

Coast Geological Society – Monterey Research Conference

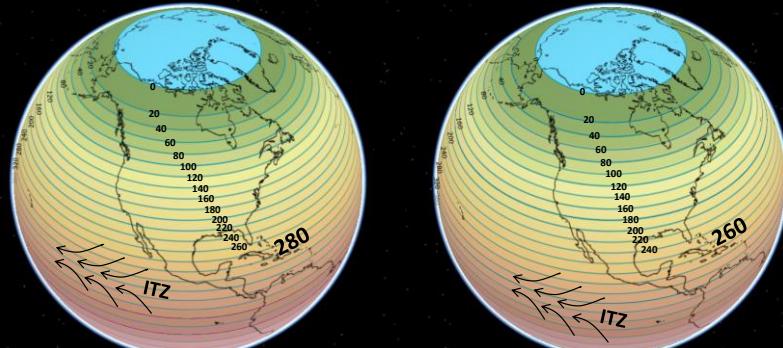


An Attempt to Tie the Laskar Insolation Curve
to a Core from the Monterey Formation

by John Dunham

This is my attempt to look for a relation between climate cycles and rock types in a Monterey core.

Insolation in watts/sq. m. at Northern Winter Solstice -



-15K: 280 w/sq.m. Bahamas 0: 260 w/sq.m. Bahamas

My interest in climate cycles came from work on shallow water carbonates. Changes in intensity of solar radiation produce expansions and contractions of the intertropical convergence zone, which produce wet and dry cycles that are recognizable on carbonate platforms.

Jacques Laskar is director of French National Center Astronomy. His team calculated long term Earth orbital parameters that produce changes in Earth's insolation with time.

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DOI: 10.1051/0004-6361:20041335
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**Astronomy
&
Astrophysics**

A long-term numerical solution for the insolation quantities of the Earth

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**Astronomy
&
Astrophysics**

La2010: a new orbital solution for the long-term motion of the Earth*

J. Laskar¹, A. Fienga^{1,2}, M. Gastineau¹, and H. Manche¹

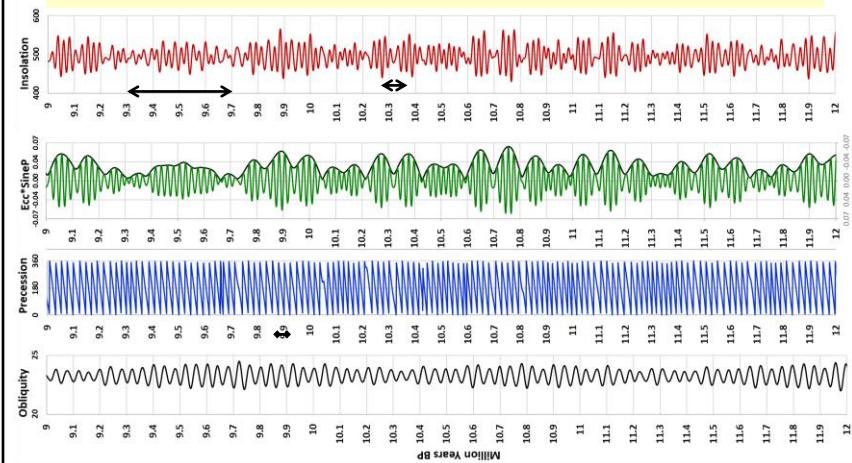
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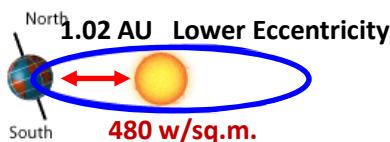
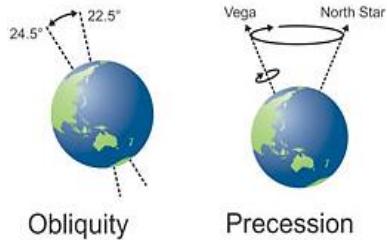
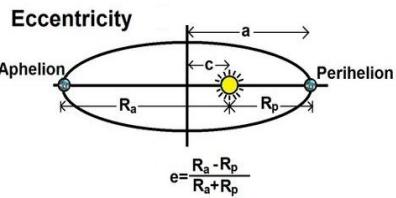
Insolation data come from a team led by Jacques Laskar at the French Center for Astronomy.

Laskar is the modern successor to Milankovitch. He has modeled changes in Earth's eccentricity, obliquity, and axial precession over the past 100 million years.

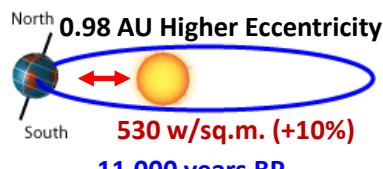


Laskar is the modern successor to Milankovich. He has modeled changes in Earth's eccentricity, obliquity, and axial precession over the past 100 million years. He wrote Program Insola, which computes variations in solar energy based on orbital parameters.

Positive and Negative Interference of Cycles -



North Pole points away from sun at Perihelion



North Pole points toward sun at Perihelion

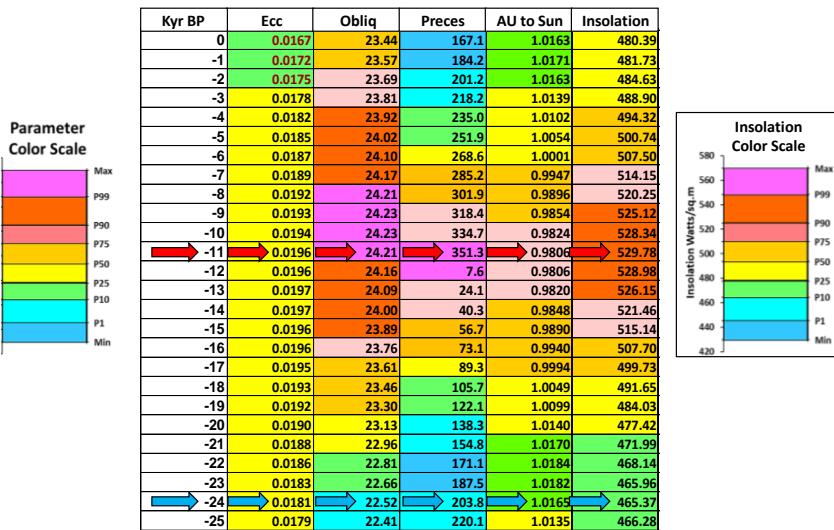
Eccentricity of Earth's orbit changes from nearly circular to highly elliptical over hundreds of thousands of years. Earth is closer to the sun at times of high eccentricity. Insolation peaks in the northern hemisphere on the summer solstice, when the north pole is pointed at the Sun. Insolation is especially high when the pole points at the sun on the same day that earth is also closest to the sun at Perihelion.

Program Insola written as an Excel Spreadsheet -

Kyr BP	Ecc	Obliq	Preces	AU to Sun	Insolation
0	0.0167	23.44	167.1	1.0163	480.39
-1	0.0172	23.57	184.2	1.0171	481.73
-2	0.0175	23.69	201.2	1.0163	484.63
-3	0.0178	23.81	218.2	1.0139	488.90
-4	0.0182	23.92	235.0	1.0102	494.32
-5	0.0185	24.02	251.9	1.0054	500.74
-6	0.0187	24.10	268.6	1.0001	507.50
-7	0.0189	24.17	285.2	0.9947	514.15
-8	0.0192	24.21	301.9	0.9896	520.25
-9	0.0193	24.23	318.4	0.9854	525.12
-10	0.0194	24.23	334.7	0.9824	528.34
-11	0.0196	24.21	351.3	0.9806	529.78
-12	0.0196	24.16	7.6	0.9806	528.98
-13	0.0197	24.09	24.1	0.9820	526.15
-14	0.0197	24.00	40.3	0.9848	521.46
-15	0.0196	23.89	56.7	0.9890	515.14
-16	0.0196	23.76	73.1	0.9940	507.70
-17	0.0195	23.61	89.3	0.9994	499.73
-18	0.0193	23.46	105.7	1.0049	491.65
-19	0.0192	23.30	122.1	1.0099	484.03
-20	0.0190	23.13	138.3	1.0140	477.42
-21	0.0188	22.96	154.8	1.0170	471.99
-22	0.0186	22.81	171.1	1.0184	468.14
-23	0.0183	22.66	187.5	1.0182	465.96
-24	0.0181	22.52	203.8	1.0165	465.37
-25	0.0179	22.41	220.1	1.0135	466.28

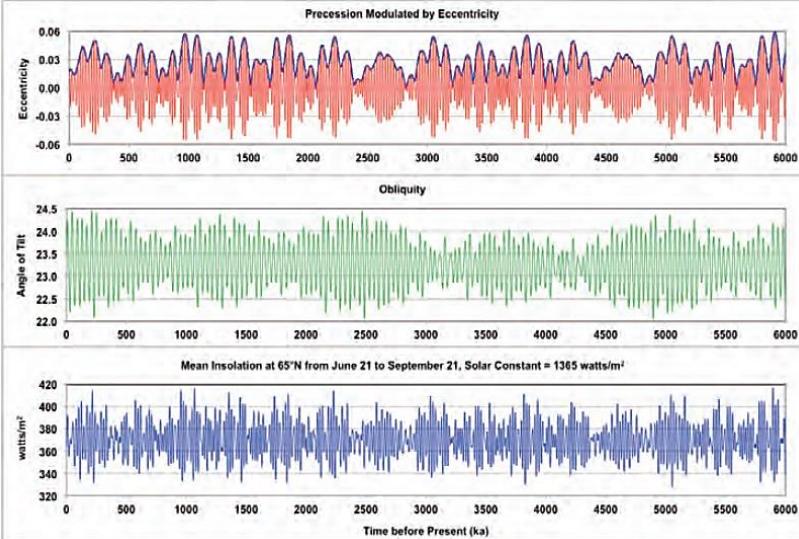
I reformatted Program Insola as an Excel spreadsheet. Hot colors in parameter cells show conditions conducive to high insolation.

Positive and Negative Interference of Cycles -



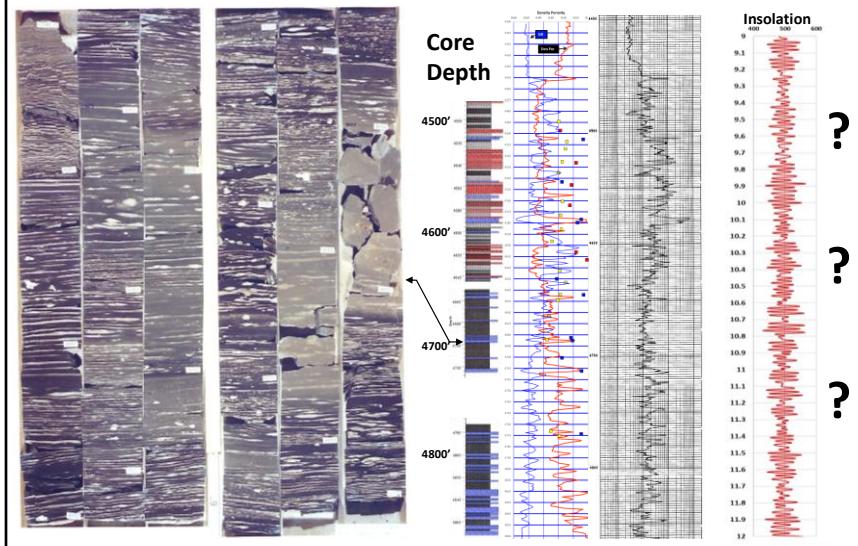
When hot-color conditions line up, Insolation is high. You can download this sheet to make your own calculations.

Hill and Bell, 2019, Milankovitch Stratigraphy Miocene-Pleistocene Offshore Central California



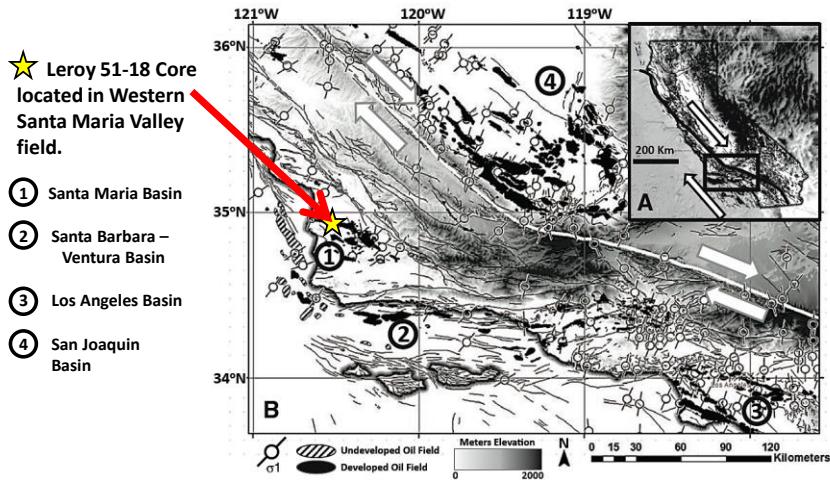
After working on Insola, I was interested to see Rick Behl and Pamela Hill's paper describing recognition of Milankovitch cycles in offshore California sediments. Their results supported the idea that Monterey Formation stratigraphy might be influenced by orbital cyclicity.

Leroy 51-18 Core: Monterey Formation from Santa Maria Valley Field, Santa Maria Basin



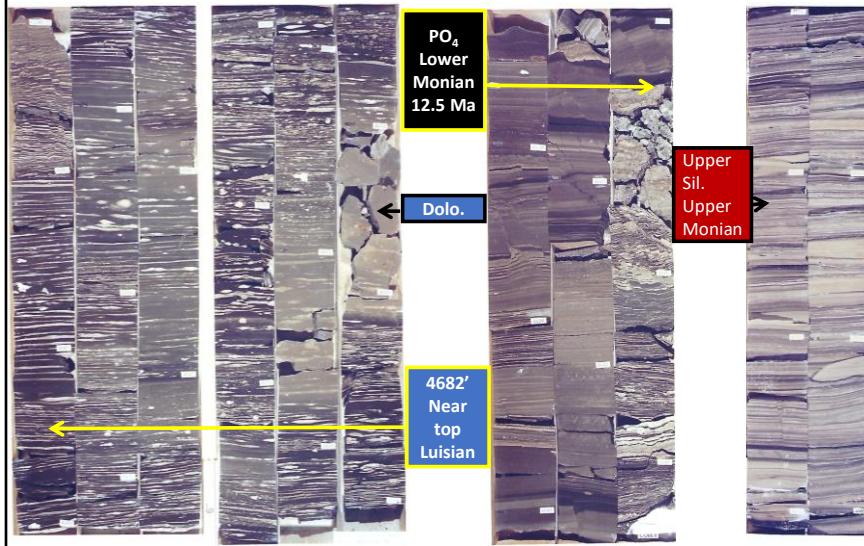
I had Program Insola, and also had core data. 40 years ago, Union Oil Company cored a well in Santa Maria Valley field for the purpose of documenting a Monterey well log interpretation. After seeing the Hill and Behl paper, I wondered if rocks in my core might tie to insolation data.

Location of Leroy 51-18 Core in Santa Maria Valley Field, Onshore Santa Maria Basin



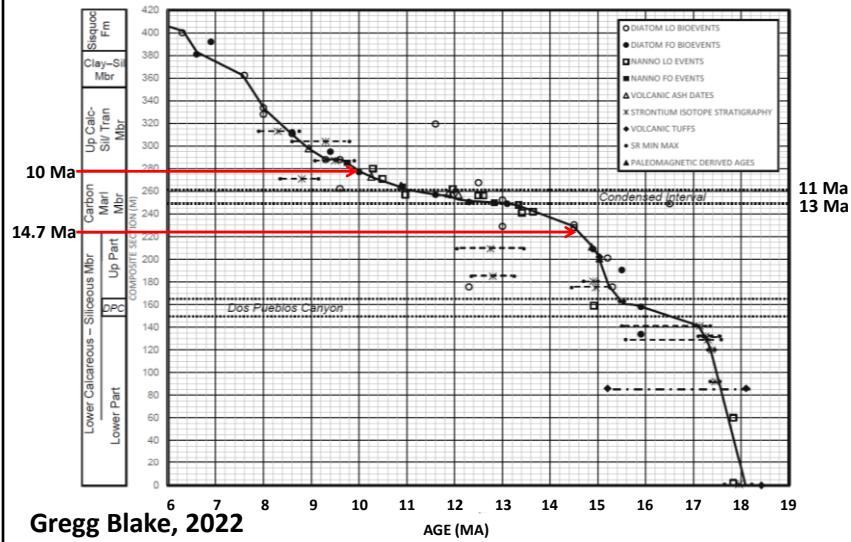
The Leroy 51-18 core comes from the onshore Santa Maria basin. The core recovered over 300' of Monterey rock including opal-CT porcelanites and cherts in the Upper Siliceous unit, highly radioactive organic mudstones of the Carbonaceous Marl unit, and interlayered dolostone and phosphatic mudstone in the Lower Calcareous unit.

Age Control Based on Benthic Forams and on Ages Assigned to Key Stratigraphic Events -

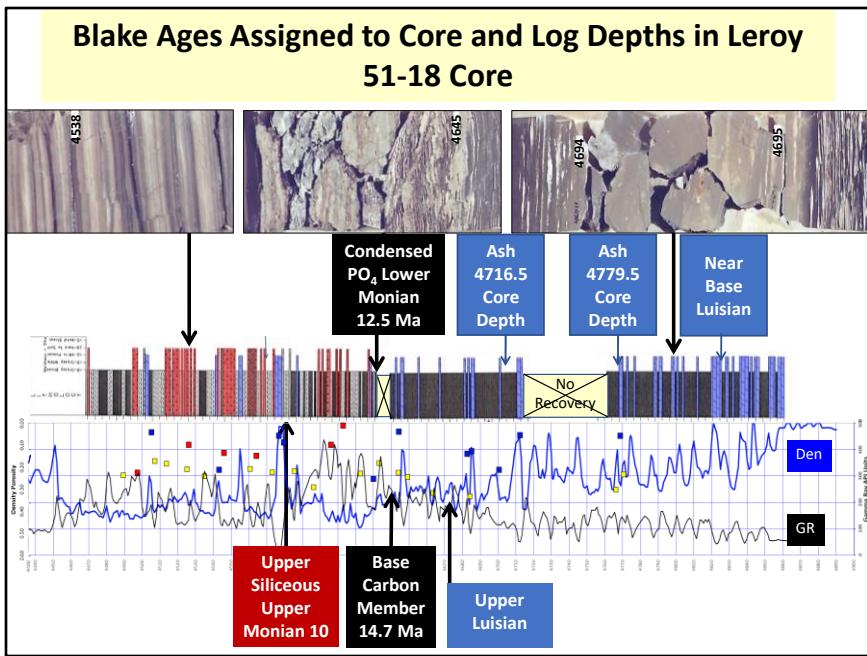


Insolation curves are scaled in AGE, while cores are scaled in DEPTH. Obviously, precise age control is necessary to match cores to Laskar curves. Age control for the Leroy core is not good. Age calls from 40 years ago identified the base of the core as near base Luisian while the middle of the core is in uppermost Luisian. I attempted to augment these picks with age calls for stratigraphic contacts based on a regional study by Gregg Blake.

Blake Regional Study Used to Assign Ages to Key Stratigraphic Events -

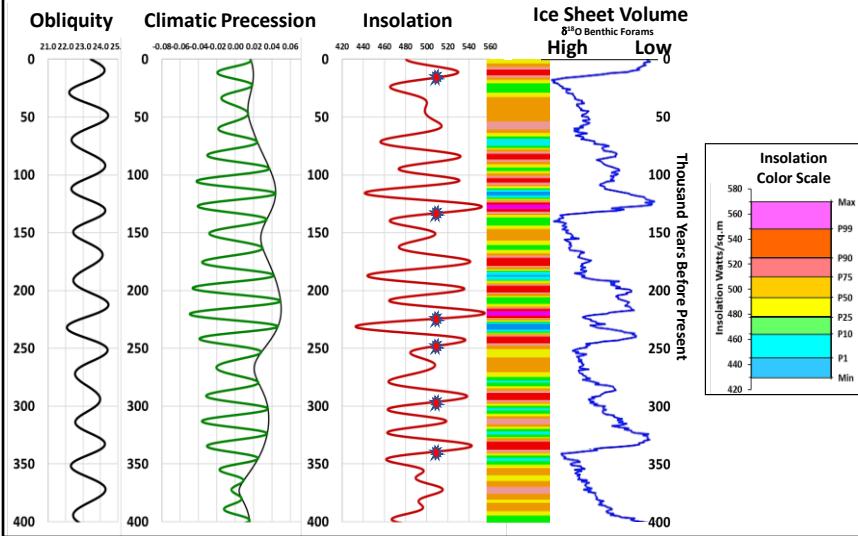


Blake's regional study published in the GSA Garrison Volume set an age of 14.7 Ma to the top of the Lower Calcareous unit, and an age of 10 Ma to the base of the Upper Siliceous unit. Both of these contacts are clearly visible in the Leroy Core, so these ages were tied to those depths in the well.



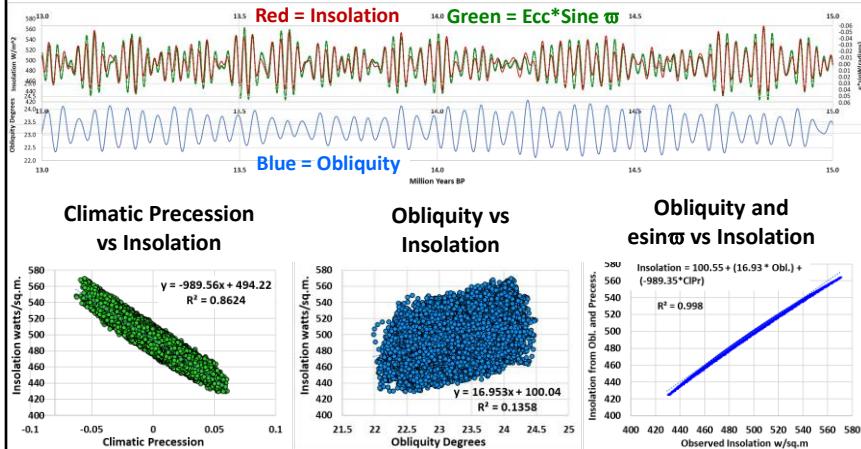
Benthic foram picks bracket the Lower Calcareous Unit within the Luisian stage. Base of the Carbonaceous Marl unit is marked by an increase in gamma-ray log intensity at 4645' log depth. A Blake age of 14.7 Ma was assigned to this depth. The base of the upper Siliceous unit is picked at 4580' log depth based on decrease in gamma ray intensity and increase in pure-silica opal-CT porcelanite and chert. This depth has a Blake age of 10 ma. The age span within the Carbonaceous Marl unit is 4.7 Ma, over a stratigraphic thickness of only 65 feet, indicating very slow sedimentation and presence of condensed intervals, as interpreted by Blake for the Carbonaceous Marl section.

Orbital Cycles Positively and Negatively Interfere with One Another; Insolation Peaks are Tipping Points



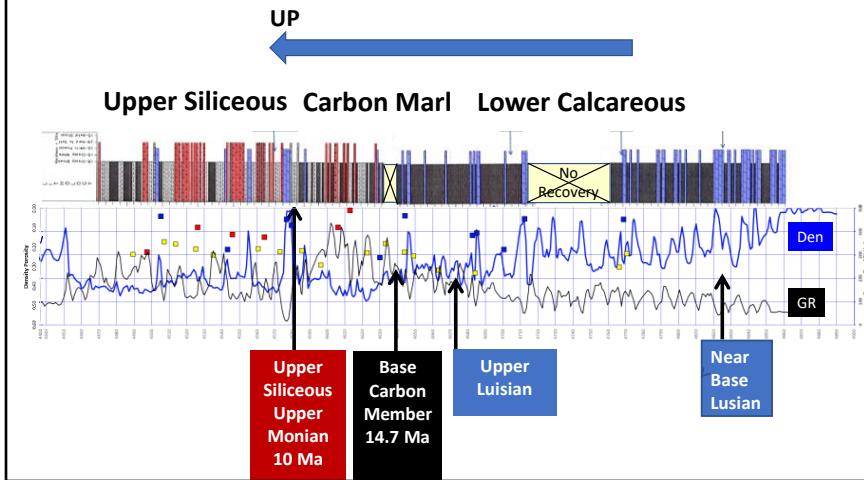
Before attempting to tie curves to cores, I'll show an example of how insolation cycles can induce climate change. Professor Lis-ecki of UCSB presented this example at a Coast Geological Society meeting. Insolation peaks triggered climatic tipping points that resulted in repeated collapse of Pleistocene continental ice sheets. I added the insolation color bar to help you visualize the duration of high and low insolation intervals. Ice-sheets collapsed immediately after reaching insolation tipping points. Ice-sheets regrew during long cool intervals between tipping points.

Climatic Precession Explains 86.2% of Insolation Variation, Obliquity Explains 13.6%, Together They Explain 99.8% of Insolation Variation



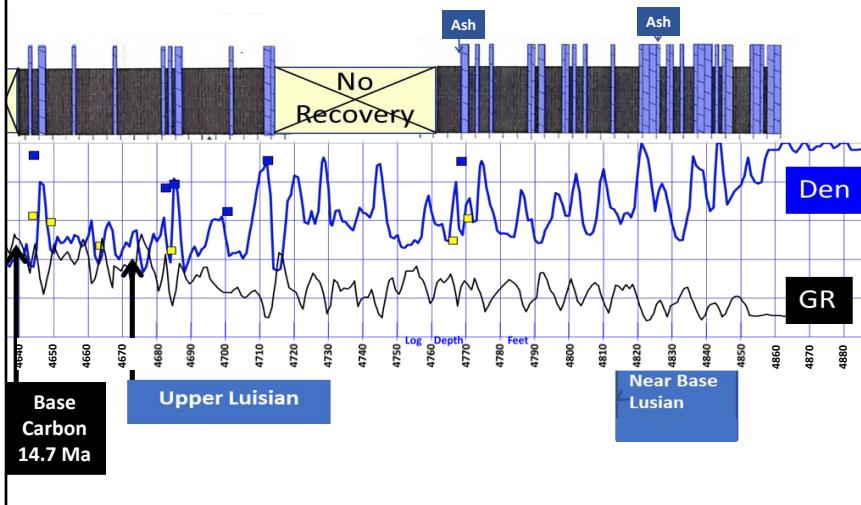
Is there a dominant orbital parameter that controls insolation? The answer is yes. The curve at the top shows a close correspondence between insolation and climatic precession which is eccentricity times the sine of precession angle. The match is better when reinforced by obliquity and worse when interfered by obliquity. Multiple regression shows that Climatic Precession explains 86% of insolation variation, with the balance explained by Obliquity. So, Climatic Precession is the dominant influence and is the place to start for curve matching.

Lower Calcareous Unit Composed of Relatively Thin Dolostone Beds and Thicker Phosphatic Mudstones.

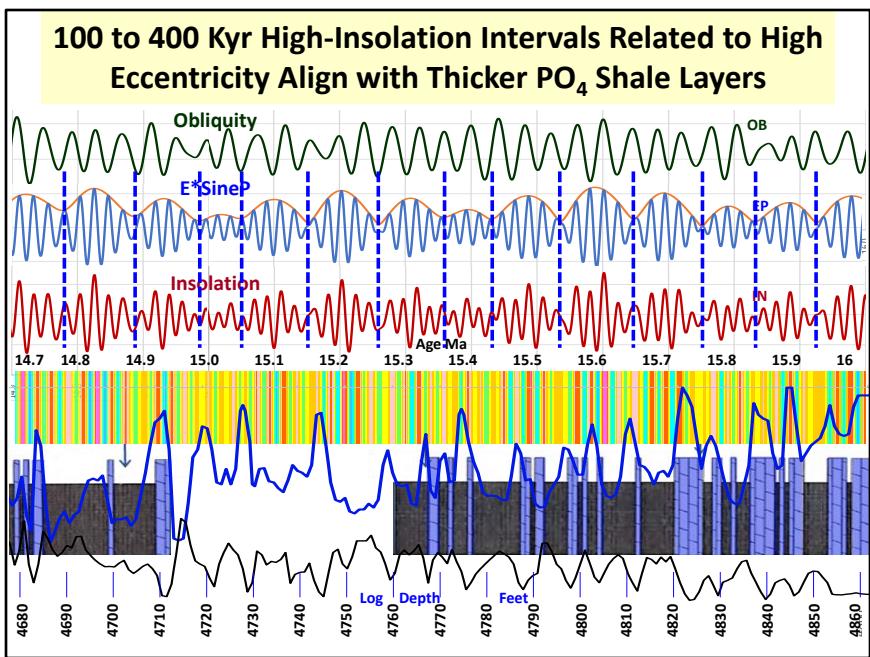


The first curve match attempt will focus on the Lower Calcareous Unit which is a simple succession of relatively thin dolostone beds separated by thicker phosphatic mudstone layers.

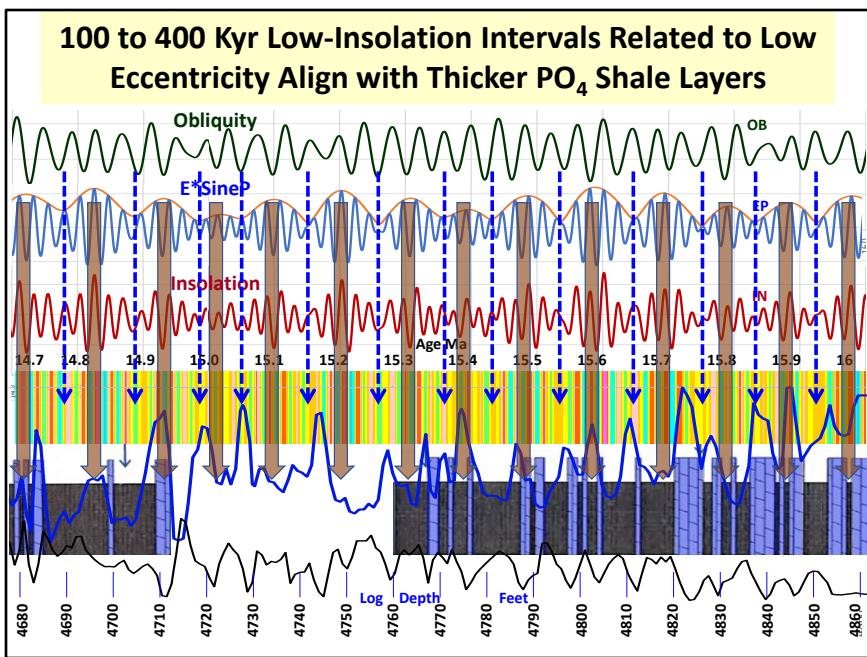
Age to Depth Tie: 14.7 Ma at 4640' Log Depth; 16 Ma at 4860' Log Depth



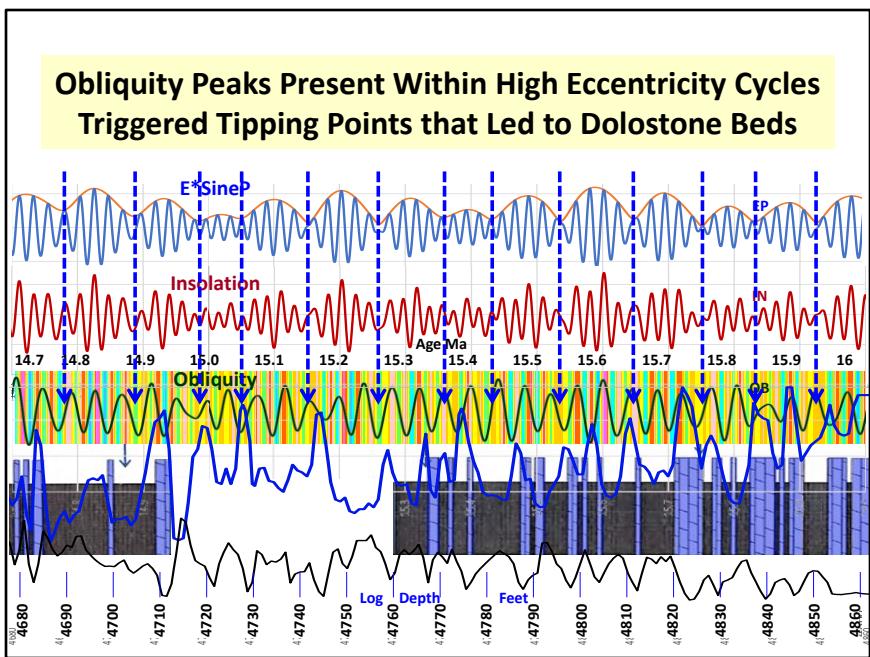
The age to depth match ranges from 14.7 Ma at 4640' Log Depth to 16 Ma at 4860' Log Depth.



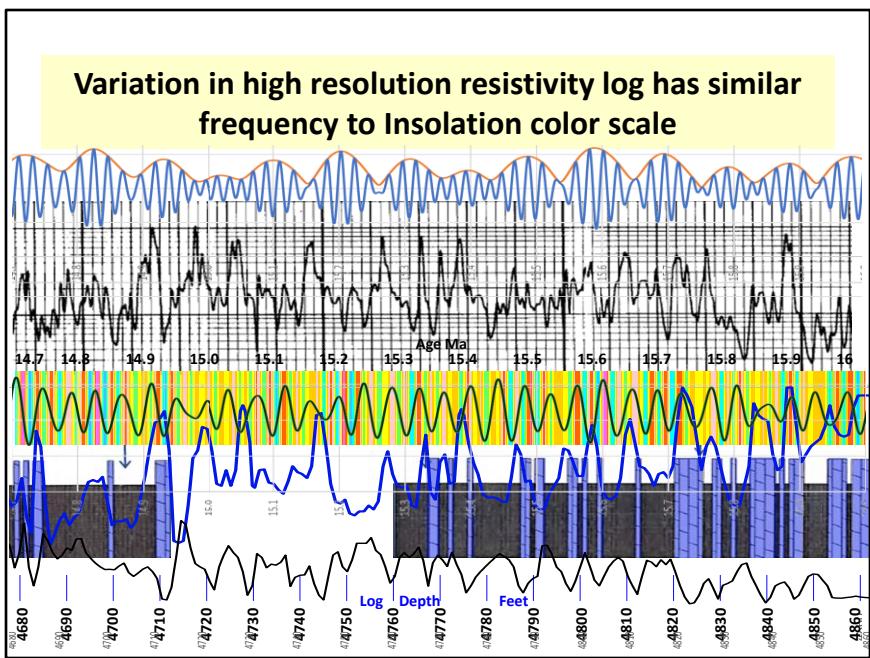
During globally warm conditions of the Middle Miocene Climatic Optimum, distinct peaks and troughs in the Climatic Precession Curve divide the Insolation curve into sections of high and low amplitude cycles. Insolation peaks and troughs were driven by Climatic Precession cycles.



Insolation peaks powered expansion of the intertropical convergence zone, leading to higher rainfall and runoff and increased sedimentation of fine terrigenous detritus, and thicker mudstone intervals. Narrower low insolation intervals match to thinner dolomite beds. Climatic precession powers the thicker intervals, while a positive coincidence of climatic precession and obliquity cycles trigger tipping points that lead to dolomite beds.



The wavelength of the obliquity curve is close to the frequency of the dolomite cycle. However, the driving force is Climatic Precession which determines the duration of mudstone intervals. If obliquity triggers a tipping point during an interval of low Climatic Precession, then conditions are favorable for dolomite, but if Climatic Precession is high, the obliquity cycle may skip a beat.



This 40-Year Old Micro-Resistivity log shows high-frequency variation similar to the 20 thousand-year precessional component of the Climatic Precession curve. Changes in higher and lower seasonality drive these highest frequency cycles. In contrast, 100-thousand-year eccentricity cycles generate longer-term brighter and dimer insolation periods. A favorable coincidence of obliquity and climatic precession may tip conditions to dolomite.

Article

Cyclic evolution of phytoplankton forced by changes in tropical seasonality

Nature 601, 79–84 (2022)

<https://doi.org/10.1038/s41586-021-04195-7>

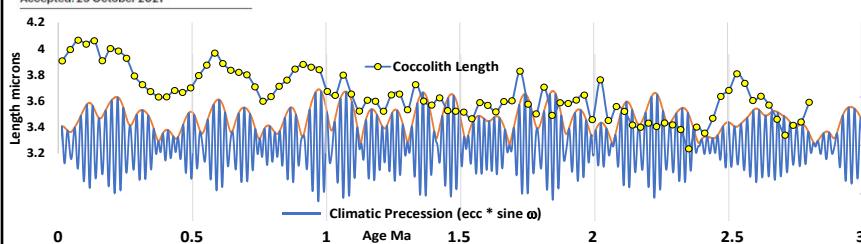
Received: 30 October 2020

Accepted: 29 October 2021

Luc Beaufort^{1,2}, Clara T. Bolton^{1,2}, Anta-Clarisse Sarr¹, Baptiste Suchéras-Marx¹,

Yair Rosenthal², Yannick Donnadieu¹, Nicolas Barbin^{1,2}, Samantha Bova^{2,4},

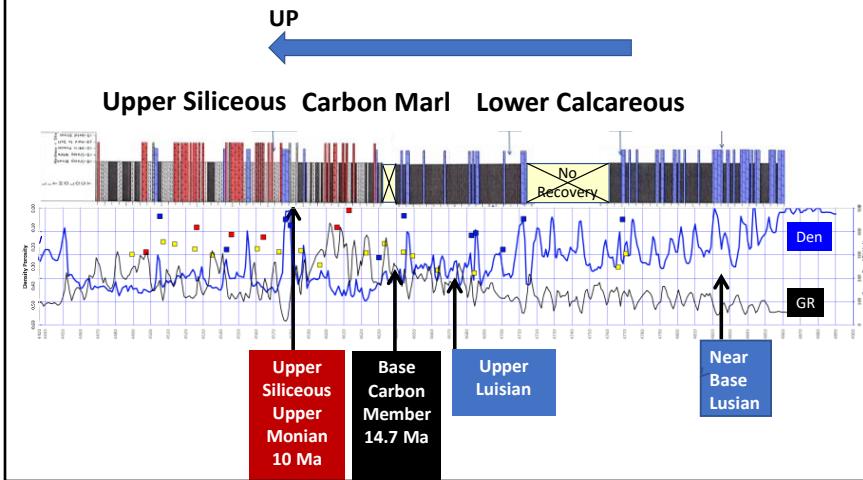
Pauline Cornault^{1,5}, Yves Galy¹, Emmeline Gray^{1,6}, Jean-Charles Mazur¹ & Martin Tétard¹



"we show that during the last 2.8 million years the morphological evolution of coccolithophores was forced by Earth's orbital eccentricity with rhythms of around 100,000 years and 405,000 years" ... "reduced seasonality favors species of mid-size coccoliths" ... "enhanced seasonality favors a larger range of coccolith sizes" ...

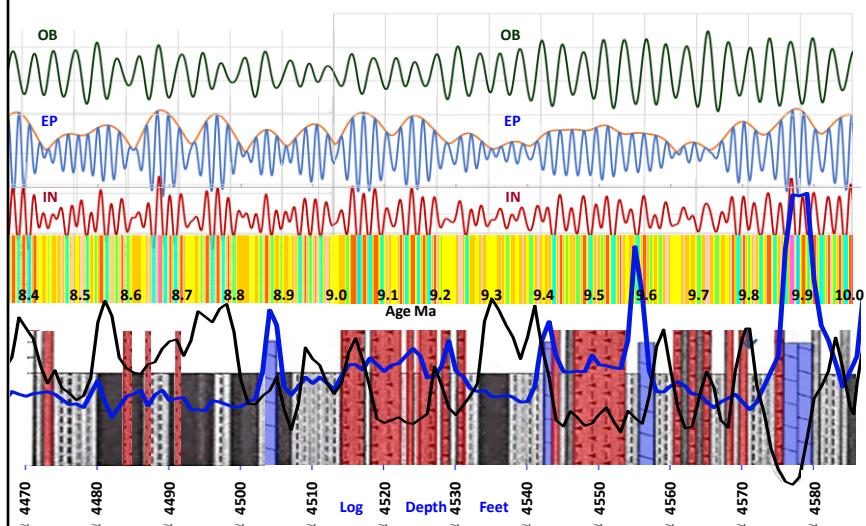
Is there any evidence that orbital cycles could have an influence on phytoplankton? This recent paper published in Nature shows that there is a strong association between orbital eccentricity and coccolith size. Reduced seasonal contrast during periods of low Climatic Precession favored species of smaller coccoliths. The authors also point to the effects of coccolith burial on the carbon cycle through sequestration of inorganic carbon in the form of calcium carbonate.

Upper Siliceous Unit Has Thick Layers of Pure Silica Opal-CT Chert and Porcelanite.



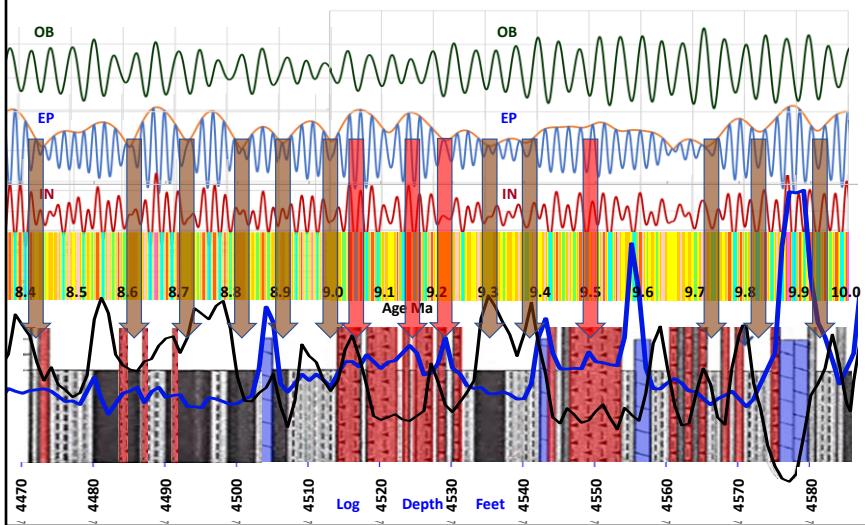
The next match will focus on the Upper Siliceous Unit which has thick layers of pure silica opal CT porcelanite and chert separated by thinner mudstone and dolostone layers. This unit is Monian in age and was deposited as the Miocene climate shifted to icehouse conditions.

100 to 400 Kyr High-Insolation Intervals Related to High Eccentricity Align with Thicker Chert and Dolostone.



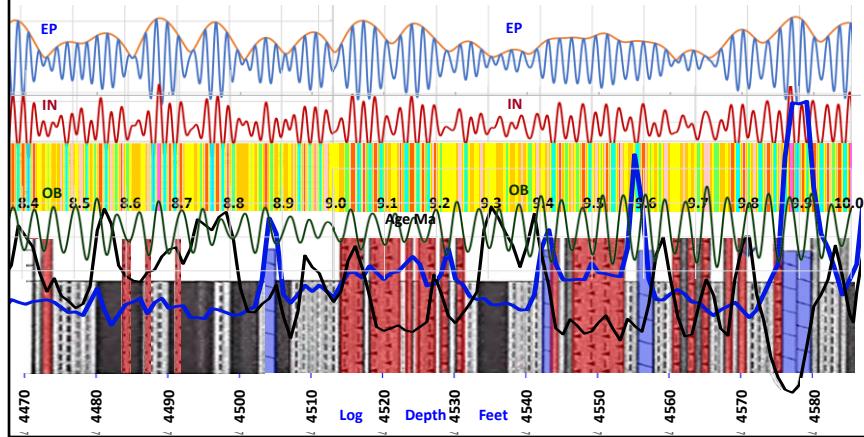
Climatic Precession cycles divide the insolation curve into intervals of higher and lower amplitude. However, in contrast to the greenhouse conditions of the earlier climatic optimum, conditions were colder and dryer in the Monian. During this epoch, periods of high insolation seemed to favor the growth of siliceous plankton. Higher eccentricity resulted in heightened seasonal contrast, leading to stronger winds and currents, and enhanced upwelling conditions.

100 to 400 Kyr High-Insolation Intervals Related to High Eccentricity Align with Thicker Biogenic Siliceous Units.

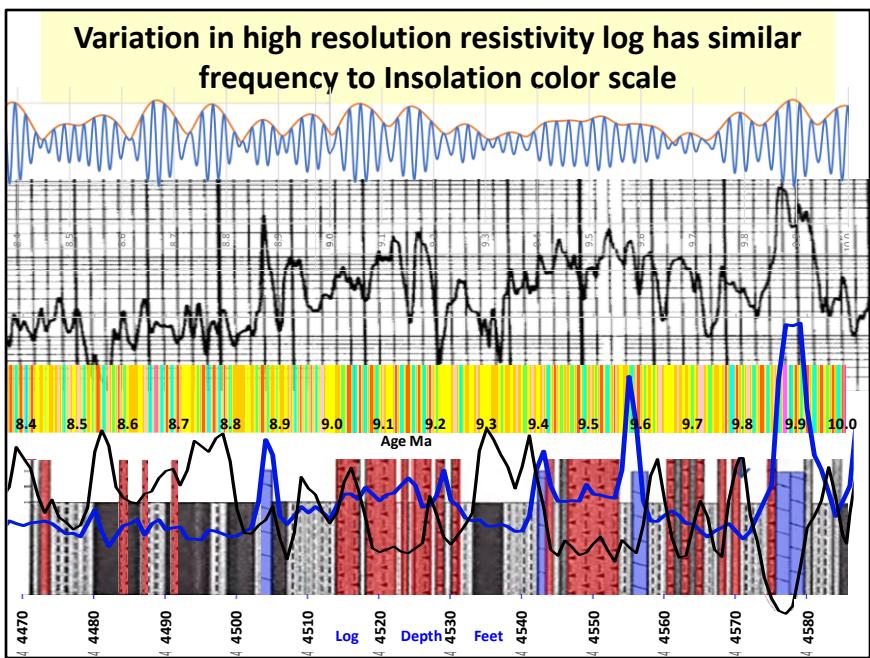


Interpretation is that increased energy is delivered alternately to northern and southern hemispheres during times of high eccentricity, leading to higher wind and current energy in the atmosphere-ocean system, resulting in enhanced upwelling, and more favorable conditions for siliceous plankton. It would be interesting to know if there have been any studies of diatoms and eccentricity cycles similar to the coccolith study.

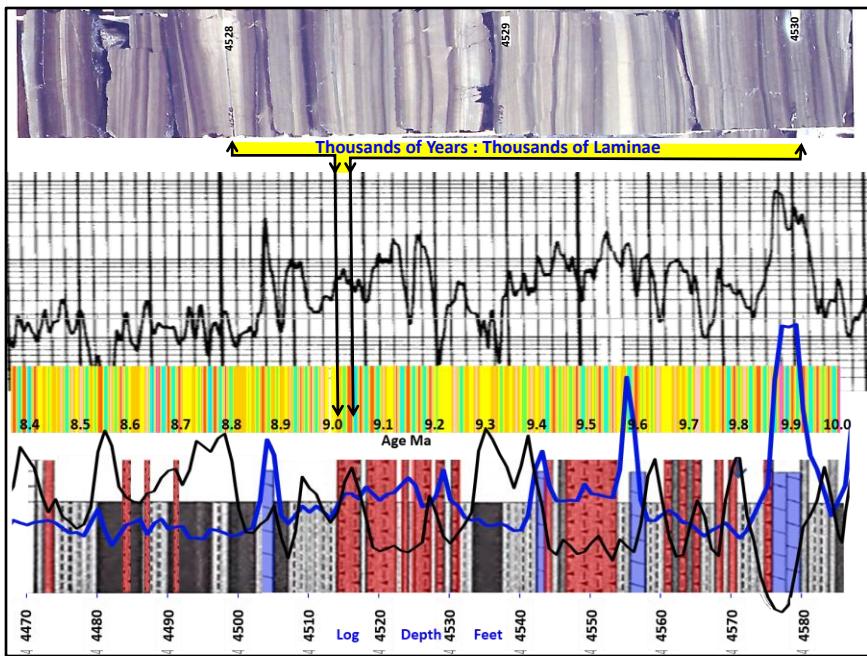
Obliquity Troughs Present Within High Eccentricity Cycles Produce Thin Mudstones within Thicker Biogenic Units



Obliquity cycles during times of high eccentricity appear to mark tipping points that control fine-scale interlayering within thicker biogenic units.



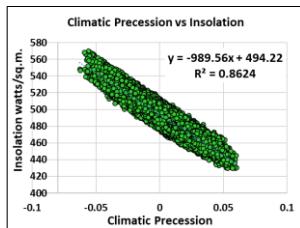
High frequency variation in resistivity log corresponds to high frequency insolation changes driven largely by precession.



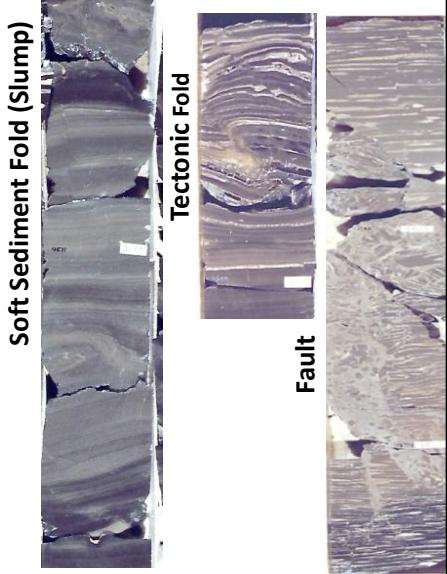
This is a thought experiment involving order of magnitude estimates. This 2-foot thick section of core projects onto the Age Scale with a span of about 10000 years. Assuming about 50% compaction, the order of magnitude of the uncompacted sedimentation rate is about 100 meters per million years, similar to estimates from other studies presented here. How many laminae can you count within this 2' interval? I estimate thousands of them. Lisa White wondered if the laminae in Lompoc Diatomite might be annual to decadal climate signals. I wonder the same here.

Explained and Unexplained Variability:

Coefficient of determination for Climatic Precession vs Insolation indicates 86% of the variability of Insolation can be explained by the predictor variable Climatic Precession. Other factors must account for the remaining 14%.



Regarding my attempt to fit orbital parameters to core data, there are mismatches, but I interpret that a significant portion of lithology variation can be explained by orbital data. Factors that account for **unexplained variation** might include tectonic deformation, soft-sediment deformation, and mass-transport events. Geologic data isn't "messy", it's complicated.

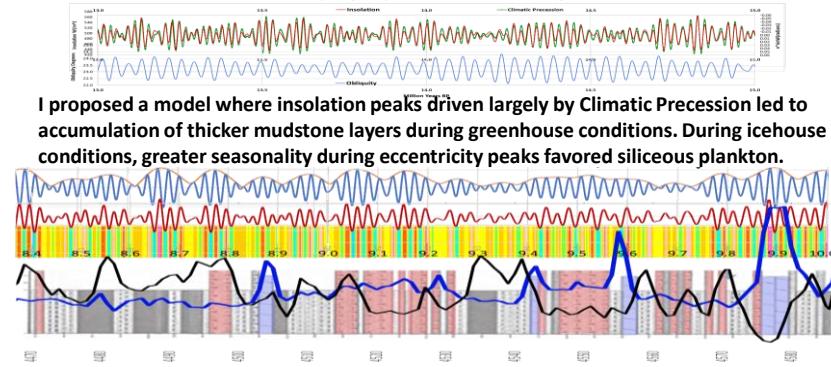


Earlier, we talked about Explained and Unexplained Variability. A close look at my comparisons reveal that I can't explain all core variation by a match to orbital curves. There is an element of unexplained variation. Some errors result from geologic processes, including tectonic deformation, soft-sediment deformation, and mass-transport events. Although I can't explain all the variation in this core, I interpret that orbital curves can explain a significant portion of the lithologic variation. Some people explain mismatches by saying that geologic data is messy. I won't invoke that excuse. Geologic data isn't "messy", but it can be complicated.

In Summary: I presented for your use a spreadsheet that you can use to display orbital parameters and insolation variation for the past 50 million years.

Kyr BP	Ecc	Oblig	Preces	AU to Sun	Insolation
0	0.0167	23.44	167.1	1.0163	480.39
-1	0.0172	23.57	184.2	1.0171	481.73
-2	0.0175	23.69	201.2	1.0163	484.63
-3	0.0178	23.81	218.2	1.0139	488.90
-4	0.0182	23.92	235.0	1.0102	494.32

I showed that Climatic Precession (Eccentricity * Sine Precession) explains 86% of Insolation variation, while Obliquity explains the remaining variation.



I proposed a model where insolation peaks driven largely by Climatic Precession led to accumulation of thicker mudstone layers during greenhouse conditions. During icehouse conditions, greater seasonality during eccentricity peaks favored siliceous plankton.

In summary, you can download my spreadsheet to display insolation and orbital data for the past 50 million years. I showed that climatic precession explains 86% of insolation variation, while Obliquity explains the remaining balance. I proposed a model where insolation peaks driven primarily by Climatic Precession led to the accumulation of thicker mudstone layers during greenhouse conditions. In contrast, insolation peaks led to increased siliceous plankton during icehouse conditions. I don't have sufficient age control to prove this, but I hope that through future research, some of you might assign absolute ages to individual Monterey beds.

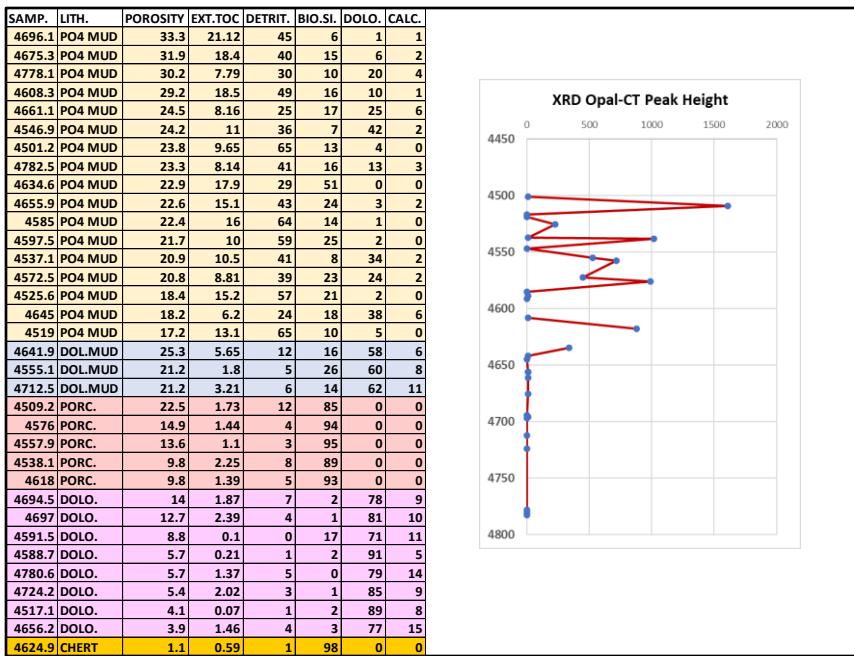
Download Insolation Spreadsheet at:
www.github.com/jdunham76/monterey22



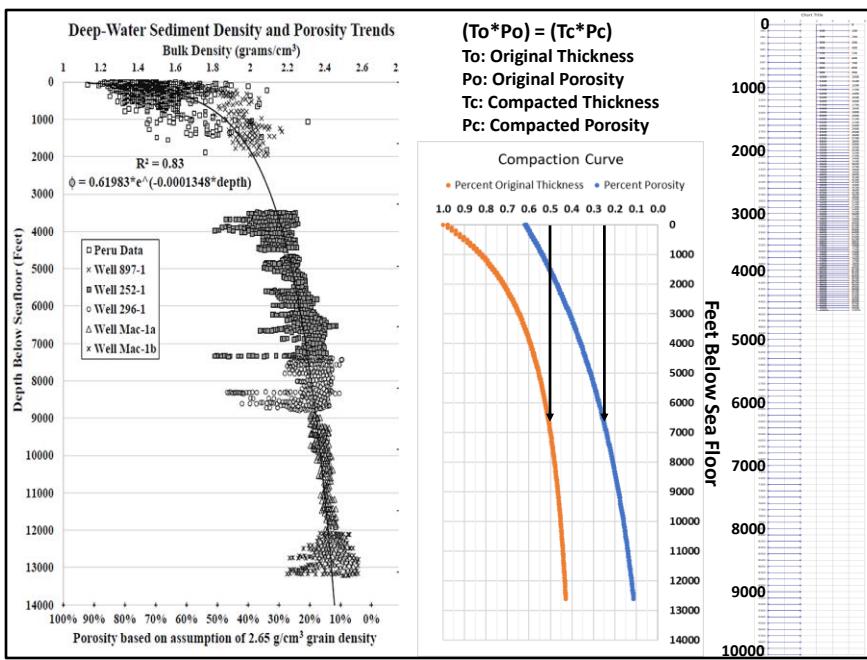
Questions?

You can download the Insolation Spreadsheet at this web site, along with core photos and a copy of this presentation. Are there any questions?

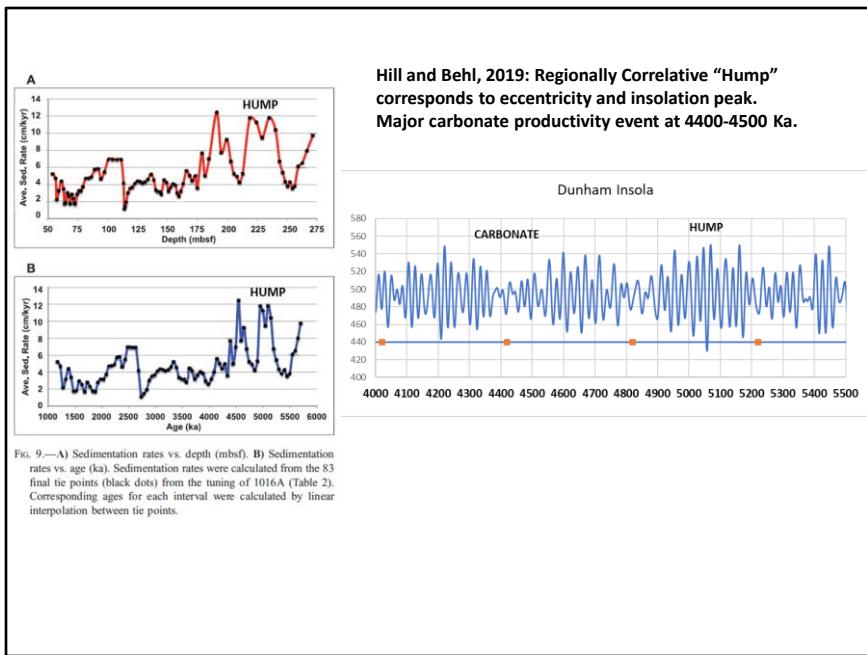
BACKUP SLIDES



Porosity, TOC, and Composition Data from Leroy Core. Opal-CT to quartz transition at about 4650' Core Depth.



Compaction estimate based on decrease in porosity with depth. 50% compaction reached by about 6000' total burial prior to uplift.



Hill and Behl documented the relation between high eccentricity and increased deposition of fine terrigenous clastics in the California Borderland.