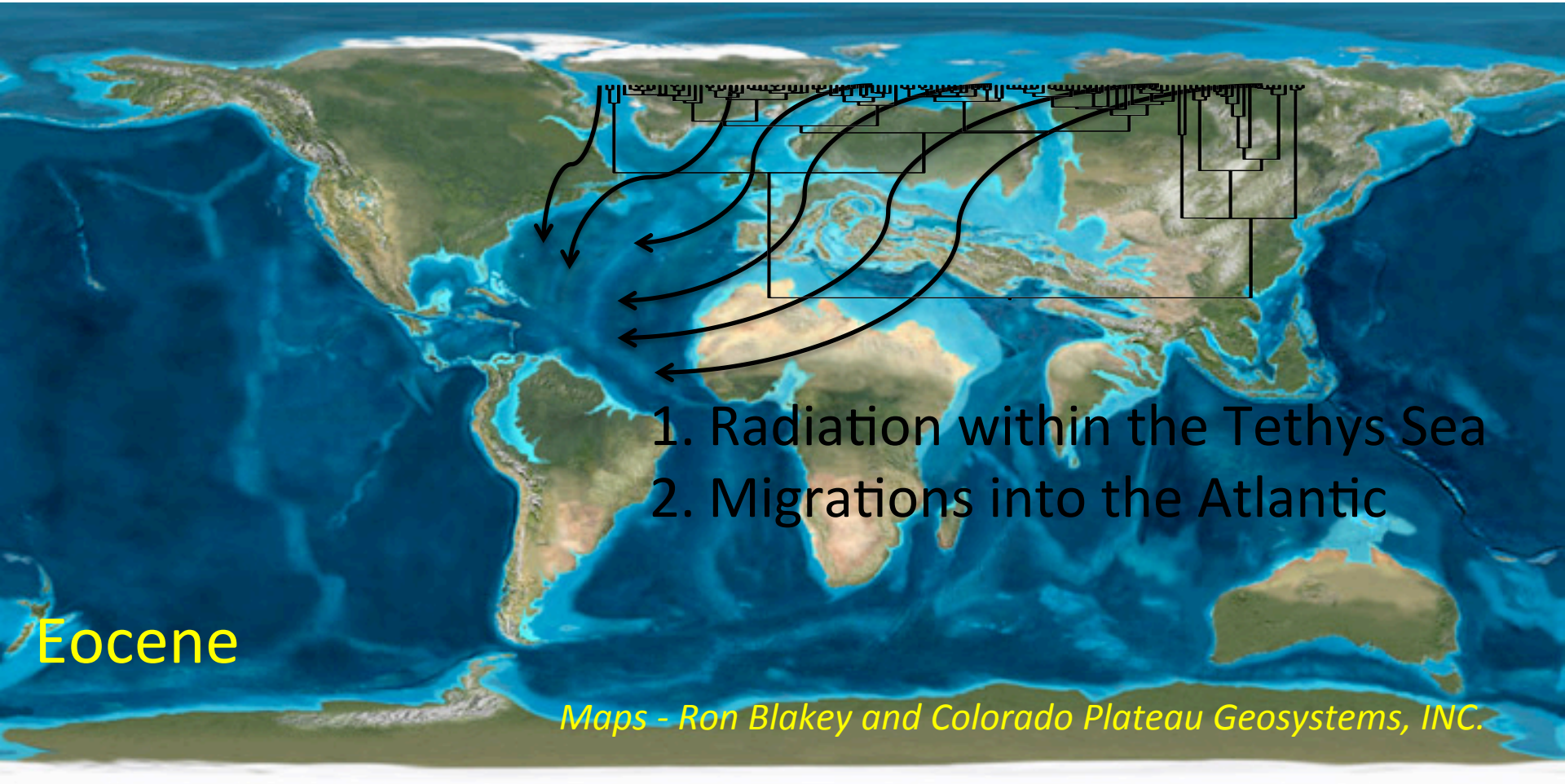


We would like to maximize information from two kinds of data…

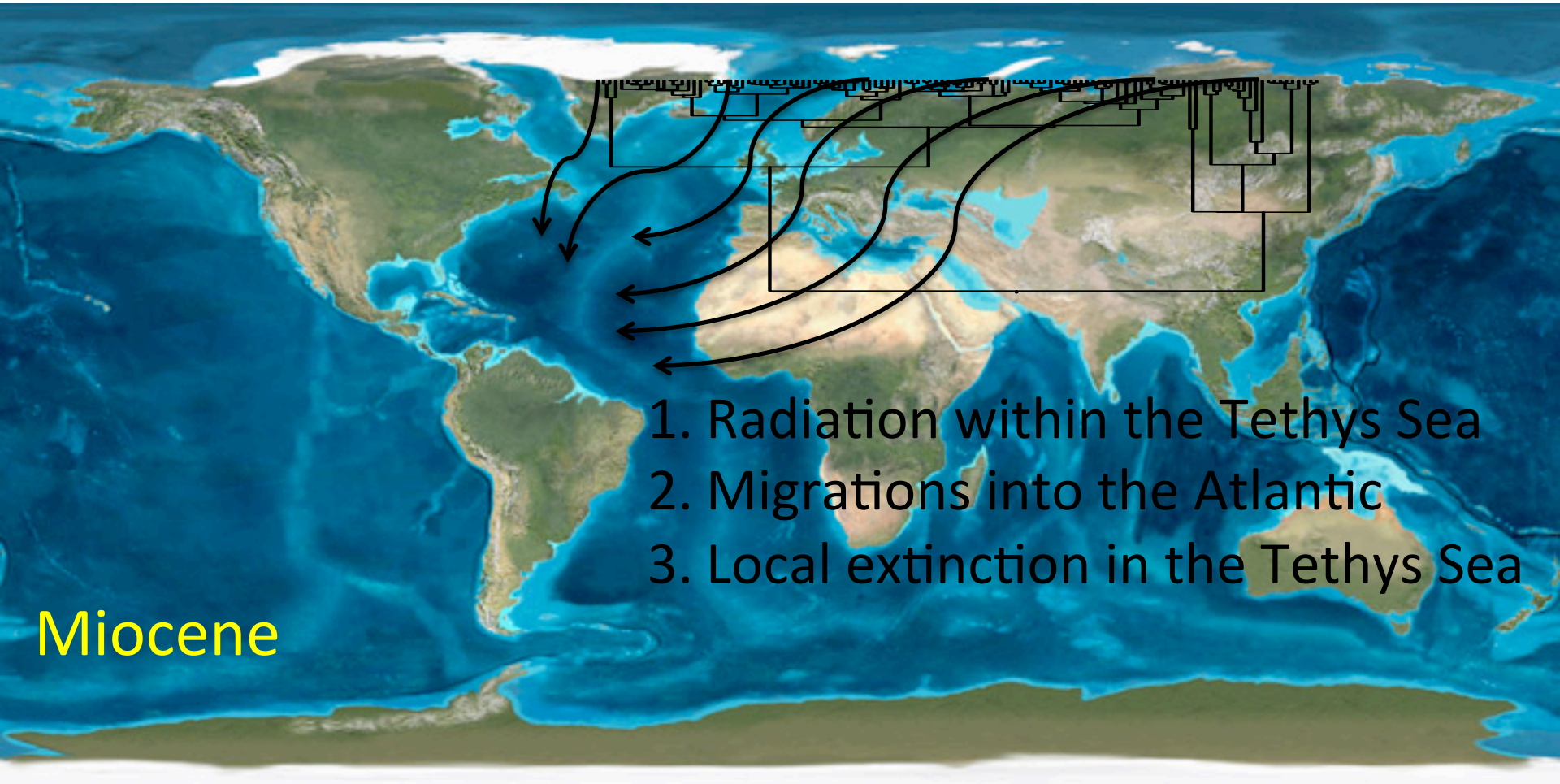
- Molecular Sequences
  - Phylogenetic relationships
  - Comparative method
- Fossil Record
  - Phylogenetic relationships (hard)
  - Dynamics of ghost taxa
  - Extinction
  - Calibrations



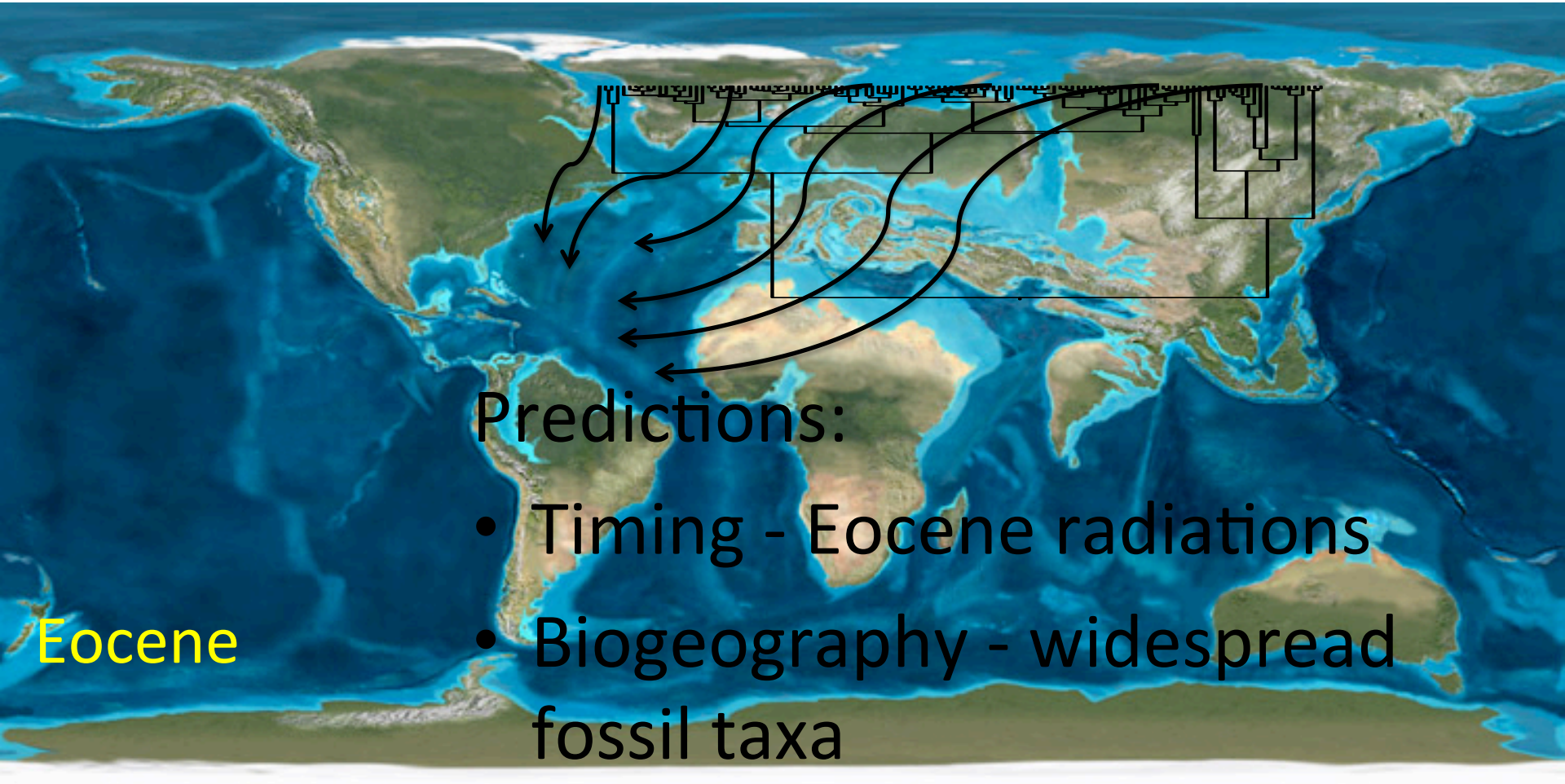
Scenario 1 - Tethyian Radiation



Scenario 1 - Tethyian Radiation



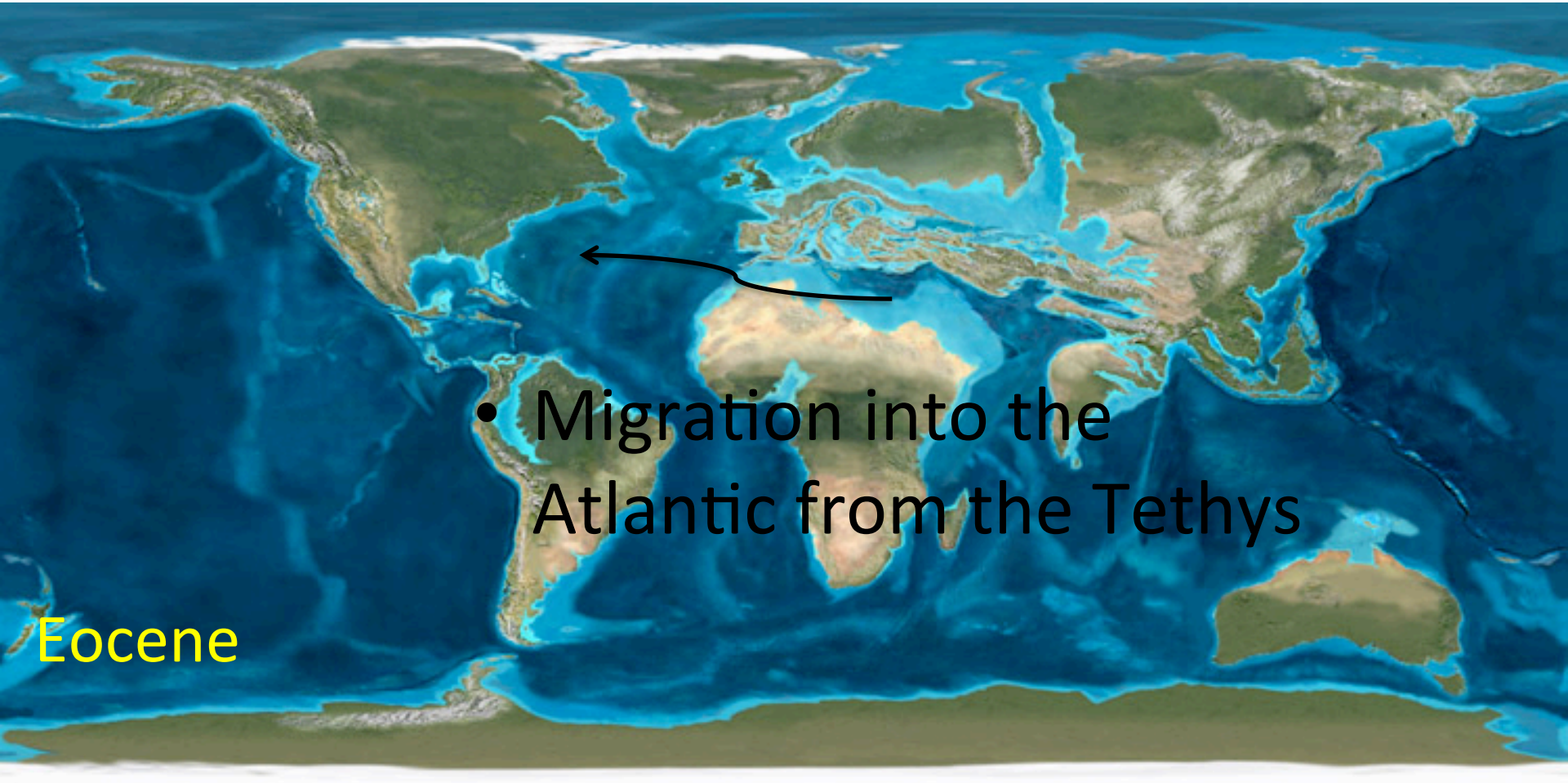
Scenario 1 - Tethyian Radiation



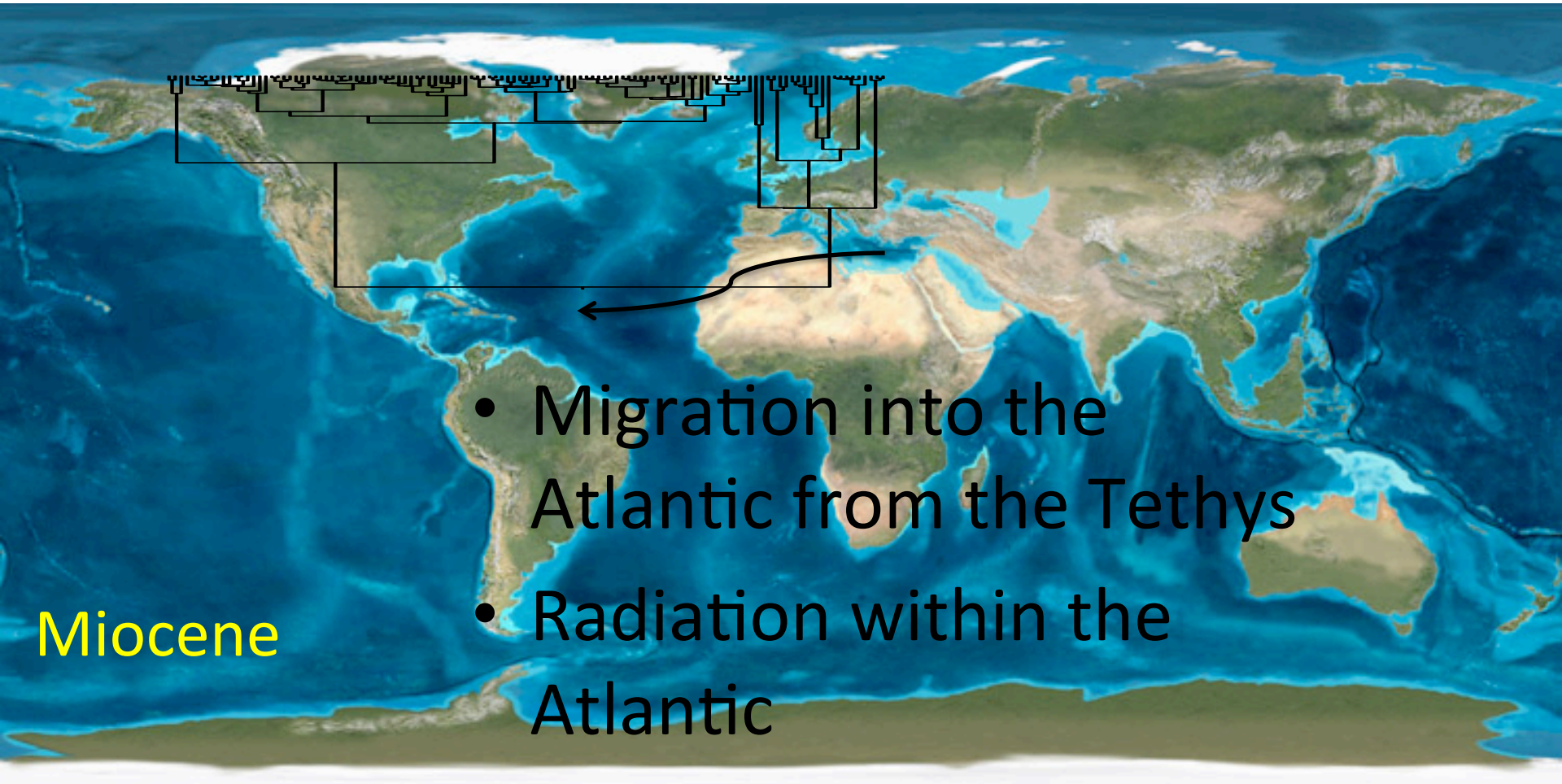
Predictions:

- Timing - Eocene radiations
- Biogeography - widespread fossil taxa

Scenario 2 – Atlantic Radiation



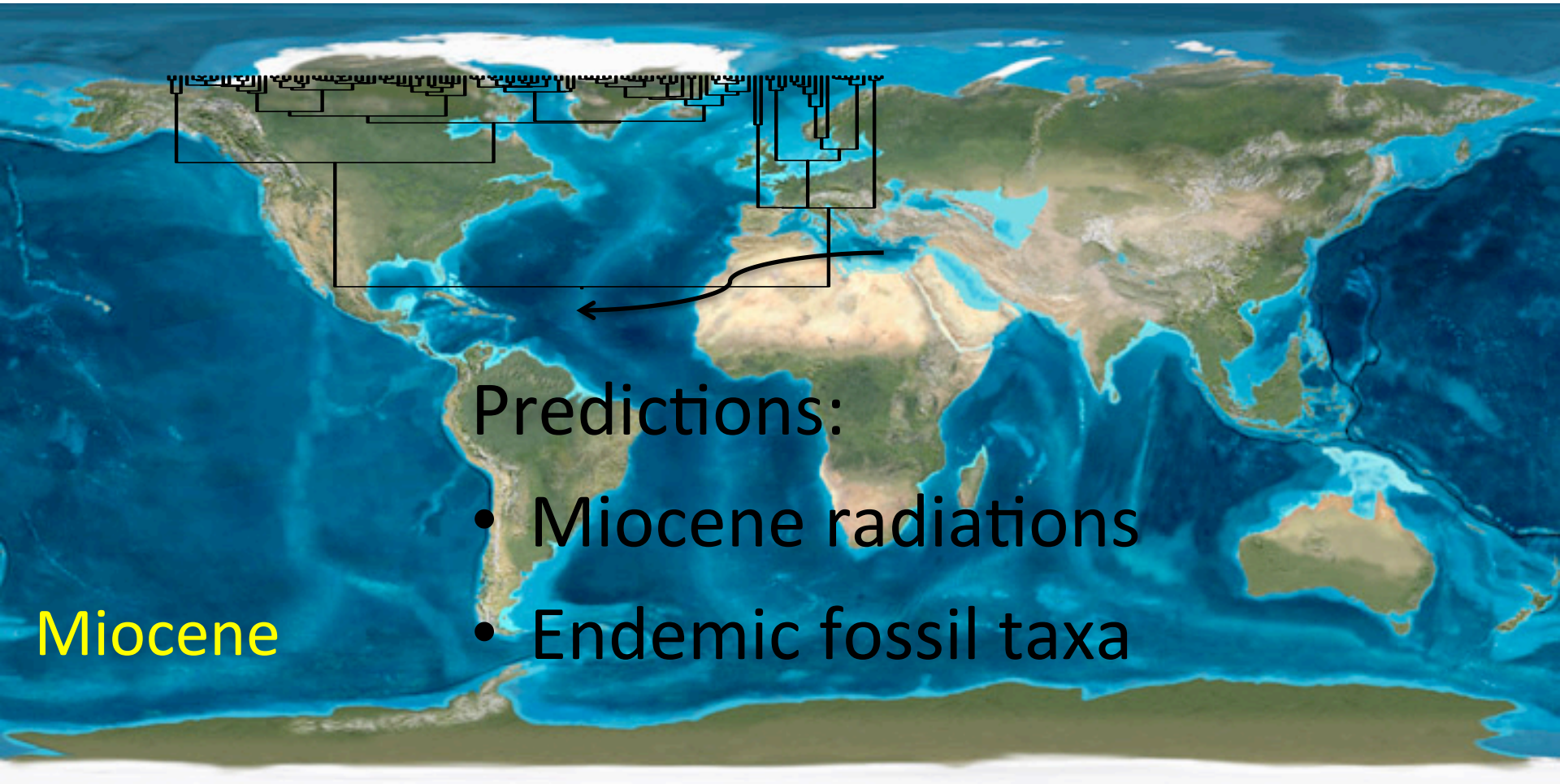
Scenario 2 – Atlantic Radiation



- Migration into the Atlantic from the Tethys
- Radiation within the Atlantic

Miocene

Scenario 2 – Atlantic Radiation



Predictions:

- Miocene radiations
- Endemic fossil taxa

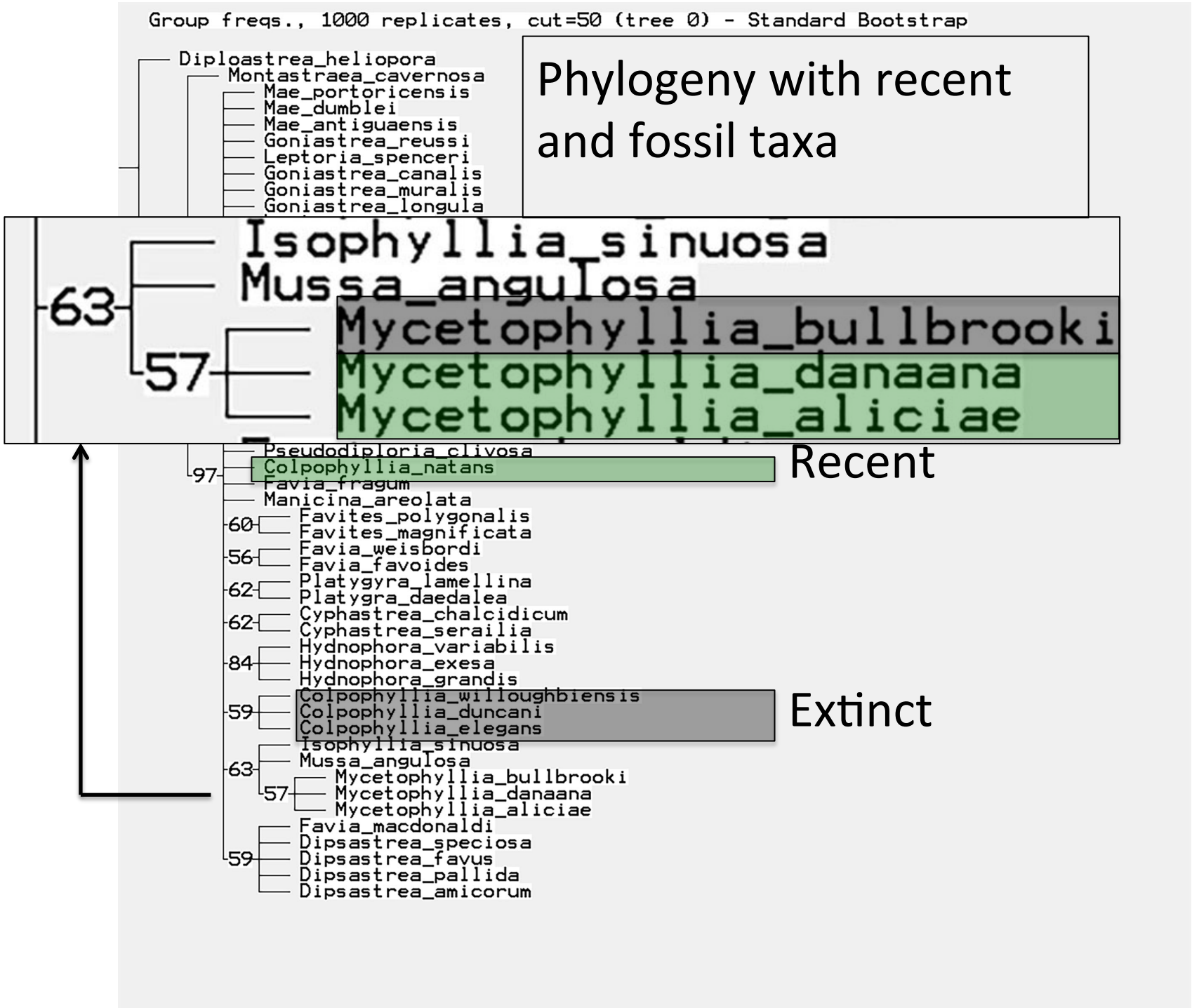
Miocene

Phylogenetic Tree
Taxonomic Sampling

- 9/10 genera
- 14/26 species
- Sampled 1 – 14 individuals/species
- Sequenced three nuclear genes in 139 samples

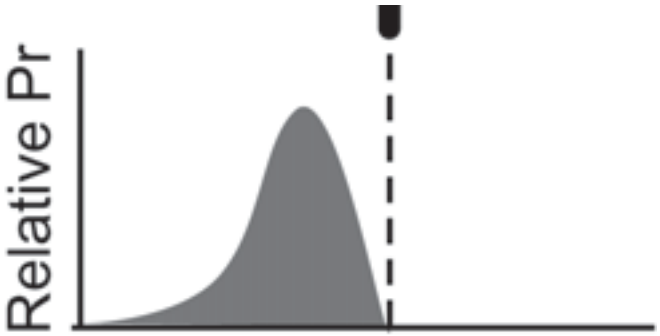
Calibrating nodes with fossils

- Place minimum constraints on node ages
- Use recent and fossil taxa to establish monophyletic nodes


Group freqs., 1000 replicates, cut=50 (tree 0) - Standard Bootstrap
Phylogeny with recent and fossil taxa
Diploastrea_heliopora
Montastraea_cavernosa
Mae_portoricensis
Mae_dumblei
Mae_antiguaensis
Goniastrea_reussi
Leptoria_spenceri
Goniastrea_canalis
Goniastrea_muralis
Goniastrea_longula
Isophyllia_sinuosa
Mussa_angulosa
63
Mycetophyllia_bullbrooki
57
Mycetophyllia_danaana
Mycetophyllia_aliciae
Recent
Pseudodiploria_clivosa
97
Colpophyllia_natans
Favia_fragum
Manicina_areolata
60
Favites_polygonalis
Favites_magnificata
56
Favia_weisbordi
Favia_favoides
62
Platygyra_lamellina
Platygra_daedalea
62
Cyphastrea_chalcidicum
Cyphastrea_serailia
84
Hydnophora_variabilis
Hydnophora_exesa
Hydnophora_grandis
59
Colpophyllia_willoughbiensis
Colpophyllia_duncani
Colpophyllia_elegans
Extinct
Isophyllia_sinuosa
63
Mussa_angulosa
Mycetophyllia_bullbrooki
57
Mycetophyllia_danaana
Mycetophyllia_aliciae
Favia_macdonaldi
Dipsastrea_speciosa
59
Dipsastrea_favus
Dipsastrea_pallida
Dipsastrea_amicorum

Calibrating nodes

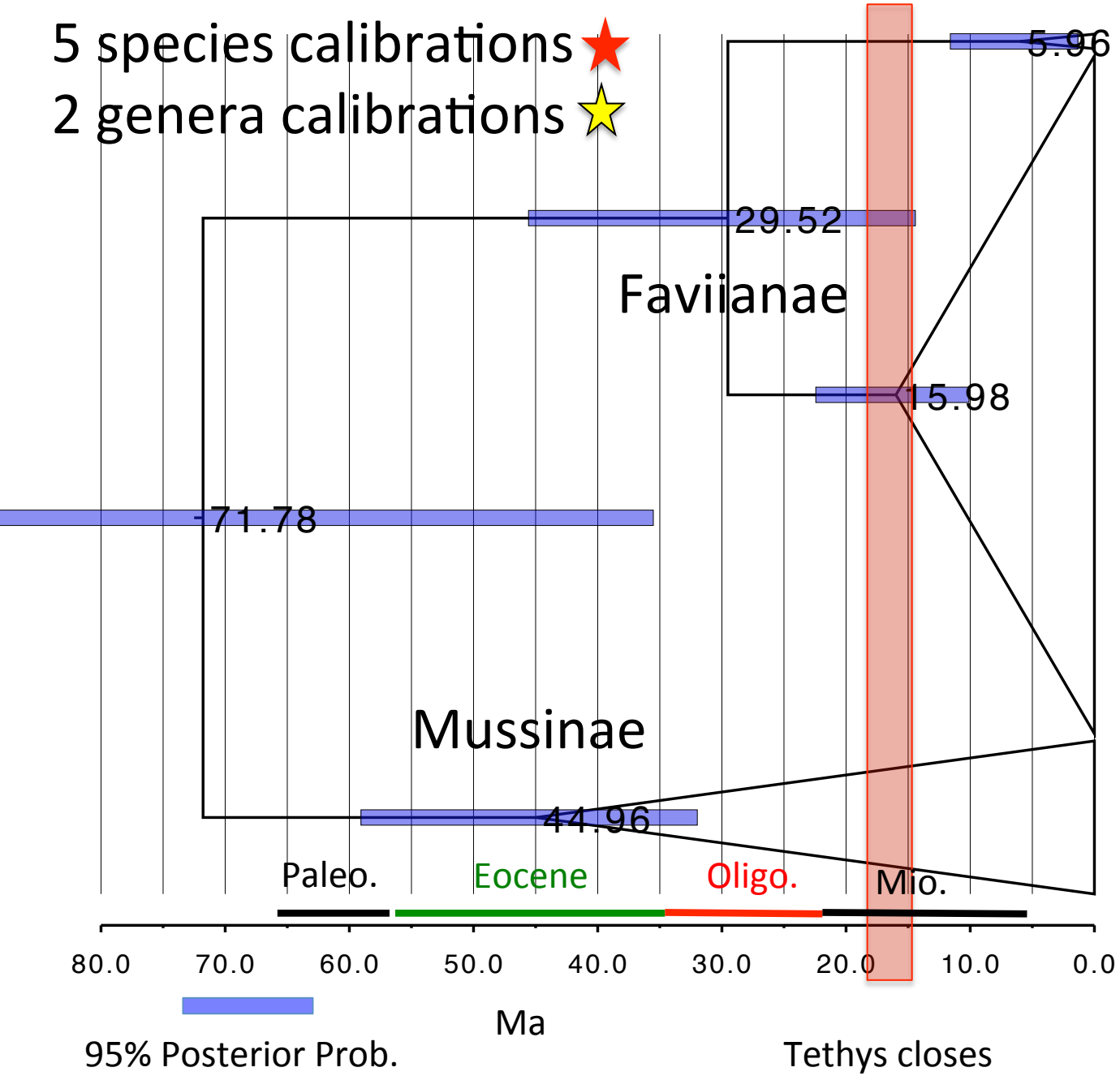
- Lognormal Prior – uncertainty of fossil record
- Multiple calibrations allows for molecular rate variation among lineages

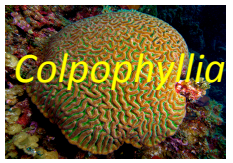


Time calibrated phylogeny

5 species calibrations ★

2 genera calibrations ★





★

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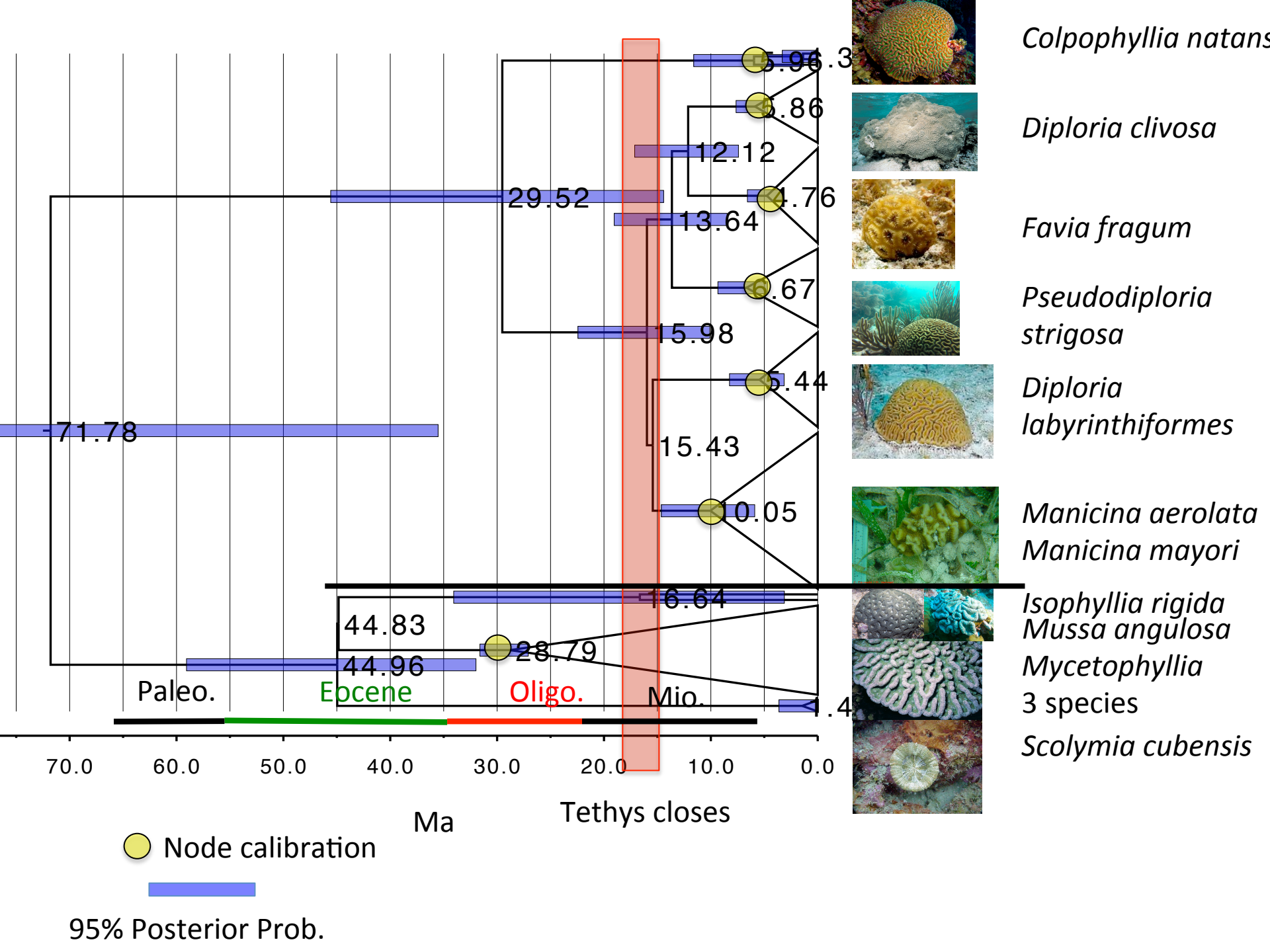
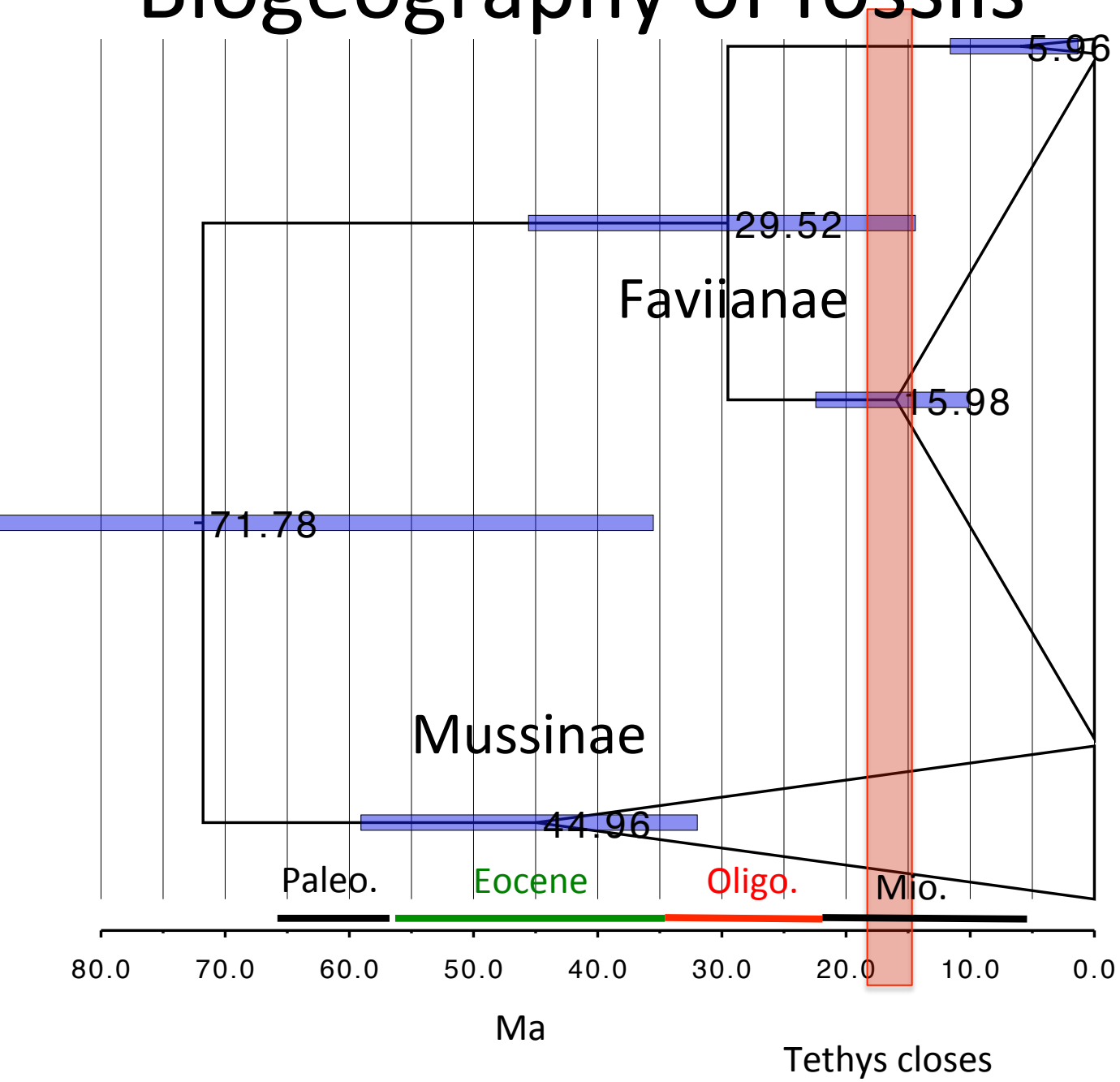
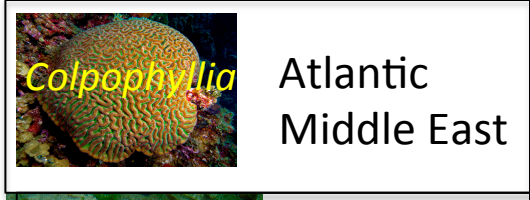
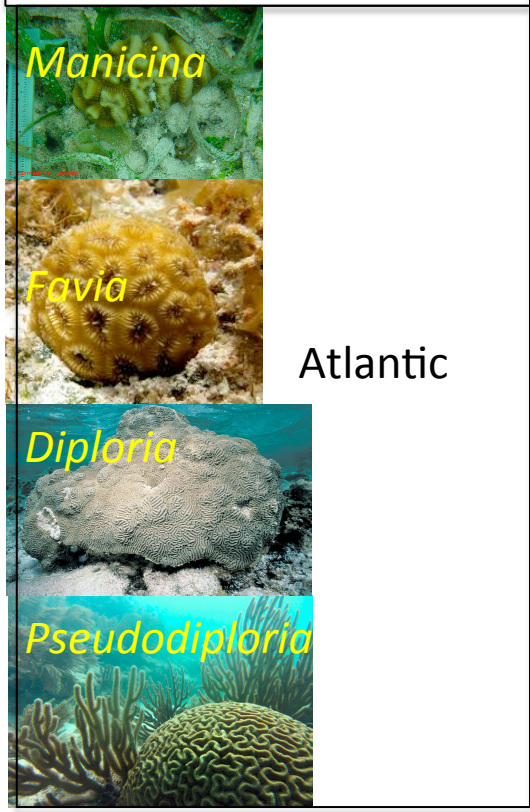
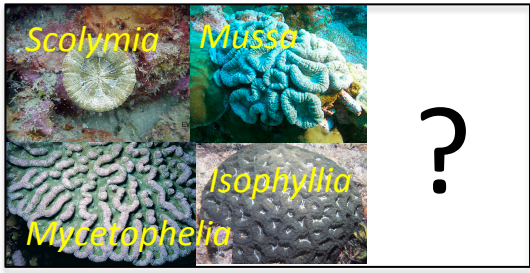

5.96
3.86
12.12
29.52
4.76
13.64
6.67
15.98
5.44
71.78
15.43
10.05
16.64
44.83
28.79
44.96
1.4
Paleo.
Eocene
Oligo.
Mio.
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Ma
Tethys closes
Node calibration
95% Posterior Prob.
Colpophyllia natans
Diploria clivosa
Favia fragum
Pseudodiploria strigosa
Diploria labyrinthiformes
Manicina aerolata
Manicina mayori
Isophyllia rigida
Mussa angulosa
Mycetophyllia
3 species
Scolymia cubensis

Biogeography of fossils

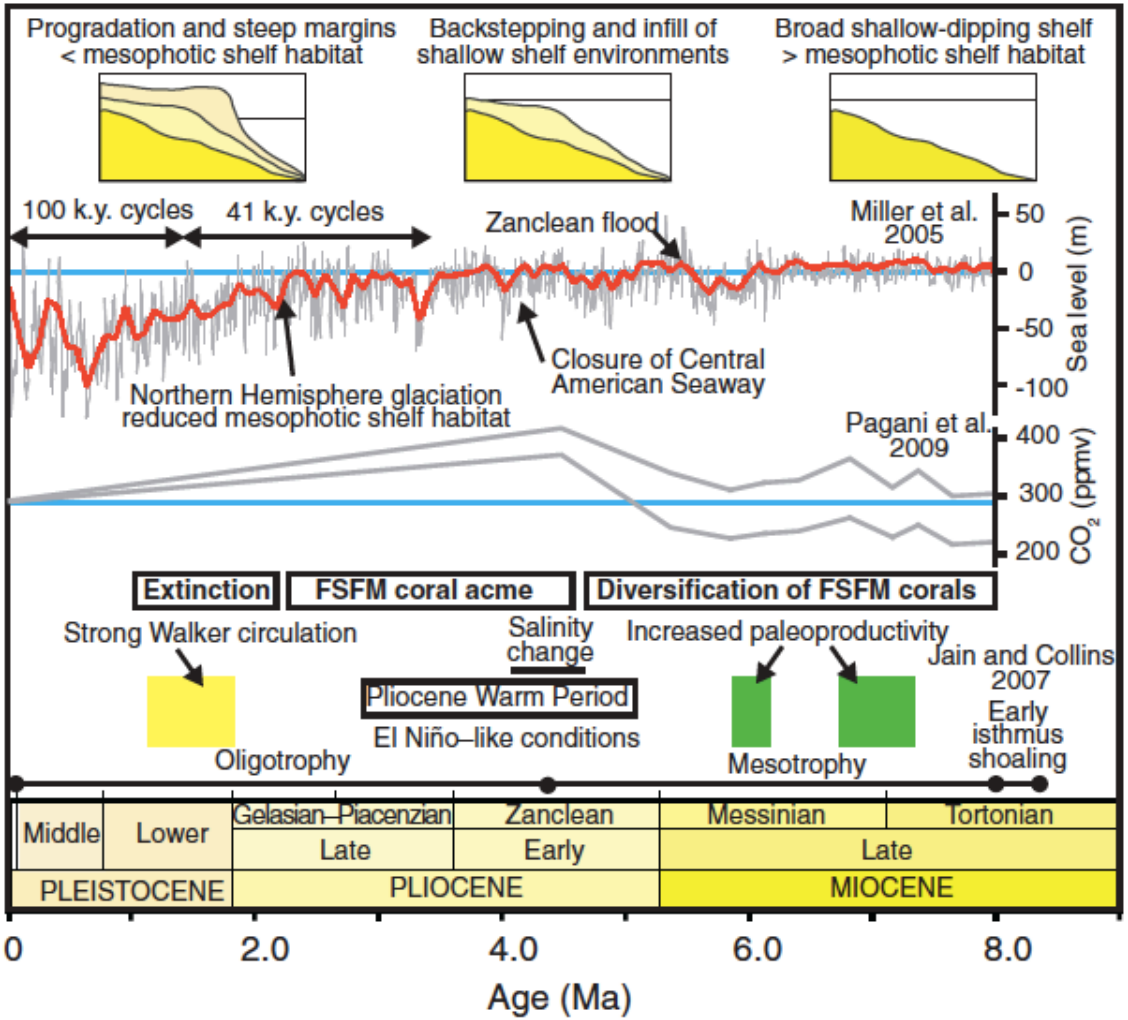








Environmental Change – late Miocene



Klaus, J. S., B. P. Lutz, D. F. McNeill, A. F. Budd, et al. 2011. Rise and fall of Pliocene free-living corals in the Caribbean. Geology **39:** 375-378.

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  - Comparative method
- Fossil Record
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  - Extinction
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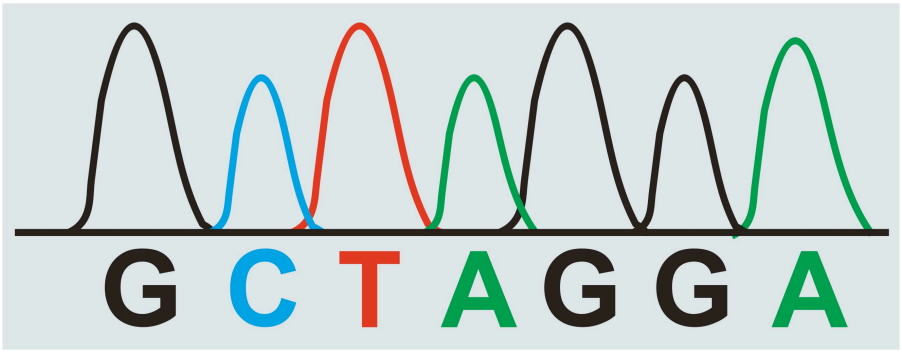
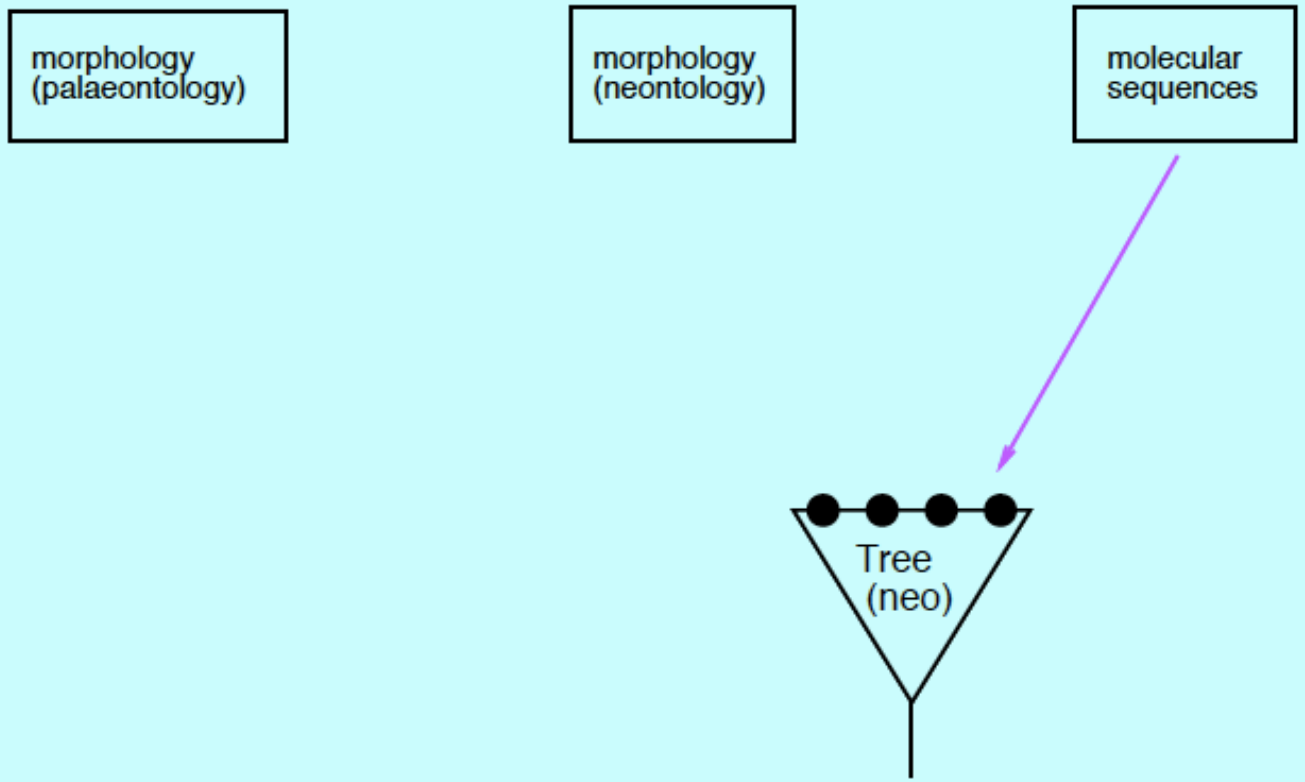


Two important papers...

- Felsenstein, J. 2002. Quantitative characters, phylogenies, and morphometrics. Pp. 27-44 *in* N. MacLeod and P. Forey, eds. Morphology, shape and phylogeny. Taylor and Francis, London.
- Revell, L. J., D. L. Mahler, R. G. Reynolds, and G. J. Slater. 2015. Placing cryptic, recently extinct, or hypothesized taxa into an ultrametric phylogeny using continuous character data: A case study with the lizard *Anolis roosevelti*. Evolution **69:** 1027-1035.

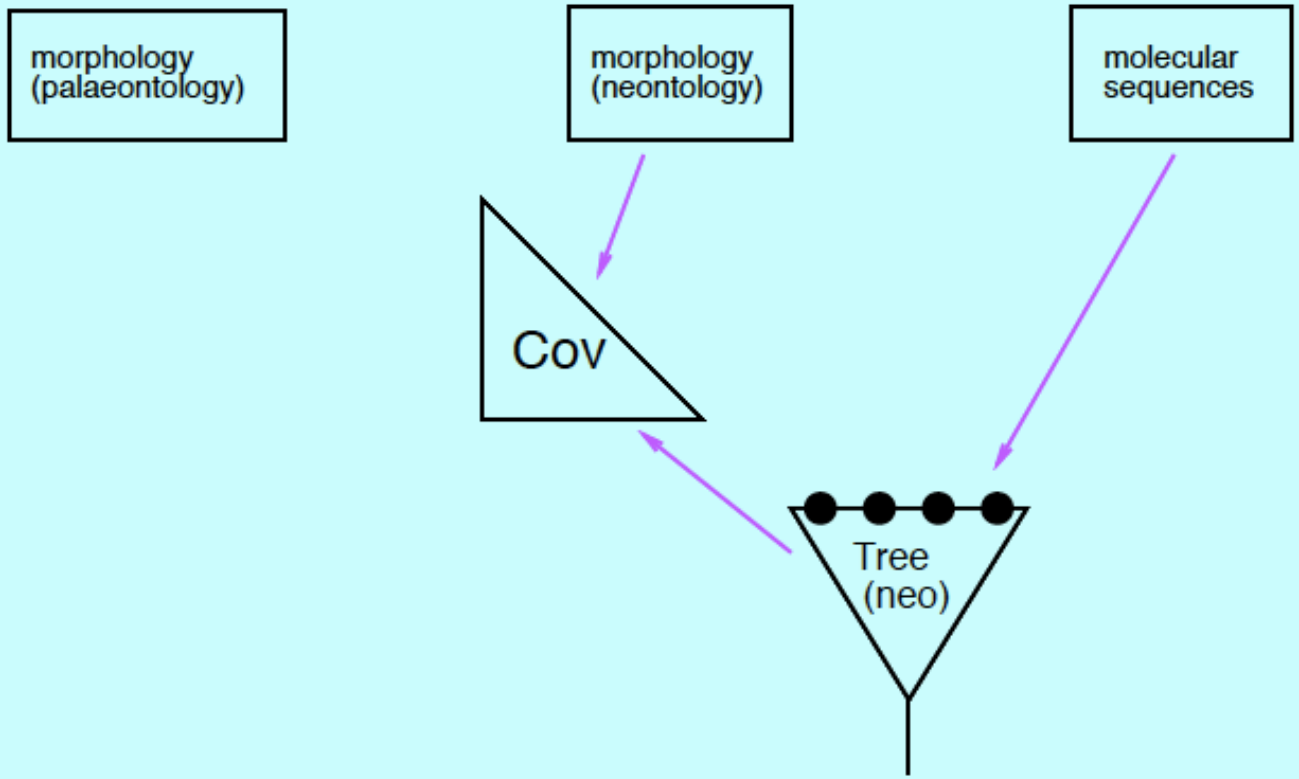
Another way of using fossils



Infer tree of present-day species from molecular sequences

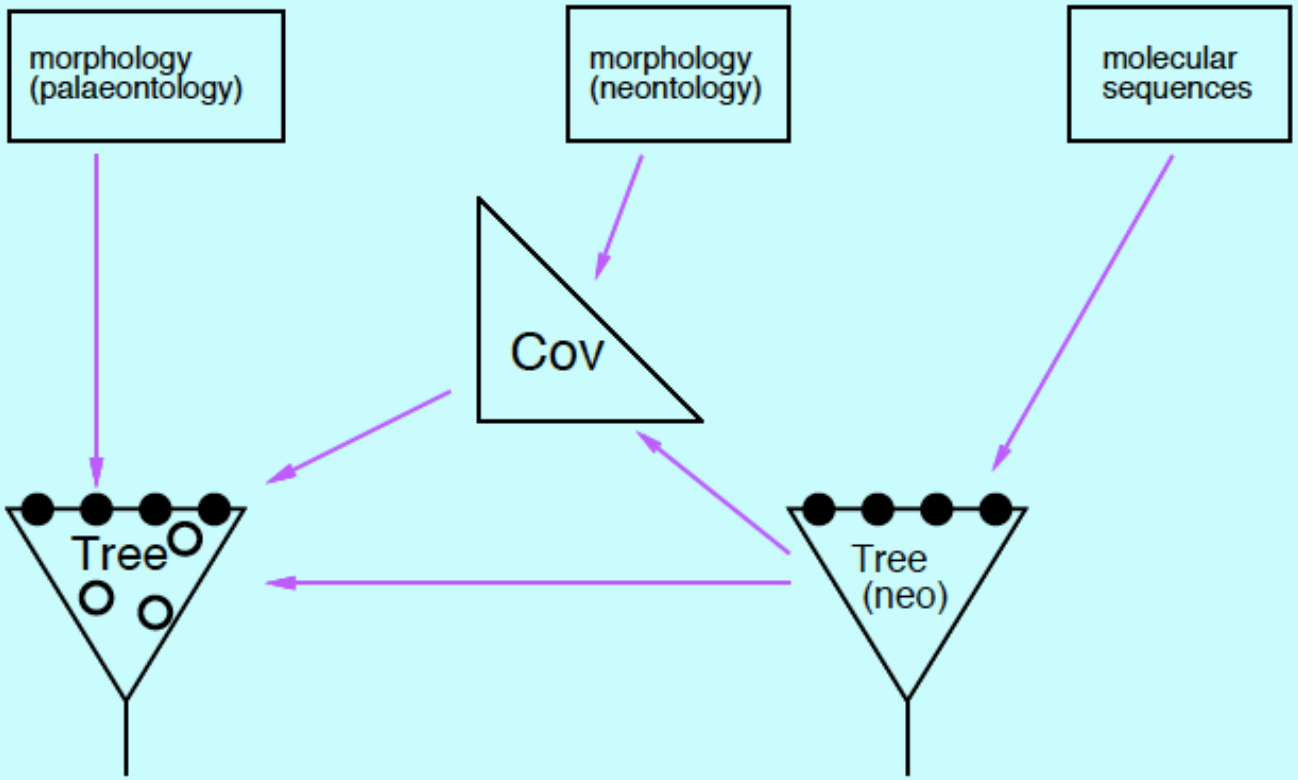
Slides are Joe Felsenstein's, with permission

Using fossils



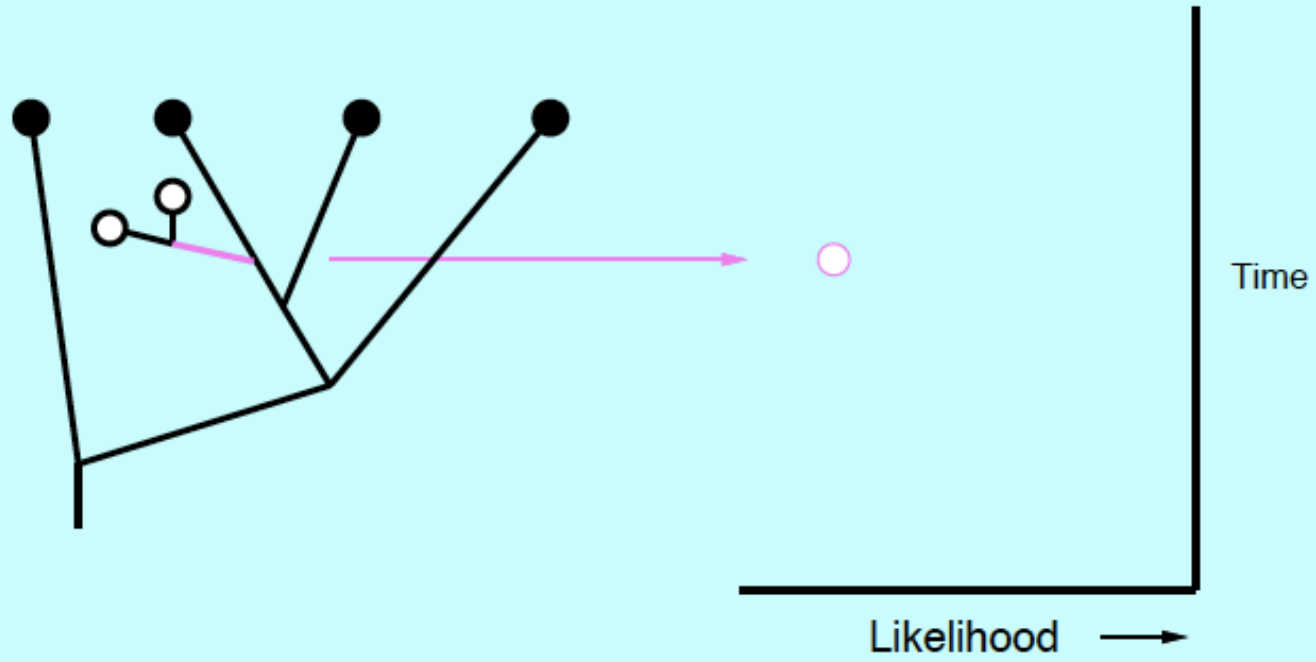
Infer covariances of morphology using it, present-day species

Using fossils



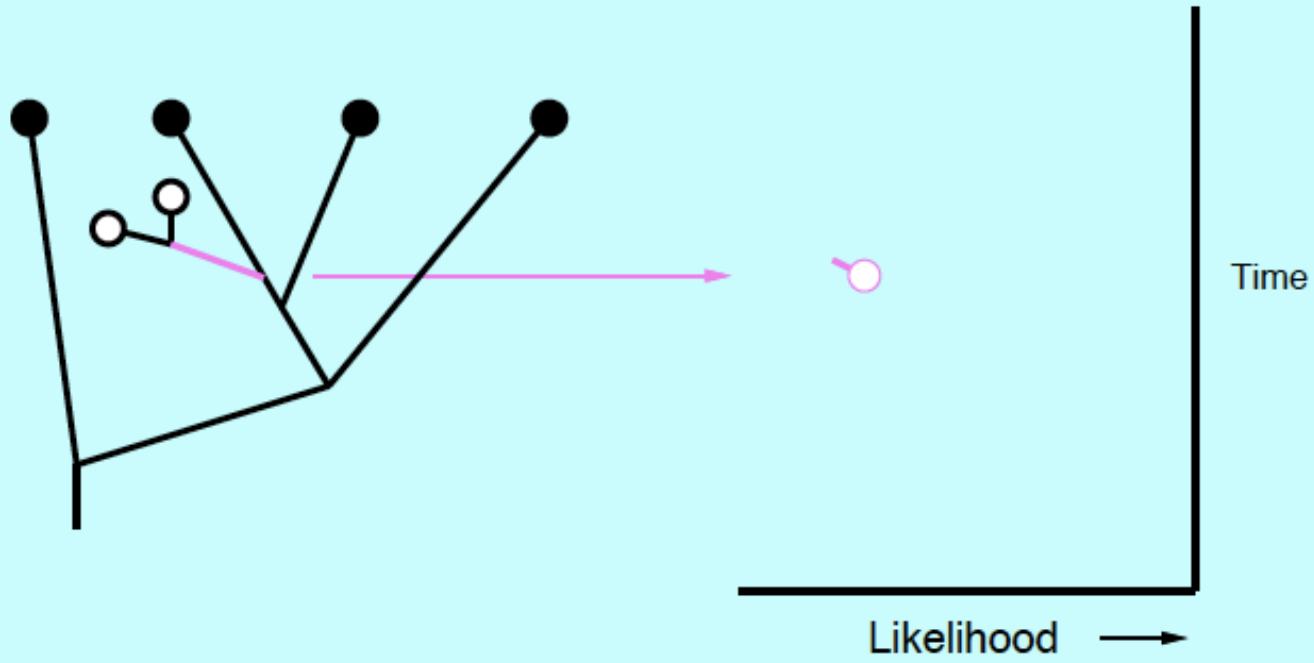
Infer placement of fossil species using their data

Using fossils



Use fossil and present-day morphology, covariances, tree, also stratigraphic models

Using fossils



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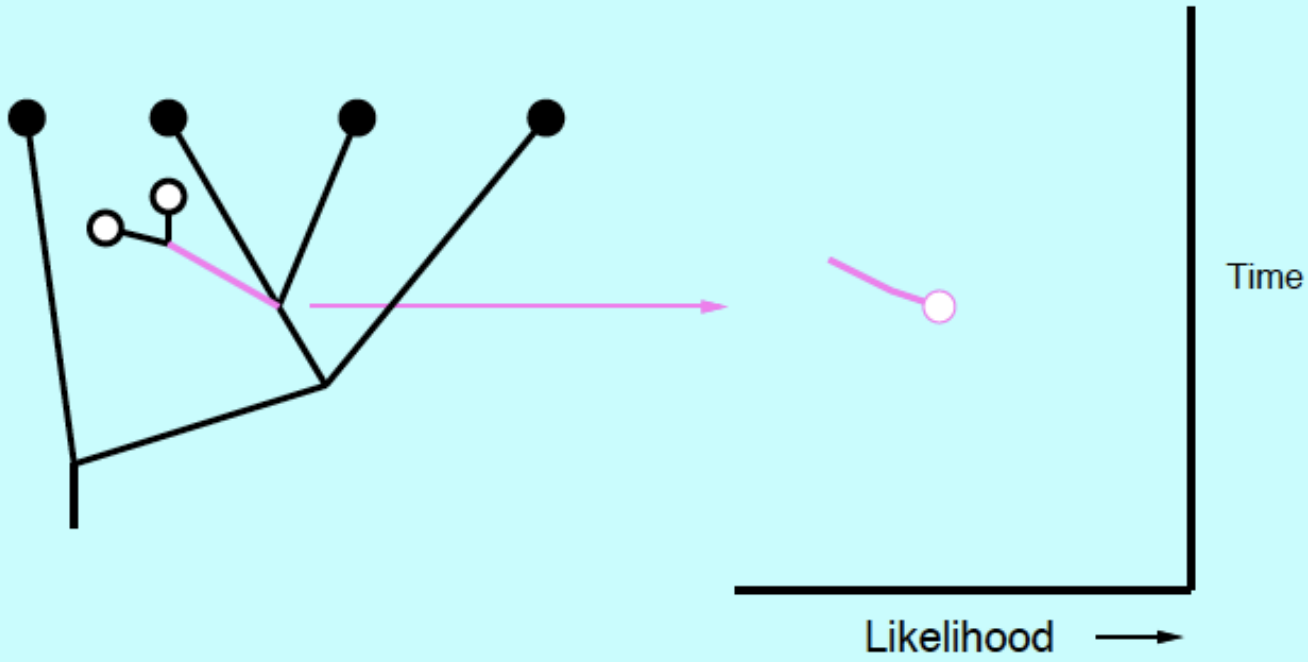

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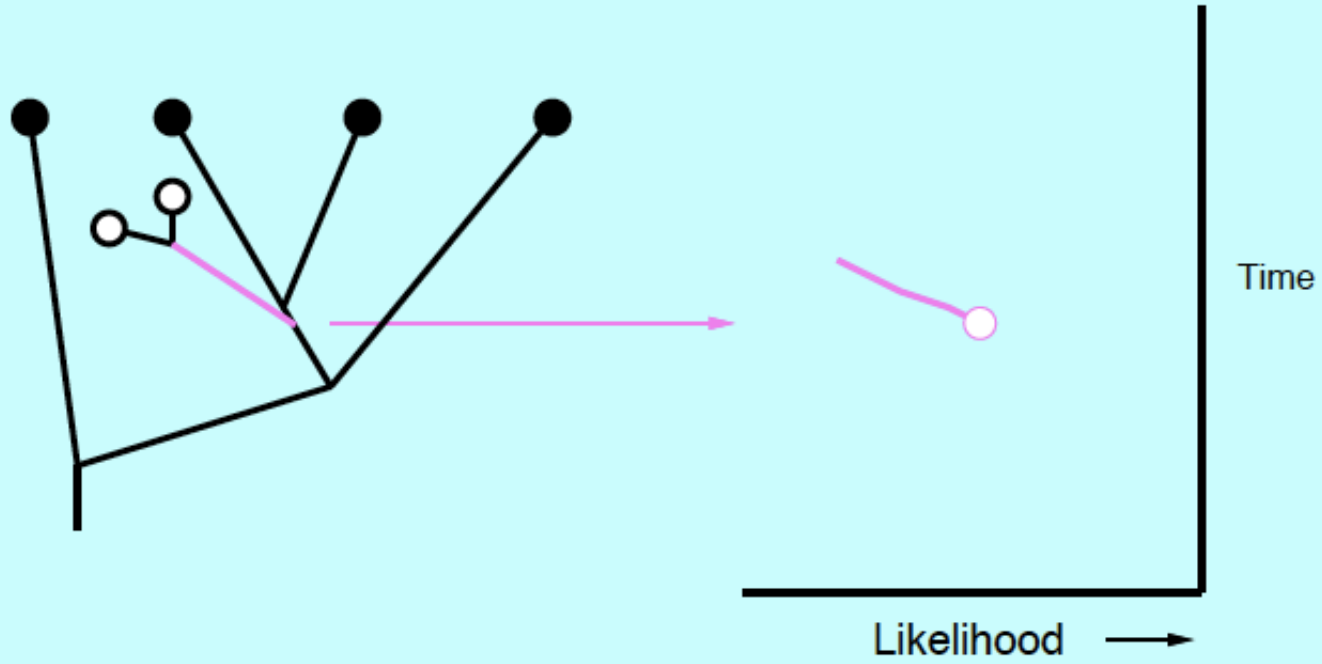

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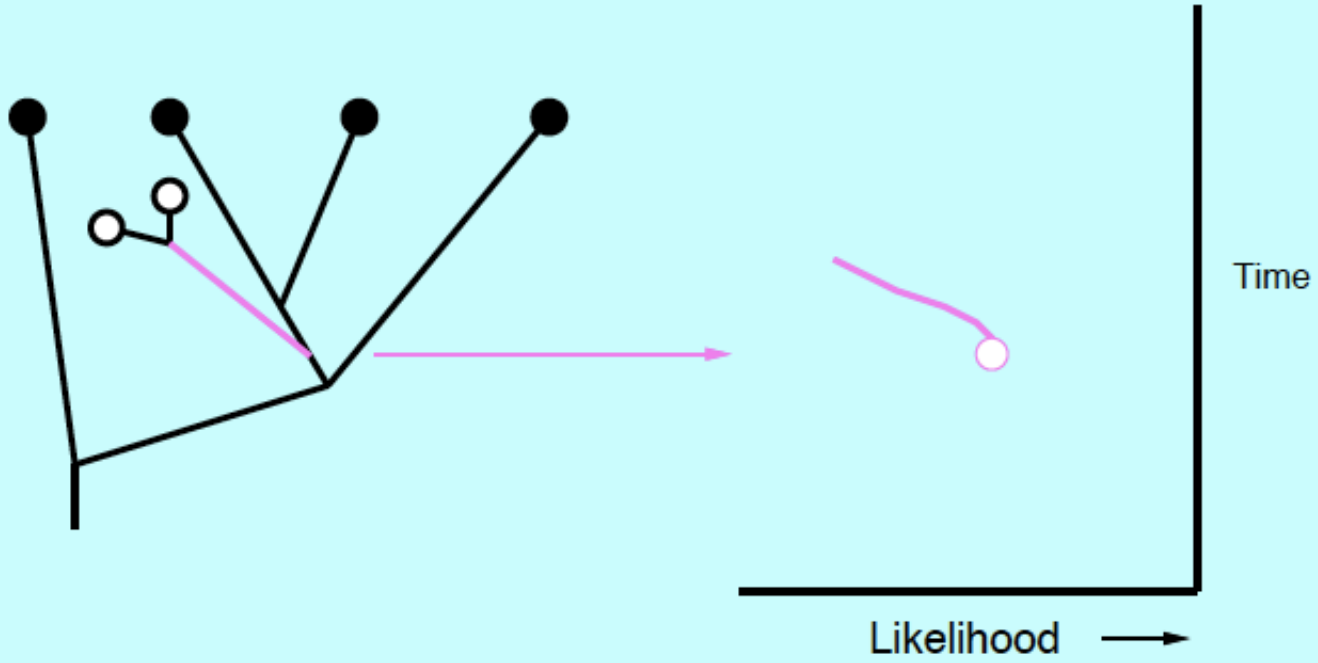

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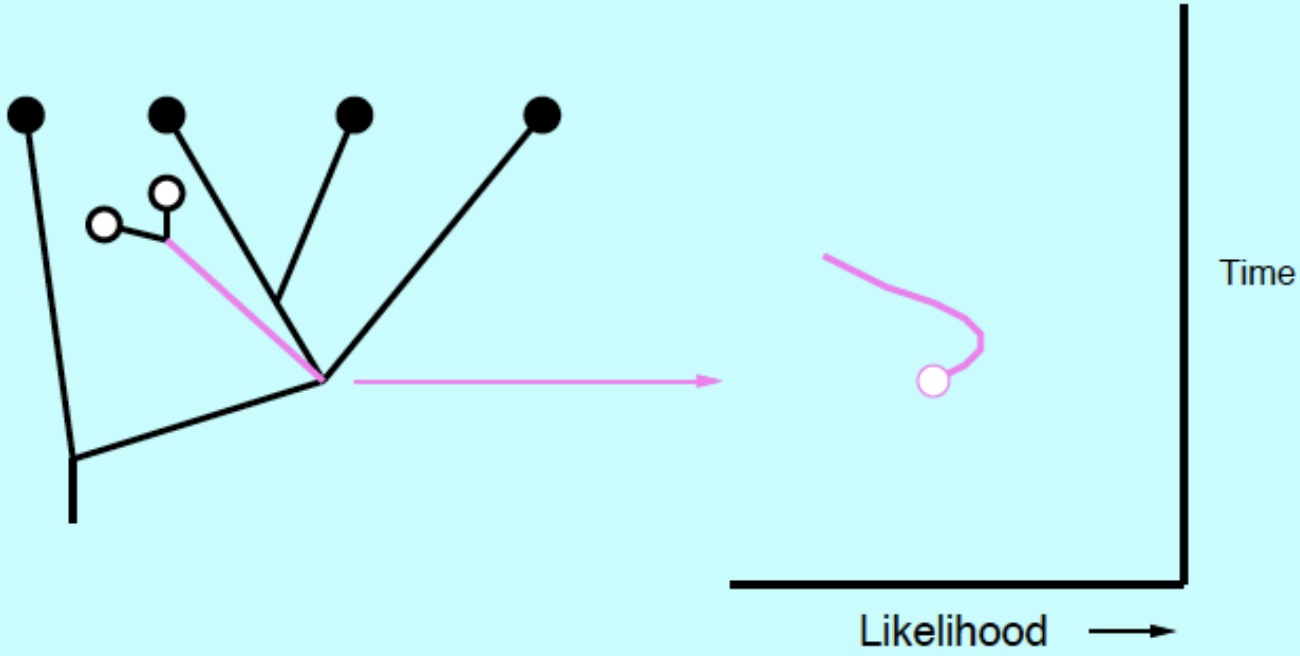
Using fossils



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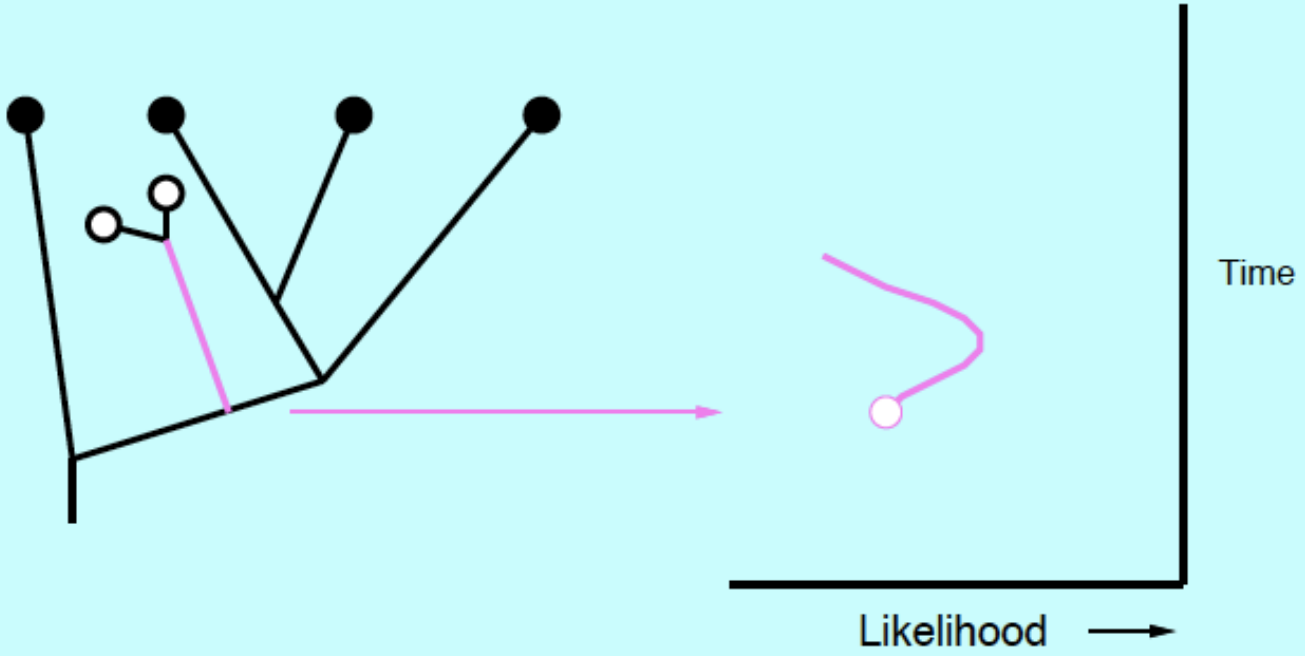
Using fossils



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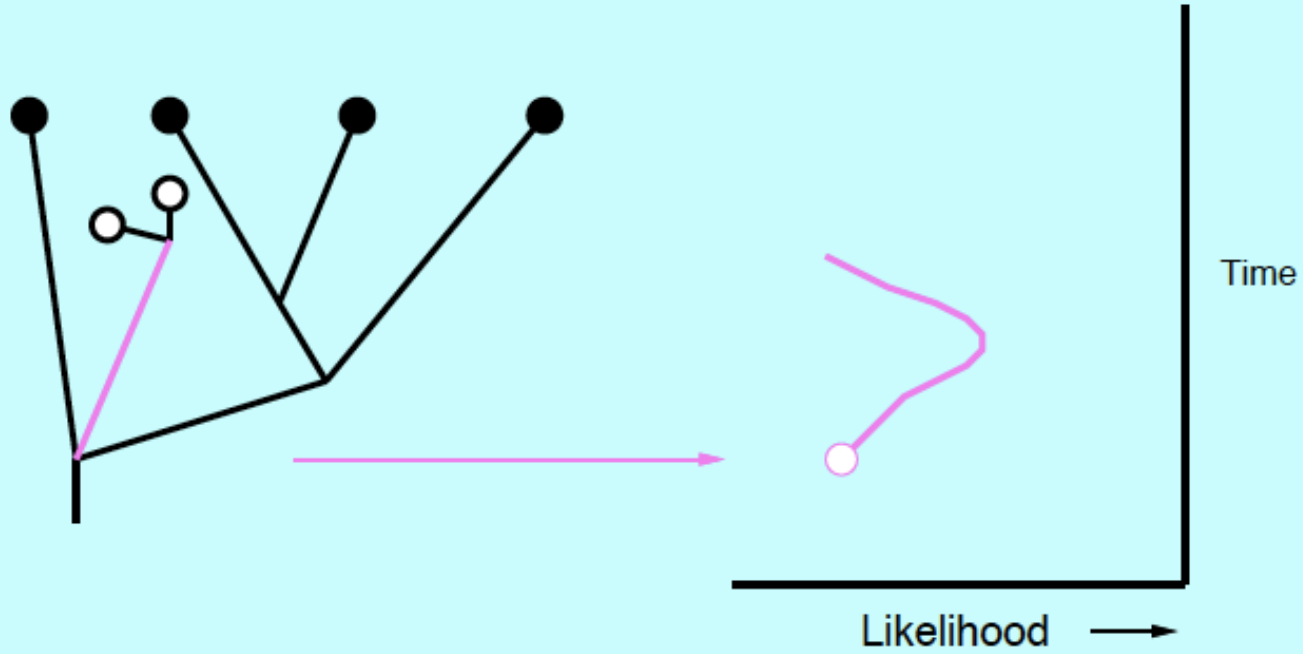

Use fossil and present-day morphology, covariances, tree, also stratigraphic models

Thanks to Nancy,
and to my many colleagues in this room

National Science Foundation
WHERE DISCOVERIES BEGIN