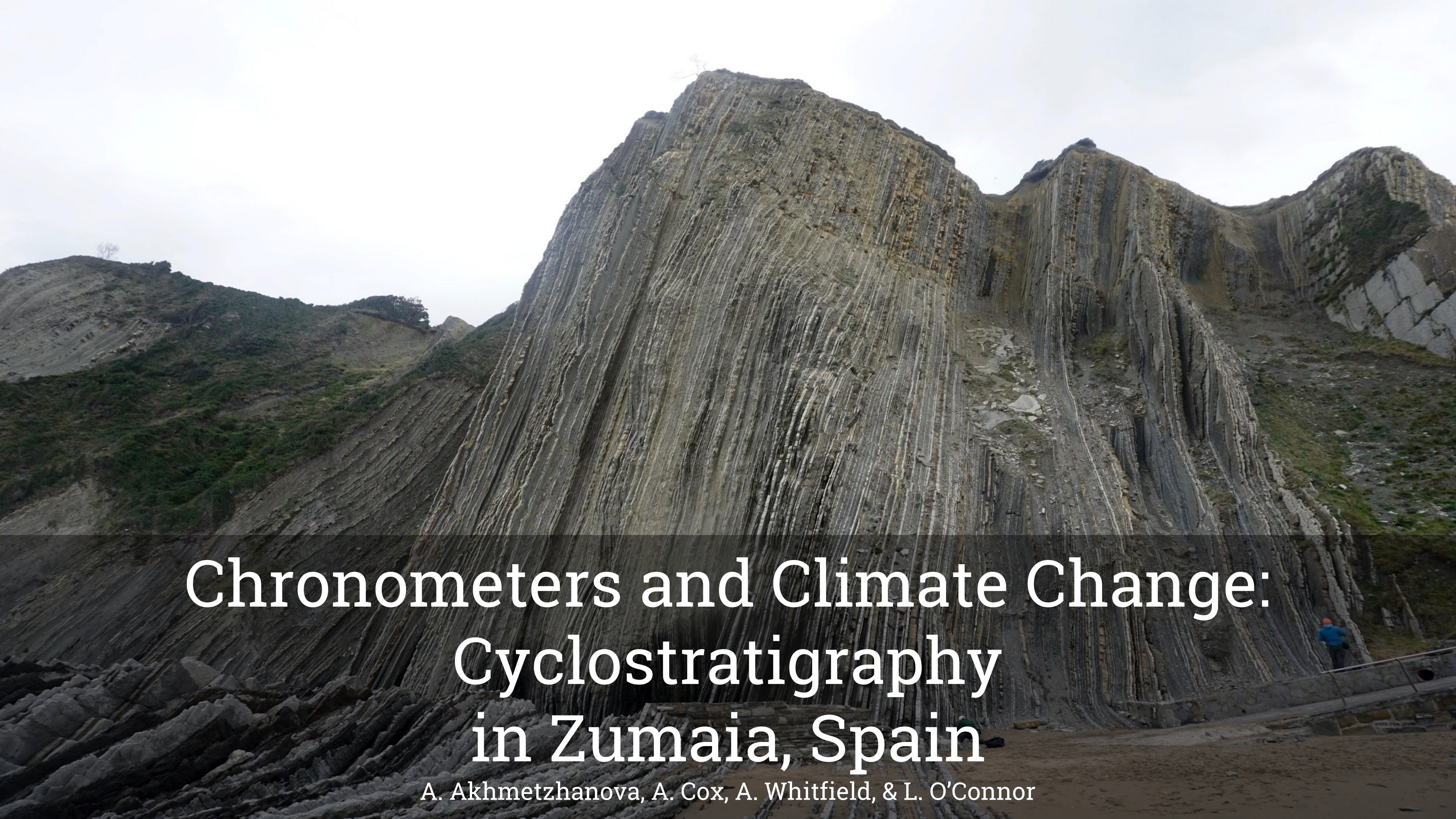


Chronometers and Climate Change: Cyclostratigraphy in Zumaia, Spain

A. Akhmetzhanova, A. Cox, A. Whitfield, & L. O'Connor

Milankovitch Cycles

Changes in orbital geometry: obliquity, tilt, eccentricity, and precession

↓

Changes in planetary temperature and seasonal heat fluctuations

↓

Transitions from glacial to interglacial time periods as result of changing climate

→

Changes recorded in the chemical composition of ice and rocks

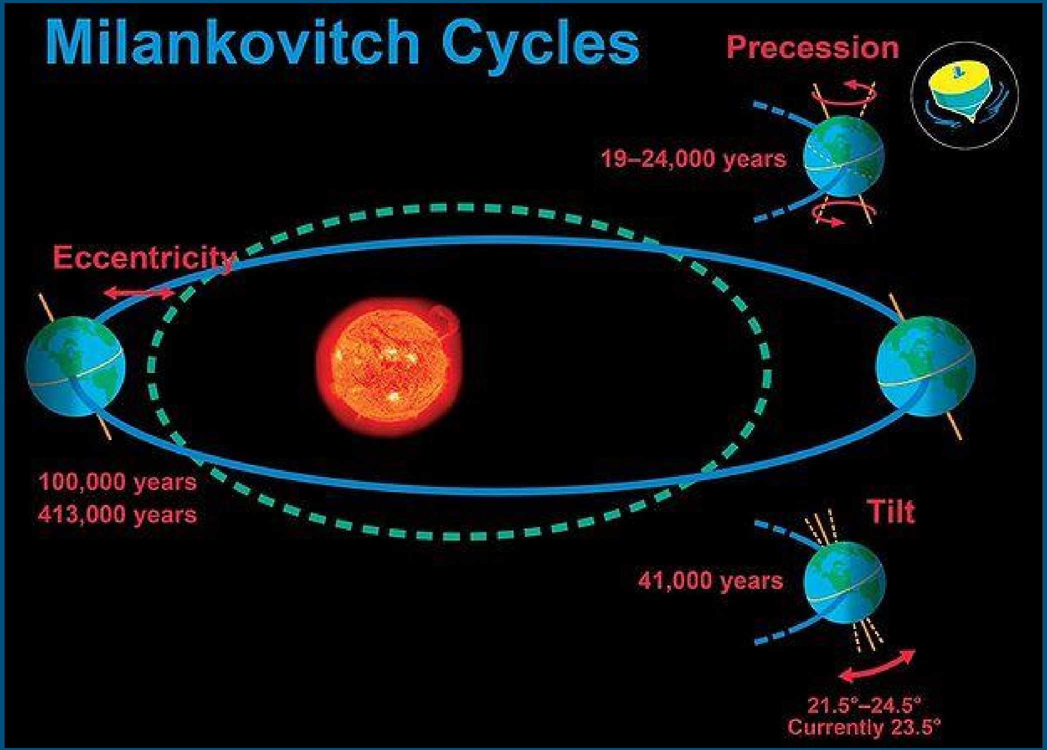


Image Credit: https://www.universetoday.com/39012/milankovitch-cycle/

Cretaceous-Tertiary (KT) Boundary ~65 Ma

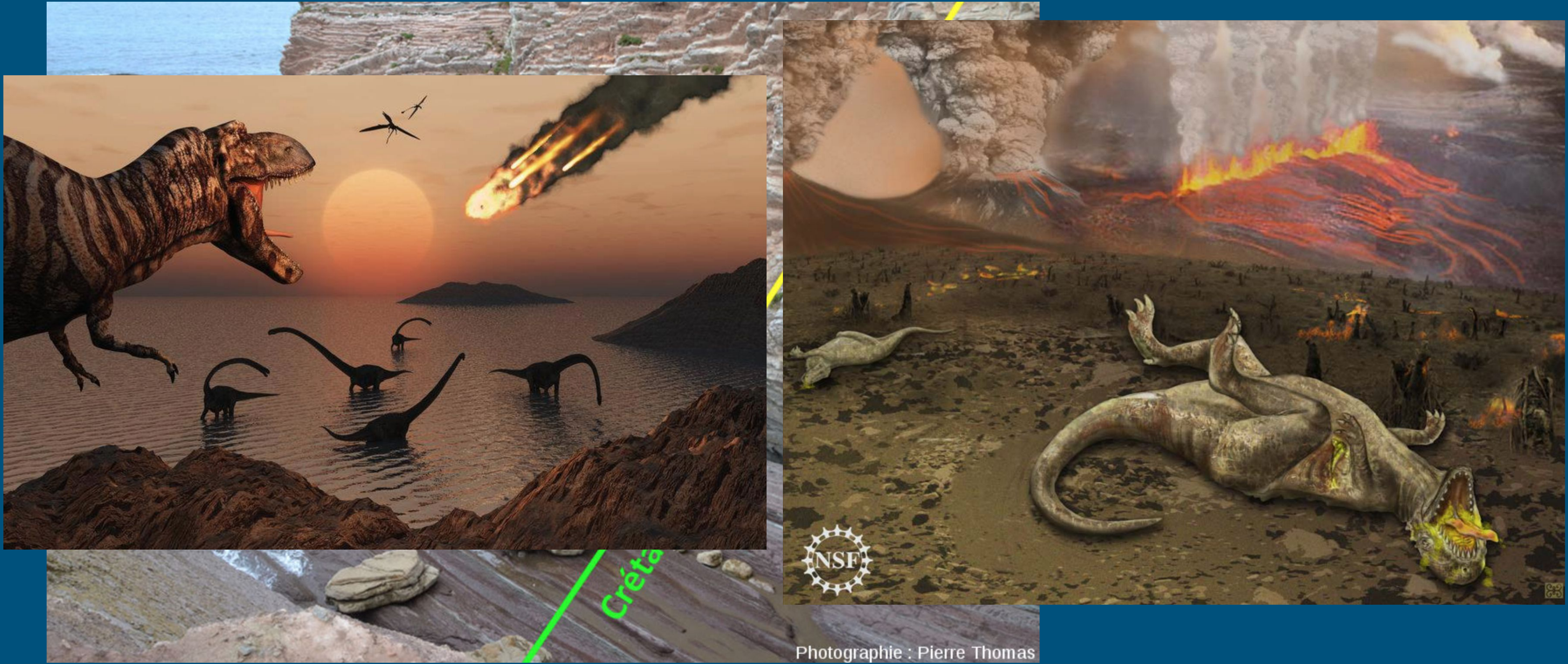


Image Credit: https://futurism.com/wp-content/uploads/2013/04/485176_441599455926469_1655029236_n.jpg

Introduction:

- **Limestone** - wackestone composed of small shells and skeletal matter
- **Marl** - mudstone containing dust and clay
- **Turbidites** - grainstone formed by sediment cascades

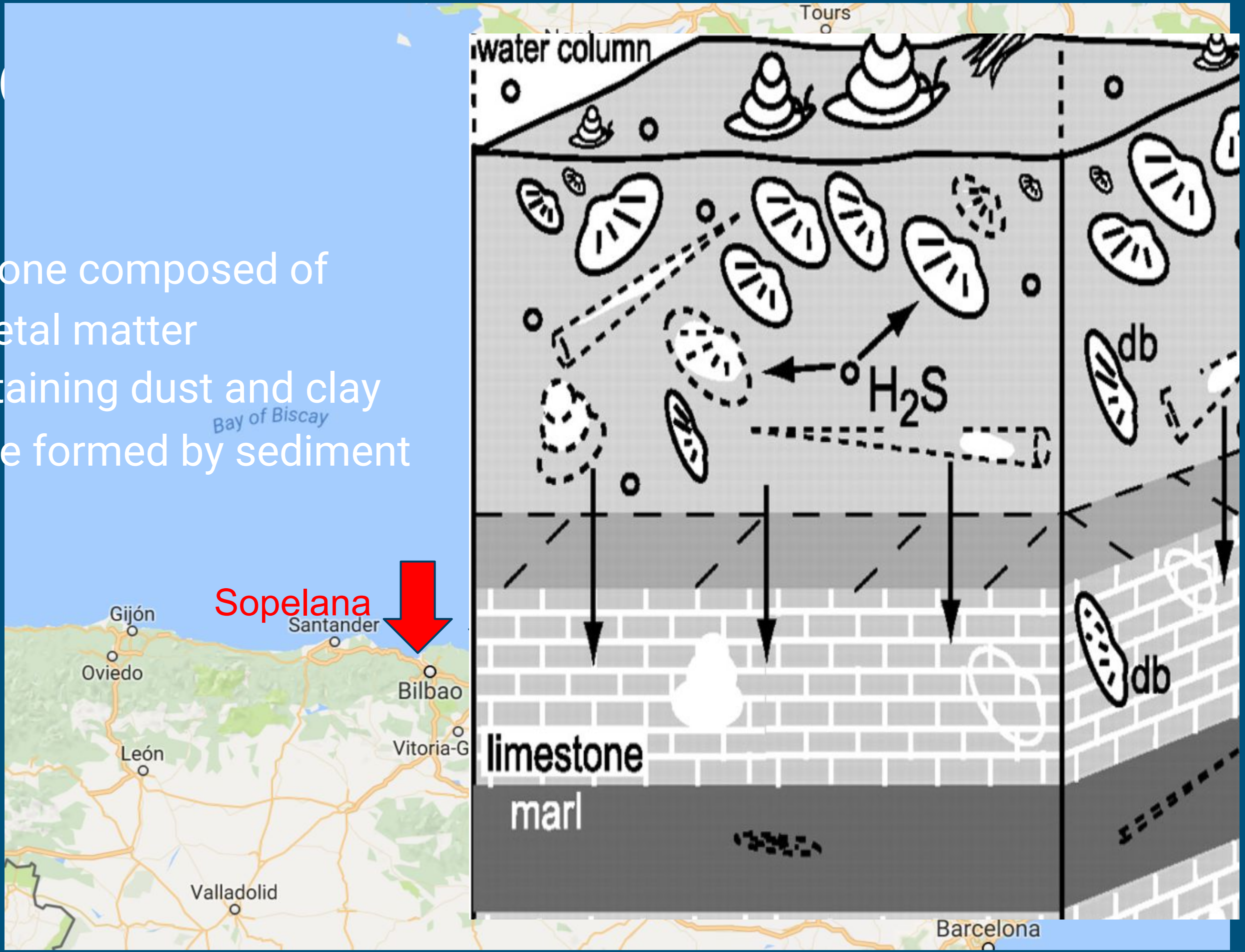


Image Credit: Wheeley, Cherns, & Wright (2008)

Video Credit:
https://www.youtube.com/watch?v=tfNLI2JW7mg

Lithologies

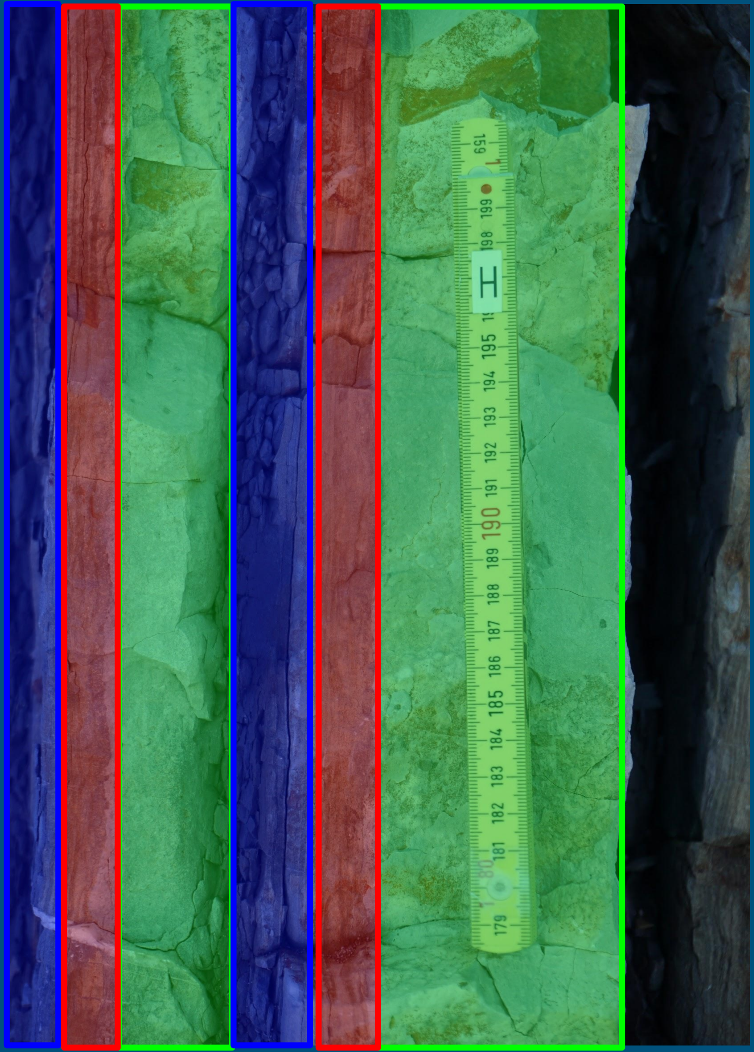


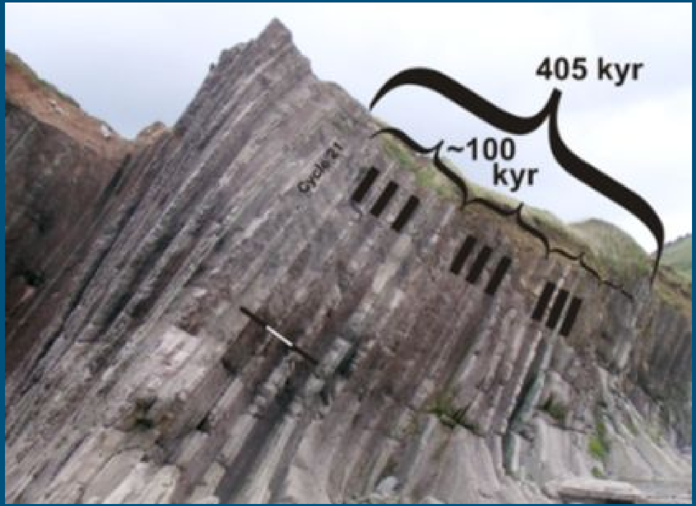
Image Credit: L. O'Connor

Prior Work by Others

FRS 135 (2015)

...et al. (2012)

Limestone-marl couplets are not caused by precession and eccentricity



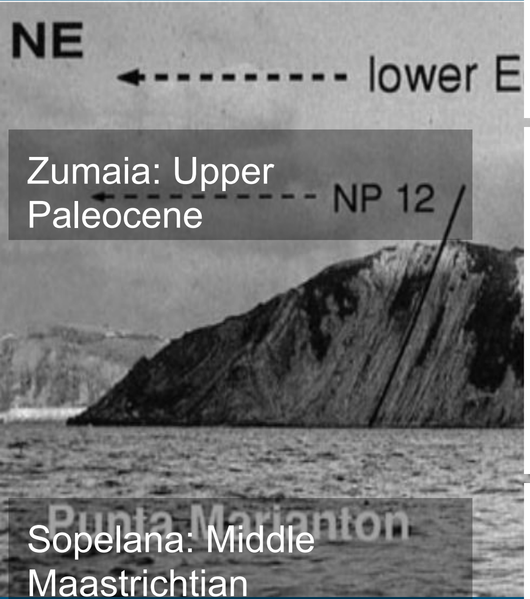
Pairings	Milankovitch Cycle
1 couplet	21,000 years
5 couplets of ~80 cm each	100,000 years
4 couplets of ~4 m each	405,000 years
~40 m pattern	1,200,000 years

...red

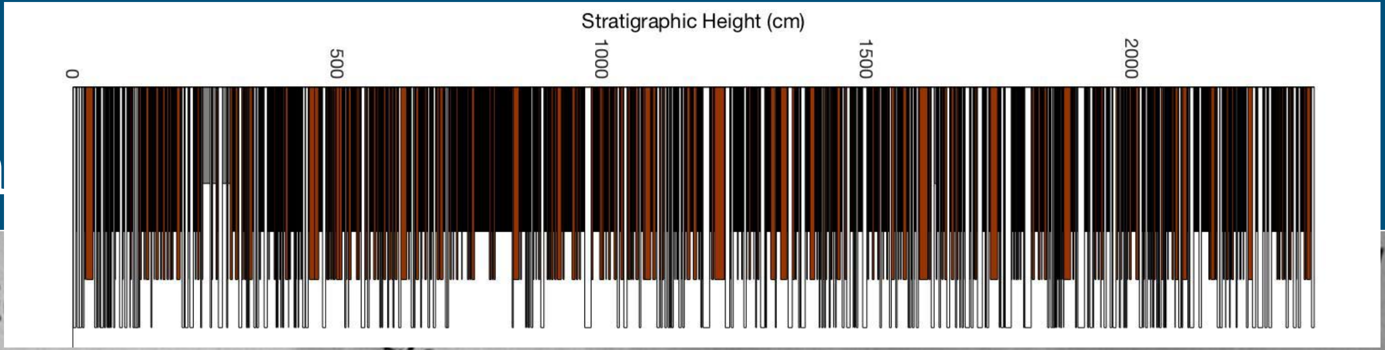
(2015)

Image Credit: Batenburg et al. (2012)

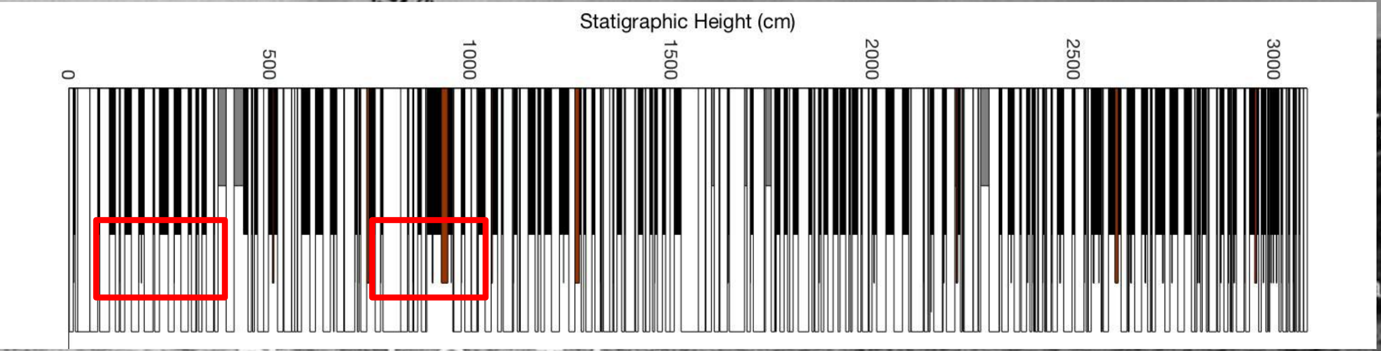
Our Section



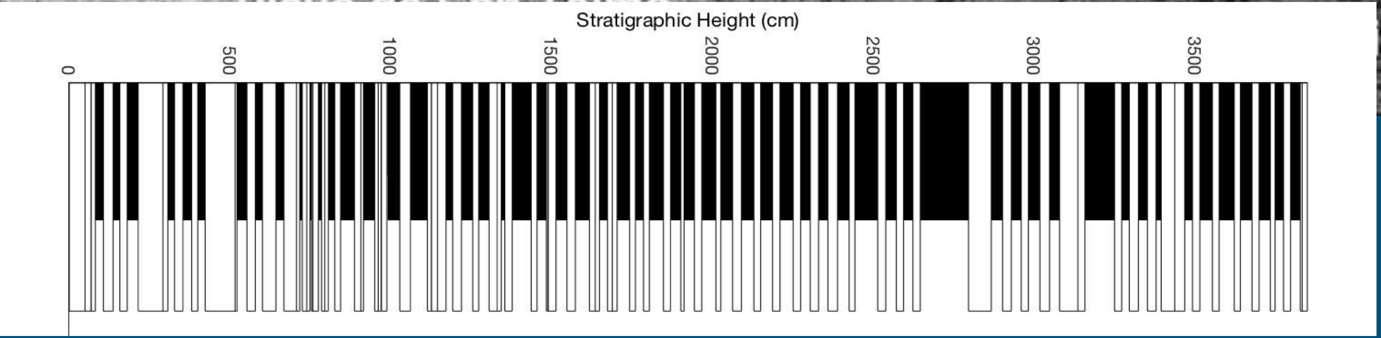
Zumaia: Lower Eocene



Zumaia: Upper Paleocene



Sopelana: Middle Maastrichtian



White=Limestone
Black=Marl
Brown=Turbidite
Grey=Cover

Method

Hypothesis: No Milankovitch Cycles

1. **Transitions** (Markov Analysis)
    a. Check turbidite-marl relationship
    b. Check limestone-marl relationship
2. **Thicknesses** (Probability Distribution)
    a. Analyze the probability of thicknesses
3. **Thicknesses** (Periodicity)
    a. Remove turbidites
    b. Assume no couplets
    c. Assume couplets
    d. Look for Milankovitch signals

Image Credit: L. O'Connor

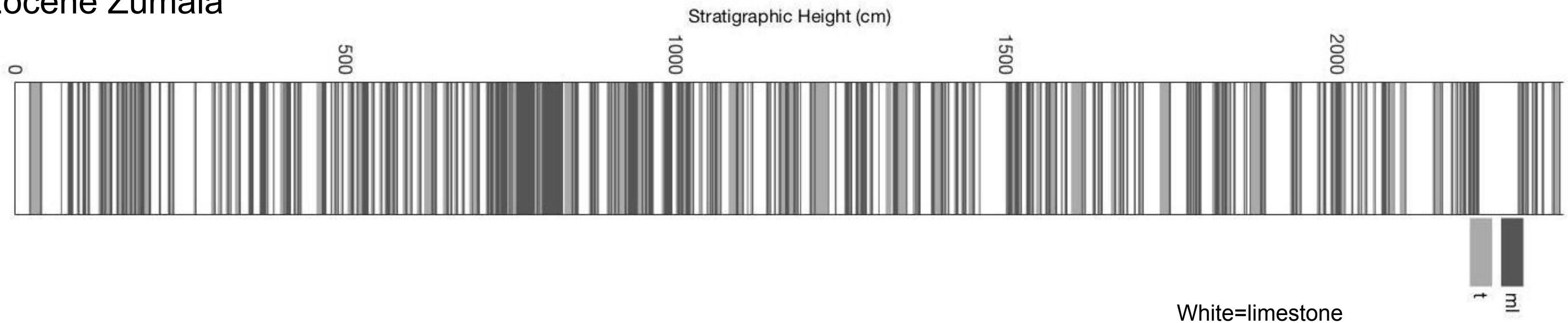
Markov Analysis

Explanation- Marls are very frequently part of the sequence that makes turbidites.
Implication- This interferes with the Milankovitch signals that Gawenda and Batenburg found in the couplets.

T =

Location and Starting State	Limestone	Marl	Turbidite
Eocene Limestone	1	57	39
Eocene Marl	53	2	45
Eocene Turbidite	2	93	3
Paleocene Limestone	12	58	22
Paleocene Marl	76	5	14
Paleocene Turbidite	2	98	0
Sopelana Limestone	28	70	0
Sopelana Marl	93	8	0
Sopelana Turbidite	0	0	0

Eocene Zumaia

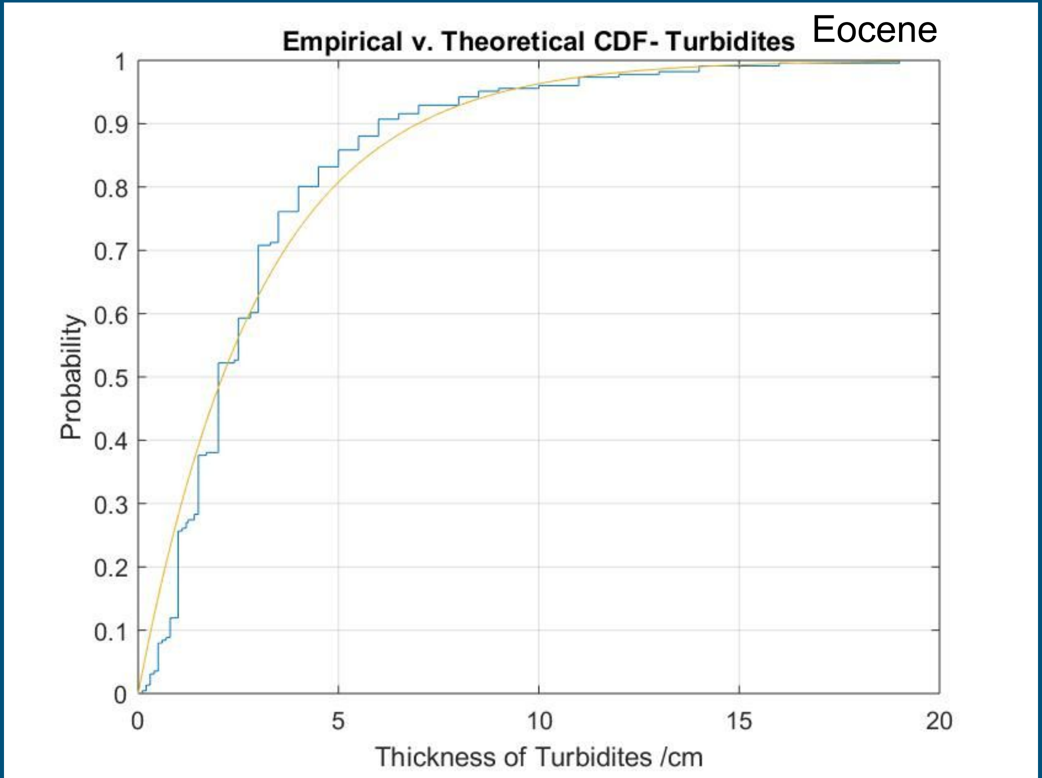


White=limestone

Layer Distribution

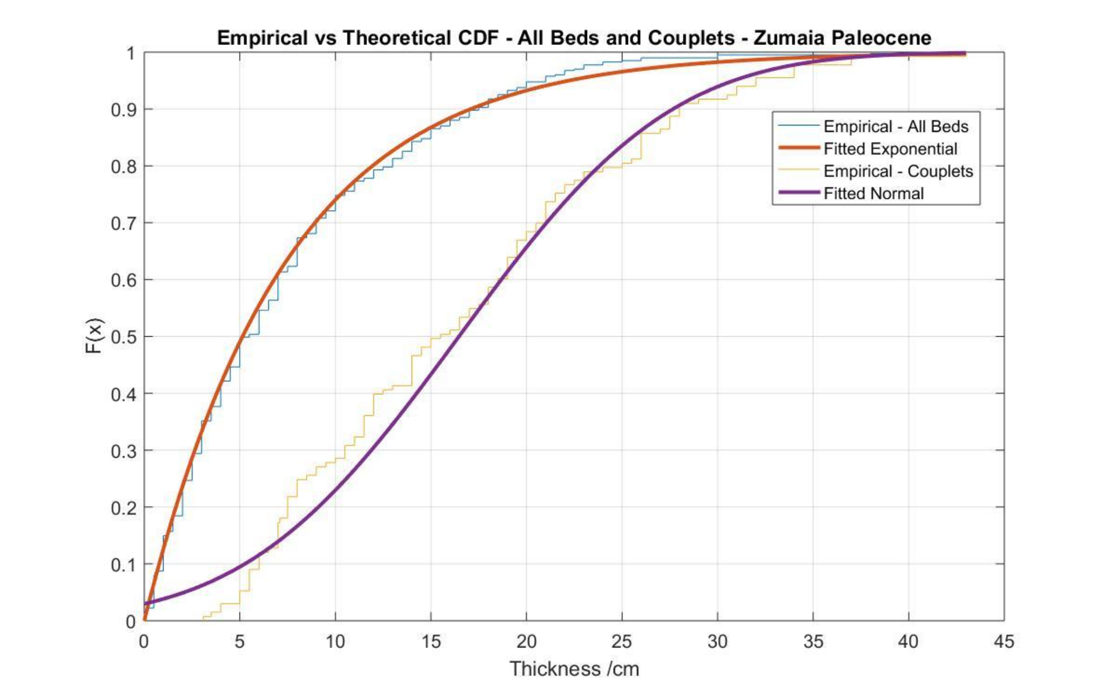
- Thickness of certain combinations of bed types will fit certain probability distributions
- Each distribution can tell us something about the nature of the depositional process of the bed, or bed couplet
- Null Hypothesis - bed thicknesses follow normal distribution and are correlated in time in a cyclical fashion.
- Exponential distribution (Wilkinson *et al.* 1999, Burgess 2008) in lithologies and no cyclicity.

Bed Thickness Distributions



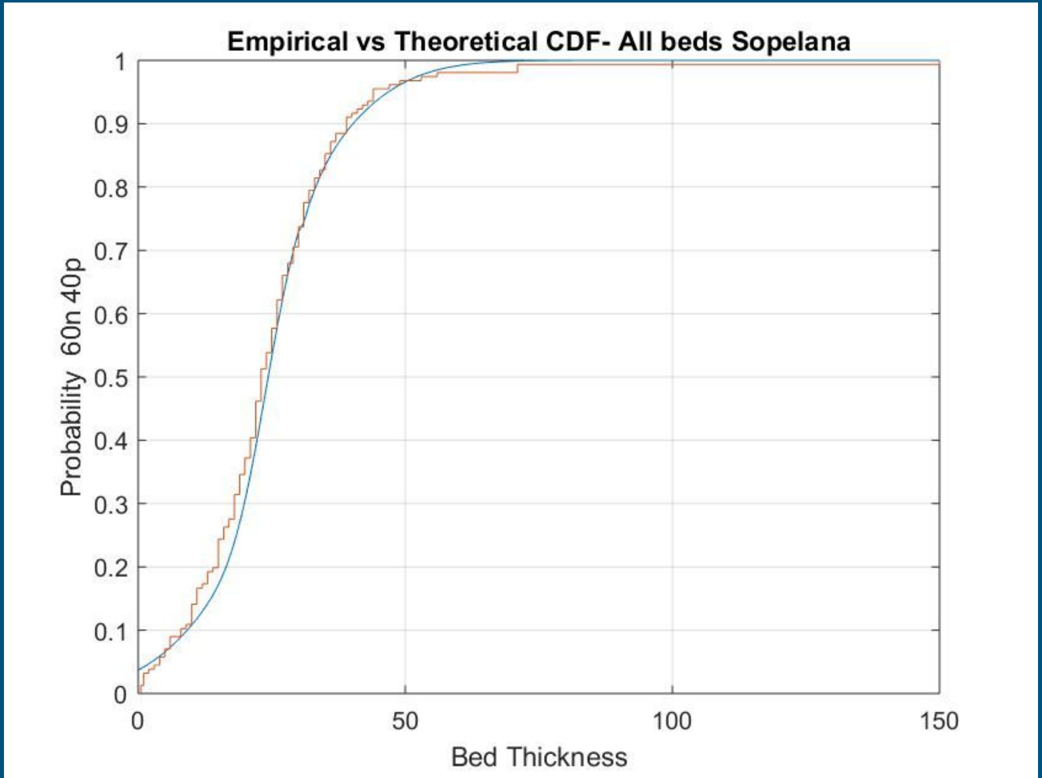
- A clear exponential fit, as expected for turbidites
- Thickness depends on whether at start or end of a Bouma sequence
- Turbidites are exponential,, so L-ML couplets that include them are also exponential.

Bed Thickness Distributions



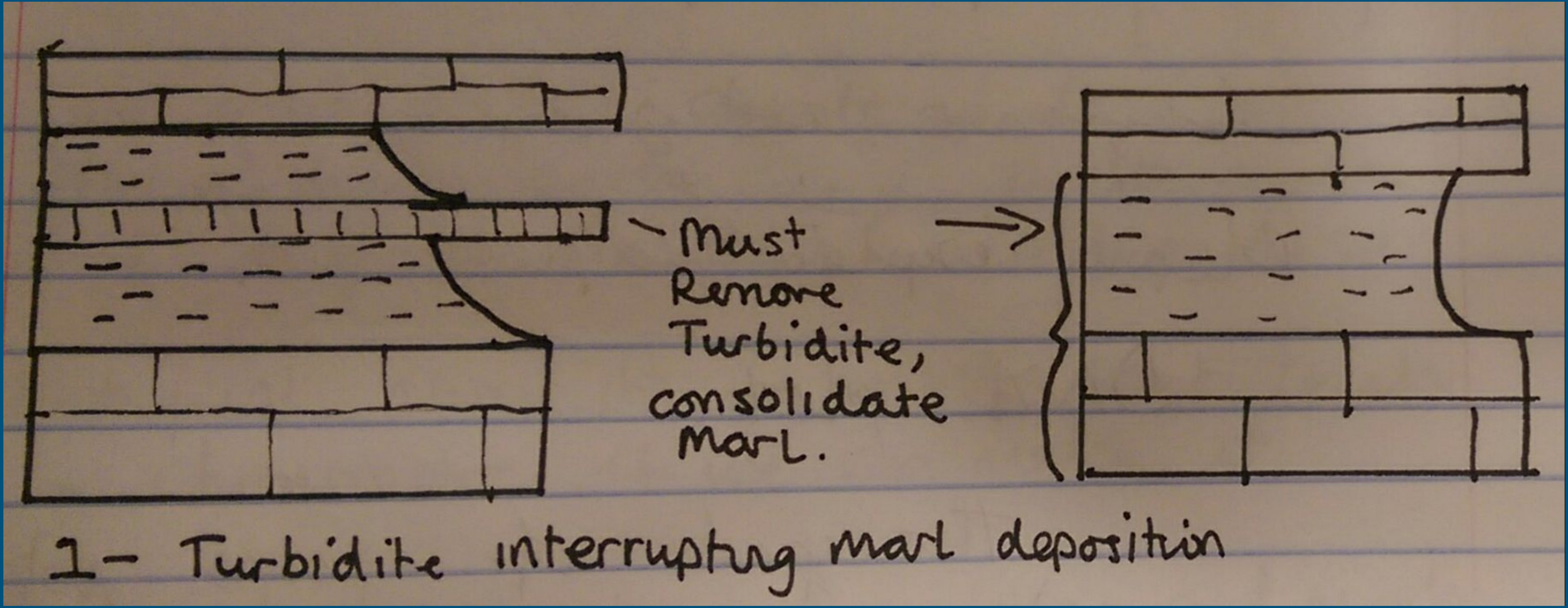
- Random Nature of Turbidites means that all bed thicknesses are exponential.
- When removing turbidites and coupling Limestone and Marl, normal distribution emerges

Bed Thickness Distributions

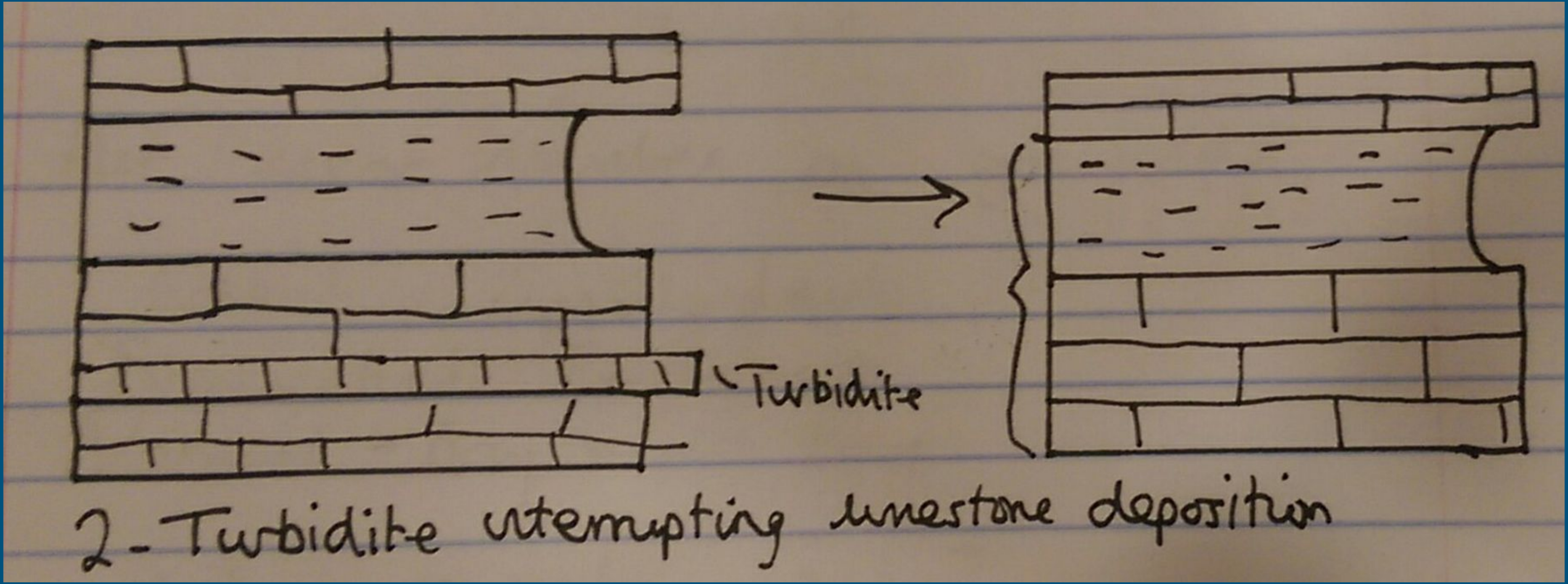


- To confirm, Sopelana (no Turbidites) has no evidence of an exponential distribution.

L-ML Couplet Ratios



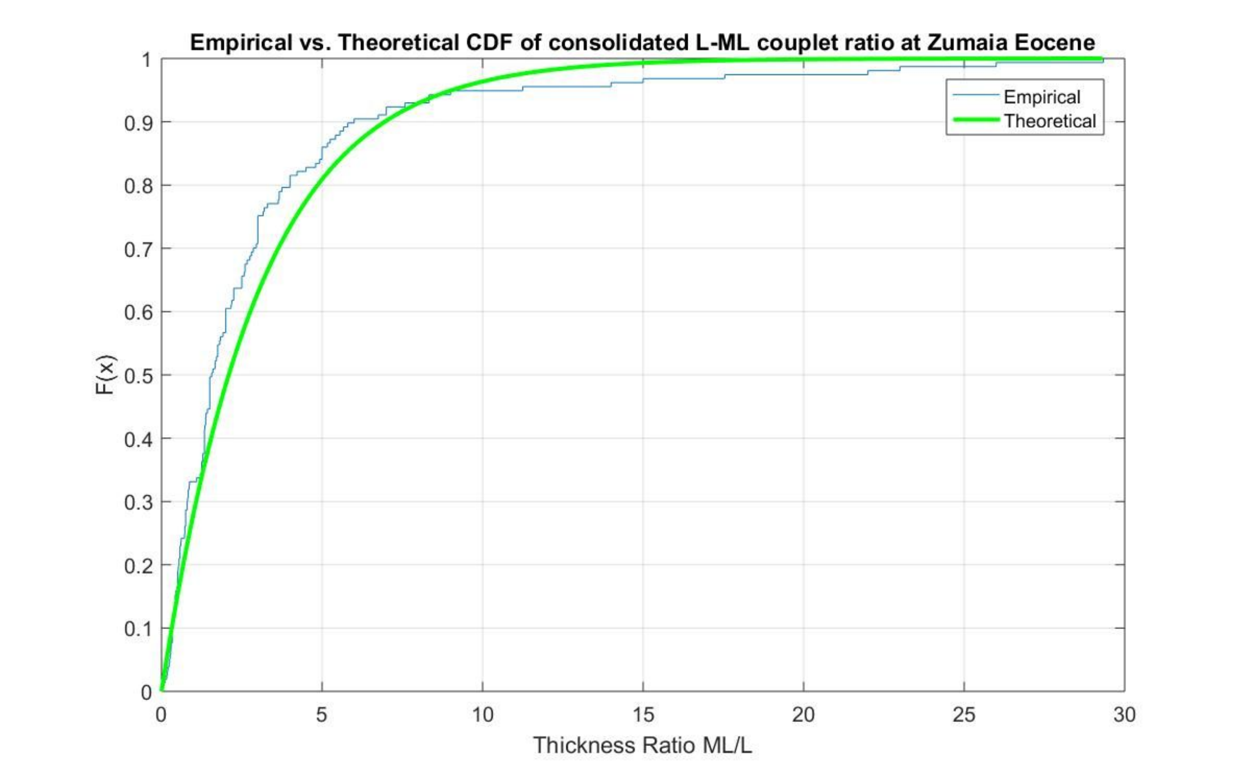
L-ML Couplet Ratios



Motive

- How variable is the ML/L ratio?
- The ambiguous Turbidites/Marl boundary could mean randomly distributed ML/L, and therefore unreliable couplets
- Is marl deposition a threshold process?

L-ML Couplet Ratios



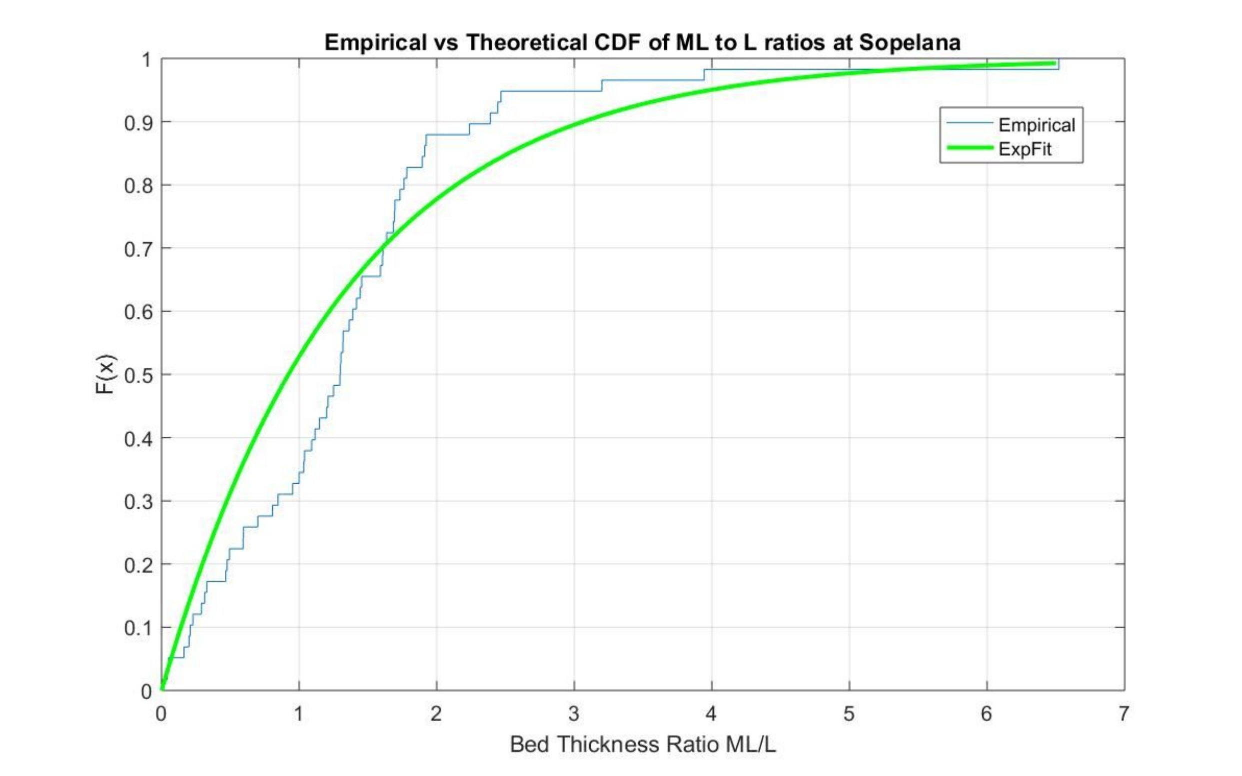
Mean - 3.02
Sd- 4.52
Sample Size - 157 beds
Fit - Exponential

L-ML Couplet Ratios

Mean - 0.96
Std - 1.30
Sample Size - 157 beds
Fit - Exponential

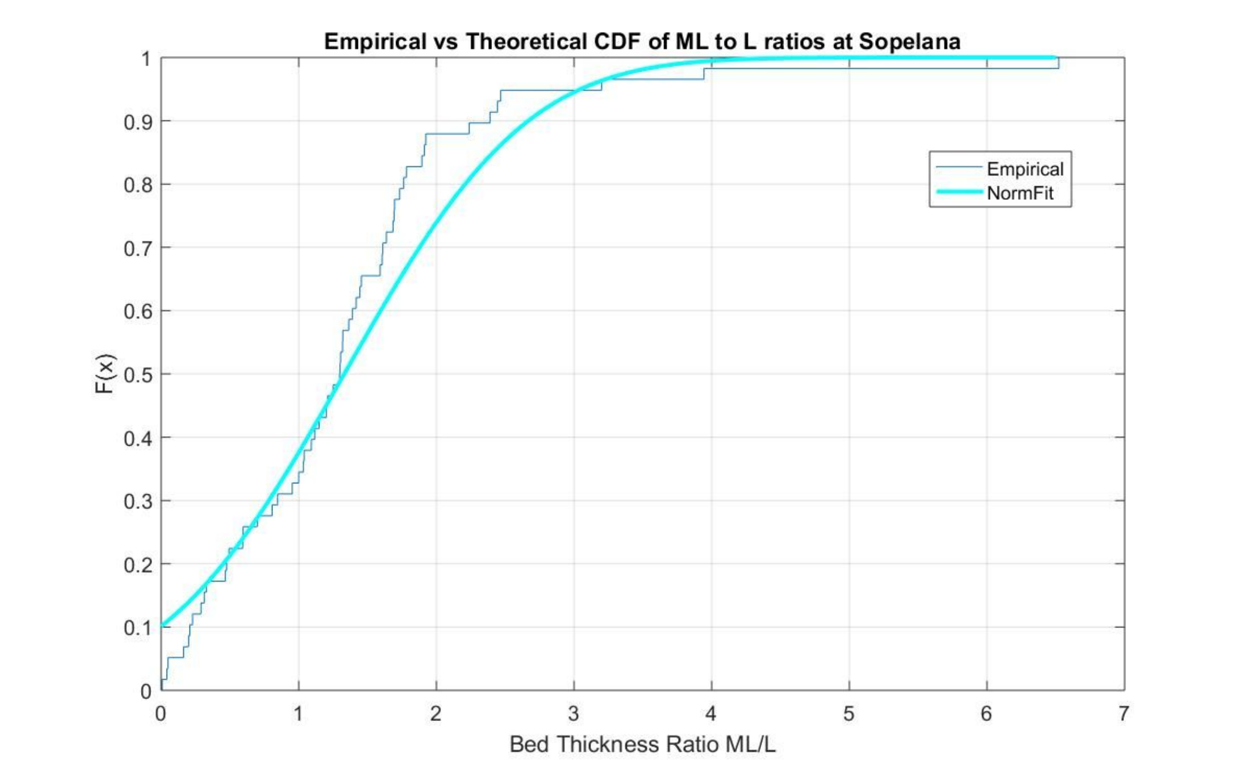
Time periods were so close- could this hint at unreliable turbidite thickness?

L-ML Couplet Ratios



Mean - 1.33
Sample Size - 58 beds
Fit - Exponential

L-ML Couplet Ratios

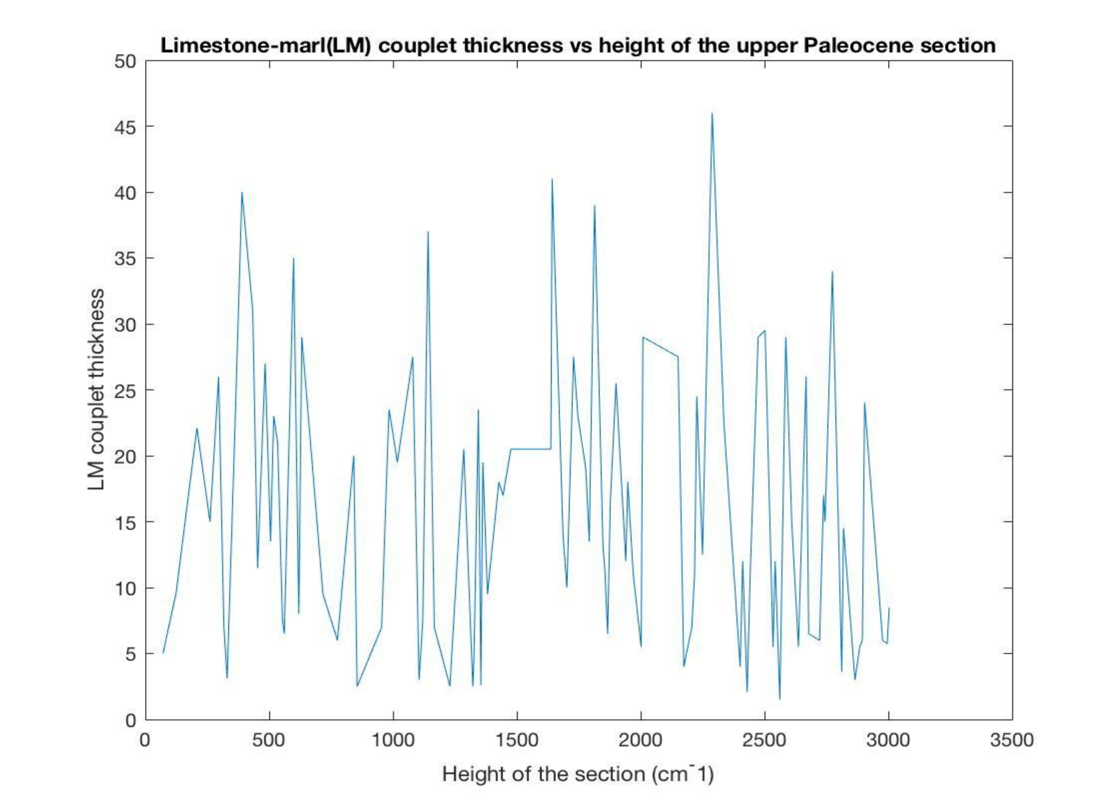


Mean - 1.33
StdDev - 1.04
Sample Size - 58 beds
Fit - Normal

Shows that:
Careful removal of turbidites will reveal normal distribution

Not a threshold process?

Testing Milankovitch Cycles Hypothesis



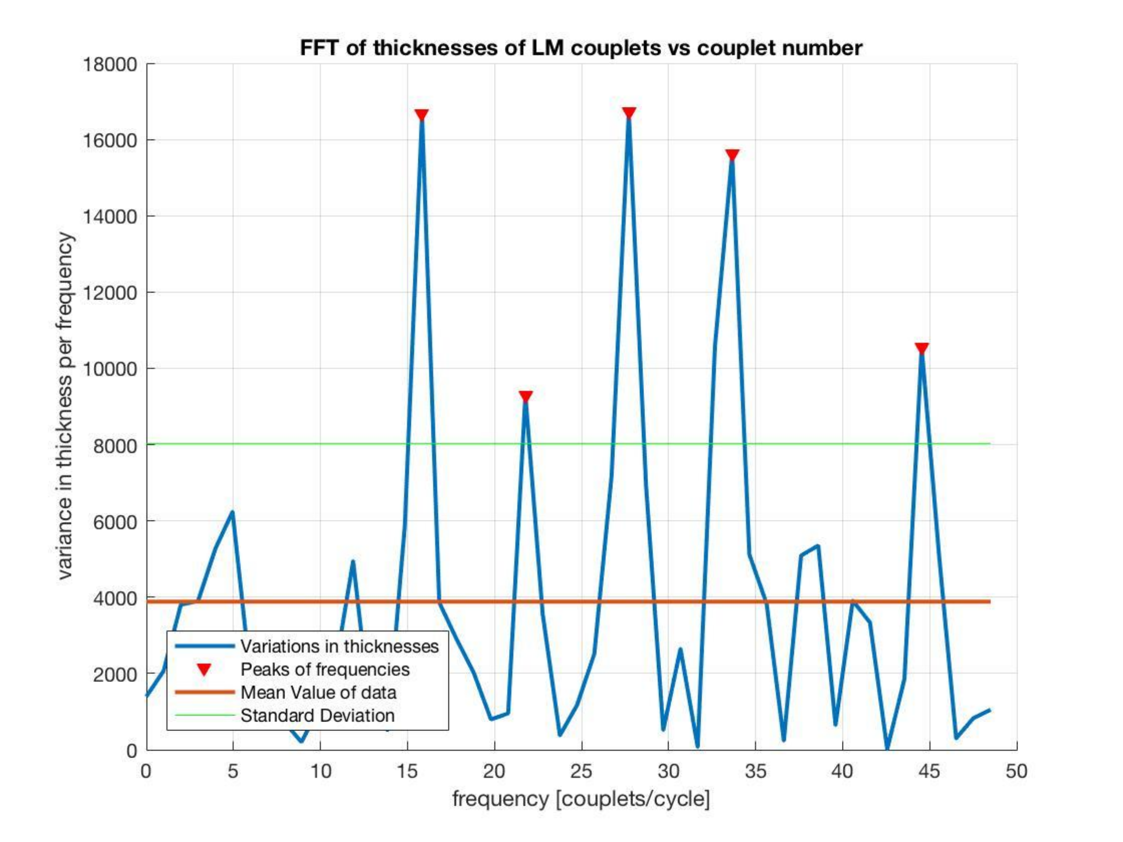
1. Identify LM couplets and calculate their thicknesses

Why?

- LM couplets are more likely to follow normal distribution/ exhibit <u>periodic behaviour</u>

2. Plot LM couplet thicknesses vs height of the section

Testing Milankovitch Cycles Hypothesis

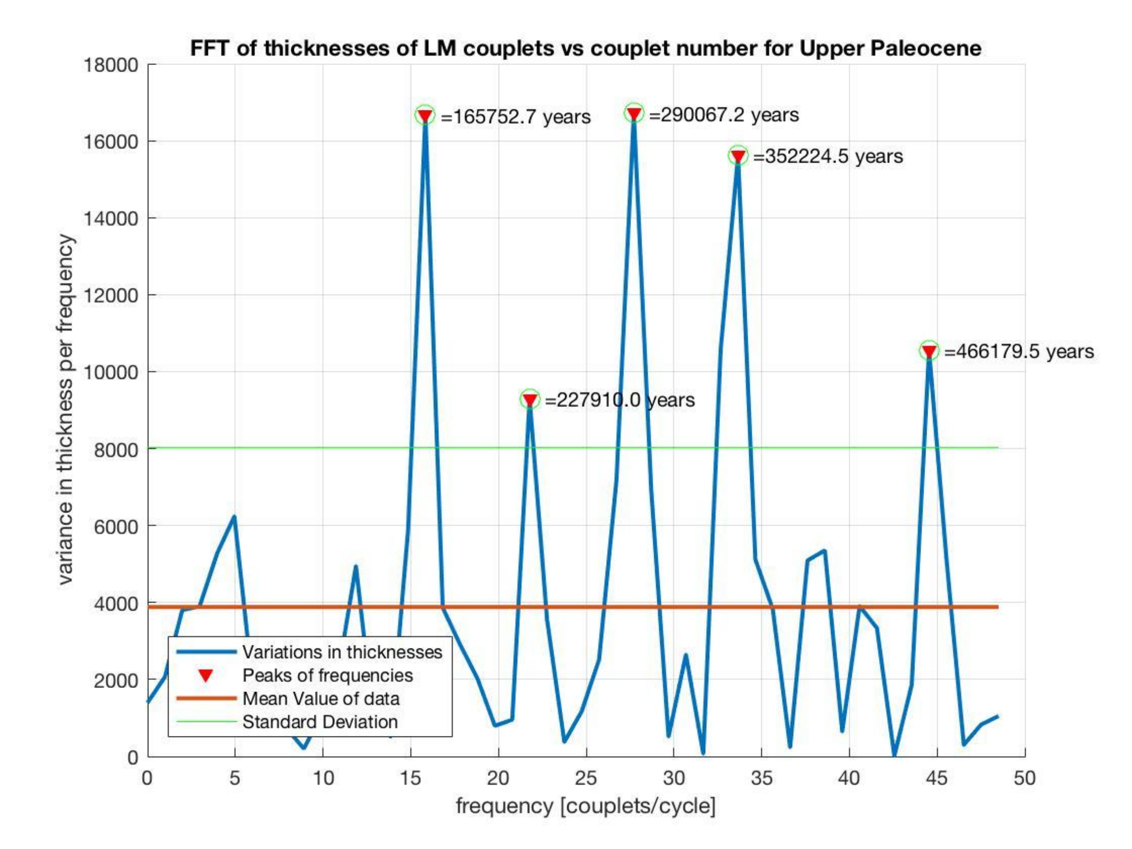


3. Periodogram of LM couplets vs couplet number

Remove noise

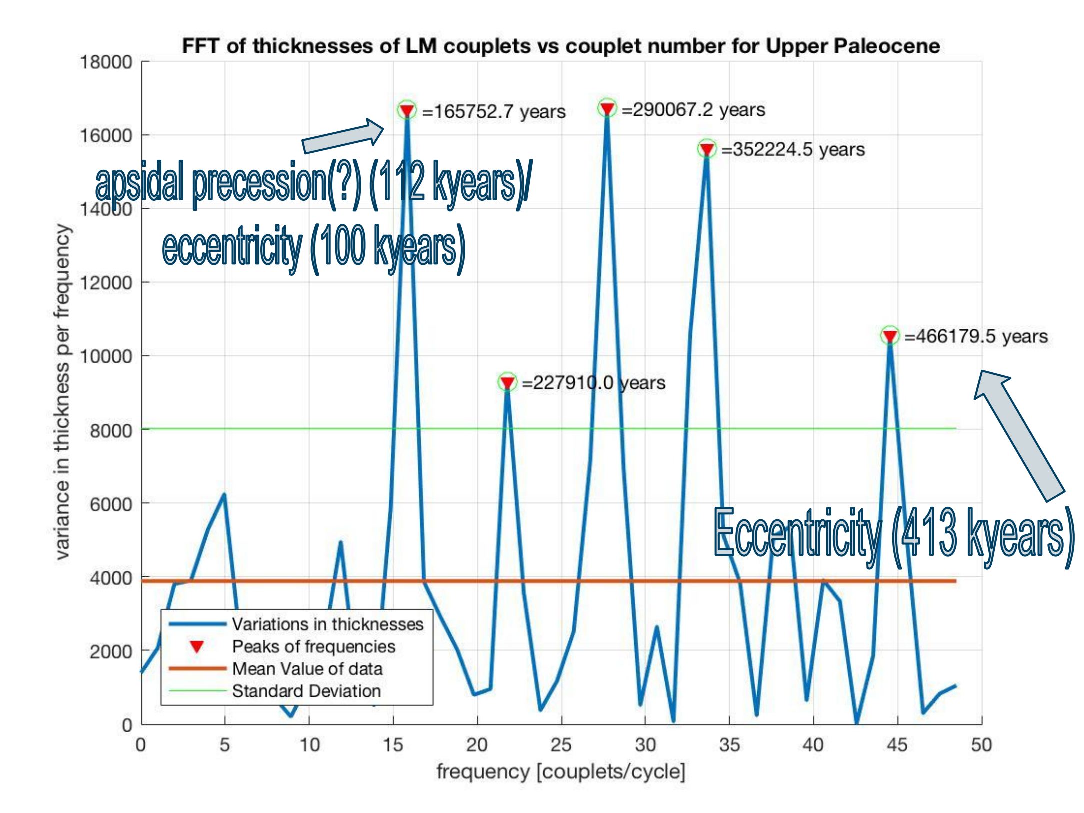
Identify peak periods of number of LM couplets/cycle

Testing Milankovitch Cycles Hypothesis



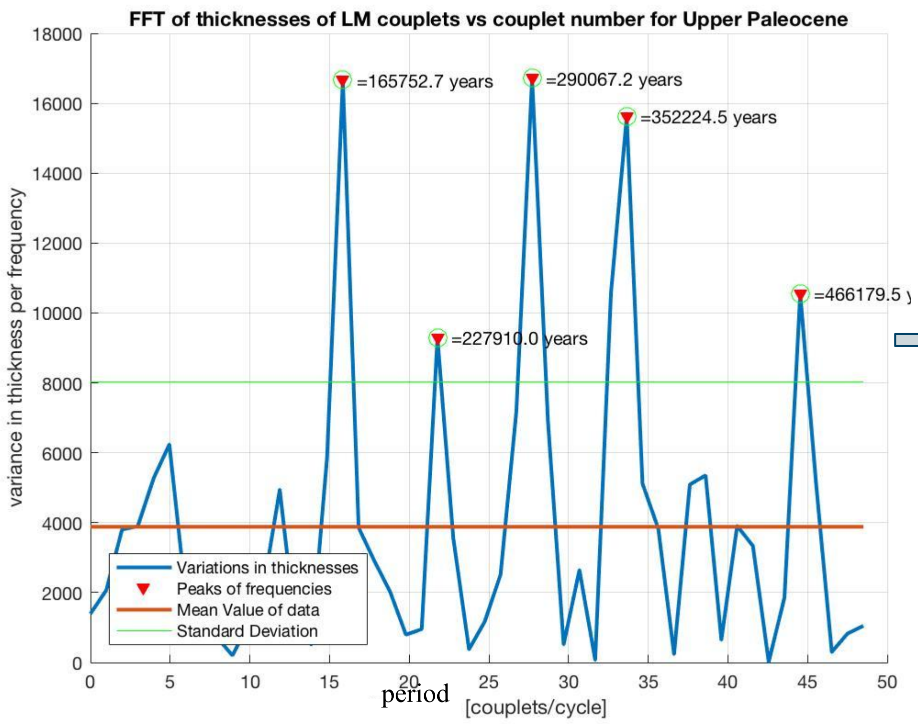
4. Using estimated sedimentation rates calculate time periods which correspond to peaks

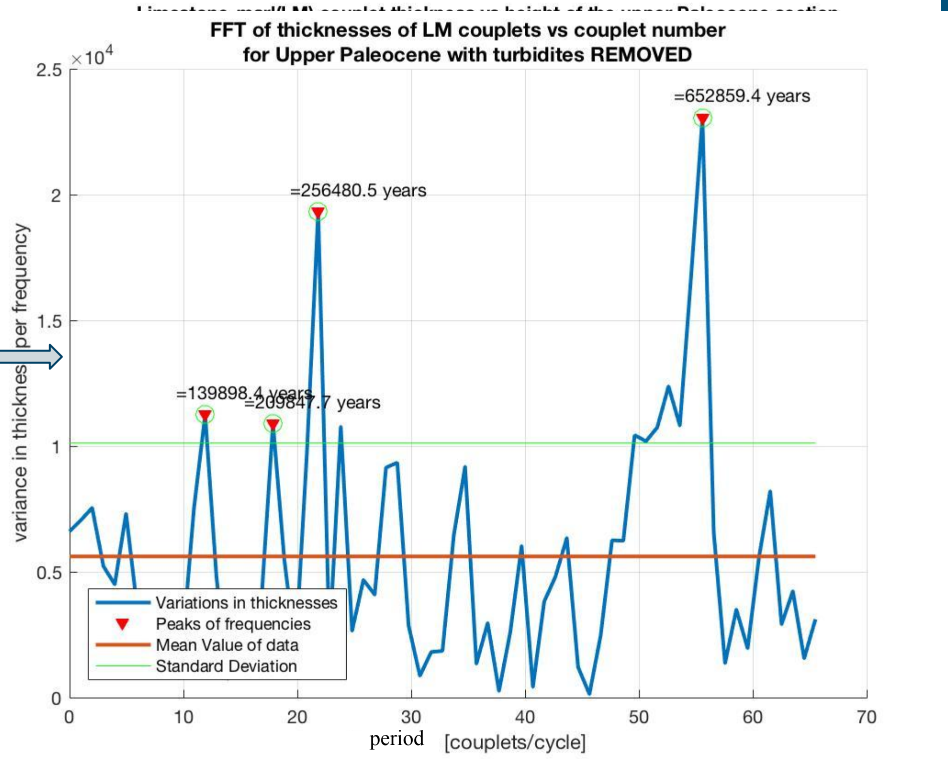
Testing Milankovitch Cycles Hypothesis



5. Look for possible Milankovitch cycles

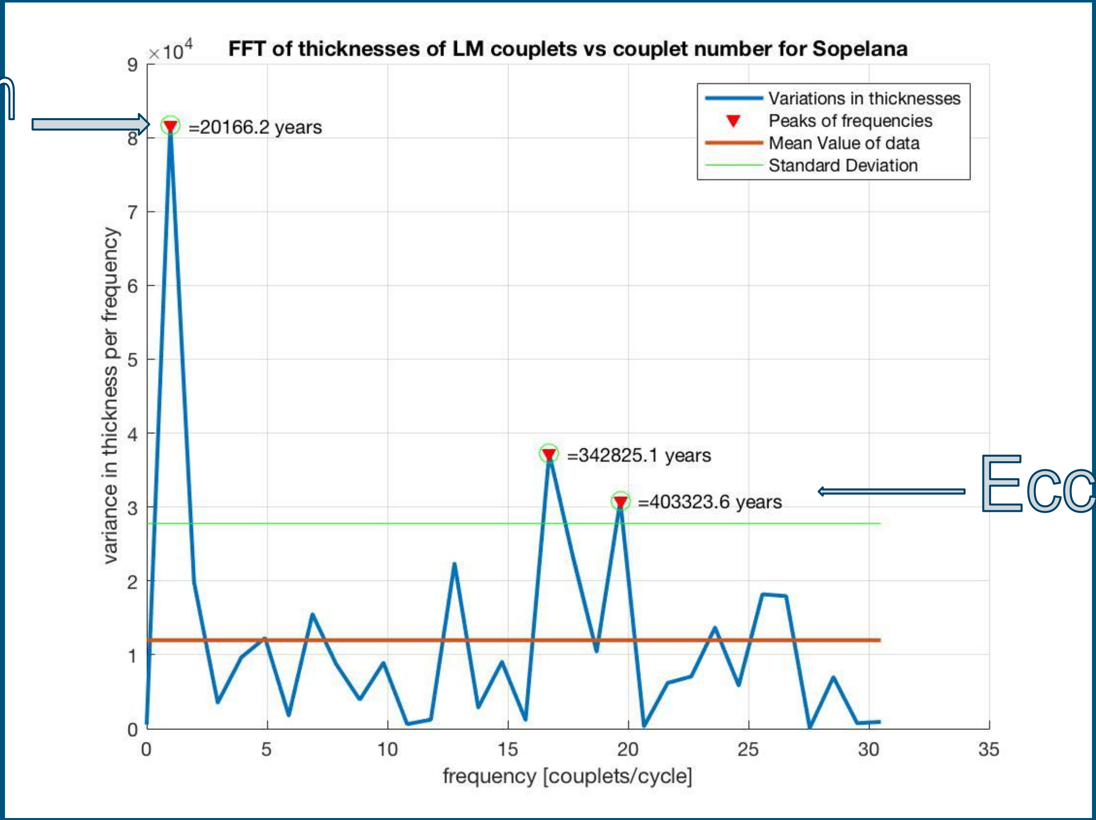
Why it is important to remove turbidites





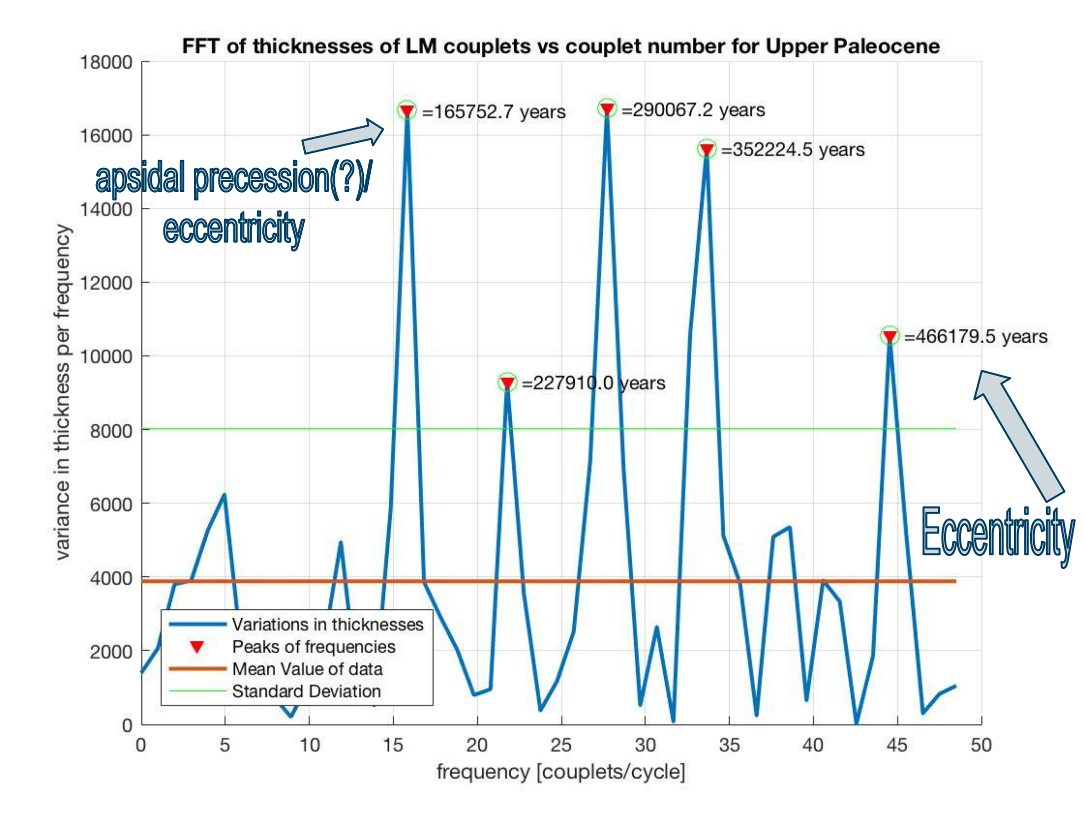
Findings: Sopelana

Axial precession



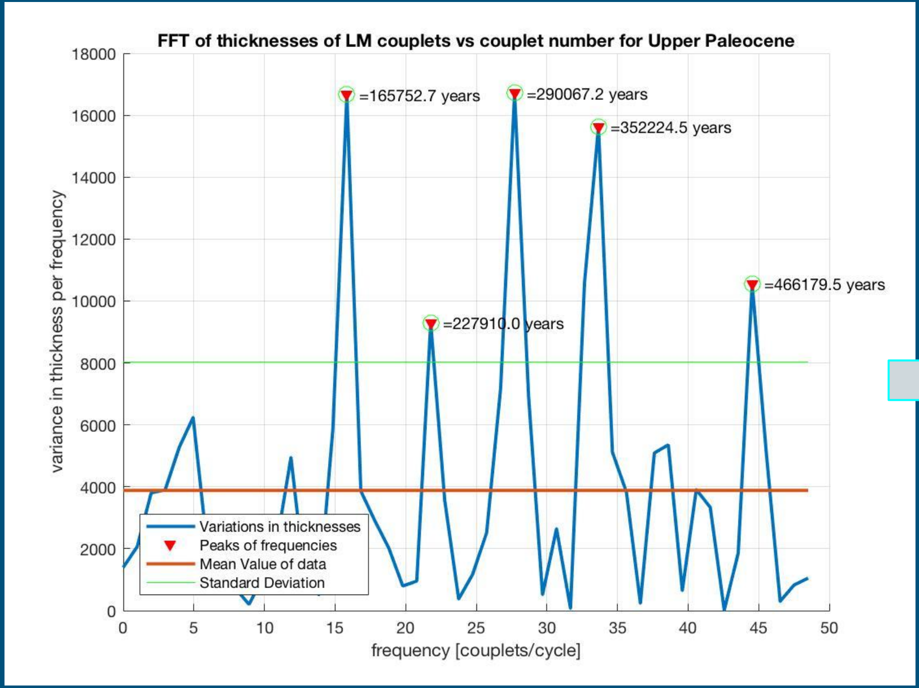
Eccentricity

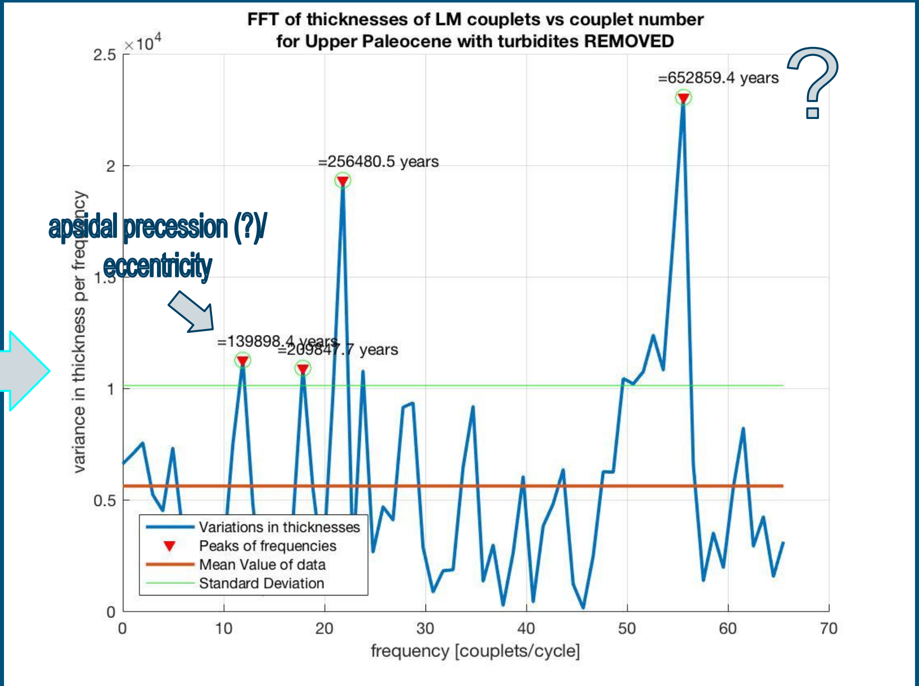
Findings: Upper Paleocene



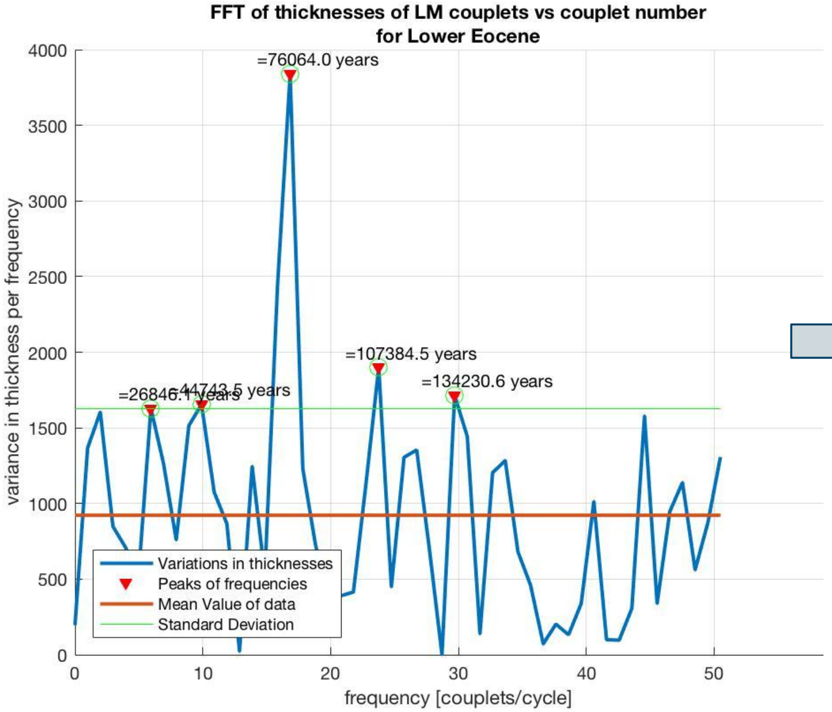
- No evidence of shorter Milankovitch cycles
- Most prominent peaks do not directly correspond to known cycles
- Evidence of long eccentricity cycle is still present

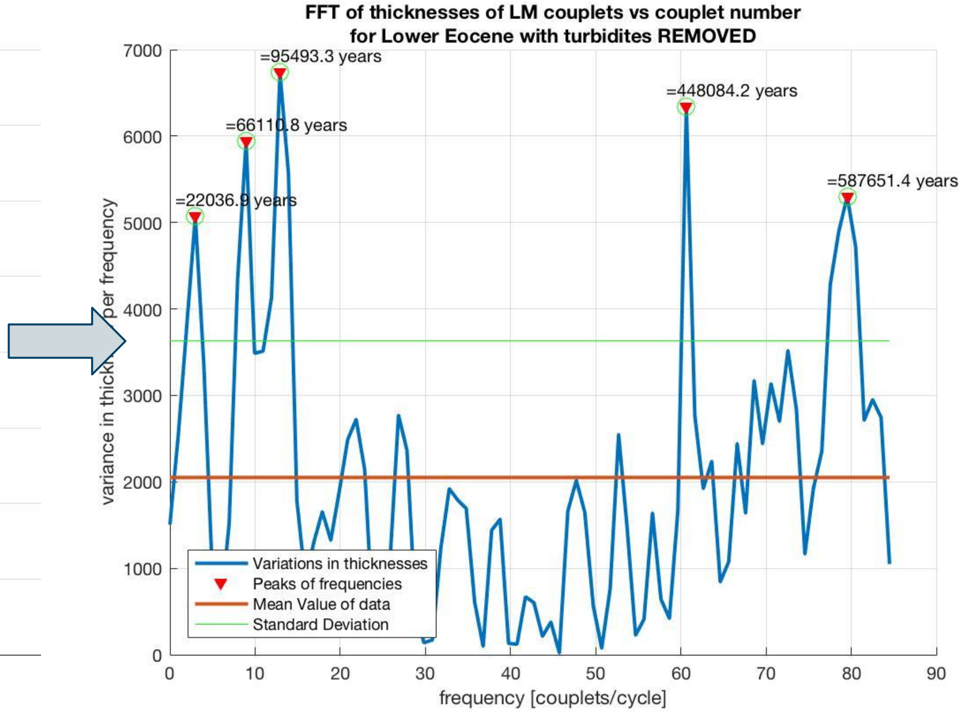
Findings: Upper Paleocene



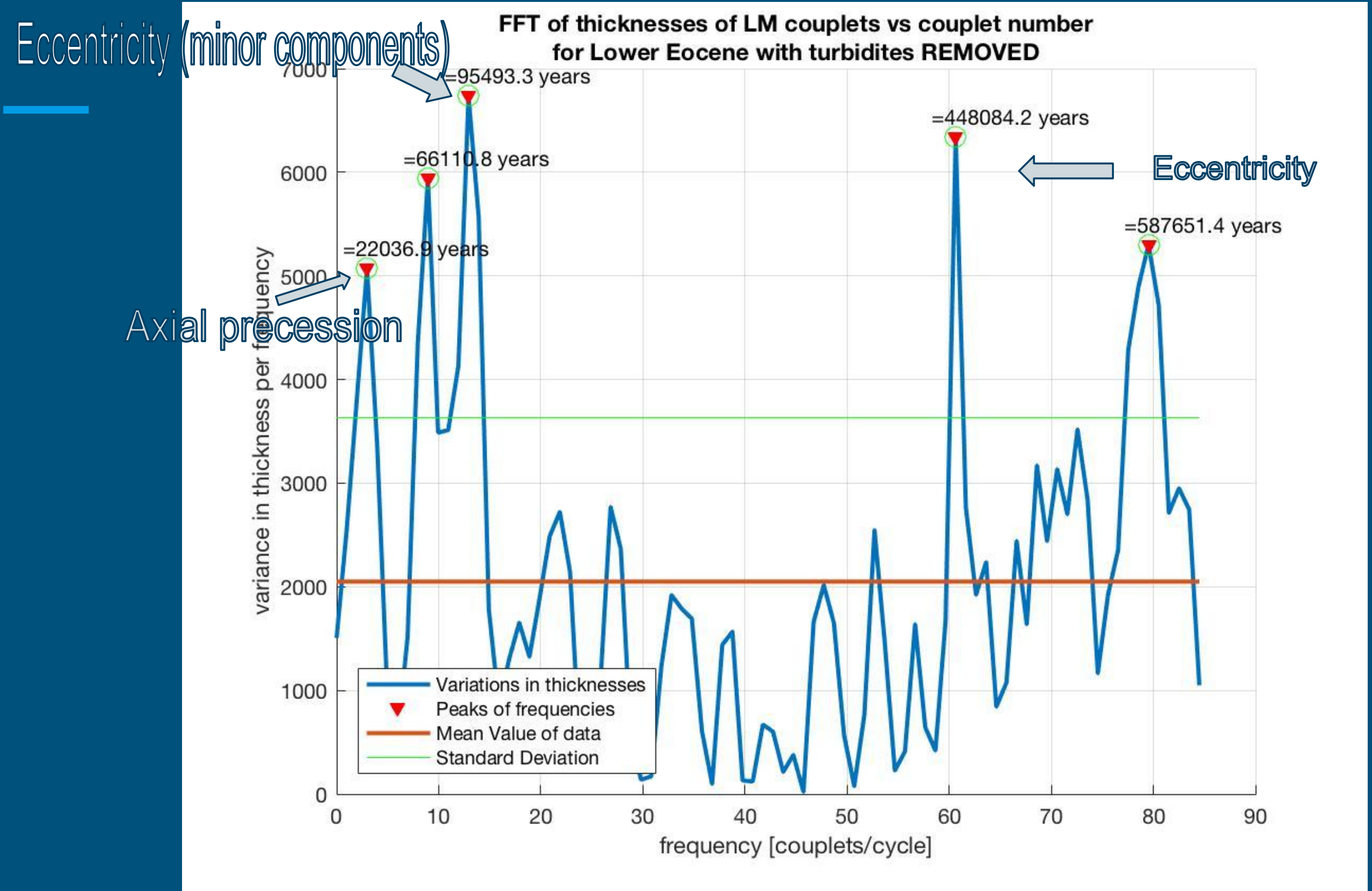


Findings: Lower Eocene





Findings: Lower Eocene



Bringing it all Together

- To understand climate in the past, we look at records in rock layers
- Milankovitch cycles are patterns in Earth's orbital changes that affect climate
- Past papers have found these cycles in the layers of Zumaia and Sopelana

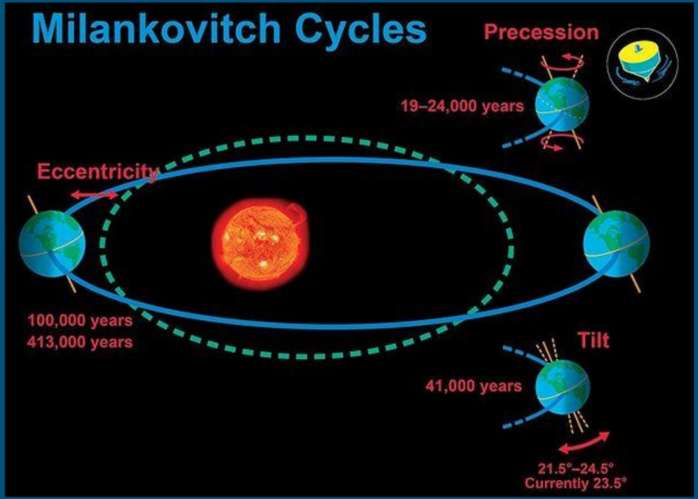


Image Credit:
https://www.universetoday.com/39012/milankovitch-cycle/

Bringing it all Together

Three main analysis methods:

- Markov: how often one type of layer follows another
  - often, marls followed turbidites
  - calls into question the coupling of limestone-marl layers
- Probability Distribution (CDF)
  - beds followed random distributions except without turbidites → became normal
  - since it was normal, it was reasonable to look for cycles
- Periodicity (Peak Finding)
  - bed thickness periodograms have peaks where strong signals occur
  - looked for Milankovitch cycles in these peaks

Conclusions

- We found Milankovitch cycles, though not as strongly as other papers did
- Removing turbidites was key in some cases
- Dominant Milankovitch cycles
  - Eccentricity (major component) ~ 413 kyears - present at all three locations
  - Axial Precession ~ 23 kyears - present at two locations
  - Eccentricity ~ 100 kyear - present at one location + one possible location

→

- Non-Milankovitch cycles were found more often than Milankovitch cycles (some of them repeated more often than Milankovitch cycles ~ 230 kyears)
- Milankovitch cycles did not always have strong signals
- We only estimated the length of time covered by the cliffs to get the sedimentation rate → we may have missed some Milankovitch cycles due to this uncertainty

...of course, we did all of these measurements with just a ruler and a hand lens, which is pretty impressive!

images from https://compleatnaturalist.com and wikimedia commons

Implications

If Milankovitch cycles can be found in rocks, we have an accurate chronometer to date events like the K-Pg boundary.

And if sedimentation in Zumaia and Sopelana bedrocks was dependent on climate, *these cycles do affect marl and limestone production.*

We modify the findings of Jared & Zhang (2015) and Batenburg et al. (2012)

References

Batenburg, S. J., Sprovieria, M., Galeb, A. S., Hilgend, F. J., Husinge, S., Laskar, J., Liebrand, D., Lirer, F., OrueEtxebarria, X., Pelosi, N., & Smit, J., 2012. Cyclostratigraphy and astronomical tuning of the Late Maastrichtian at Zumaia, *Earth and Plan. Sci. Let.*, **359**(1).

Burgess, P. M., 2008. The nature of shallow-water carbonate lithofacies thickness distributions, *Geology*, **36**(3), 235–238.

Diedrich, N. W. & Wilkinson, B. H., 1999. Depositional cyclicity in the Lower Devonian Helderberg group of New York State, *The J. of Geol.*, **107**, 643–658.

Gawenda, P., Winkler, W., Schmitz, B., & Adatte, T., 1999. Climate and bioproductivity control on carbonate turbidite sedimentation, *J. of Sed. Research*, **69**(6).

Wheeley, J. R., Cherns, L., & Wright, V. P., 2008. Provenance of microcrystalline carbonate cement in limestone-marl alterations, *J. of the Geolo Soc., London*, **165**, 397.

Acknowledgements

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Image Credit: L. O’Connor

Questions

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