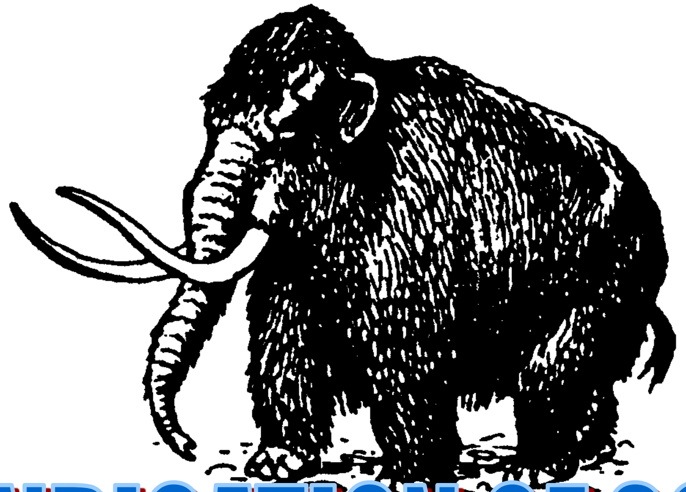

CLIMATIC INDICATION OF SOLAR ACTIVITY VARIATIONS MILLIONS OF YEARS AGO

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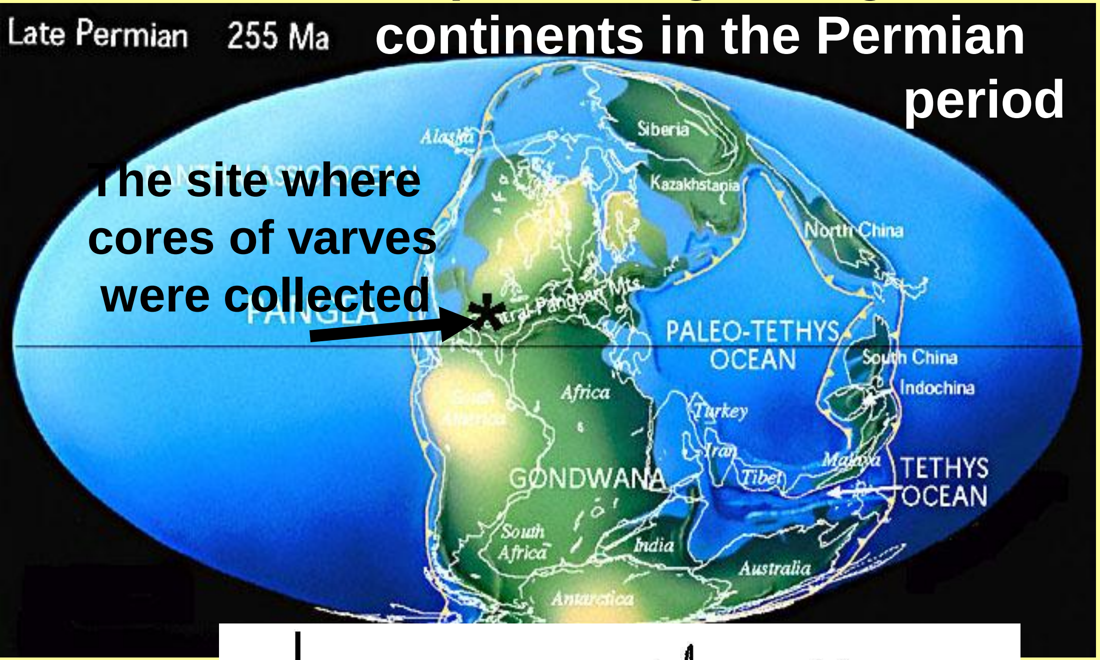
Introduction

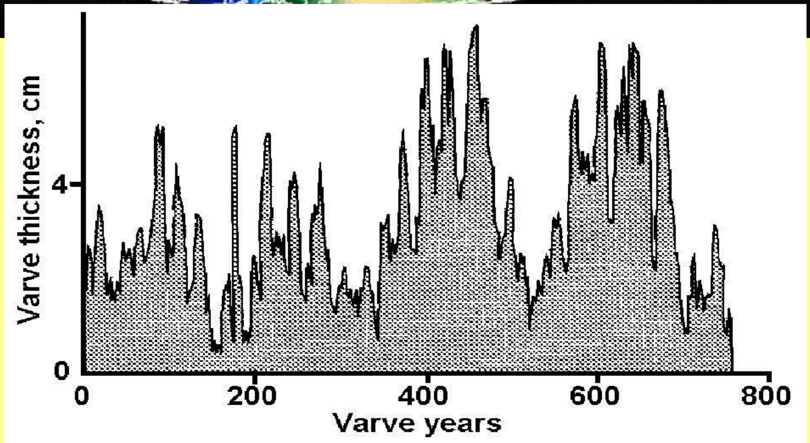
At present a large body of palaeoclimatic data with annual time resolution is available. As a rule, these data relate to the time interval of the last 10–15 thousand years. At the start of the 20th century the founder of dendrochronology A.E.Douglas discovered that there was a 11 year cyclicity in radial tree ring growth, and he attributed this periodicity to the climatic effect of the 11-year solar cycle (Schwabe cycle) (Douglass, 1919; 1926; 1936). In later years other researchers analyzed dendrochronological and other palaeoclimatic materials with layered structure (varves, aerosol densities in Greenland and Antarctic ice cap layers, etc.) and revealed indications of climatic variations corresponding to fundamental solar activity cycles: 22–23 years (Hale cycle), 80–100 years (Gleissberg cycle), ~200 years (Suess-deVries cycle) Note that periodicities of around 30 and 17–18 years rather often can be observed in climatic oscillations as well. The former is referred to as the Bruckner cyclic. The 17–18-year periodicity can be attributed to the effect of cyclicity in lunar tides (lunar Saros cycle – 18.6 years) (Currie, 1993; Cook et al., 1997; Hoyt and Schatten, 1997). Thus, climatic variations can be a useful indicator of the existence of solar activity periodicities. This climatic indicator can be used to estimate solar forcing during time intervals for which other methods are inapplicable. Direct measurements of variation in solar activity (sunspot observations) cover only an interval of about the last 400 years, and cosmogenic ^{14}C and ^{10}Be isotopes widely used for estimation of solar activity in the past have a half-life period of 5730 and about 1.5 million years. For this reason, they cannot be used to analyze variations in solar activity during the time intervals of millions of years in the past. Indirect information on cyclicities in solar activity during those time intervals can be obtained from analysis of climatic variations. The aim of this work was to analyze unique palaeoclimatic data with time resolution from one to several years for the time interval from 260 to 12 million years in the past. In our study all three types of palaeoclimatic data were subjected to spectral and wavelet analysis with the aim of revealing climatic periodicities in the past. The data obtained were compared with present-day solar and climatic periodicities.

Climate change around 250 million years ago (Permian period)

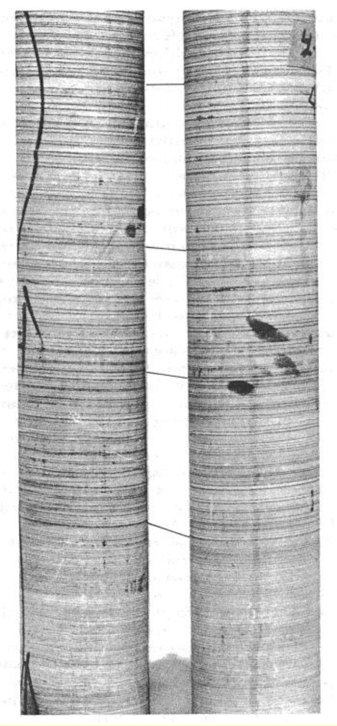
Map showing configurations of continents in the Permian period



The site where cores of varves were collected



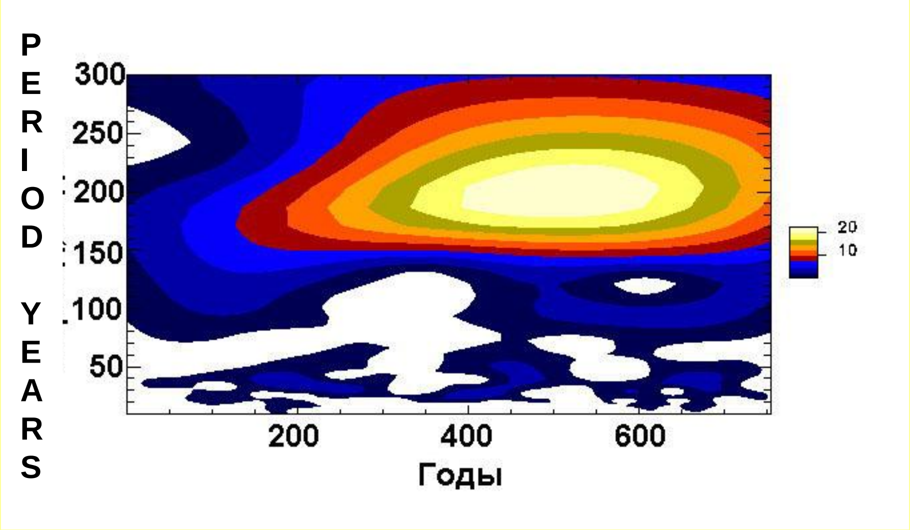
Variations in thickness of annual layers of varves in the Permian Castle Formation (250 million years ago) for the time interval of 800 years, Texas, USA (Dean, 2000).



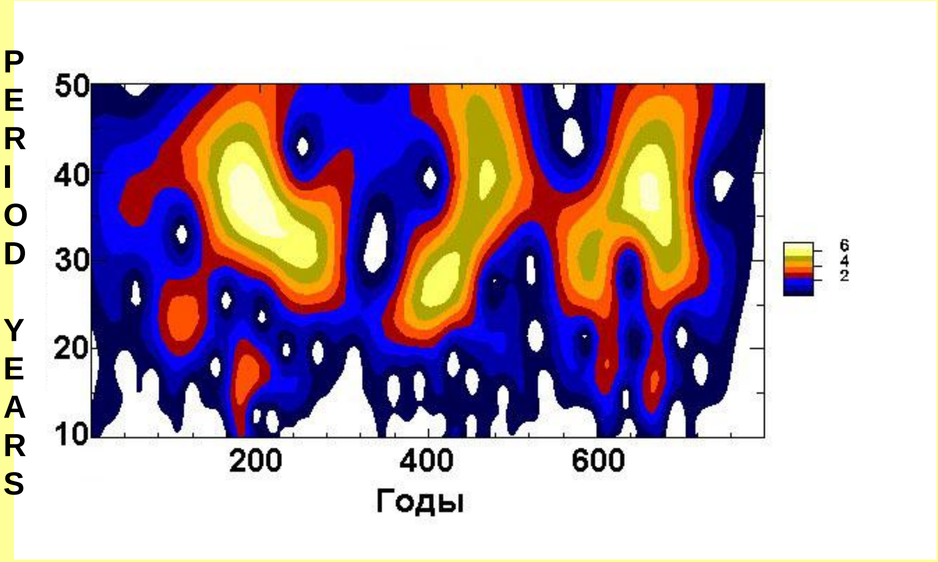
Cores of varves from Permian Castile Formation in Western Texas.

Climate change around 250 million years ago (Permian period)

Range of periods 10-300 years

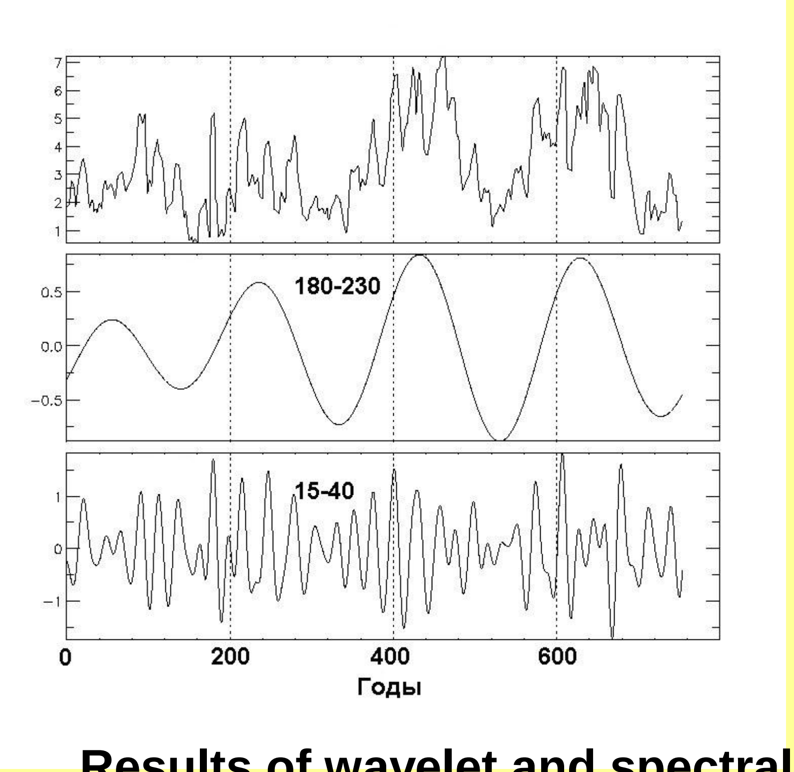


Range of periods 10-50 years



Results of wavelet analysis (Morlet basis) of variations in varve thickness in the Permian Castle Formation (250 million years ago) for the time interval of 800 years, Texas, USA.

Climate change around 250 million years ago (Permian period)



Variations in thicknesses of varve layers.

Results of filtering of variations in varve thicknesses in the range of periods 180-230 years.

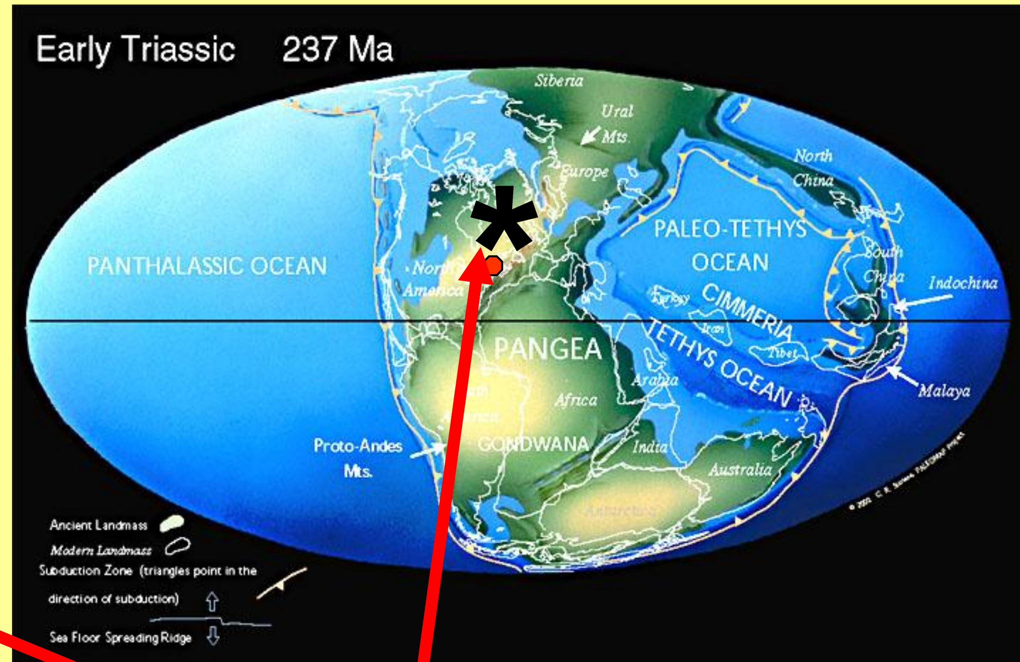
Results of filtering of variations in varve thicknesses in the range of periods 15-40 years.

Results of wavelet and spectral analysis of variations in varve thickness in the Permian Castle Formation (250 million years ago) has revealed climate changes which can be attributed to ~ 200-year solar activity cycle.
The tree-ring variability has shown also decadal cyclicity.

Decadal climate oscillation amplitude is modulated by quasi-two-hundred-year cyclicity.

Climate change around 250 million years ago (Permian-Triassic Boundary)

Map showing configurations of continents in near the Permian-Triassic Boundary



Position of the Lyons Sandstone- Lykins Formation.

Climate change around 250 million years ago (Permian-Triassic Boundary)

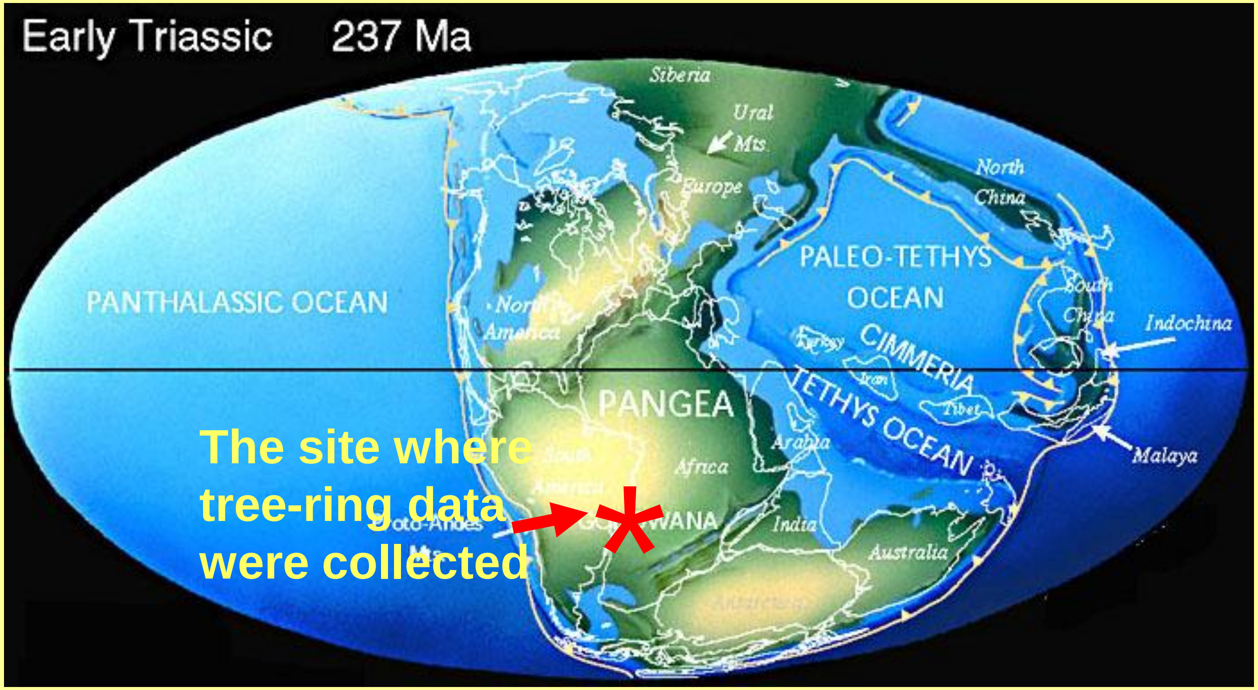
The view of annual layers in the Lyons Sandstone.

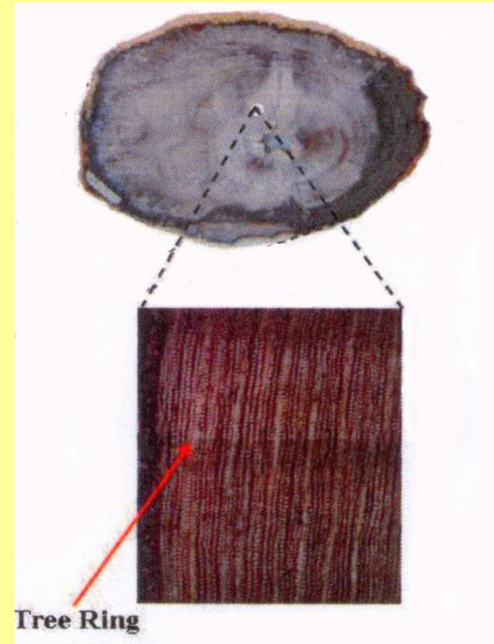
The analysis of periodicity of the annual layers with different colour in the Lyons Sandstone (Colorado, USA) has shown the existence of the following periods:

4-5; 7-9: 10-12 and 32-34 years

Author [deForest Palmer, Science, 1917] suppose that 10-12 year periodicity relate to solar influence and 32-34 year periodicity is Brückner cycle.

Climate change around 200 million years ago (Triassic period)

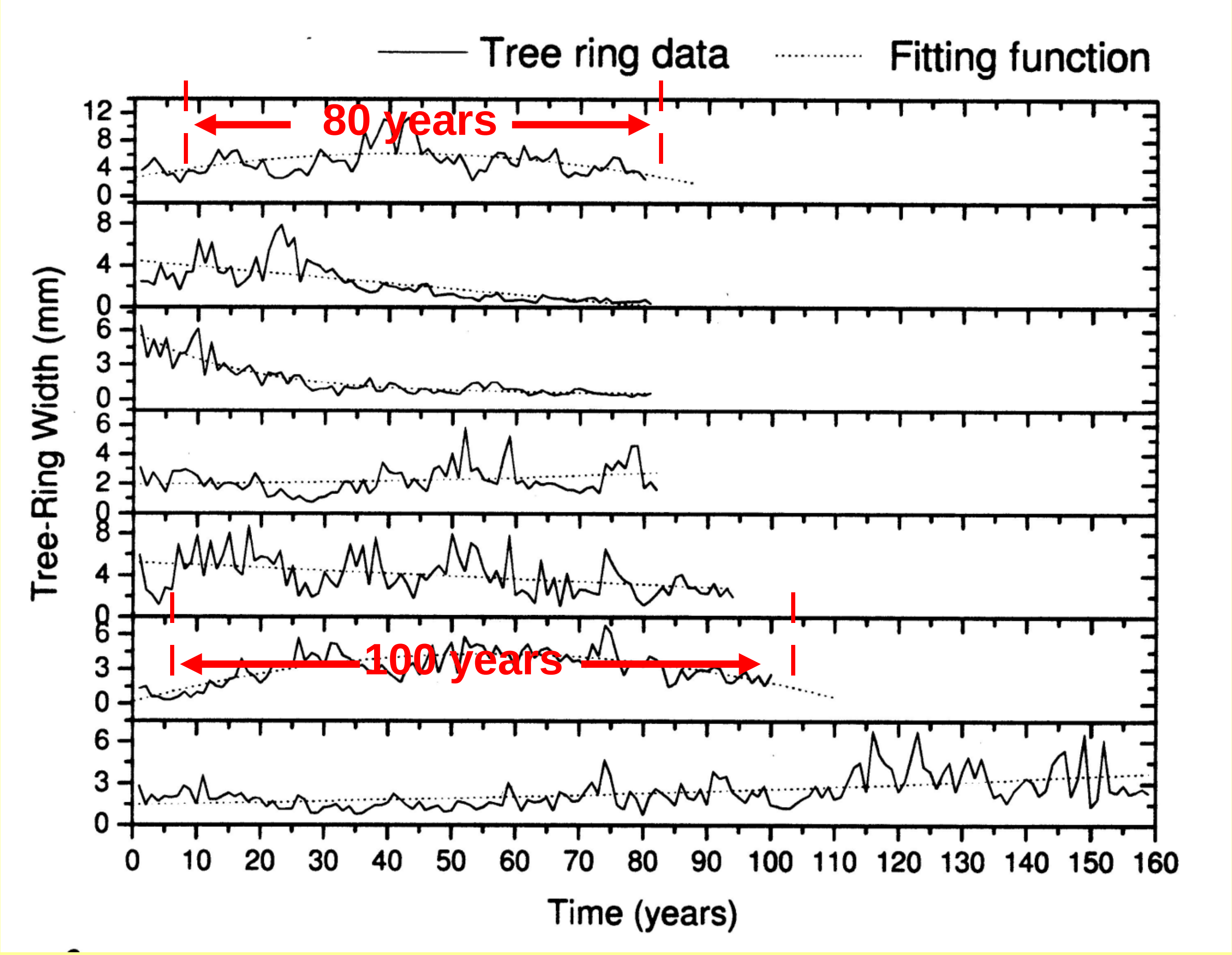




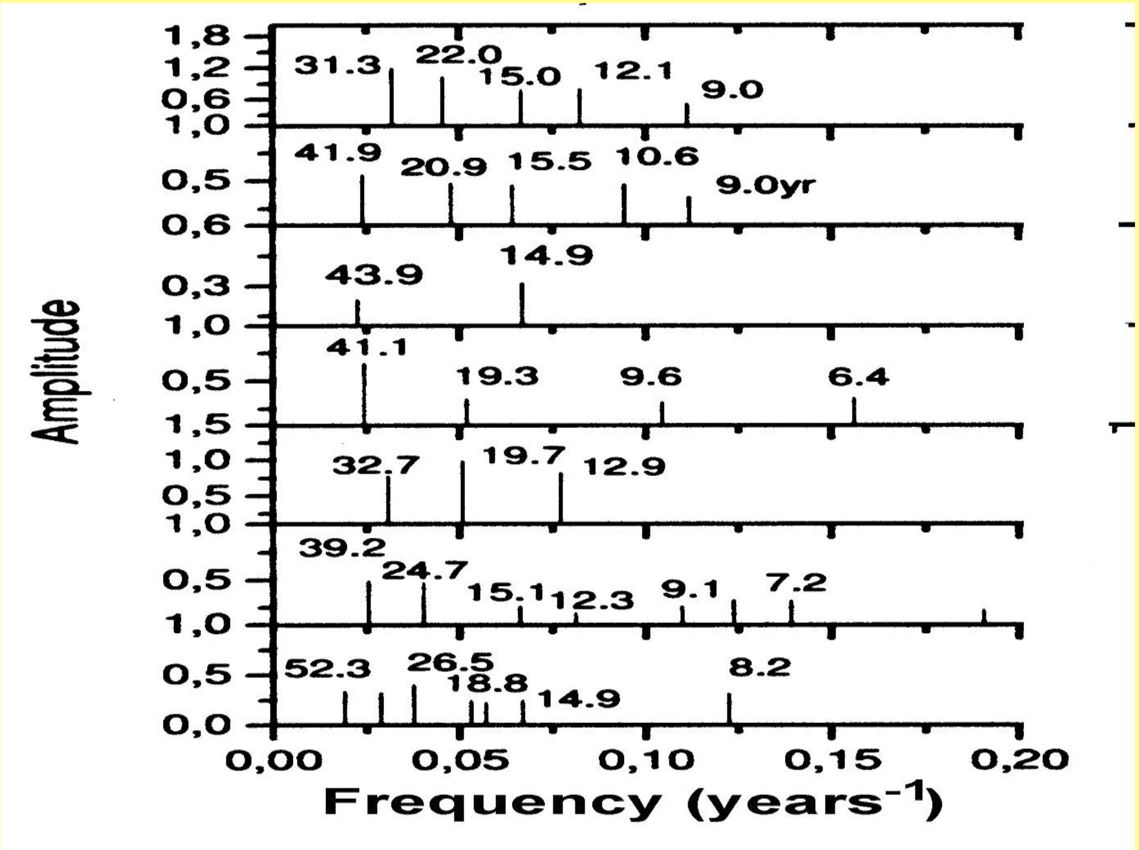
Positions of continents in the Triassic period.

Example of a petrified forest (conifer-related *gymnosperm*) from the Triassic period at Mata and Sao Pedro do Sul in Southern Brazil [Prestes et al, 2010].

Climate change around 200 million years ago (Triassic period)



Climate change around 200 million years ago (Triassic period)

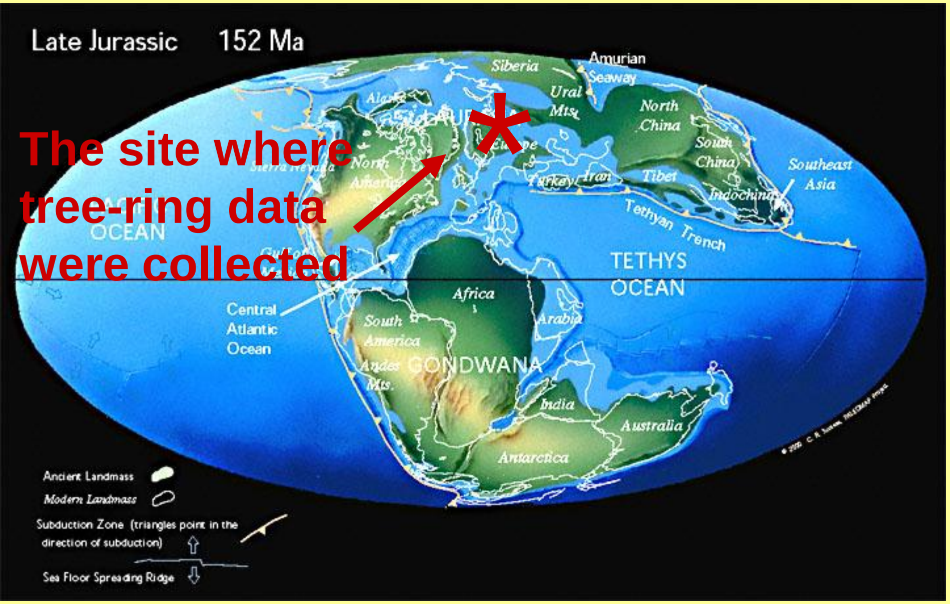


Results of spectral analysis of variations in tree-rings of fossil forest in Southern Brazil.

Analysis of variations in ring widths of the *gymnosperm* tree that grew about 200 million years ago has revealed climate changes which can be attributed to 90-110, 11-12 and 22-year solar activity cycles and also Bruckner cyclicity (31-32 years). The tree-ring variability has shown also 15-16 and 39-43 year cyclicity.

Climate change around 140-150 million years ago (Upper Jurassic)

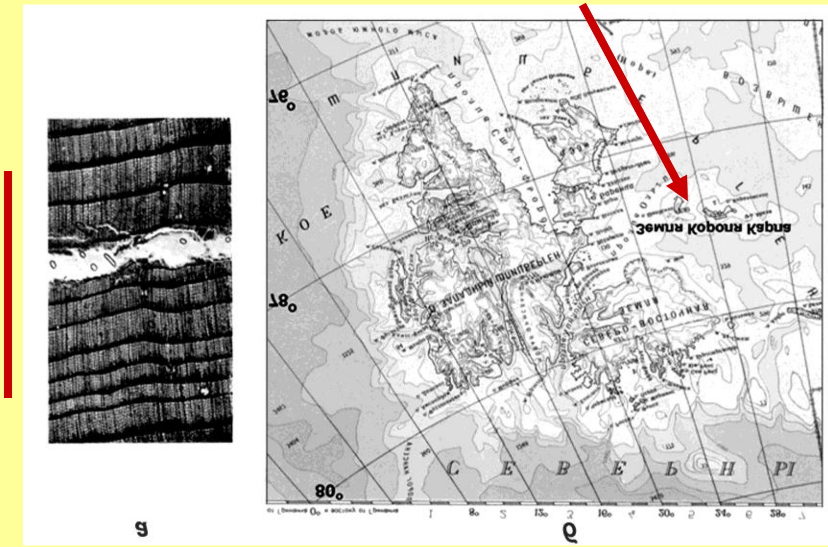
Positions of continents in the upper Jurassic period



Svalbard

The von König-Karls-Land

10 rings

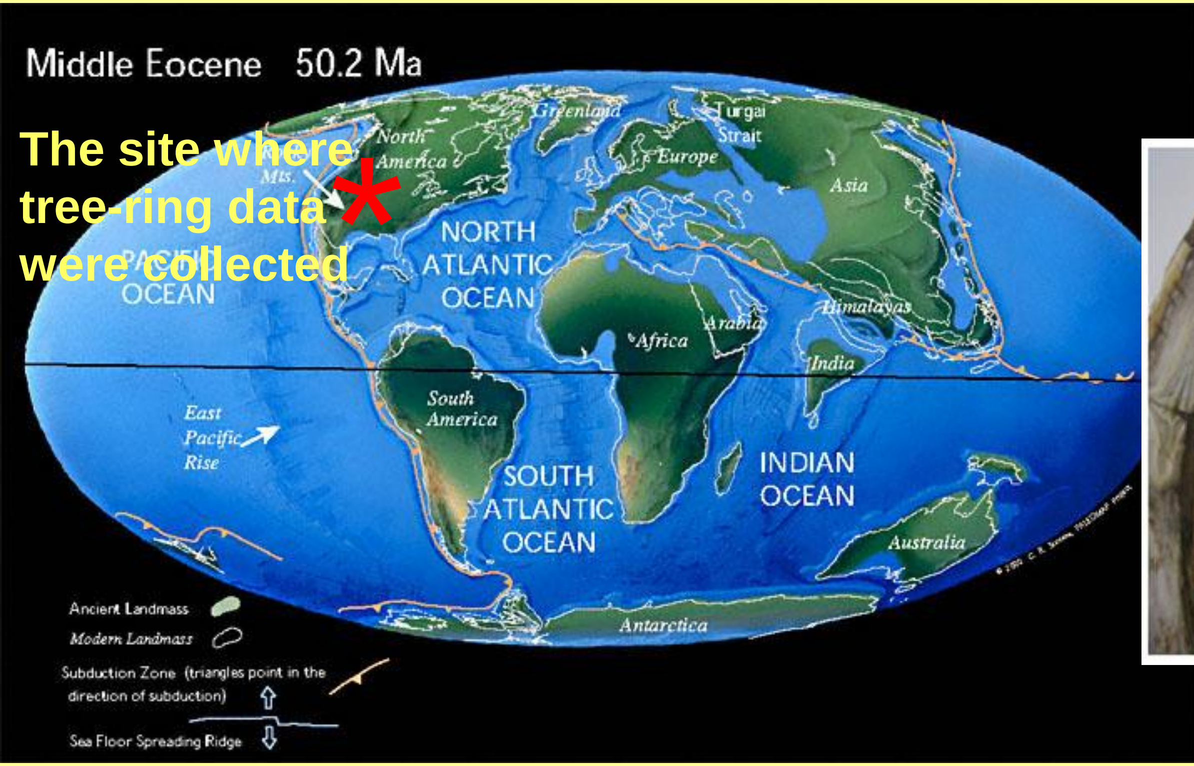


The most northern region where fossil petrified forest *Protopiceoxylon exstinctum* was collected: The von König-Karls-Land ($78^{O}55$'N, $28^{O}10$'E).

The numbers of the tree-ring between the most narrow and most broad tree-rings are 10 or 11 rings. Thus possible periodicity of climate change in this most northern region could be around 22-years which relate to the solar Hale cycle. The age of petrified forest was about 140-150 million years [Gothan, 1912].

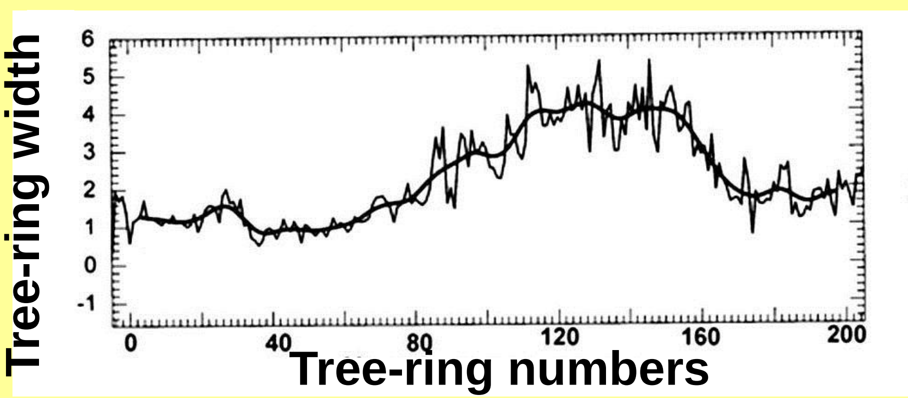
Climate change around 50 million years ago (Middle Eocene)

Positions of continents in the Middle Eocene period

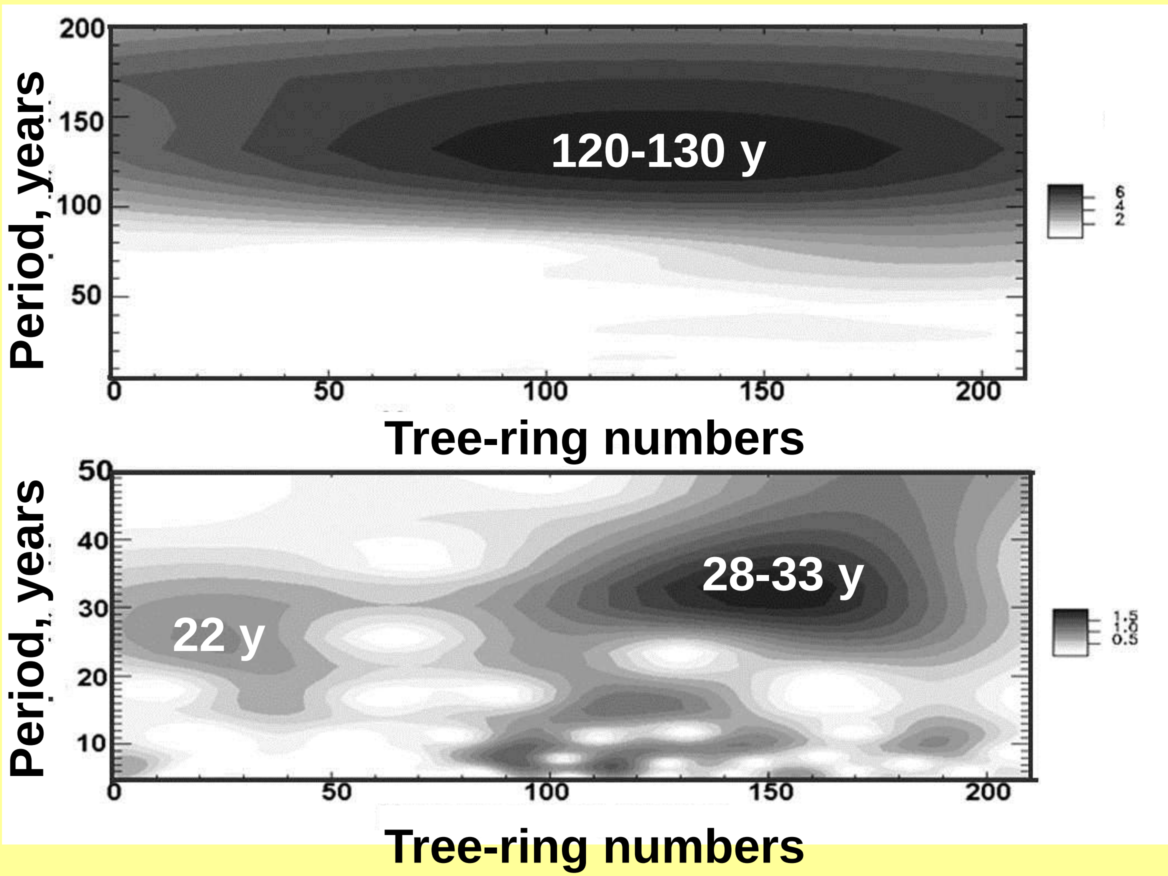


заповедника (Окаменевший Лес) в Калифорнии (США) [www.petrifiedforest.org].

Example of a petrified conifer forest from the Middle Eocene period at Oregon/Nevada region in USA (from museum “The Petrified Forest” California, USA).

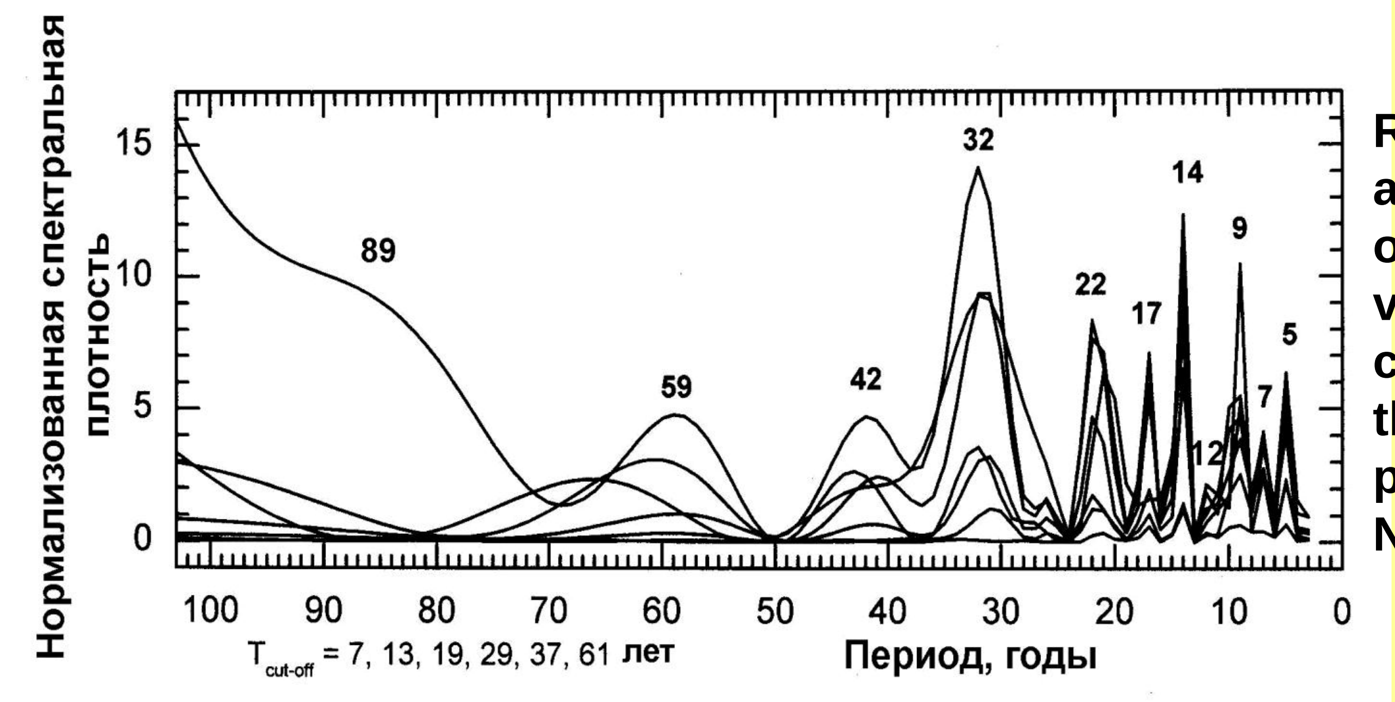


Climate change around 50 million years ago (Middle Eocene)



Results of wavelet analysis (Morlet basis) of tree-ring width variations of petrified conifer forest from the Middle Eocene period at Oregon/ Nevada region in USA.

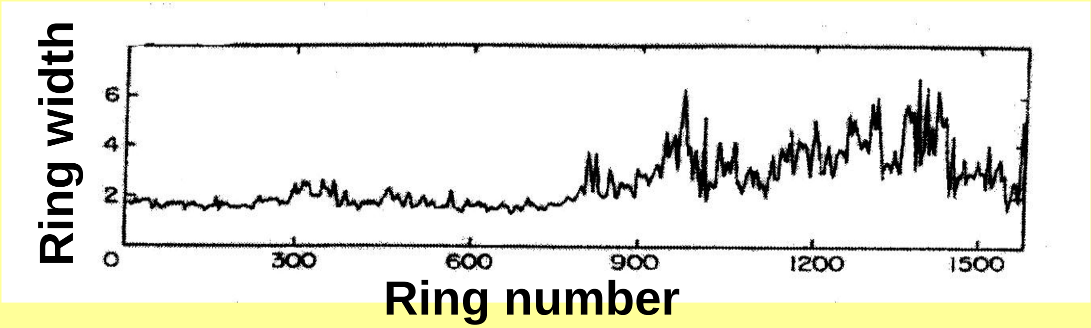
Climate change around 50 million years ago (Middle Eocene)

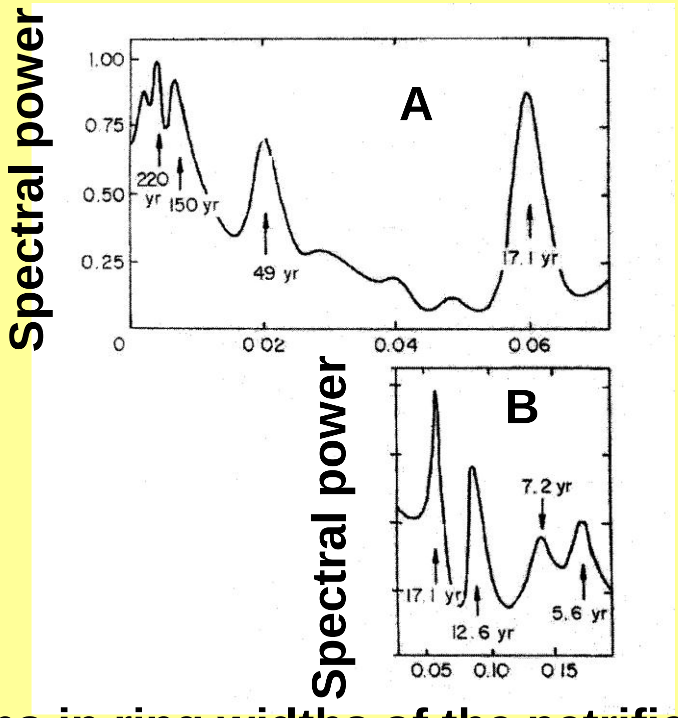


Results of wavelet analysis (Morlet basis) of tree-ring width variations of petrified conifer forest from the Middle Eocene period at Oregon/ Nevada region in USA.

Wavelet and spectral analysis of variations in ring widths of the petrified conifer tree that grew about 50 million years ago has revealed climate changes which can be attributed to 90-130, ~ 60 and 22-year solar activity cycles and also Bruckner cyclicity (~32 years). The tree-ring variability has shown also 17, 9, 7, and 5 year cyclicity, which observe also in recent time.

Climate change around 15-20 million years ago (Miocene)





Location of the fossil tree 15-20 million years old: Taxodioxylon gypceum, recent Sequoia sempervirens 1575 rings, 3.5 meter diameter stump (Kurths et al., 1993).

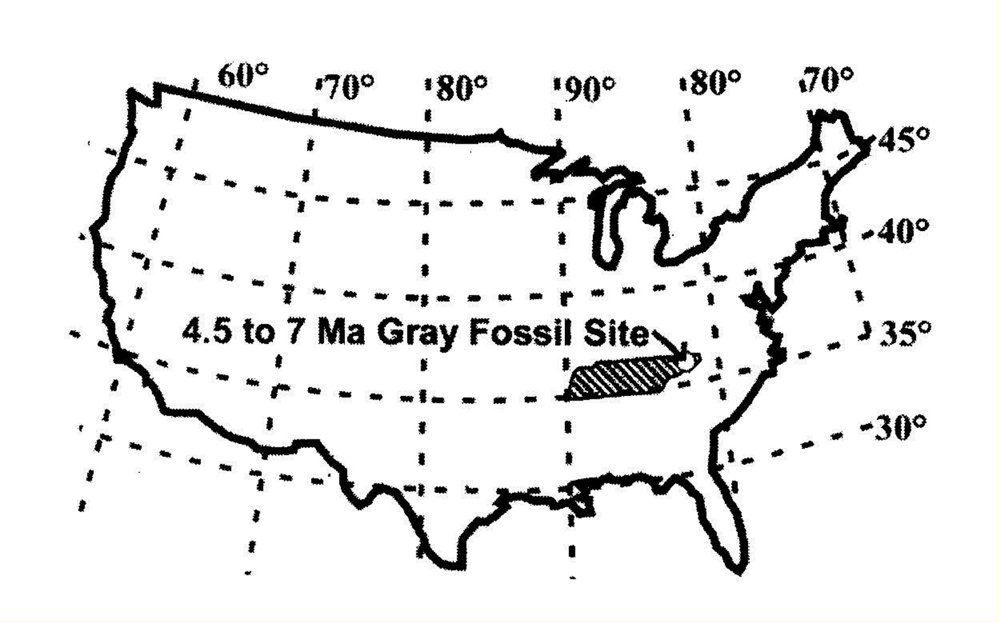
Result of spectral analyses of fossil tree ring width.

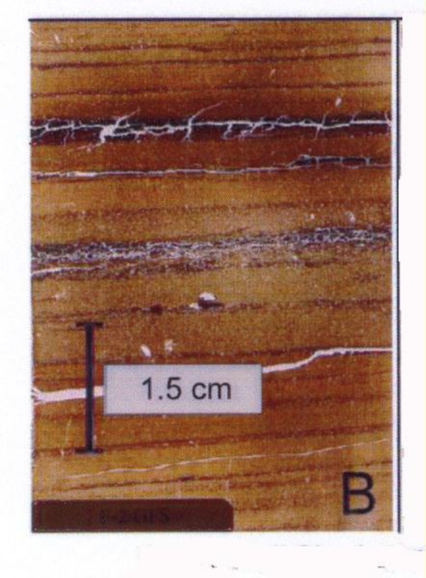
A-after 5-year smoothing of the width record.

B – without smoothing of the width record.

Spectral analysis of variations in ring widths of the petrified conifer tree that grew about 15-20 million years ago has revealed climate change which can be attributed to ~ 200, 49-150, and 12-year solar activity cycles
The tree-ring variability has shown also ~17 cyclicity, which observe also now.

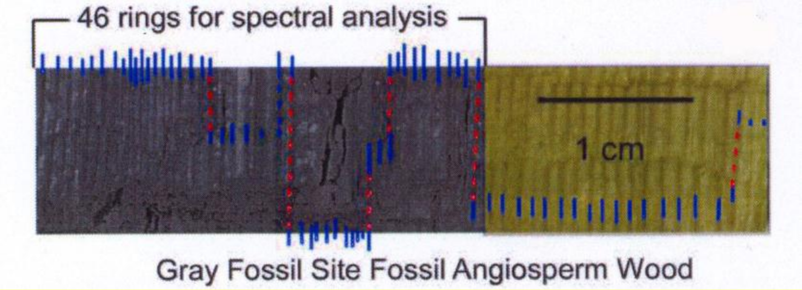
Climate change around 5-7 million years ago (late Miocene - early Pliocene)





Varves

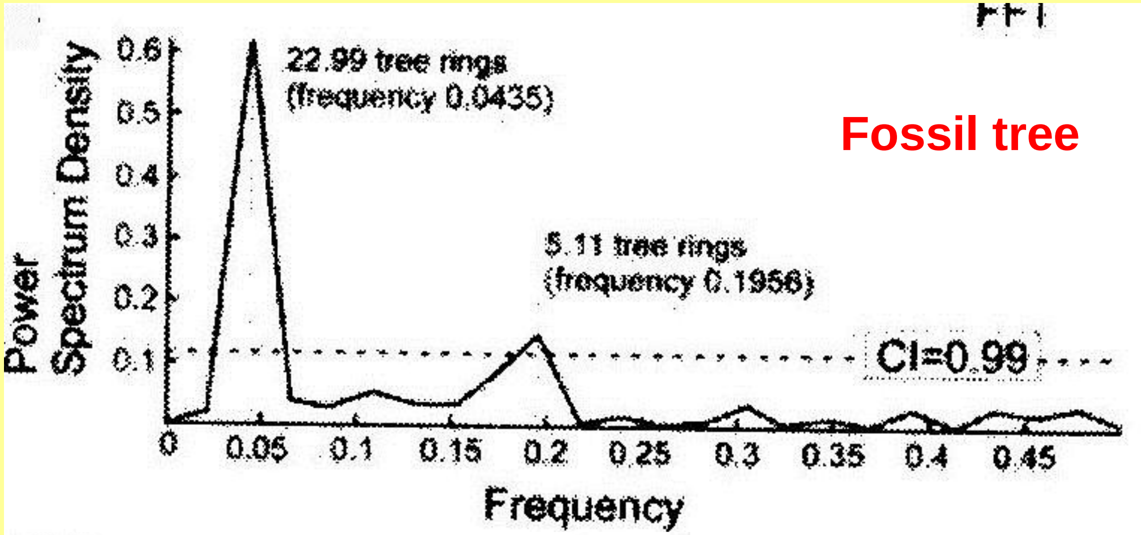
Location of the fossil tree and varves 5-7 million years old.



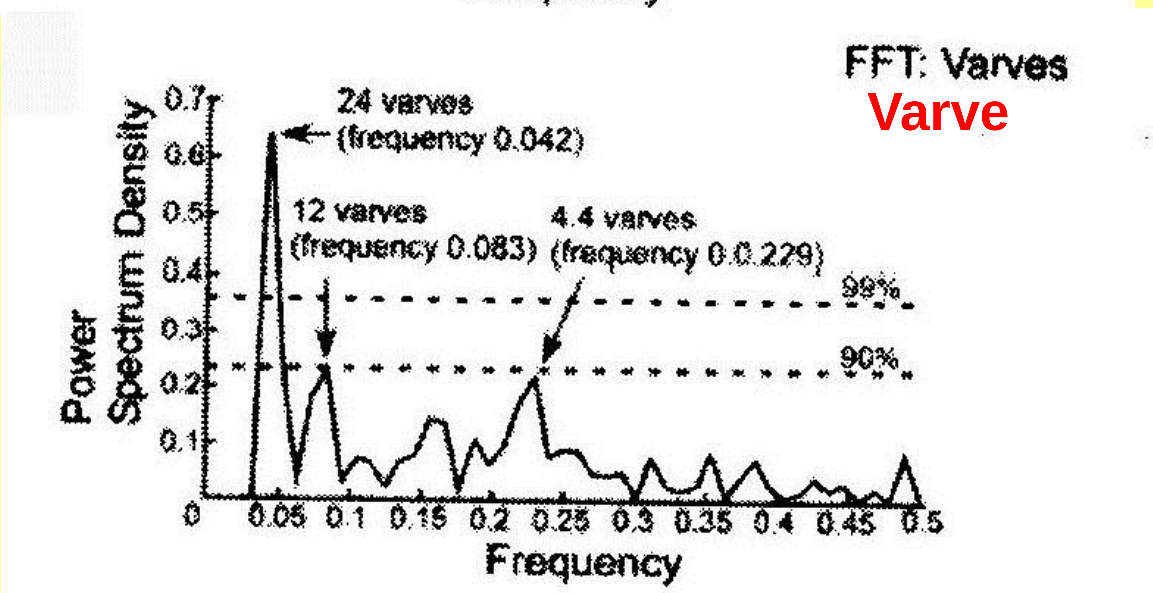
Tree-rings

(Shunk, 2009)

Climate change around 5-7 million years ago (late Miocene - early Pliocene)



Result of spectral analyses of fossil tree ring width and varve thickness.



Result of spectral analyses has shown existence of 12 and 23-24 year periodicity.

Conclusion

- **In the past (150-5 millions years ago) climate variations clearly exhibited quasi-two-hundred-year and quasi-secular periodicities . It can be supposed that these climate oscillations were due to the influence of deVries and Gleissberg solar cyclicities on climate parameters.**

- **Spectra of climate oscillations in the past show the existence of ca 11 year and 23-24 year cyclicity which can be related to Schwabe and Hale solar periodicity .**

- **Climate oscillation also exhibit Bruckner cyclicity (31-34 years) and 17-year variation which have been observed also in the recent time.**