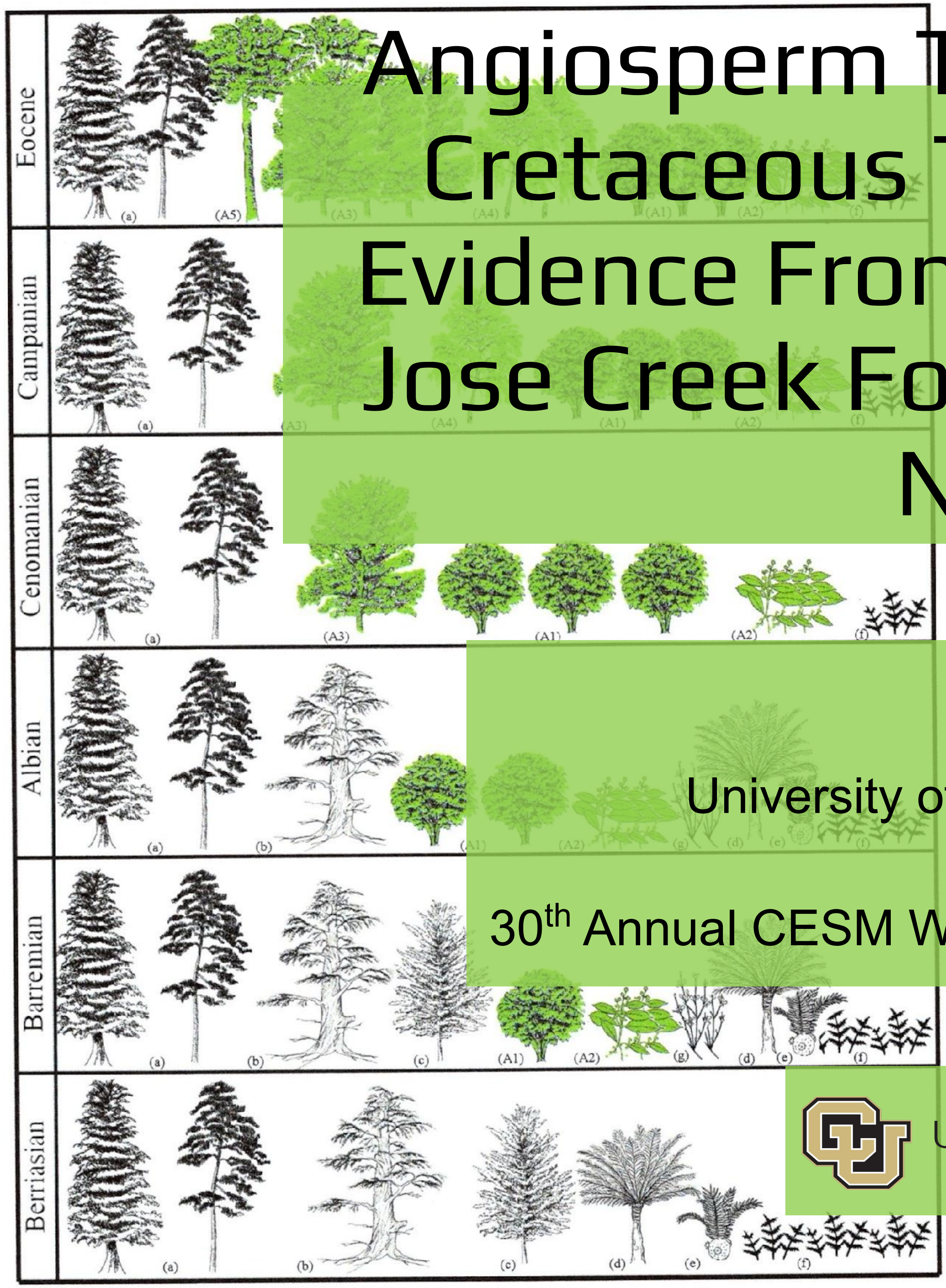

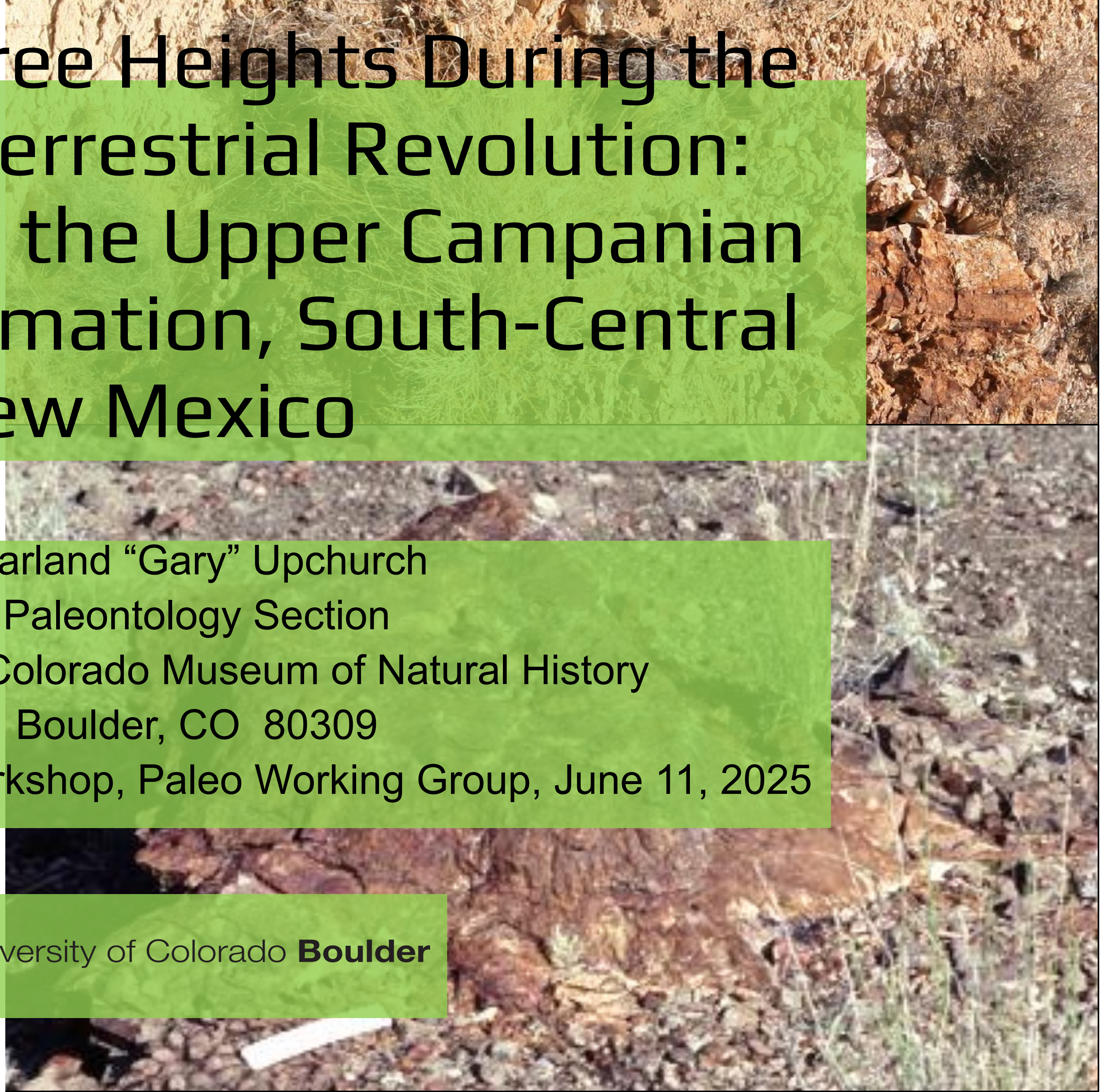

Angiosperm Tree Heights During the Cretaceous Terrestrial Revolution: Evidence From the Upper Campanian Jose Creek Formation, South-Central New Mexico

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University of Colorado **Boulder**

Introduction

- Cretaceous rise of angiosperms revolutionized terrestrial ecosystems
  - Conifers, other gymnosperms, ferns
  - Displaced by woody and herbaceous angiosperms
- Major impacts on land surface
  - Hyper-diverse vegetation
  - Altered land surface physics
    - Slow growing, slow transpiring gymnosperms and ferns
    - Fast growing, fast transpiring angiosperms

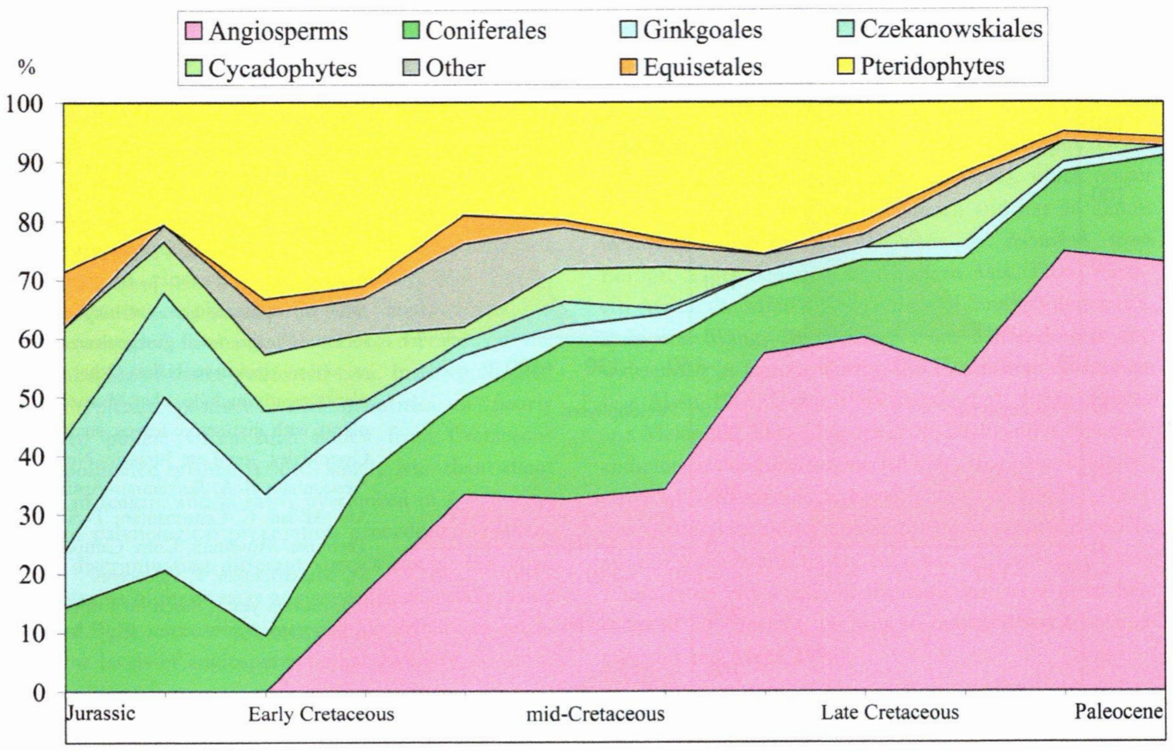


Figure 19.2 Changes in diversity patterns for major land plant groups from the Late Jurassic to the Early Cenozoic (Paleocene) of Northeastern Russia based on leaf fossils from 12 stratofloras distinguished during this interval. The first appearance of angiosperms is in the Early Albian. Pteridophytes are mainly ferns in this case and exclude Equisetales. Data from Samylina (1974) and Goloneva (1998).

From Friis, Crane, and Pedersen, 2011, Fig. 19.2

When did angiosperms become both tall and dominant?

- Big Cedar Ridge, Meeteetse Formation, Wyoming
  - 4 km long volcanic ash bed, ~73 Ma
  - *In situ* wetland flora, fern dominance
  - Diverse low stature angiosperms
  - Trees were conifers
  - Extrapolation: Angiosperms not large trees until Cenozoic
- More globally based reconstructions
  - Angiosperm trees by Cenomanian
  - Full canopy height not until Cenozoic

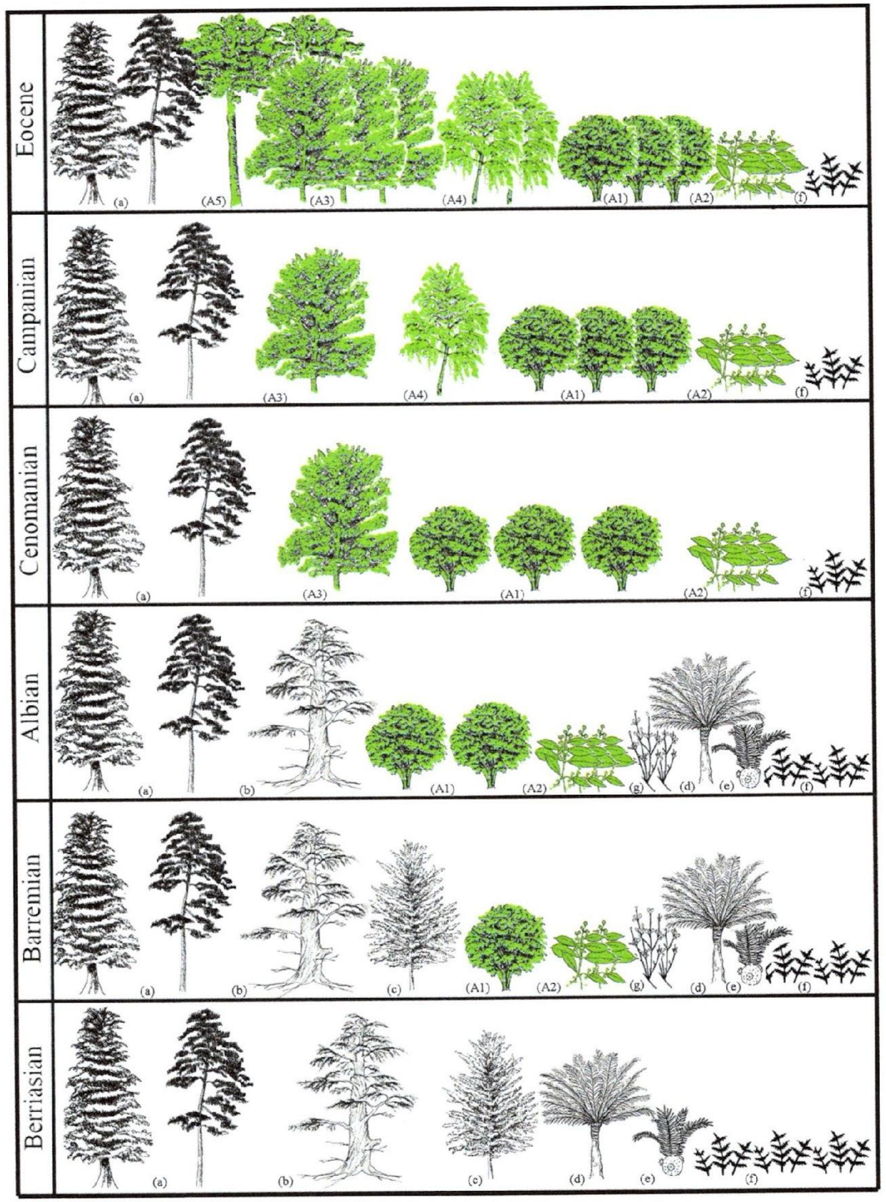
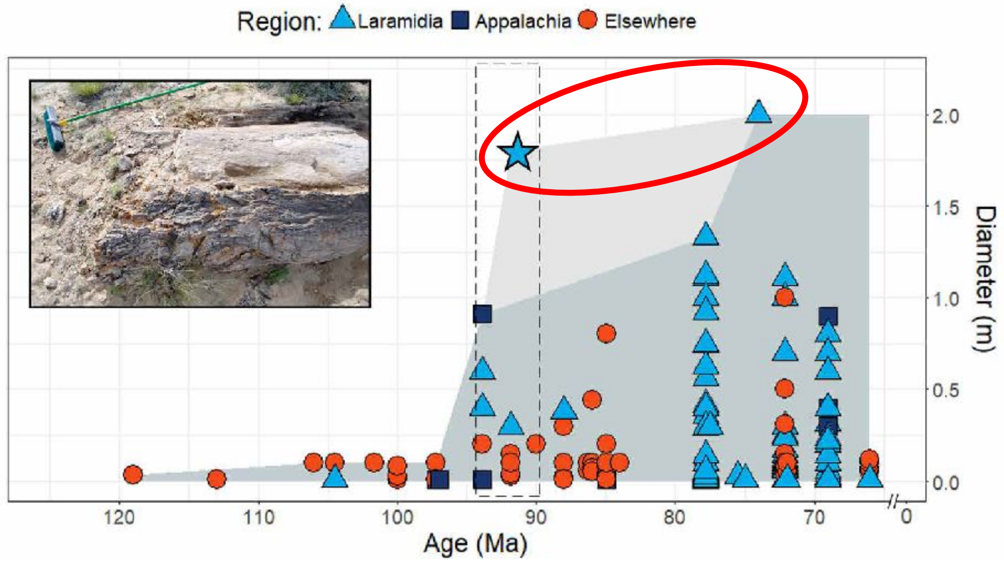


Figure 19.5 Summary of vegetational changes through the Cretaceous and Cenozoic in southern Laurasia for selected intervals from the Berriasian to Eocene showing angiosperm expansion. (a) conifers; (b) cheirolepidiaceous conifers; (c) ginkgoaleans; (d) cycads; (e) bennettitaleans; (f) ferns; (g) ephedroids; (A1) angiosperm shrubs; (A2) angiosperm herbs; (A3) angiosperm trees, insect-pollinated; (A4) angiosperm trees, wind-pollinated; (A5) angiosperm trees, canopy; (A: angiosperm aquatics, shown only in Figure 19.4) Angiosperms in green. Modified from Crane (1987).

Friis, Crane, and Pedersen, 2011, Fig. 19.5

Record of Dicot Stumps and Logs

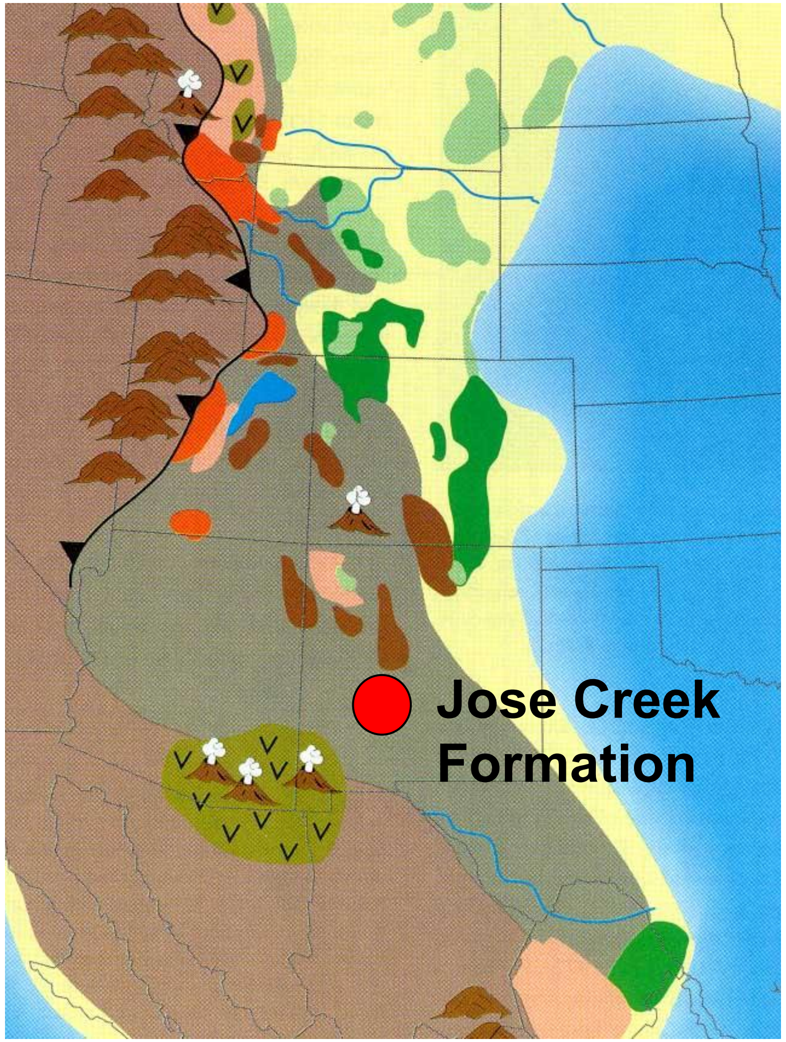
- Nathan Judd et al., 2018
  - (*Science Advances*, v. 4, eaar 8568)
- Global compilation of angiosperm stump/log diameters
  - Steady size increase through Late Cretaceous
  - Major outliers in Laramidia
    - Ferron Sandstone Member, Mancos Shale, Utah
      - 1.8 m diameter log
    - Jose Creek Formation, New Mexico
      - Stumps and logs up to 2 m diameter



Question addressed by this talk

- Do these large dicot trees indicate that angiosperms reached the height of modern tropical canopy trees during the Late Cretaceous?
  - Prior to the Cenozoic
  - Important component of Cretaceous forest vegetation
  - What environments?
- Outline of remaining talk
  - Sources of data
  - Method of analysis
  - Comparison
    - Estimated Cretaceous tree heights
    - Modern tropical forests
  - Implications

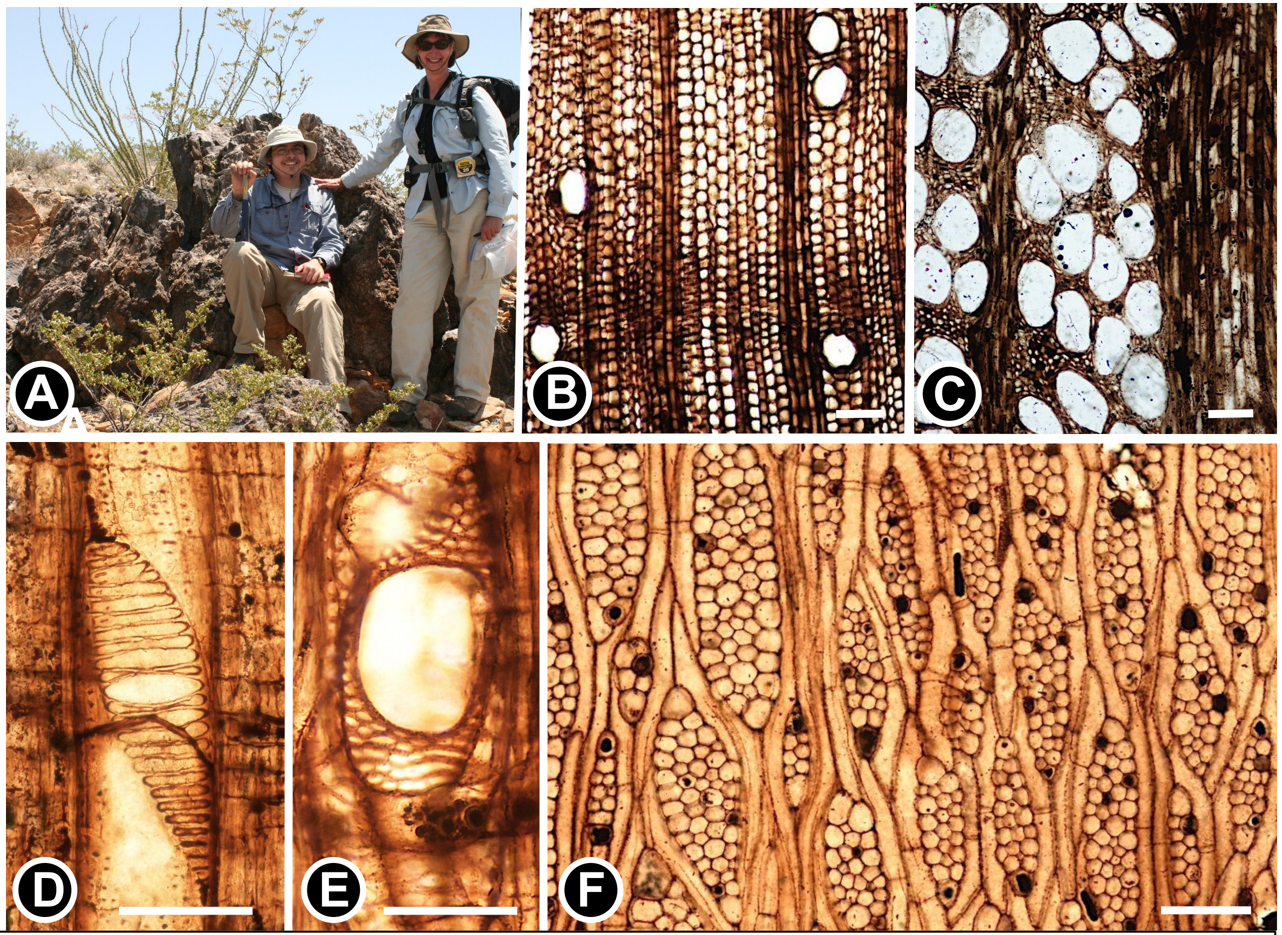
The Late Cretaceous Jose Creek Flora



- Jose Creek Formation
  - South-central New Mexico, USA
  - Interior setting, >100 km from seaway, *terra firma*
- Late Campanian: 76–72 Ma
  - U-Pb dating zircons (Amato et al., 2017)
- Diverse flora of leaves, woods, fruits, seeds
  - Megathermal (tropical) climate
- Abundant, diverse, well-preserved woods
  - Conifers
  - Dicots
  - Monocot stems (palms, others)
- *In situ* woods (stumps), logs, wood fragments
- Taxonomic data
  - Publications of Estrada-Ruiz et al. (*Int. J. Plant Sci.)*
  - Unpublished dissertation, Joan Parrott
- Stump/log measurements
  - Upchurch (with Emilio Estrada, Joan Parrott, Greg Mack)

The Jose Creek Wood Flora

- Dicots, palms, conifers
- >50 stumps and logs
- Hundreds of pieces (float)
- Detailed preservation of tissue
  - >38 dicot wood types
    - At least 20 from trees
  - 5–8 types of palms
  - Numerous conifers, multiple lineages
  - High diversity for a wood flora
- Excellent preservation
  - Silicification
  - Abundant volcanic ash
- Majority of species represent trees
  - >10 cm diameter
  - Modern forestry: trees >10 cm Diameter Breast Height (DBH)

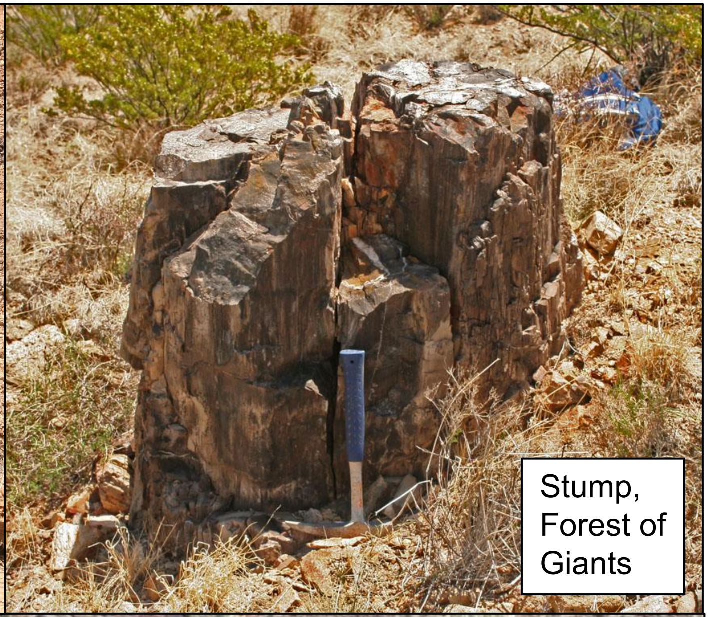


A. Stump of fossil dicot that measures 3.7 m in diameter at the base. Drs. Emilio Estrada-Ruiz and Joan Parrott provide scale. **B,C.** Cross section of two different fossil dicot woods. The large circular cells are vessel elements, which transport water inside the plant. **D.** Side view of vessel element with ladderlike (scalariform) perforations, which connect two adjacent cells. **E.** Side view of vessel element with a simple perforation. **F.** Side view of wood showing elongate fiber cells that run up and down, and storage tissue called rays. The dark spots are secretory cells in the rays.

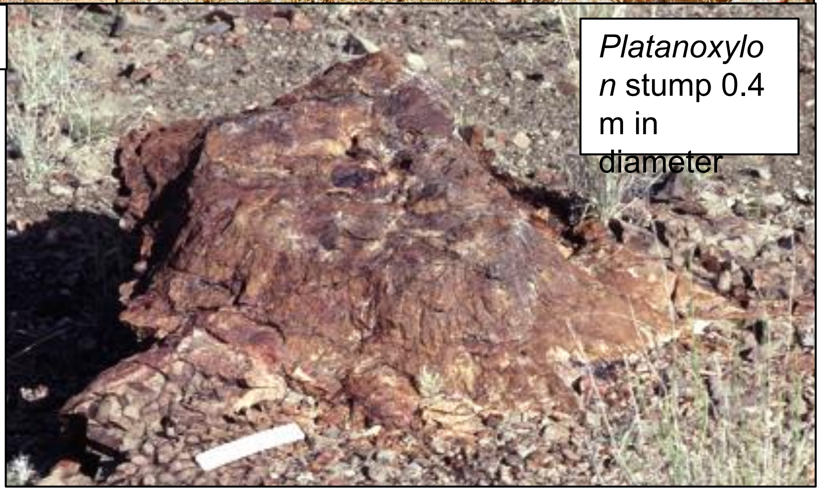
Jose Creek Formation, Tree Diameters

- Diameter measurement
  - Stumps: above the lateral roots
    - Approximate DBH
  - Logs: diameter at widest part
    - Minimum DBH
    - Above base of tree, missing bark ++
  - Fragments
    - Minimum diameter, missing outer tissues
    - Estimate minimum radius, multiply by 2
  - Range of tree diameters
    - 13 cm: Minimum diameter, dicot fragment
    - 0.4 to 2 m: Actual diameter, dicot stumps and logs
    - Conifer stumps and logs: ≤1.5 m

Log of Lauraceae



Stump, Forest of Giants



Platanoxylon stump 0.4 m in diameter

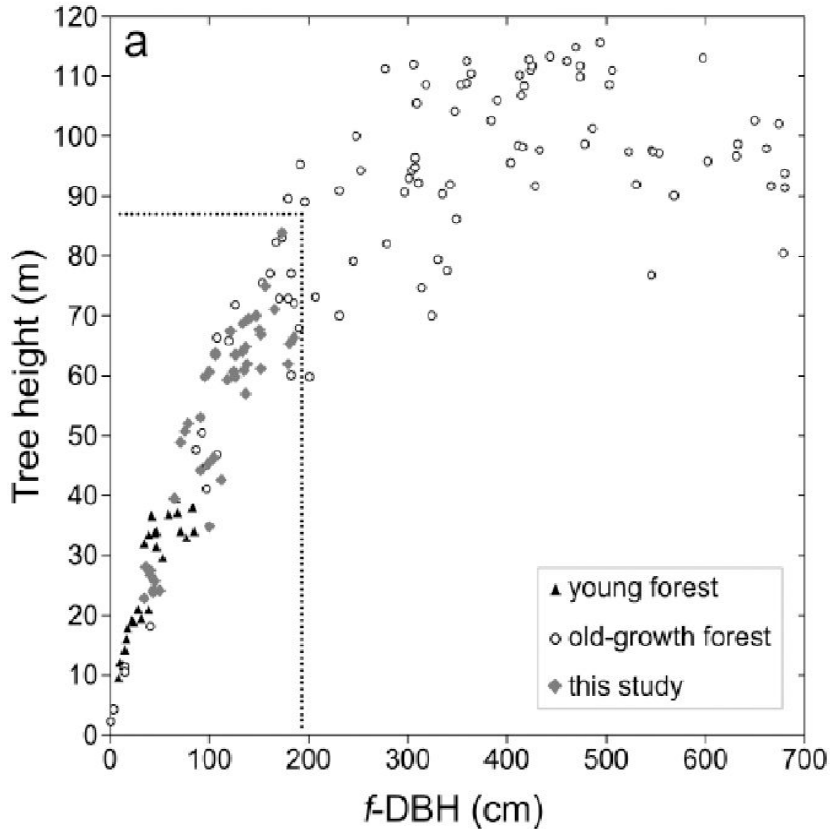
Forest of Giants: Late Cretaceous Riparian Forest

- Dicot stumps and logs
  - Massive overbank sandstone
  - Exclusively dicots, no conifers
    - 18 analyzed specimens
  - Tree diameters
    - 0.6 to 2 m
    - Average D = 1.1 m
  - Mature forest
    - Numerous stumps with heart rot
  - Dicot with plank buttresses
    - Mother Stump: Buttresses 3.7 m across
  - *Paraphyllanthoxylon* largest taxon
    - 15 stumps and logs
    - 0.7–2 m, majority >1 m diameter
  - Other taxa smaller
    - One specimen each
    - Sapotaceae, Lauraceae, Rosales
    - 0.6–0.8 m diameter

Mother Stump (*Paraphyllanthoxylon*), buttress roots 3.7 m across. Drs. Emilio Estrada-Ruiz and Joan Parrott provide scale

Big is big, but how tall is tall?

- Allometry
  - Trees: Trunk diameter can estimate height
    - Height proportional to Diameter Breast Height (H α D)
    - Non-linear: Height levels off relative to Diameter
  - Forestry and tropical ecology
  - Example equations
    - Exponential: $H = a + D^b$
    - Power: $H = aD^b$
    - Log-log: $Log_{10} H = 1.59 + 0.39 (log_{10}D) -0.18 (log_{10}D)^2$
    - Michaelis-Menten: $H = 58.0D^{0.73} / 21.8 + 58.0D^{0.73}$
    - Values of constants and exponents vary with site, taxon
      - Exponent often ~0.65, but can be much lower
  - Generic equations, tropical sites
    - All trees, not specific species or record trees
    - Average height of top 5% of specimens
      - Canopy and emergent species
      - Comparison of fossil tree species to those of modern forests



Height vs Diameter Breast Height for *Sequoia sempervirens* (coastal redwood). From Sillett et al., 2019, *Journal of Forest Ecology and Management*, v. 433, p. 349–363.

Forest of Giants: Allometric Equations

- Height estimates
  - Error in all estimates—within & between sites
  - >10 equations, each tree
  - Feldpausch et al., 2011 (log-log)
    - *Biogeosciences*, v. 8
    - 283 sites, 22 tropical countries
    - Asia, South America, Africa
    - Dry and moist forest sites used here
  - Banin et al., 2012 (3 parameter exponential)
    - *Global Ecology and Biogeography*, v. 21
    - Asia, South America, Africa
    - Values for top 5% of tree height
  - Martinez Cano et al., 2019 (Michaelis-Menton)
    - *Biogeosciences*, v. 16
    - Barro Colorado Island, Panama
  - Niklas, 1994 (log-log)
    - *American Journal of Botany*, v. 81
    - Woody species, both dicots and conifers

Forest of Giants: Tree Heights

- Average Height of forest
  - 25–50 m, mean of averages = **35 m**
- Tallest trees (D = 1.8–2 m, n = 2)
  - 32–57 m, mean of averages = **45 m**
- Plank buttresses, Mother Stump
  - Stem ~1.8 m in diameter above buttresses
  - Plank buttresses characteristic of tropical canopy and emergent trees

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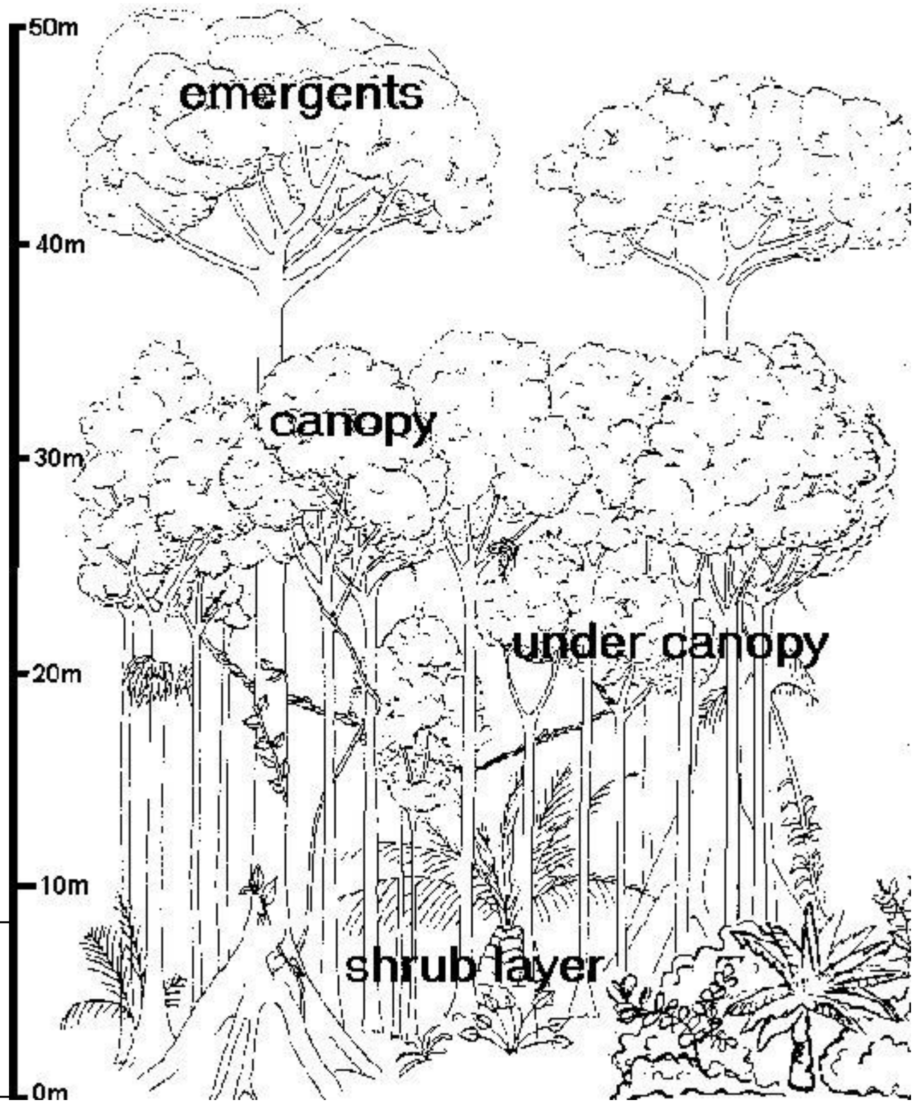

Drawing from Bennett, 2009

Forest of Giants: Tree Heights

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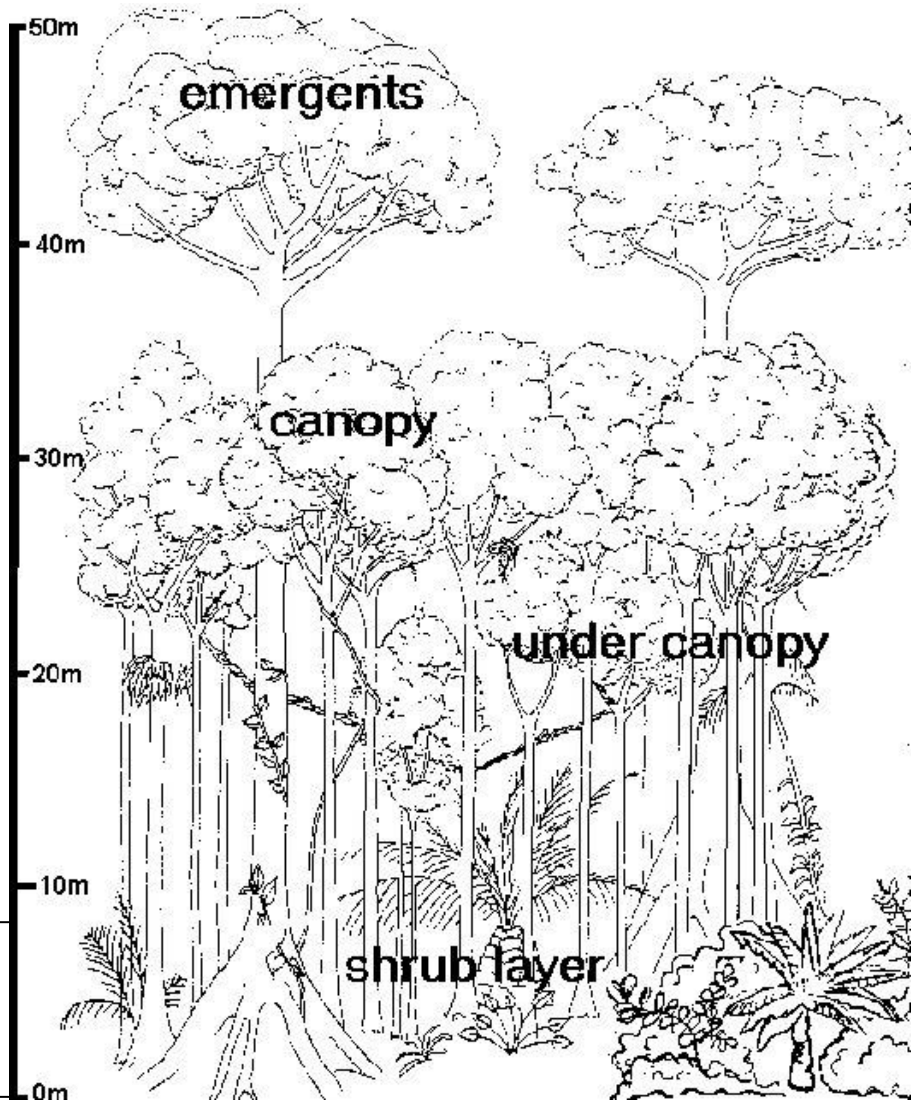
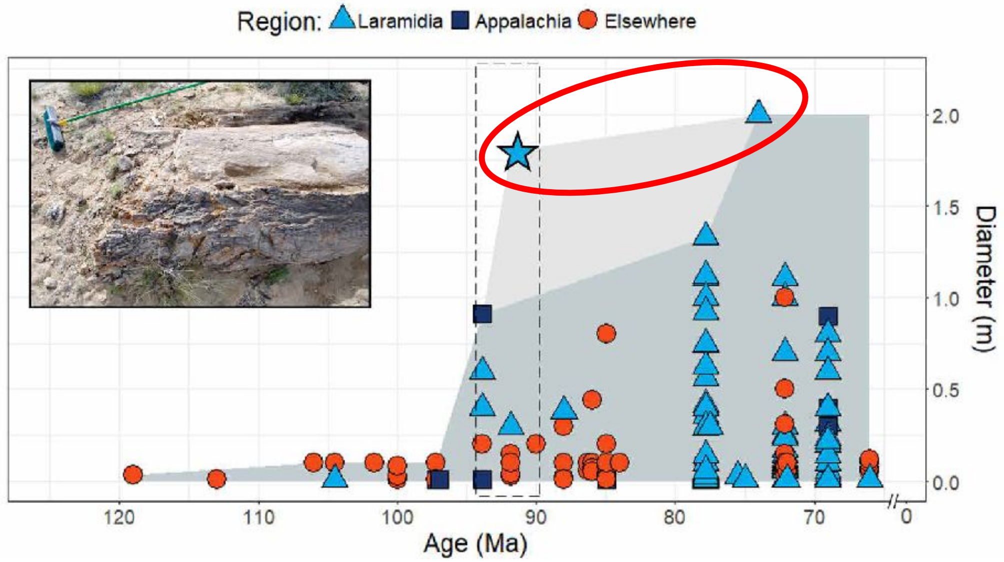
- Plank buttresses, Mother Stump
  - Stem ~1.8 m in diameter above buttresses
  - Plank buttresses characteristic of tropical canopy and emergent trees
- Number of specimens, H, average of top 5%
  - Banin et al., 2012, reference floras
    - Asian sites: 4, plus 8 within 1 S.D.
    - South American sites: 2 within 1 S.D.
    - African sites: 12 within 1 S.D.
  - **Top 5% of tree heights characterize the canopy and emergent strata of modern tropical forests, not the understory.**



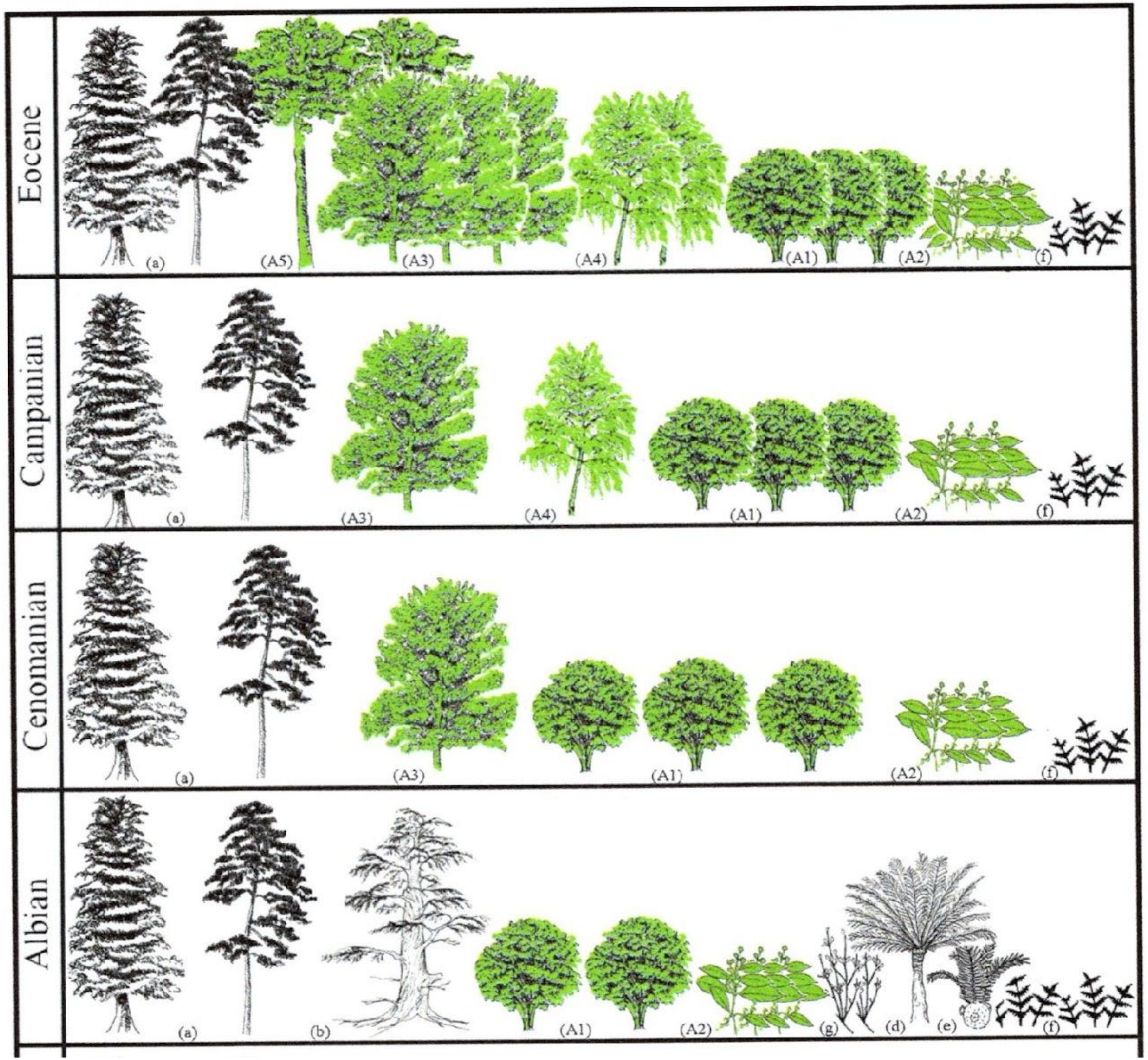
Drawing from Bennett, 2009

Overview and Significance of Results (Judd et al. again)

- Fossil dicot trees 1.8–2 m in diameter
  - Top 5% of modern tropical tree heights
  - Within 1 S.D. of the average
  - Height of canopy and emergent species of the tropics
  - Ferron Sandstone
    - Dicots reached the height of modern tropical canopy trees no later than the Turonian (or were very close).
  - Forest of Giants
    - Corroboration
    - Tall dicot dominated forests evolved no later than the late Campanian

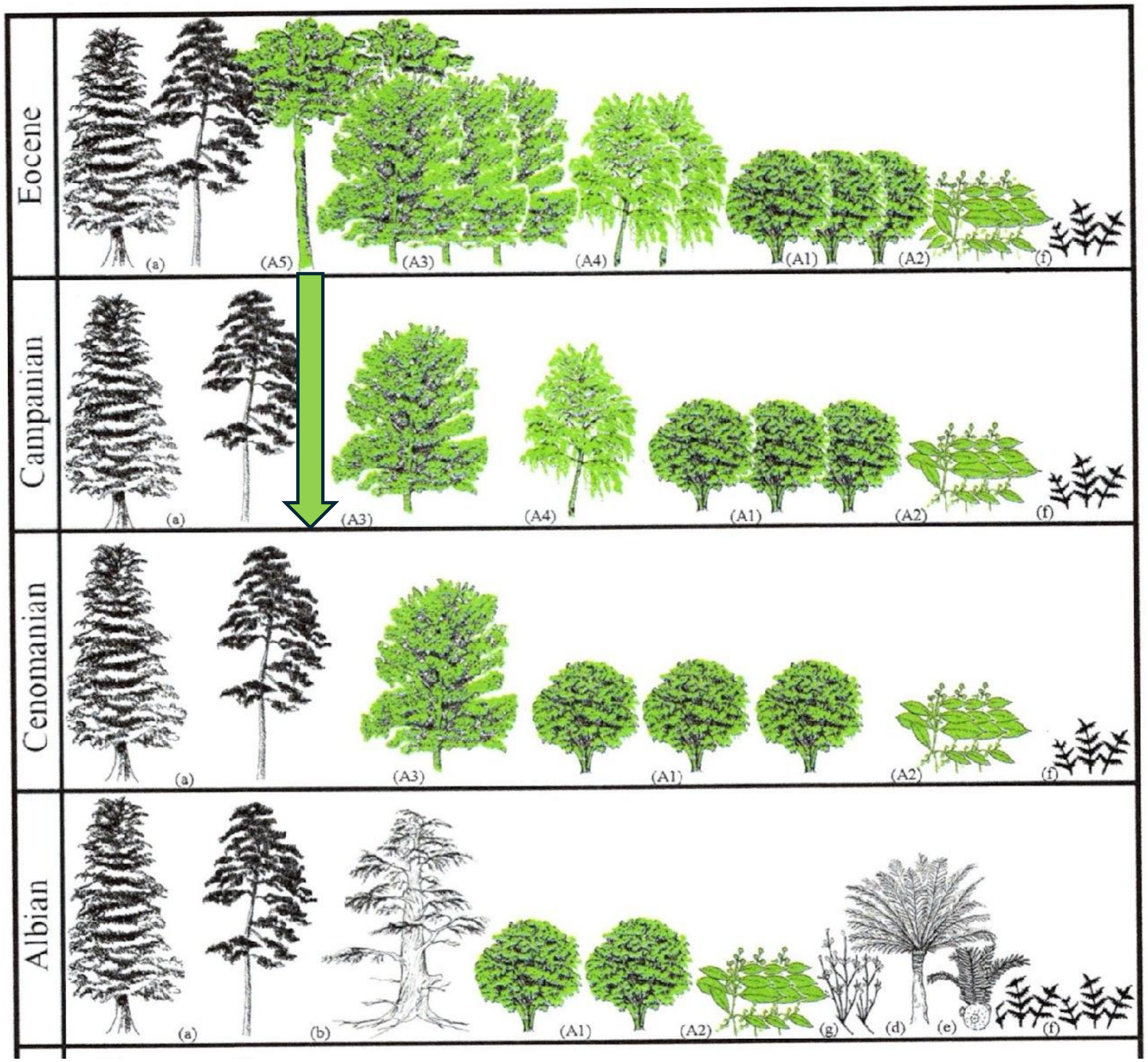


- Need to modify the commonly held model of angiosperm forest evolution
  - Canopy-height dicots not just a Cenozoic



From Friis, Crane, and Pedersen, 2011, Fig. 19.5

- Need to modify the commonly held model of angiosperm forest evolution
  - Canopy-height dicots not just a Cenozoic phenomenon
  - Evolved during the Late Cretaceous
  - Landscape variation
    - Coeval wetlands with large conifers (New Mexico fossil forest)
    - Dominant dicot trees on floodplains (Texas)
    - Tall dicots restricted to megathermal regions until Cenozoic?



From Friis, Crane, and Pedersen, 2011, Fig. 19.5

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- Research support
  - National Science Foundation Grant DEB-655885 to Garland Upchurch, Texas State University
  - Field expenses, Department of Biology, Texas State University
  - Current institution: University of Colorado, Boulder
- Field access
  - Armendaris Ranch, New Mexico
    - Tom Waddell (manager)
    - Ted Turner (owner)
- Sources of data
  - Estrada-Ruiz et al., *Int. J. Plant Sci.* (2012, 2018)
  - Dissertation of Joan Parrott, Texas State University (2019)
  - Field measurements of Upchurch, Estrada-Ruiz, Parrott, and Mack

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