The Biogeography of ‘Sluggish’ Evolution: The Impact of Geographic Range Size on Extinction Selectivity in Pennsylvanian Brachiopods of The North American Mid-continent

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Extinction Selectivity

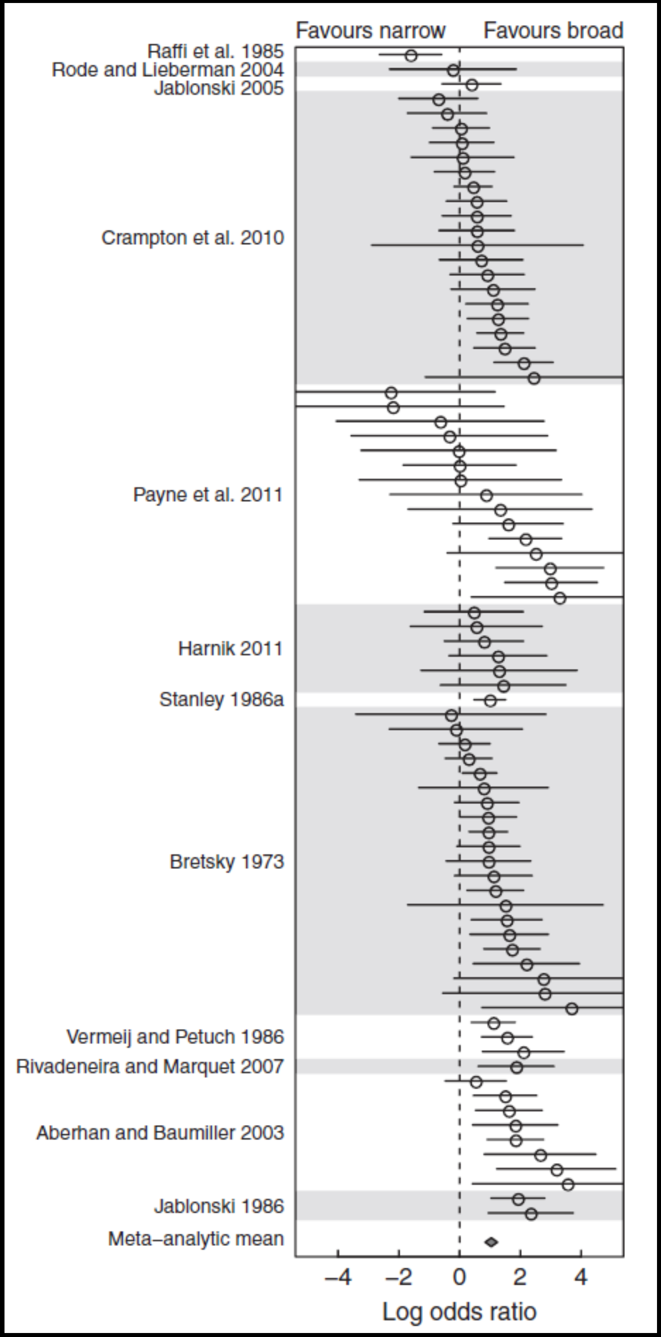
- What characteristics help to buffer species from extinction?
- Proposed Traits (Mace et al., 2008; McKinney, 1997):
    - Abundance
    - Body size
    - Geographic range size
- Numerous studies have supported the importance of geographic range size

Kiessling and Aberhan, 2007; Payne and Finnegan, 2007; Harnik et al., 2012; Saupe et al. 2015

Geographic Range Size

- Broader is better
- Beneficial during background extinctions (Jablonski, 1986; Powell, 2007) and regional mass extinctions (Kiessling and Aberhan, 2007)
- Beneficial during **some** of the 'Big 5' mass extinctions (Jablonski, 1986; 2008)
- Breaks down where extinction driver is truly global (Kiessling and Aberhan, 2007) or the event is extremely rapid (Erwin, 1996)
- May vary with overall extinction rate (Payne and Finnegan, 2007)

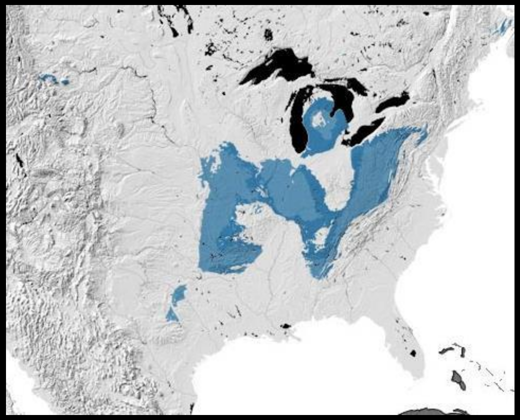
- Does large geographic range size buffer against extinction during times of 'sluggish' evolution?



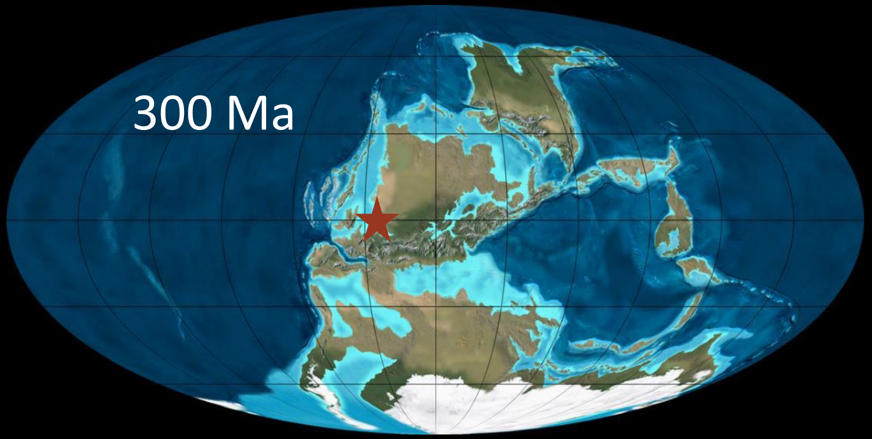
Orzechowski et al., 2015

Pennsylvanian – Mid-continent

- Late Paleozoic Ice Age
- Stable, cyclic climate and sea level (Heckel, 2008; Horton et al., 2012)
- Time of 'sluggish' evolution
  - Low rates of extinction
  - Low rate of origination
  - late Mississippian until the early Permian (Stanley and Powell, 2003; Powell, 2005)

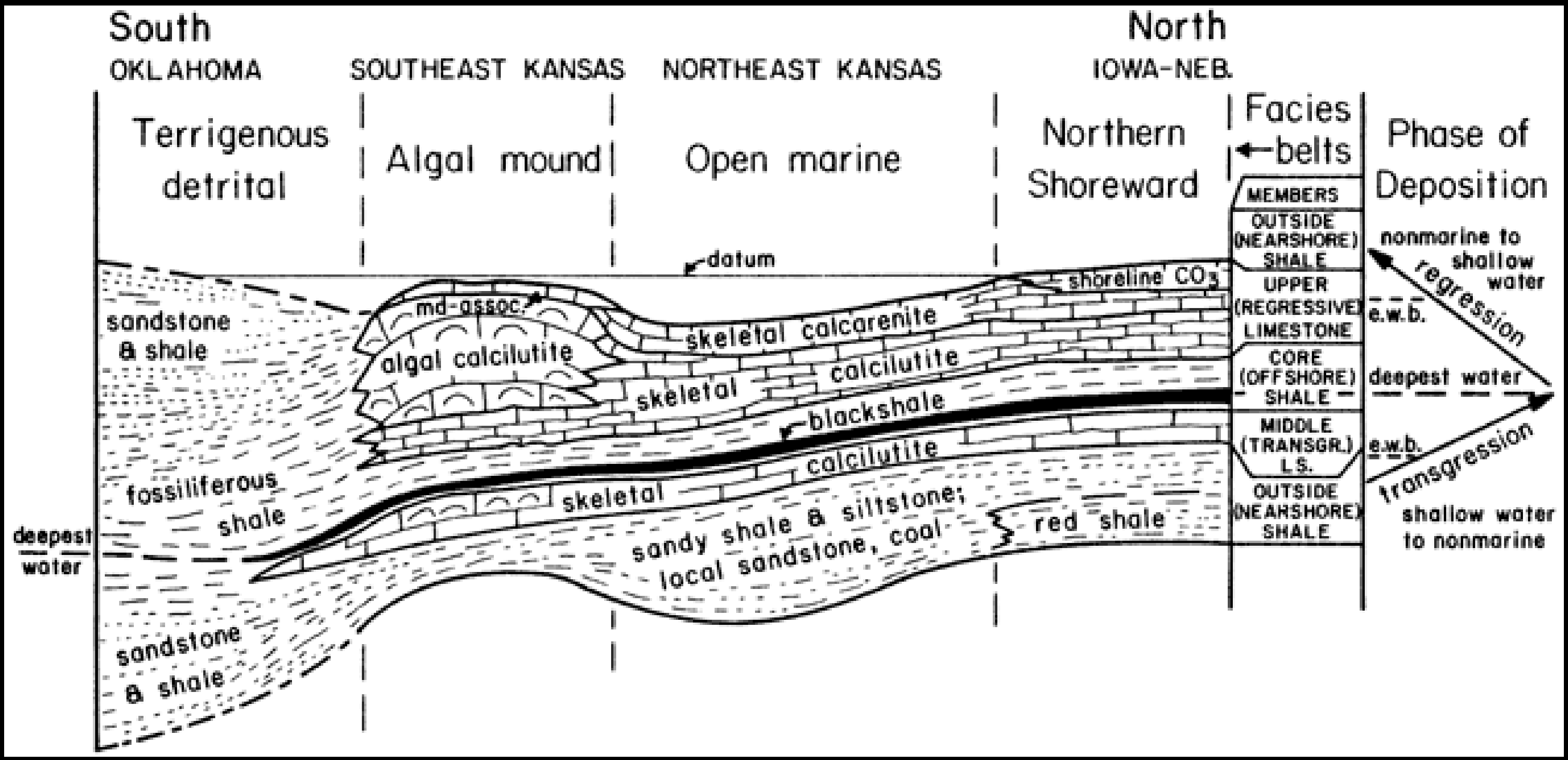


USGS



Ron Blakey

Homogenous Ramp

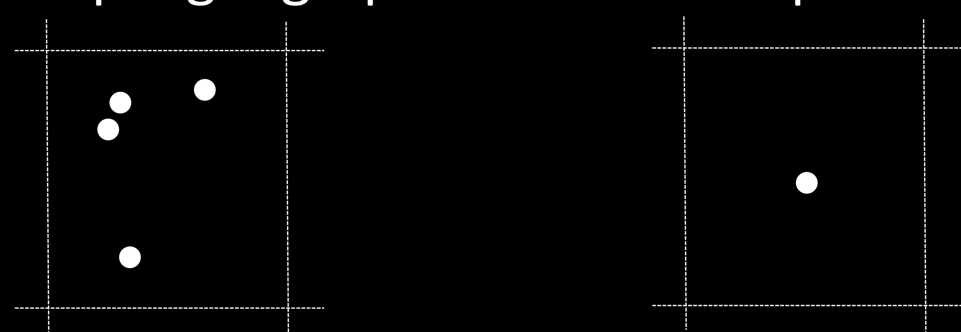


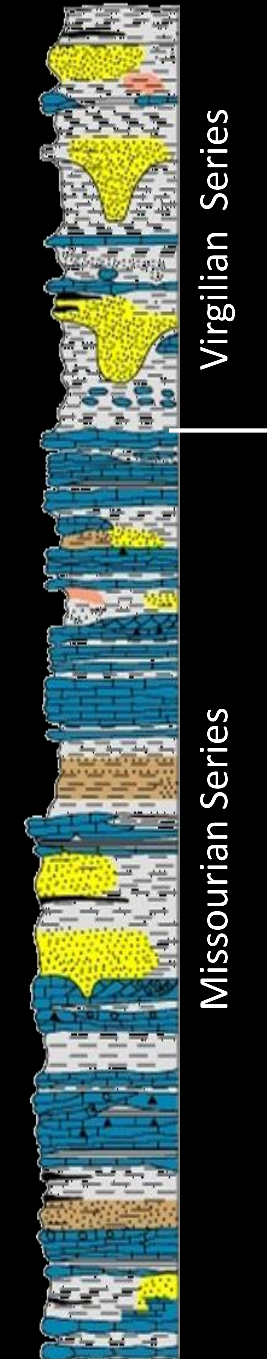
Approach

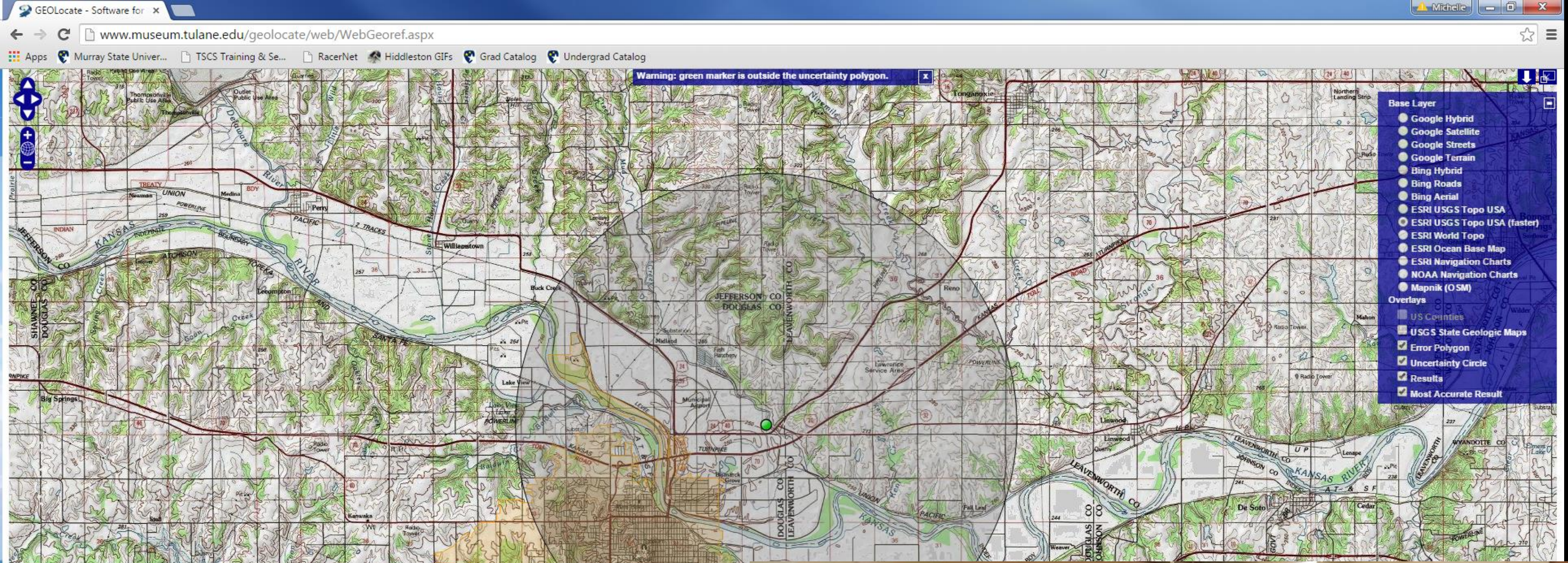
- Question: Does large geographic range size buffer against below average levels of background extinction?
- Brachiopod material from the University of Kansas and Yale Peabody museum collections
- Recently cataloged and georeferenced
  - Part of an NSF-funded iDigBio (Integrated Digitized Biocollections) initiative
  - Within ADBC (Advancing Digitization of Biodiversity Collections)

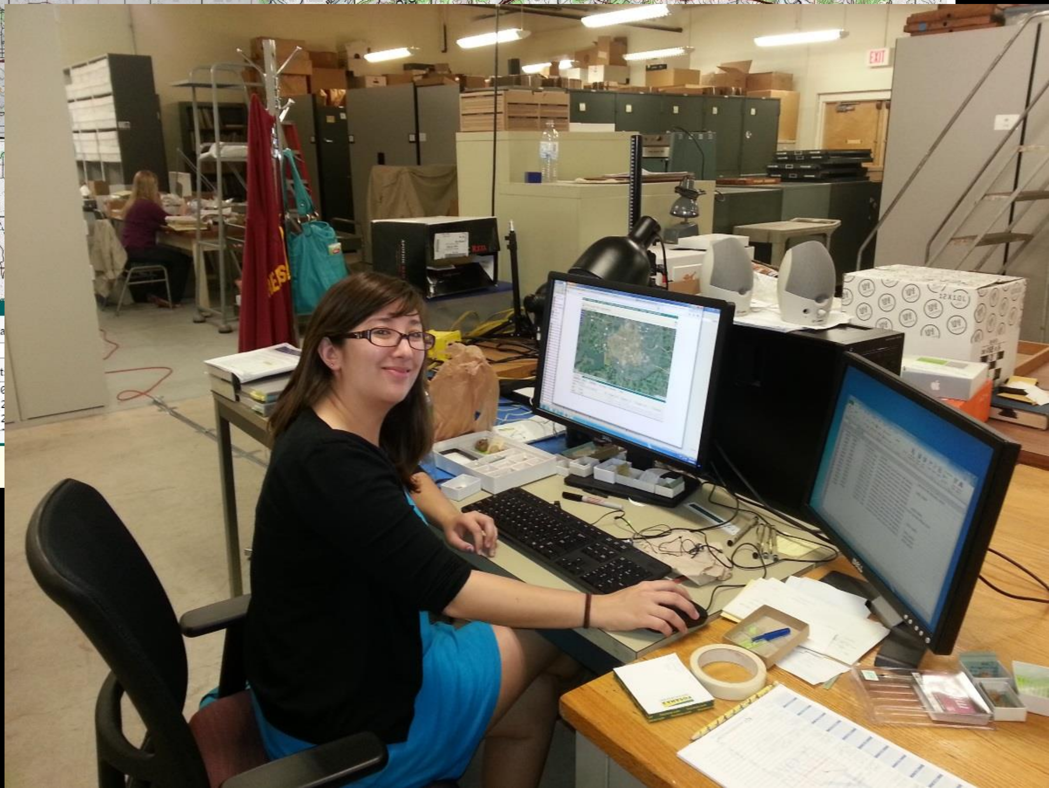
Methods

- 26,832 brachiopod specimens
- Updated taxonomy, 141 species
- Chronostratigraphic correlations (N. American stages)
  - Removed singletons (n=1) found in only 1 time bin
- Applied 10 km buffer around points
- Spatially culled points with 0.025˚ x 0.025˚ grid
  - 2,462 unique geographic occurrence points







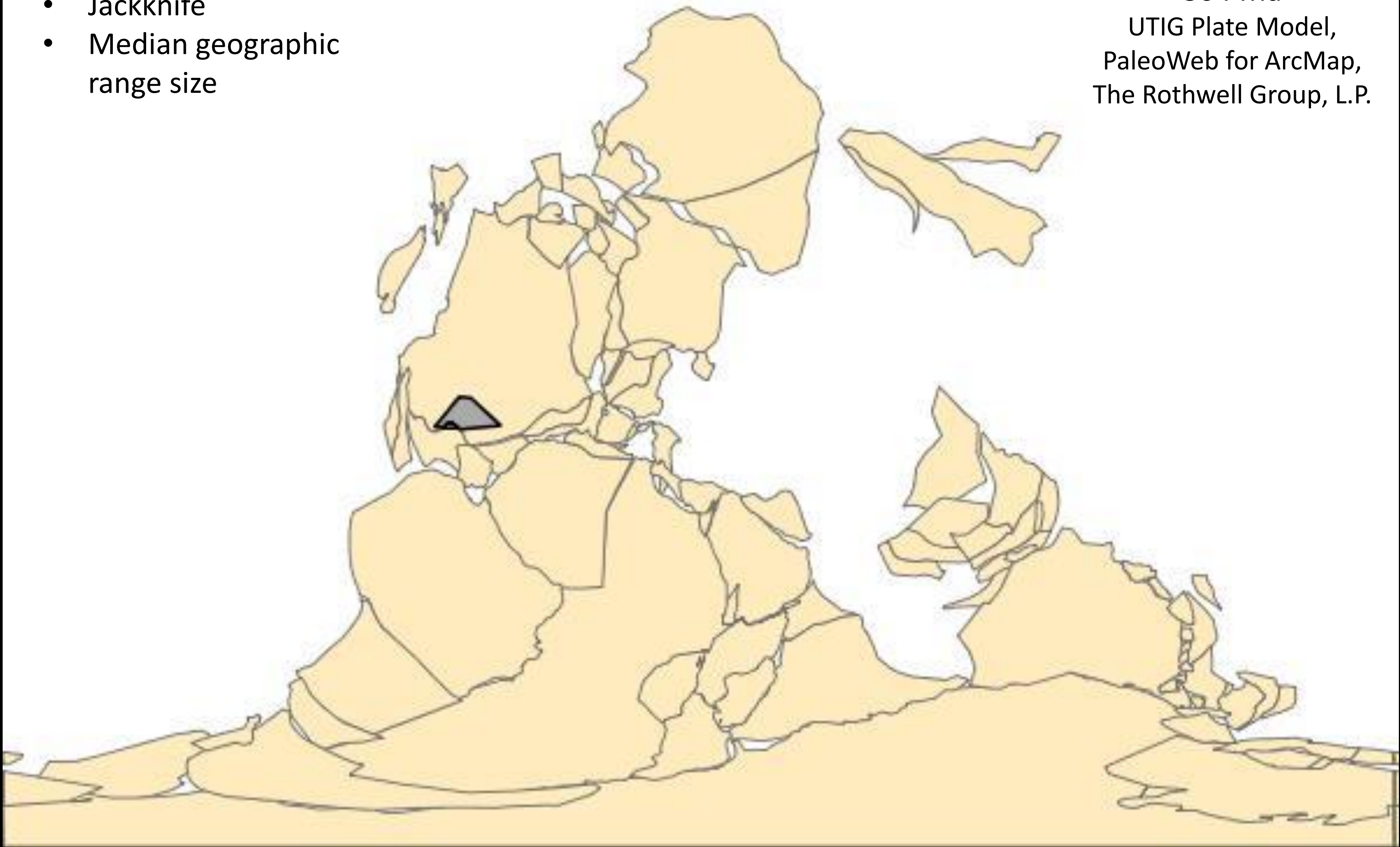


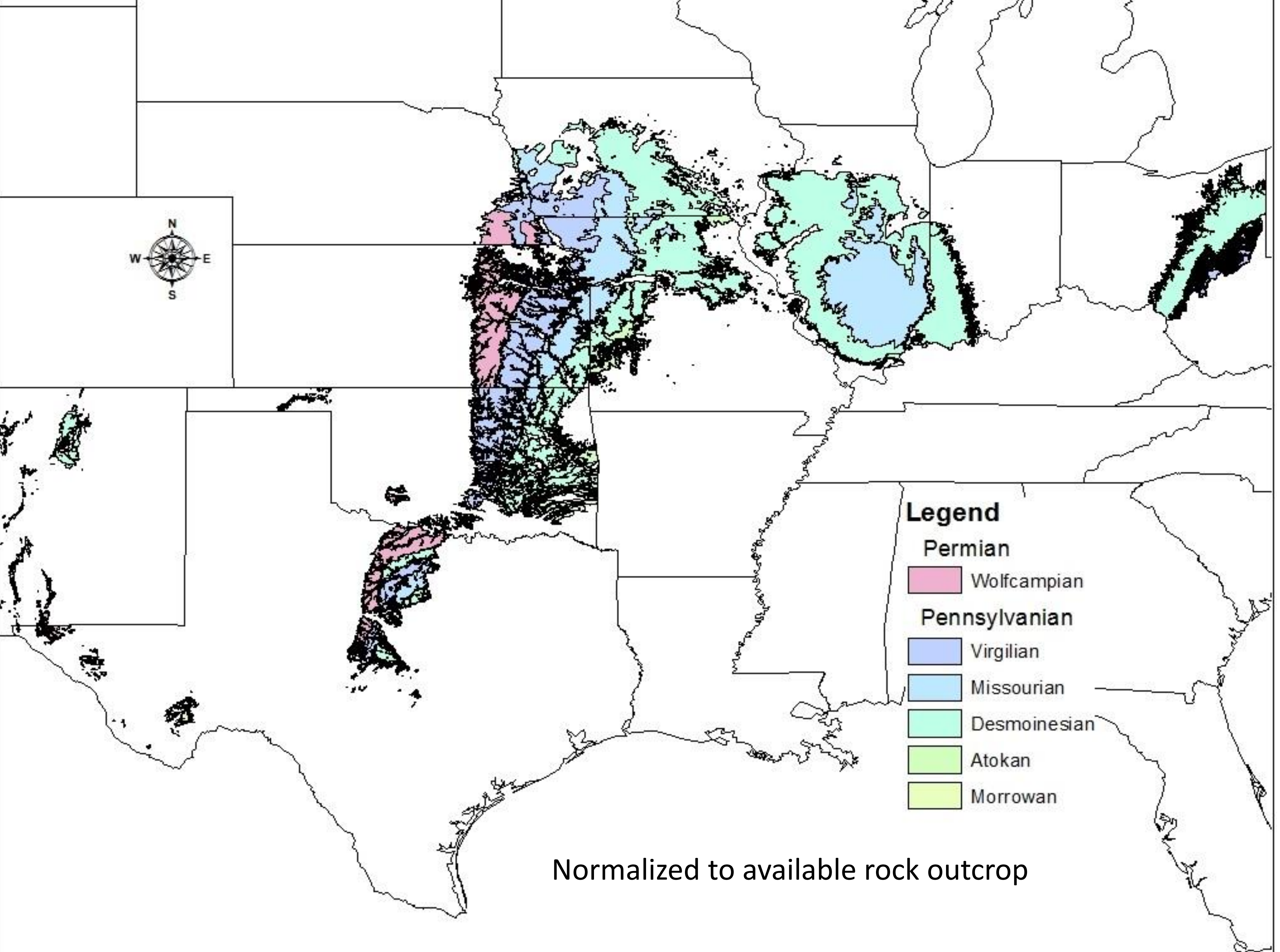
Georeferencing

Paleogeographic Reconstruction

- Convex hull
- Jackknife
- Median geographic range size

Hystriculina washensis
304 Ma
UTIG Plate Model,
PaleoWeb for ArcMap,
The Rothwell Group, L.P.





Normalized to available rock outcrop

Extinction & Origination Rates

$$q_i = -\ln[(N_{bt})/N_b]/\Delta_t$$

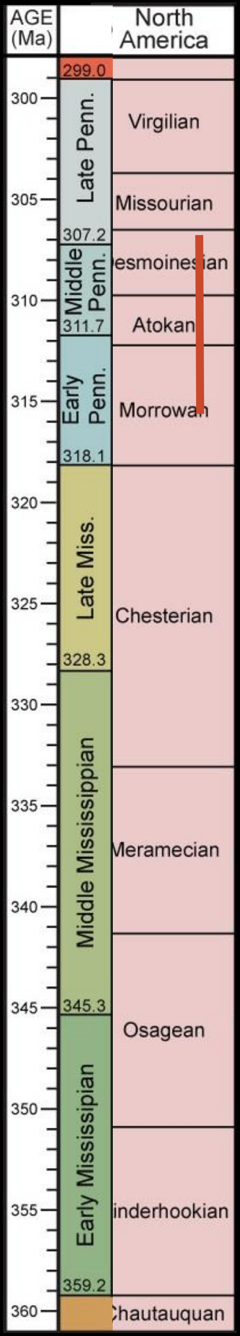
Time Bin	Per Million Year Extinction Rate	Per Million Year Origination Rate
Morrowan	0	0.16
Atokan	0	0.01
Desmoinesian	0.04	0.07
Missourian	0.04	0.22
Virgilian	0.09	0.04
Wolfcampian	0.04	0.03

Avg. Paleozoic background extinction rates ≈0.20
(Stanley and Powell, 2003)

N_b = # species cross bottom boundary
N_{bt} = # species that cross both boundaries
Δ_t = interval duration in millions of years
(Foote, 2000)

Geographic Range Size Results

- No correlation between longevity and geographic range size of the species
  - Normalized to rock volume, Kendall's tau, P = 0.94
  - Without normalization, Kendall's tau, P = 0.17
- Surviving species not more broadly distributed than taxa that went extinct
  - Mann-Whitney U test, median geographic range size
  - Desmoinesian: n = 57, P = 0.83
  - Missourian: n = 82, P = 0.42
  - Virgilian: n = 87, P = 0.0003
  - Wolfcampian: n = 62, P = 0.59



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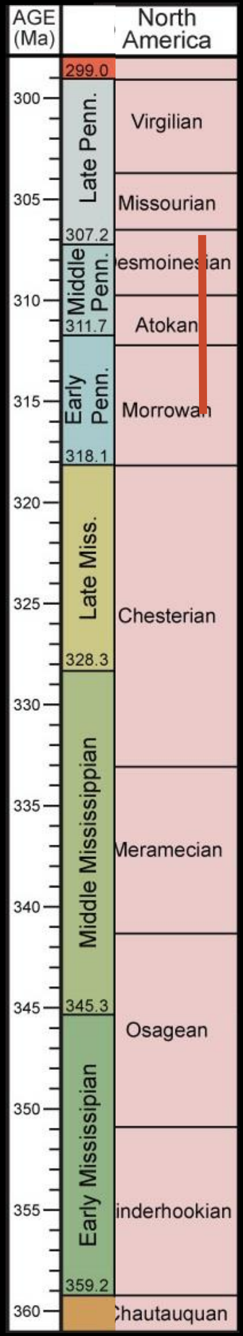
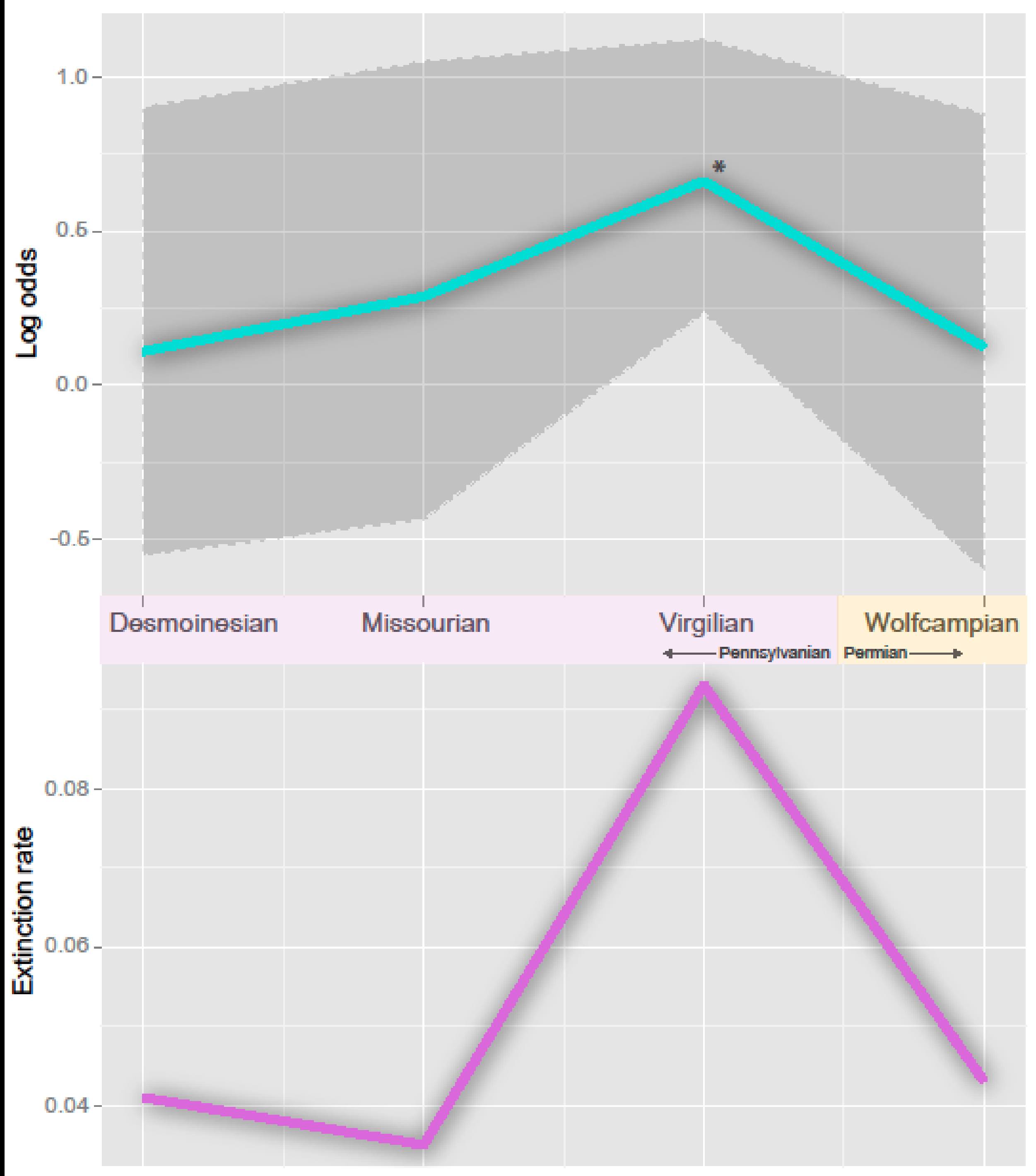


No geographic evidence of decline

Binary Logistic Regression



Preliminary Implications

- Unique driver of extinction during Virgilian relative to other time bins
  - No evidence for this interpretation within climate or sea level data
- Lower bound to the utility of large geographic range size
  - Environmental change is gradual creating few spatially-heterogeneous environmental perturbations to precipitate species extinctions
  - Other factors may be driving extinction, such as biotic interactions or chance events
- No support for diversity or abundance buffering against extinction

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