PROCEEDINGS OF THE TWENTY-SIXTH ANNUAL KECK RESEARCH SYMPOSIUM IN GEOLOGY

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JACLYN WHITE, Lafayette College
Research Advisor: David Sunderlin

INTRODUCTION

The Chickaloon Formation of Alaska was deposited in a forearc basin that developed in accordance with the tectonics that uplifted the Cretaceous-Paleogene Talkeetna Mountains and Chugach accretionary sequence. During this time there was a shift in depositional environments from marine to terrestrial conditions (Trop et al. 2003). The Chickaloon Fm. records floodbasin deposition that occurred during the Eocene. Prior analyses of fossil foliage from the Chickaloon Fm. using leaf physiognomic approaches (leaf margin analysis (LMA), provisional leaf margin analysis (PLMA), and the climate leaf analysis multivariate program (CLAMP)) indicate a warm and wet temperate seasonal climate (Sunderlin et al. 2011) in Early Eocene southern Alaska.

Fossil *Taxodioxylon* wood is also abundant in the Chickaloon Fm. Williams et al. (2010) examined the preservational conditions and taphonomy of the Chickaloon wood but the material has yet to be examined for climatic implications. The practice of using wood as a paleoclimatic indicator is well-established and also has proven to be a useful climate proxy. Falcon-Lang et al. (2005) compared mean annual growth ring width from globally distributed modern trees to modern climate data concluding that conifers provide sound approximations of climate. Growth ring analyses of fossil wood can provide valuable insight about the growing conditions of ancient trees since they are sensitive to variation in the temperature, precipitation, and seasonality of their respective environments (Creber & Chaloner 1984). For a regional example, Spicer and Parrish (1990) examined the growth rings of fossil *Xenoxylon latiporosum* in order to compare the severity of paleoenvironments from the Cretaceous North Slope of Alaska. They found that the data gathered from fossil tree rings mirrored the change of climatic conditions for that period as inferred from sedimentology and stratigraphy.

The investigation here is a modern and ancient comparison in order to learn how growth ring characters and their variability can be better read for climate implications. In this study, the cores of five living *Metasequoia* trees from the temperate Mid-Atlantic region of USA are compared to their fossil counterpart, *Taxodioxylon*, collected from the Chickaloon Fm. Specifically, this study seeks to compare the ring growth patterns, earlywood to latewood ratios, and mean sensitivities of modern trees from Pennsylvania (herein the "modern wood") to those of ancient trees from southern Alaska (herein the "ancient wood") in order to determine the Eocene depositional environment of the Chickaloon Fm. These data may be used to test past climate estimates described in Sunderlin et al. (2011) and also can provide valuable insight to climate seasonality of the Paleocene/Eocene Chickaloon Fm. and carry implications of future climate change at high-latitude environments.

MATERIALS AND METHODS

Seventeen well-preserved, permineralized *Taxodioxylon* wood specimens were collected from the upper Chickaloon Formation at the Evan Jones Mine in southern Alaska. Samples were selected based upon the quality of growth ring preservation. An effort was made to select wood with minimal distortion (see Williams et al., 2010). Modern *Metasequoia* tree cores were extracted using a 16" Haglof increment borer from three localities within the Delaware River Valley (Shawnee Resort (Shawnee-on-Delaware, PA), Lafayette College campus (Easton, PA), and the University of Pennsylvania Morris Arboretum (Philadelphia, PA).

Modern and ancient wood samples were examined based on a series of parameters including growth ring widths, earlywood to latewood widths and ratios, and mean sensitivities. Growth ring width is a function of how productive a tree is for one growing season. Ideal conditions consisting of warm temperatures and ample precipitation will result in the accretion of thick rings of xylem along the periphery of the tree and this is repeated yearly. It is typical to see that during the lifetime of most trees, growth ring width decreases as the tree ages. During the first several years of growth a tree rapidly produces xylem but xylem thickness in each growth ring levels off as the tree grows taller and wider (Creber & Chaloner 1984). In addition, measurements of earlywood and latewood were determined. From these measurements, the ratio of earlywood to latewood for each growth ring was calculated. Earlywood widths are governed by the past climate conditions and the accumulated nutrients of previous years. Exceptionally cold springs and winters result in smaller earlywood cells (Creber & Chaloner 1984). Latewood ring widths are affected by the temperature and water availability of the environment late in the growing season. Also, brief growing seasons result in decreased latewood cell production. Therefore, the earlywood to latewood ratio is a revealing method of determining how favorable growing conditions are for one season in a tree's lifetime. Following the methods in Spicer and Parrish (1990), mean sensitivity was computed for all modern and ancient trees. Mean sensitivity is a measure of inter-annual variability in ring width according to the equation

$$M.S. = \frac{1}{n-1} \sum_{t=1}^{t=n-1} \left| \frac{2(x_{t+1} - x_t)}{x_{t+1} + x_t} \right|$$

where x_t is ring width i and x_{t+1} is the width of the adjacent younger ring. Trees with a mean sensitivity below 0.3 are thought to have grown in an environment with relatively stable conditions from one year to the next and are given the description "complacent" (Spicer & Parrish 1990). A mean sensitivity of greater than 0.3 is typical of trees that have grown in variable environments with inconsistent growing conditions from one year to the next. They are described as "sensitive". Average growth ring width and earlywood-latewood variations were plotted for the course of a tree's lifetime in order to compare growing patterns between the Chickaloon and modern temperate assemblages. Average earlywood-latewood ratios and mean sensitivity were also plotted for each tree for comparison. Although high latitude light regime and seasonality effects of higher latitude may play an important role (see Sunderlin et al. 2011 and discussion below) the data are presented from the modern and ancient woods in tandem here and this study is the first of its kind.

RESULTS

ANCIENT WOOD

Ancient wood sampled exhibited decreased growth ring production with age (Figure 1). Approximately 12% of ancient wood samples showed "complacent" growth with mean sensitivities of less than 0.3. The majority (n=15) of specimens from the ancient wood assemblage exhibited "sensitive" growth (Figure 2). The degree of variation in "sensitivity" was greater for the ancient wood assemblage than the modern wood assemblage, however that may have to do with the sample size and this difference is not significant. On the extreme, specimens "JW 16" and "JW 34" were calculated to have mean sensitivities of greater than 0.8 (Figure 2).

Specimens from the ancient wood assemblage exhibit small earlywood to late wood ratios (Figure 3). Earlywood growth varies between 1.9 and 2.8 times greater than latewood widths. While total growth ring width decreases across an ancient tree's lifetime, the earlywood-latewood ratio remains fairly constant throughout perhaps having to do with the infrequency of sampling the full ring history through to the center of the fossil trees.

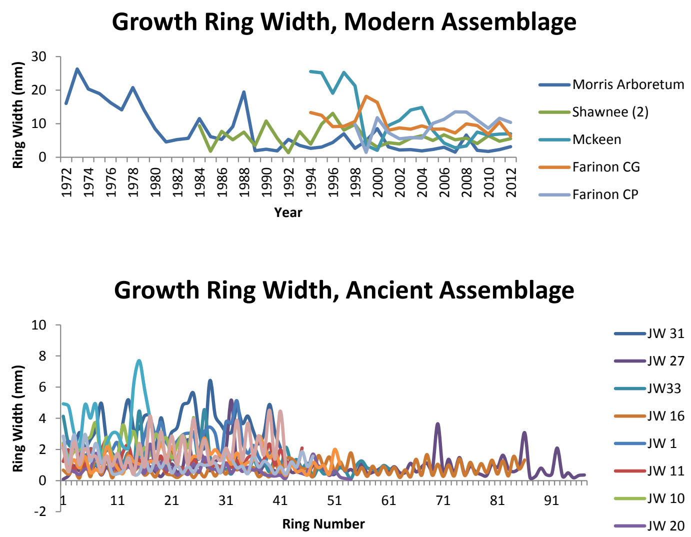

Fig. 1: Total ring width versus age for modern (above) and ancient (below) assemblages. Charts show typical growth history patterns of rapid xylem production early in a tree's life and more constant, decreased xylem production as a tree ages.

MODERN WOOD

Modern wood samples showed high rates of xylem production and growth ring width during the first several years of the trees life reflecting the expected trend of declining tree growth with age (Figure 1). Approximately 20% of modern wood samples showed "complacent" growth with mean sensitivities of less than 0.3. The majority (n=4) of specimens from the modern wood assemblage exhibited "sensitive" growth. Of these four trees from the modern assemblage that exhibited "sensitive" growth, mean sensitivities were similar and showed little variation. The greatest mean sensitivity calculated came from the specimen "Shawnee" with a value of 0.57 (Figure 2). On average, the modern assemblage of wood has a large earlywood-latewood ratio. Earlywood growth varies between 3.6 and 6.7 times thicker than latewood growth for the assemblage. Moreover, the disparity between earlywood growth and latewood growth is appreciably larger during the first 5-7 years of the trees lifetime than any time later (Figure 3).

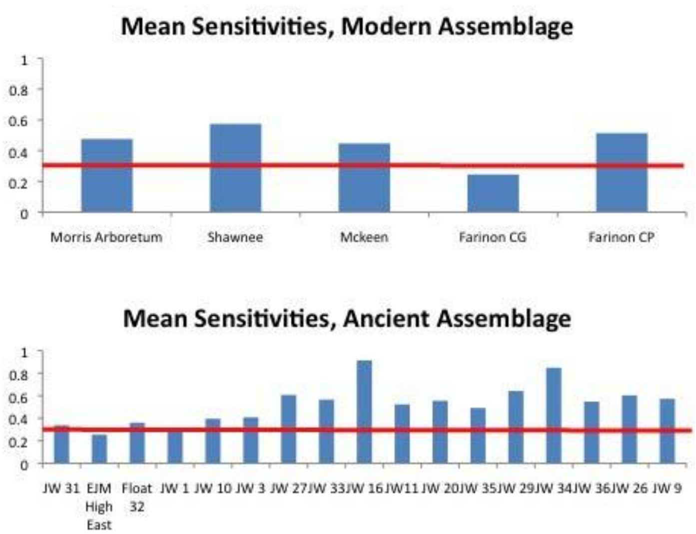

Fig. 2: Mean sensitivities calculated for modern (above) and ancient (below) assemblages. Mean sensitivity describes inter-annual variability and a mean sensitivity of greater than 0.3 is described as "sensitive" growth while a mean sensitivity less than 0.3 is described as "complacent" tree growth. Red line indicates the 0.3 threshold.

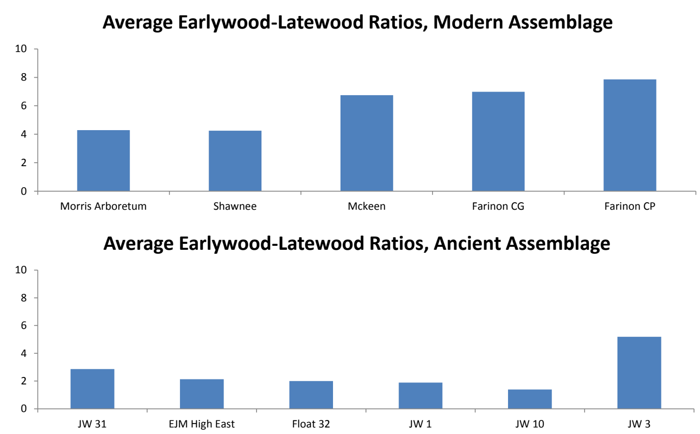

Fig. 3: Average earlywood to latewood ratios calculated for each specimen of the modern (above) and ancient (below) assemblages. The modern wood assemblage overall has greater earlywood-latewood ratios compared to the ancient wood assemblage typically resulting from markedly greater earlywood growth per growth ring.

DISCUSSION

Trees from the modern wood assemblage sampled from temperate Pennsylvania, by many measures, show greater wood productivity than trees from the ancient wood assemblage from Paleocene-Eocene Alaska. This can be predominantly attributed to appreciably greater earlywood production in modern Mid-Atlantic wood. Since earlywood growth is a reflection of the severity of prior winters and springs (Creber & Chaloner 1984), this indicates that, as expected, modern trees growing in the lower-latitude Mid-Atlantic region of the northeast United States experience milder winters and springs than did ancient trees from the Chickaloon Fm. even considering the similarity of the Pennsylvania mean annual temperature (~12°C) as compared to that estimated by Sunderlin et al. (2011) for the Chickaloon depositional environment (11-14.5°C). Interestingly, latewood growth rings were similar between modern Mid-Atlantic and ancient Alaskan wood assemblages. Because latewood growth is affected by late summer water availability as well as contemporaneous temperature conditions (Creber & Chaloner 1984), it can be inferred that modern assemblages and ancient assemblages experienced similar precipitation and temperature regimes during the middle to late summer.

The effect of latitude on each assemblage's xylem production is difficult to discern, mostly having to do with a lack of warm temperate climate modern analogs that experience light seasonality as must have been the case in Paleocene/Eocene Alaska. Because high latitudes experience little to no sunlight during the winter months it is not surprising that the ancient wood assemblage in this study demonstrates harsher winters and springs than the Mid-Atlantic modern assemblage. Earlywood growth in the ancient wood assemblage is limited by the cooler temperatures and restricted light regime during the late winter and early spring. Contrastingly, the modern wood assemblage is exposed to sunlight throughout the entire year and likely experiences warmer temperatures during the winter and spring months. Both modern and ancient assemblages show "sensitive" growth for the majority of specimens. While it is interesting that both assemblages reflect environments with substantial variation in growing conditions from year to year, it is also meaningful to note that specimens exhibiting "sensitive" growth from the ancient wood assemblage have greater values for mean sensitivity than those exhibiting "sensitive" growth from the modern wood assemblage. Because mean sensitivity is a measure of inter-annual growth variability, this suggests that, at times, there was greater disparity in xylem

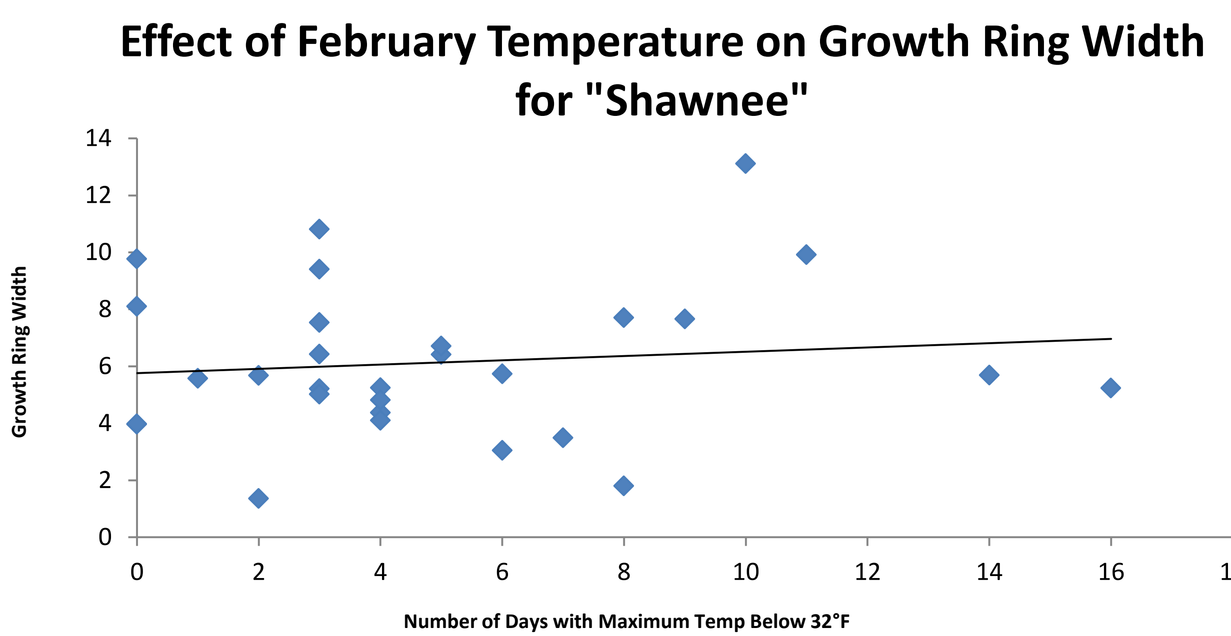

Fig. 4: Chart showing growth ring width as a function of the number of days below freezing during the month of February for the modern specimen "Shawnee". There is a positive correlation between how many days there are below freezing and the width of the growth ring.

production from year to year and variation in growing season conditions for the ancient Chickaloon Fm. depositional environment than there is for the modern temperate Mid-Atlantic environment. Therefore, if the conditions currently seen at the Mid-Atlantic region of the northeast United States are indicative of moderate variability between growing seasons, it can be surmised that the paleoenvironment of Paleocene/Eocene southern Alaska occasionally experienced times of more variable growing conditions.

A positive relationship was established for the relationship between raw modern growth ring widths and the number of days in February having a maximum temperature below freezing (32°F) of corresponding years.

After sampling 18 modern *Metasequoia* trees from the Secrest Arboretum in Northeast Ohio, Vargo et al. (2013) first proposed a negative relationship between the maximum February, June, and July temperatures of a region and the growth ring width of trees living in that region for a given year. They concluded that February temperatures high enough to melt accumulated snow could expose trees to injury from frost. Additionally, extreme heat during the summer months may decrease tree productivity. In this study, "low February temperatures" are equated to the number of days having maximum temperatures below freezing for the month of February. Similar to the results proposed by Vargo et al. (2013), it is apparent that late winter/early spring temperatures may have an impact on growth ring width for subsequent growing seasons. Using the growth history and environmental conditions of modern trees as an analogy for the environmental conditions of ancient trees, large ring growth widths of ancient trees may be interpreted as at least partially being the result of favorable out-of-growing season conditions.

CONCLUSION

This is the first study to use the comparison of the growth history of modern trees and their corresponding environmental conditions in order to infer the environmental conditions of ancient, fossilized trees from the Eocene aged Chickaloon Fm. A greater understanding of how the current environment has impacted modern tree growth will better delineate the ancient paleoenvironment affecting fossilized wood collected from the Chickaloon Fm. It is apparent from this study that the environment of the modern Mid-Atlantic region of the northeast United States has similar temperature and precipitation patterns during the summer as the Paleocene/Eocene of southern Alaska. The inter-annual variation of growing season conditions is greater for the modern environment than it was for the ~55 Ma depositional environment of the Chickaloon Fm. Additionally, winter environmental conditions appear to have differed; the Eocene paleoenvironment exhibiting less precipitation and lower temperatures during these months. The effect of winter temperatures on growth ring widths from the modern Metasequoia assemblage agrees with previous studies comparing these parameters (Vargo et al. 2013). A small growth ring width from the ancient *Taxodioxylon* assemblage is understood to have been affected by warm late winter/early spring temperatures. Results from this study agree with prior studies of paleoflora suggesting similarities in the precipitation and temperature of growing seasons between the modern Mid-Atlantic region of the northeast United States and the Paleocene/Eocene depositional environment of the Chickaloon Fm.

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