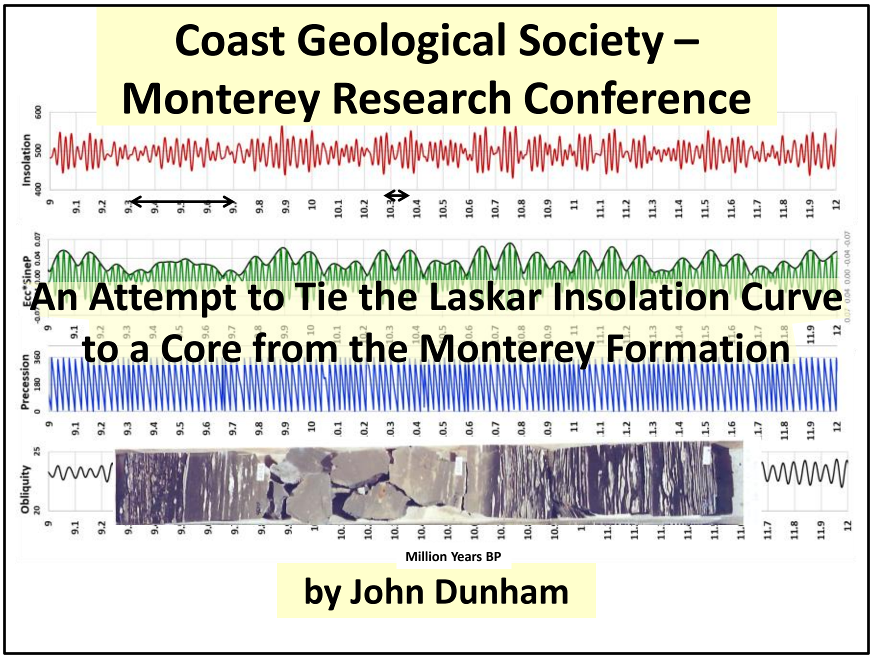
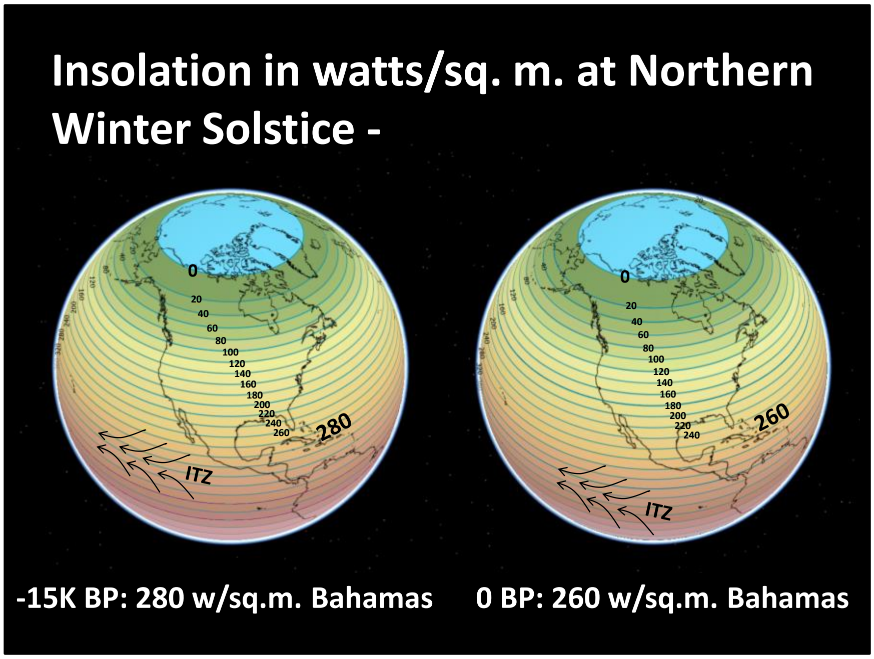


This is my attempt to look for a relation between climate cycles and rock types in a Monterey core.



My interest in climate cycles comes from work on shallow water carbonates. Changes in intensity of solar radiation produce expansions and contractions of the intertropical convergence zone. These produce wet and dry cycles 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.

A&A 428, 261–285 (2004)
DOI: 10.1051/0004-6361:20041335

Astronomy & Astrophysics

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

J. Laskar[1], P. Robutel[1], F. Joutel[1], M. Gastineau[1], A. C. M. Correia[1,2], and B. Levrard[1]

[1] Astronomie et Systèmes Dynamiques, IMCCE – CNRS UMR8028, 77 Av. Denfert-Rochereau, 75014 Paris, France
e-mail: laskar@imcce.fr
[2] Departamento de Física da Universidade de Aveiro, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal

A&A 532, A89 (2011)
DOI: 10.1051/0004-6361/201116836

Astronomy & Astrophysics

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

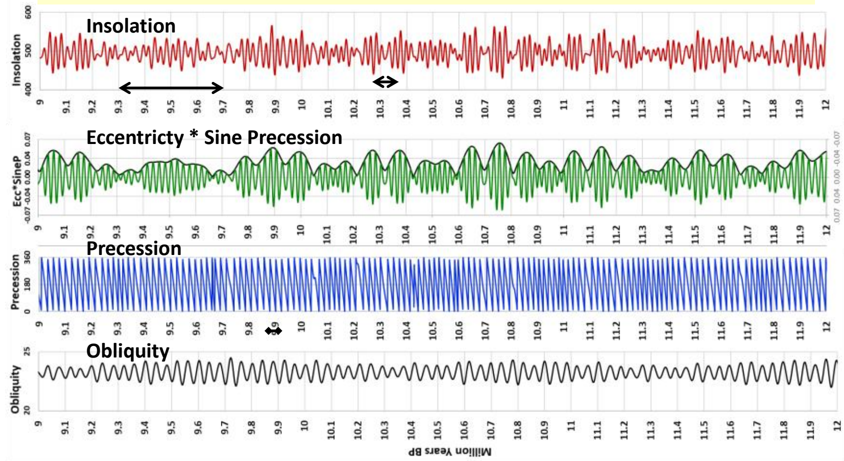
J. Laskar[1], A. Fienga[1,2], M. Gastineau[1], and H. Manche[1]

[1] ASD, IMCCE-CNRS UMR8028, Observatoire de Paris, UPMC, 77 Av. Denfert-Rochereau, 75014 Paris, France
e-mail: laskar@imcce.fr
[2] Observatoire de Besançon–CNRS UMR6213, 41bis Av. de l'Observatoire, 25000 Besançon, France

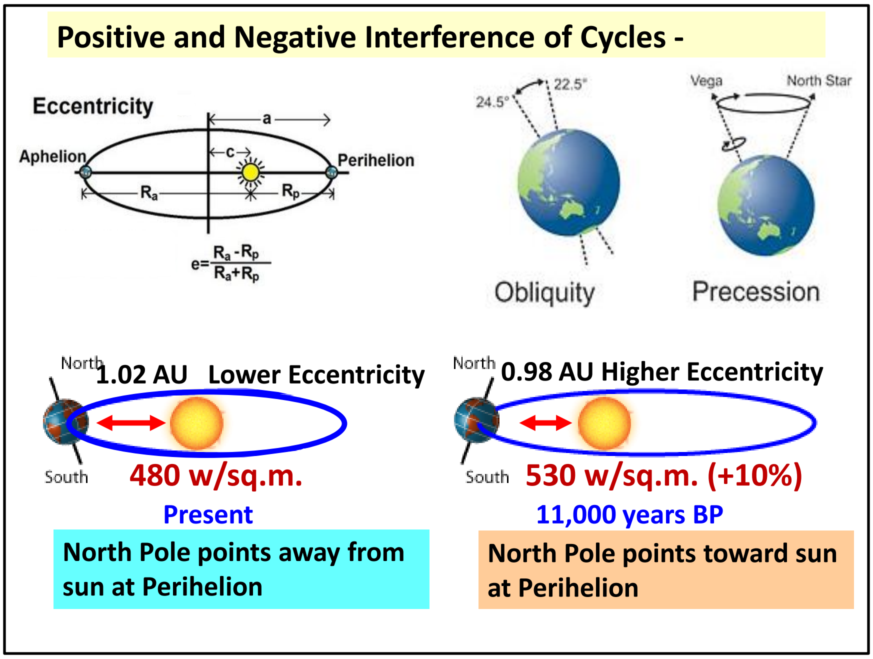
Received 5 March 2011 / Accepted 3 May 2011

Solar radiation 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.

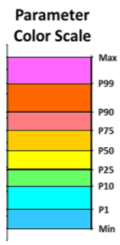


Laskar is the modern successor to Milankovich. He has modeled changes in Earth's eccentricity, obliquity, and axial precession over the past 100 million years. He wrote Program Insola, which computes variations in solar energy based on orbital parameters.

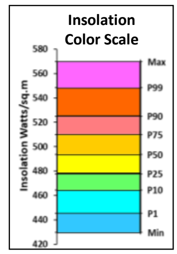


Eccentricity of Earth's orbit changes from nearly circular to highly elliptical over hundreds of thousands of years. Earth is closer to the sun at times of high eccentricity. In any single year, insolation is highest on the summer solstice, when the north pole is pointed at the Sun. However, insolation is especially high in certain years when the pole points at the sun on the same day that earth is also closest to the sun at Perihelion.

Laskar Program Insola written as an Excel Spreadsheet -



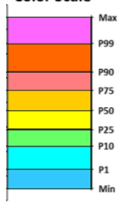
Kyr BP	Ecc	Obliq	Preces	AU Sun	Insolation
0	0.0167	23.44	167.1	1.0163	480.39
-1	0.0172	23.57	184.2	1.0171	481.73
-2	0.0175	23.69	201.2	1.0163	484.63
-3	0.0178	23.81	218.2	1.0139	488.90
-4	0.0182	23.92	235.0	1.0102	494.32
-5	0.0185	24.02	251.9	1.0054	500.74
-6	0.0187	24.10	268.6	1.0001	507.50
-7	0.0189	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 Laskar's Program Insola as an Excel spreadsheet. Hot colors in orbital-parameter cells show conditions conducive to high insolation.

Positive and Negative Interference of Cycles -

Parameter Color Scale



Kyr BP	Ecc	Obliq	Preces	AU Sun	Insolation
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-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
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-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
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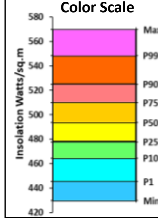
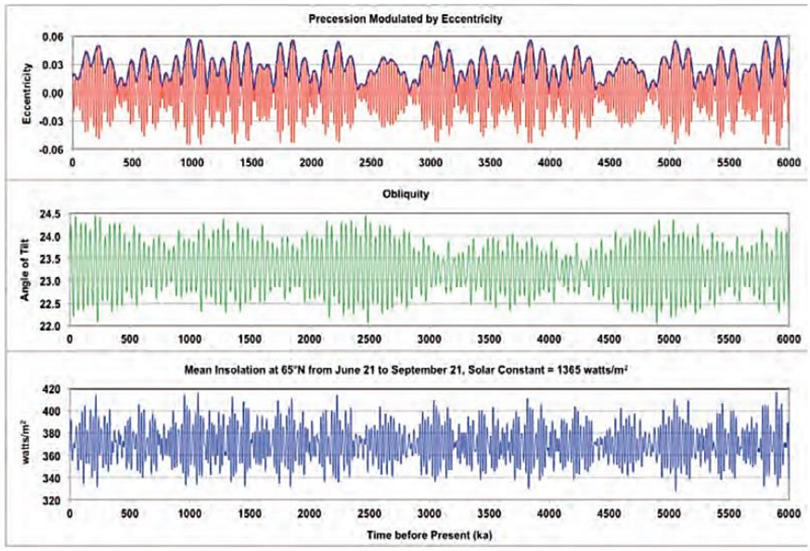
-24	0.0181	22.52	203.8	1.0165	465.37
-25	0.0179	22.41	220.1	1.0135	466.28

Insolation Color Scale



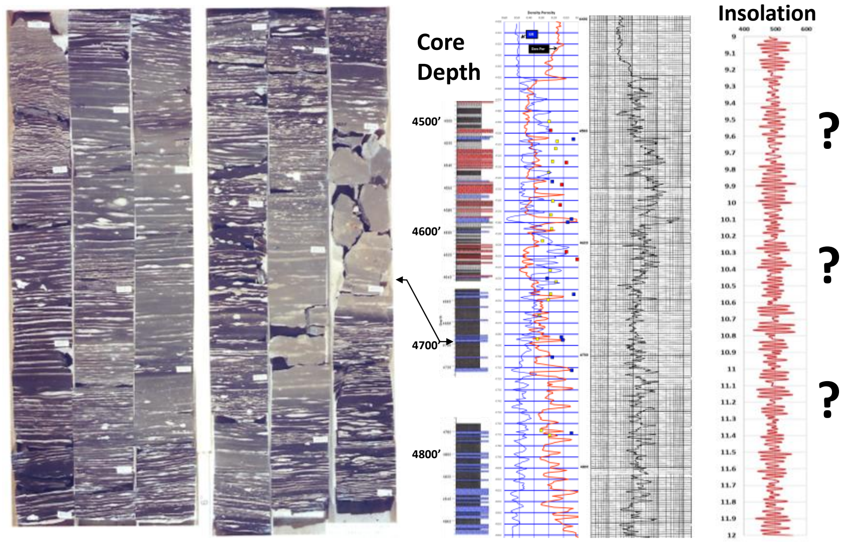
When hot-color conditions line up, Insolation is high. You can download this spreadsheet to make your own plots.

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



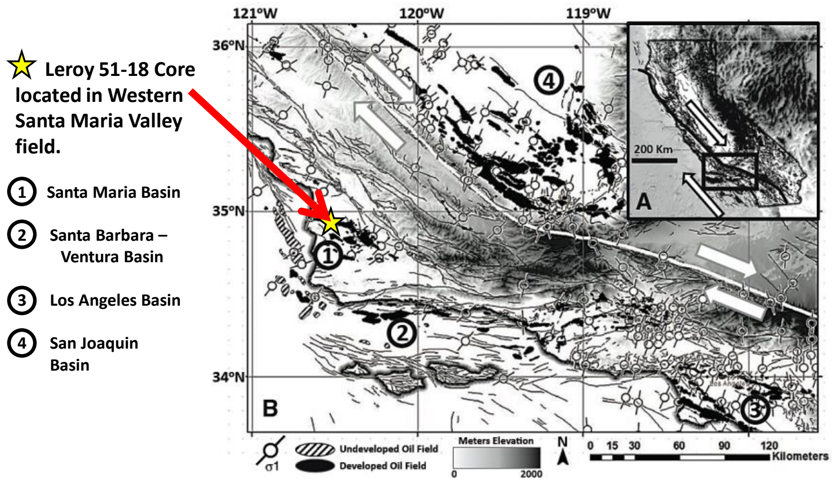
After working on Insola, I was interested to see Rick Behl and Pamela Hill's paper describing Milankovich cycles in offshore California sediments. Their results supported the idea that Monterey Formation stratigraphy might be influenced by orbital cyclicity.

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



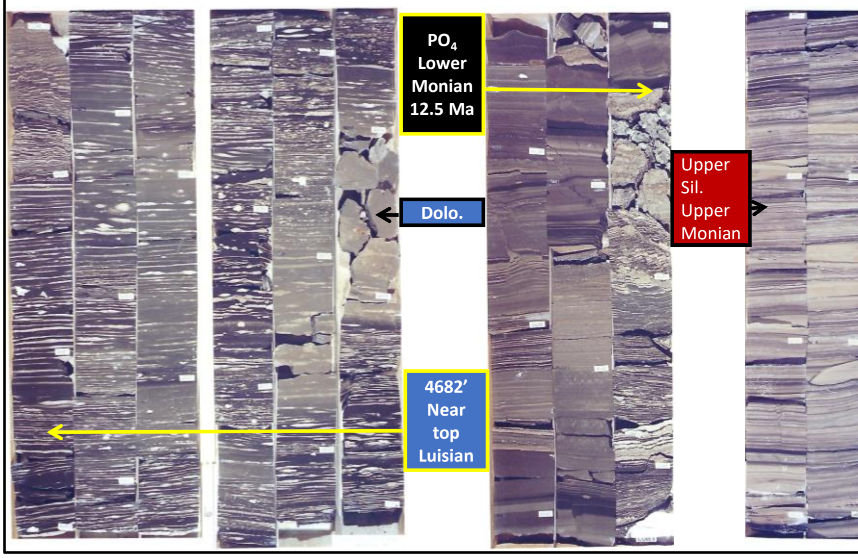
I had Program Insola, and also had data from a well that Union Oil Company cored in Santa Maria Valley field for the purpose of documenting a Monterey well log interpretation. After seeing the Hill and Behl paper, I wondered if rocks in this core might tie to insolation.

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



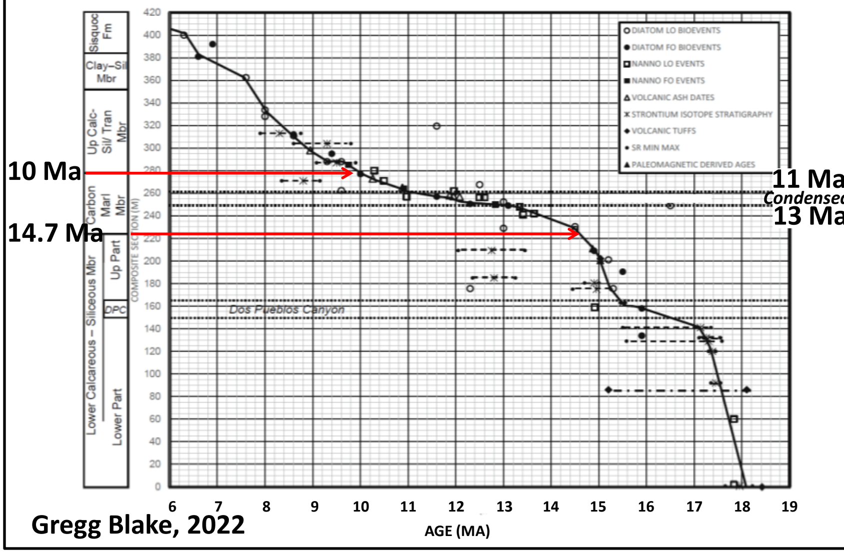
The Leroy 51-18 core comes from the onshore Santa Maria basin. The core recovered over 300' of Monterey rock including opal-CT porcelanites and cherts in the Upper Siliceous unit, highly radioactive organic mudstones of the Carbonaceous Marl unit, and interlayered dolostone and phosphatic mudstone in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

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



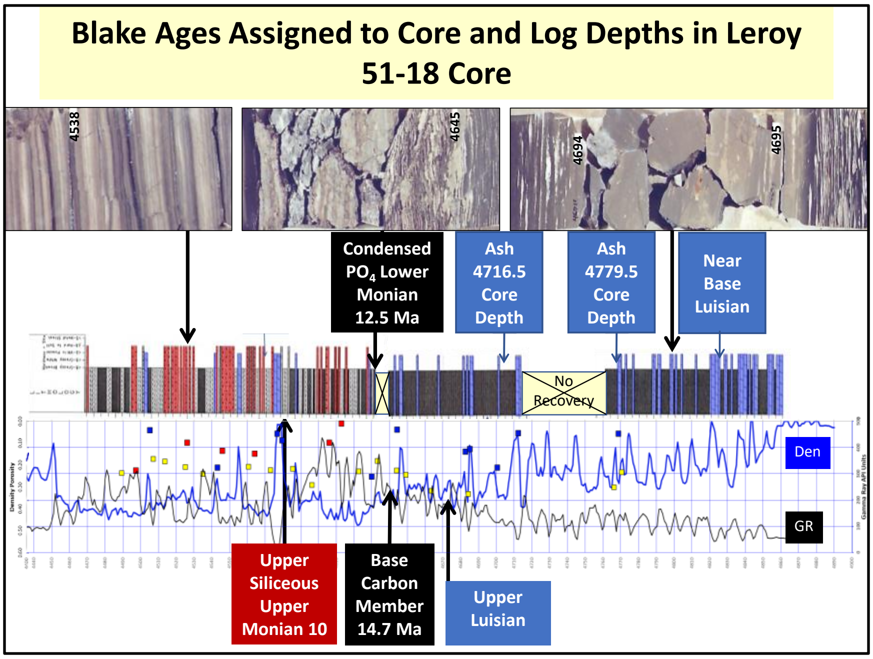
Insolation curves are scaled in AGE, while cores are scaled in DEPTH. Obviously, precise age control is necessary to match cores to Laskar curves. Age control for the Leroy core is not good. Benthic-foram picks from 40 years ago identified the base of the core as near base Luisian while the middle of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

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

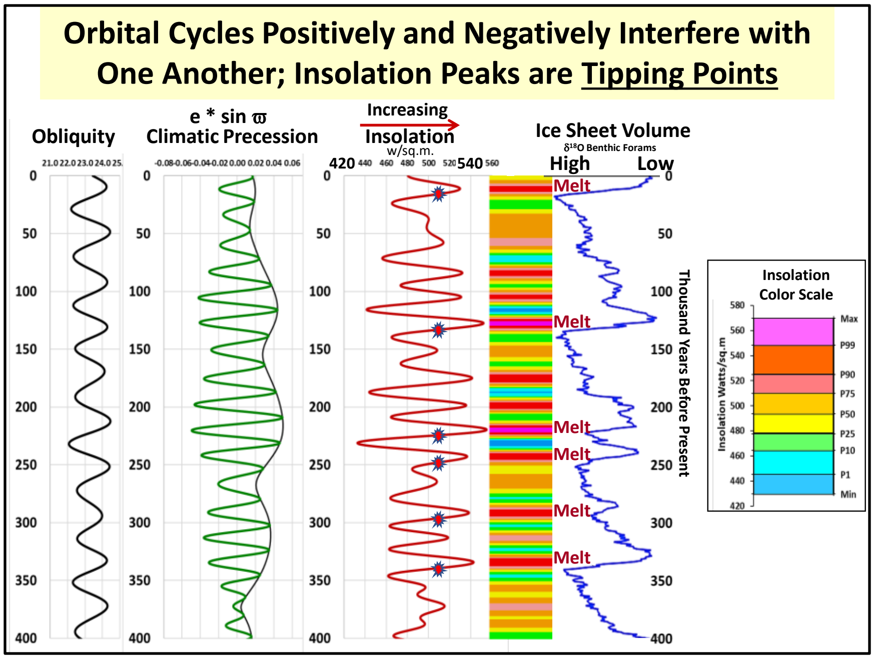


Gregg Blake, 2022

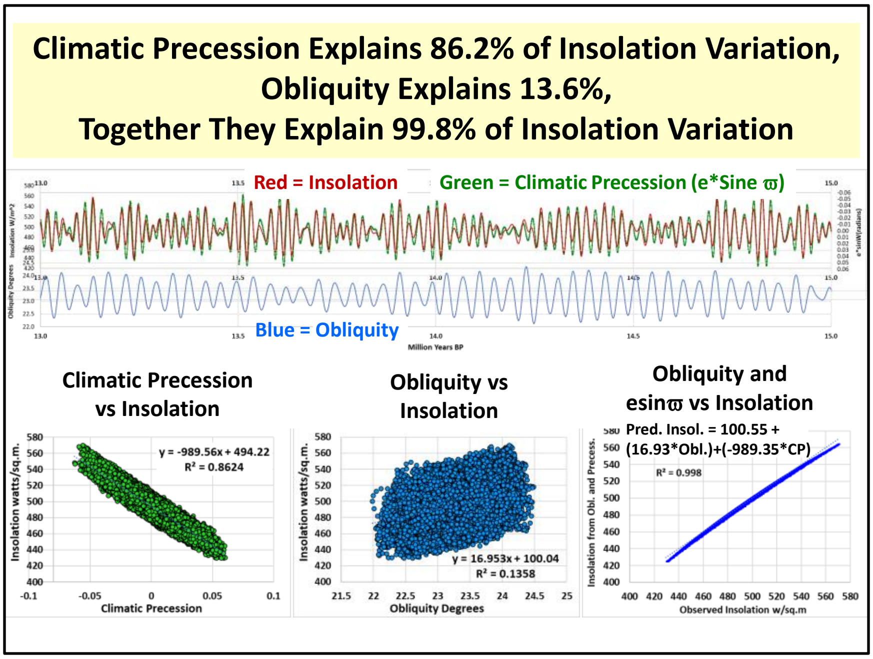
Blake's regional study published in the GSA Garrison Volume set an age of 14.7 Ma to the top of the Lower Calcareous unit, and an age of 10 Ma to the base of the Upper Siliceous unit. These contacts are visible in the Leroy Core, so those ages were tied to those core depths.



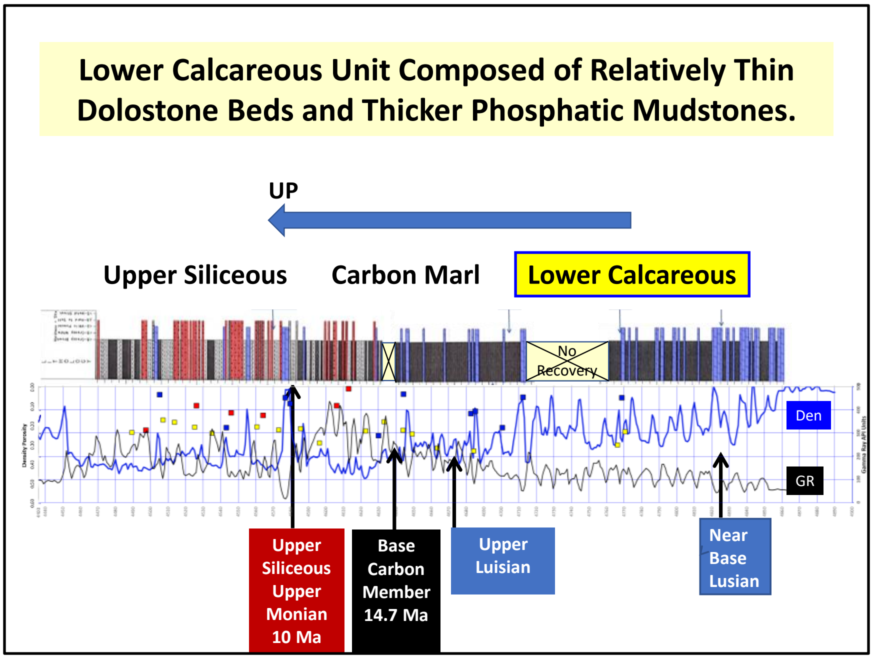
Foram picks bracket the Lower Calcareous Unit within the Luisian stage. An increase in gamma-ray intensity defines the base of the Carbonaceous Marl unit. A Blake age of 14.7 Ma is assigned to this depth. The base of the upper Siliceous unit is marked by a decrease in gamma ray intensity and an increase in pure-silica opal-CT porcelanite and chert. This horizon has a Blake age of 10 ma. The Carbonaceous Marl unit between the lower calcareous and upper siliceous units is only 65 feet thick, but it has an age span of 4.7 Ma; indicative of very slow sedimentation with condensed intervals.



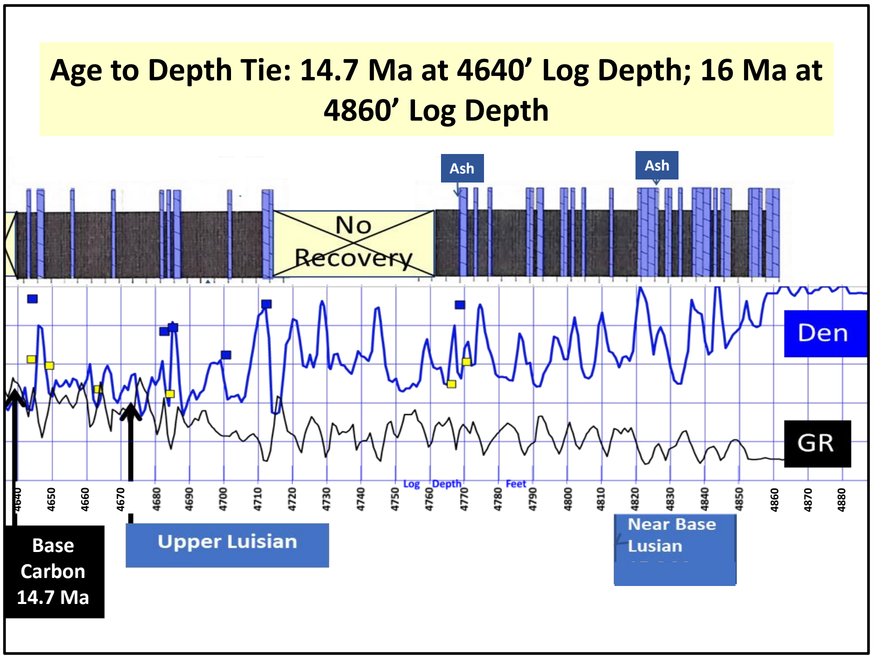
Before attempting to tie curves to cores, I'll show an example of how insolation cycles can induce climate change. Professor Lis-ecki of UCSB presented this example at a Coast Geological Society meeting. Insolation peaks triggered climatic tipping points that resulted in repeated collapse of Pleistocene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



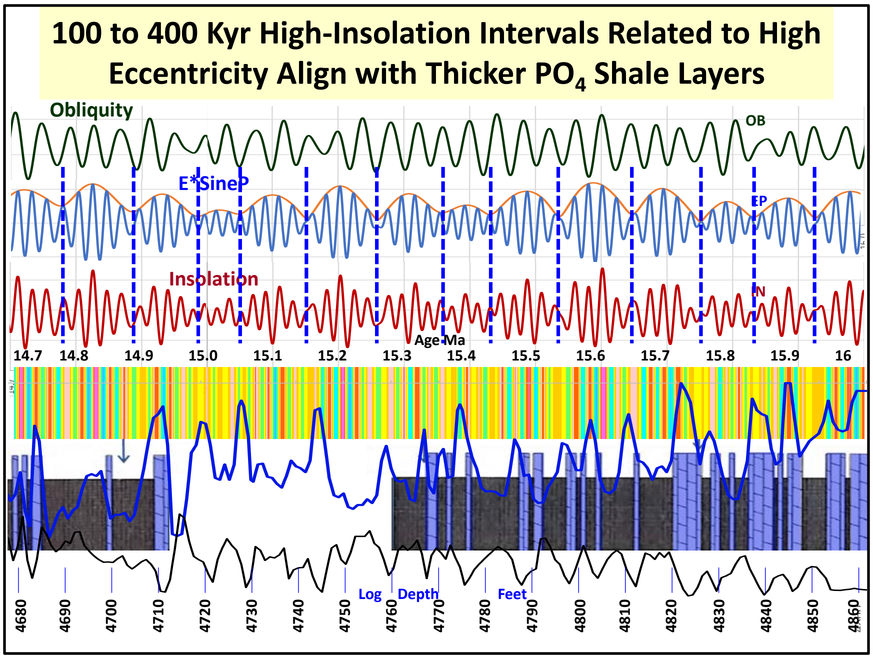
Is there a dominant orbital parameter that controls insolation? The answer is yes. The curve at the top shows a close correspondence between insolation and climatic precession, which is eccentricity times the sine of precession angle. The match is better when reinforced by obliquity and worse when interfered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



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

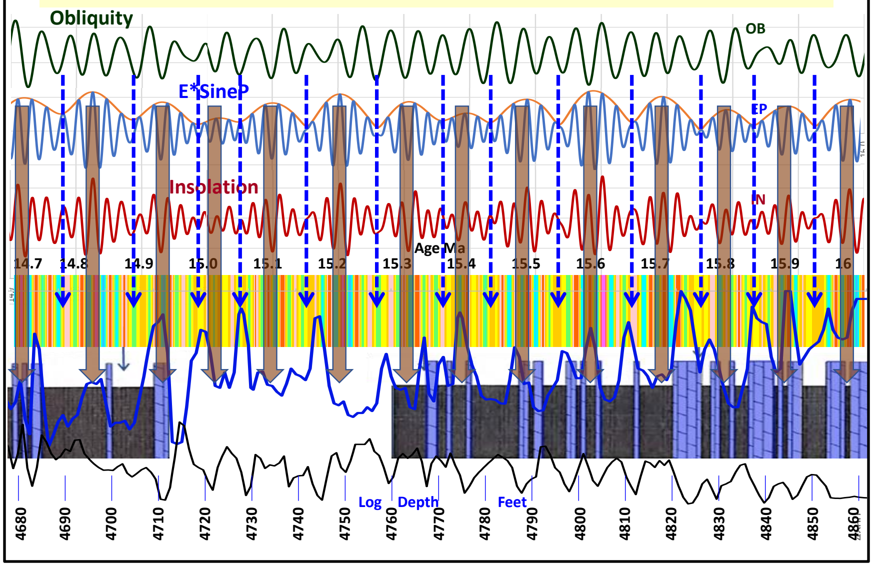


The age to depth match ranges from 14.7 Ma at 4640' Log Depth to 16 Ma at 4860' Log Depth.

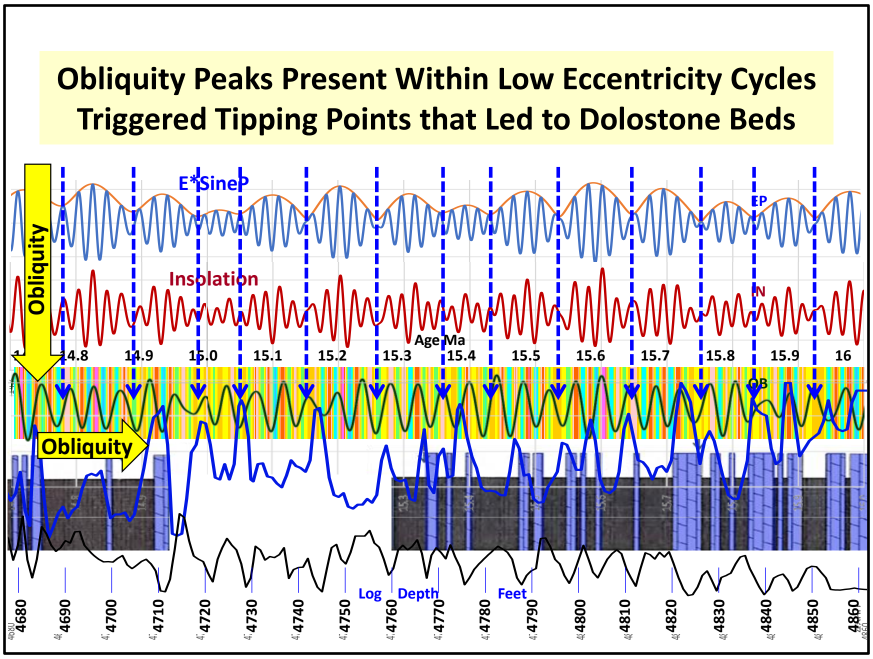


This section was deposited during the globally warm Middle Miocene Climatic Optimum. Distinct peaks and troughs in the climatic precession curve divide the Insolation curve into sections of high and low amplitude cycles. These insolation peaks and troughs were driven by Climatic Precession cycles.

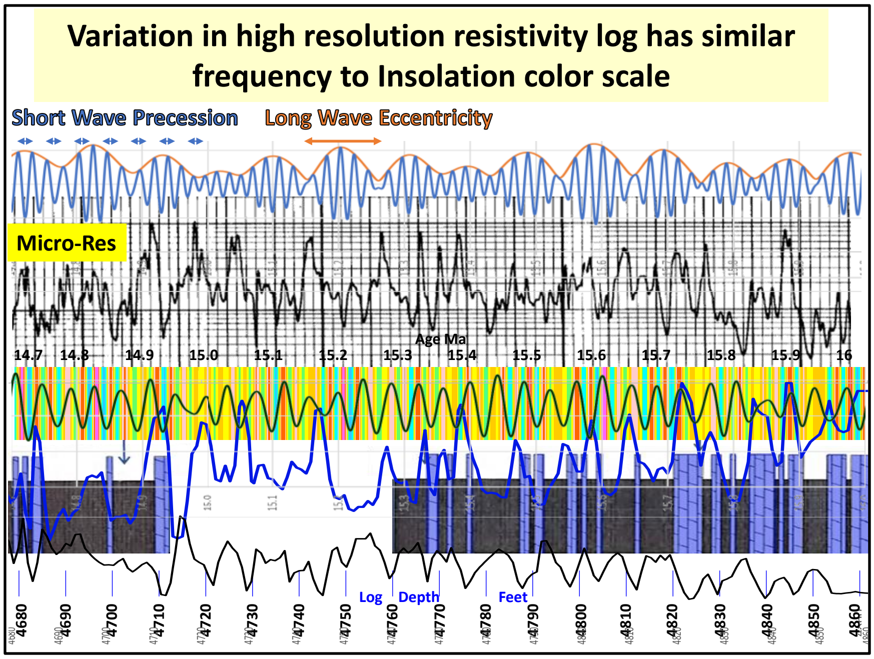
100 to 400 Kyr Low-Insolation Intervals Related to Low Eccentricity Align with Dolostone Beds



Insolation peaks fueled expansion of the intertropical convergence zone, leading to higher rainfall and runoff, increased sedimentation of fine terrigenous detritus, and thicker mudstone intervals. Narrower low-insolation intervals match thinner dolomite beds. Climatic precession powers the thicker intervals, while constructive interference of climatic precession and obliquity triggers tipping points that lead to dolomite beds.



I shifted the obliquity curve down to the color bar. The wavelength of the obliquity cycle is close to the frequency of the dolomite beds. 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 unfavorable, 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

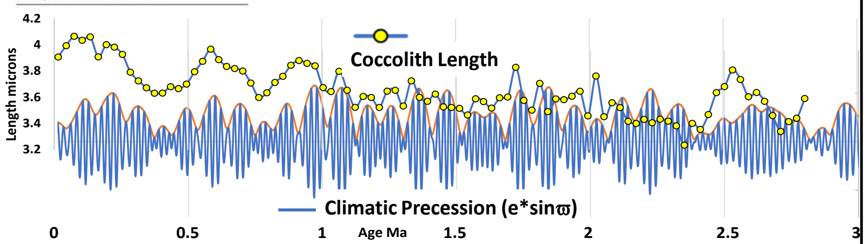
Nature 601, 79–84 (2022)

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

Received: 30 October 2020

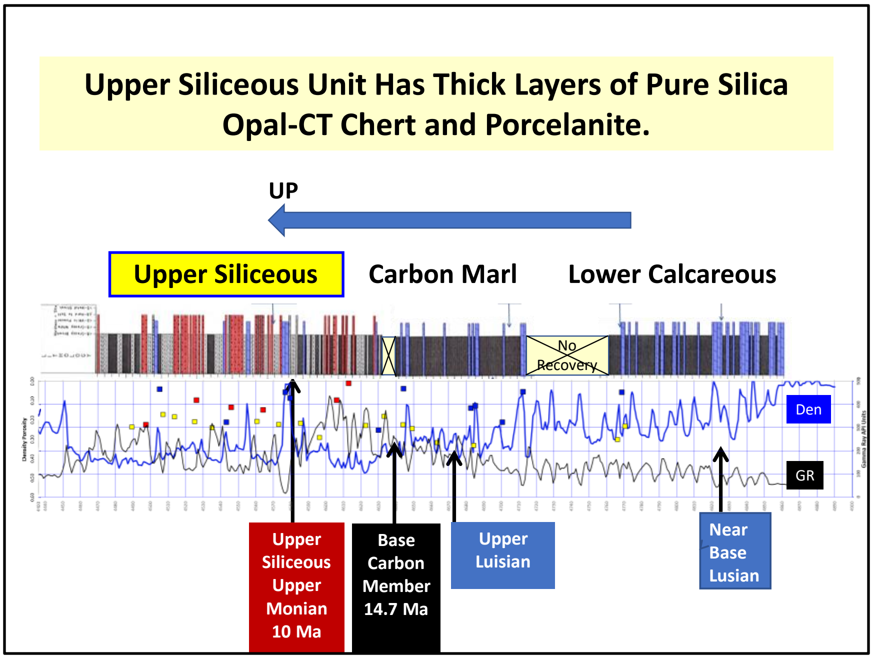
Accepted: 29 October 2021

Luc Beaufort[1✉], Clara T. Bolton[1✉], Anta-Clarisse Sarr[1], Baptiste Suchéras-Marx[1], Yair Rosenthal[2], Yannick Donnadieu[1], Nicolas Barbarin[1,3], Samantha Bova[2,4], Pauline Cornuault[1,5], Yves Gally[1], Emmeline Gray[1,6], Jean-Charles Mazur[1] & Martin Tetard[1]

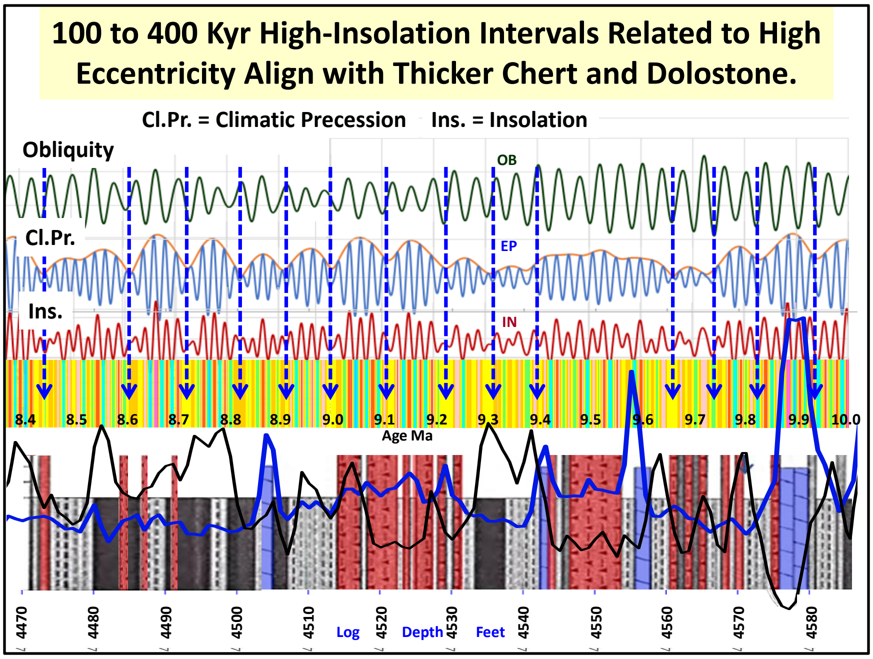


"we show that during the last 2.8 million years the morphological evolution of coccolithophores was forced by Earth's orbital eccentricity with rhythms of around 100,000 years and 405,000 years"…"reduced seasonality favors species of mid-size coccoliths"…"enhanced seasonality favors a larger range of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

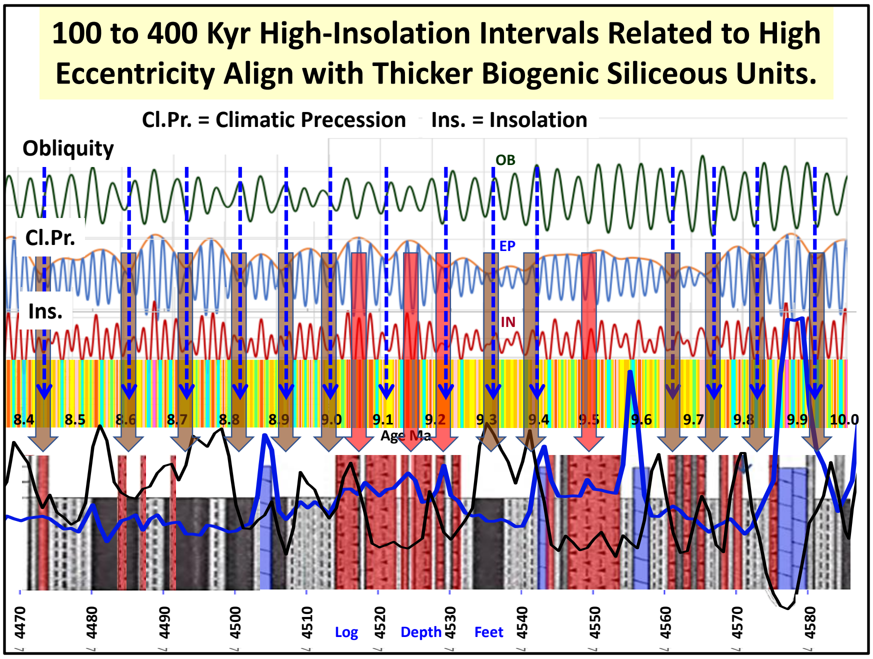
Is there any evidence that orbital cycles have an influence on phytoplankton? This recent paper published in Nature shows a strong association between orbital eccentricity and coccolith size. Reduced seasonal contrast during low Climatic Precession favored species of smaller coccoliths. The authors also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



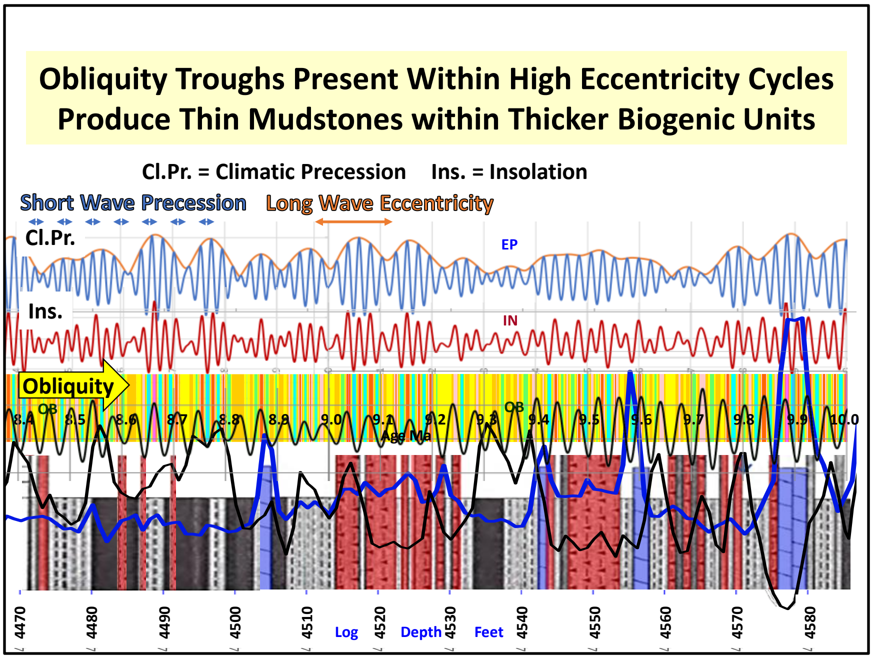
The next match focuses on the Upper Siliceous Unit, which has thick layers of pure silica opal CT porcelanite and chert separated by mudstone intervals. This unit is Monian in age, deposited as the Late Miocene climate shifted to icehouse conditions.



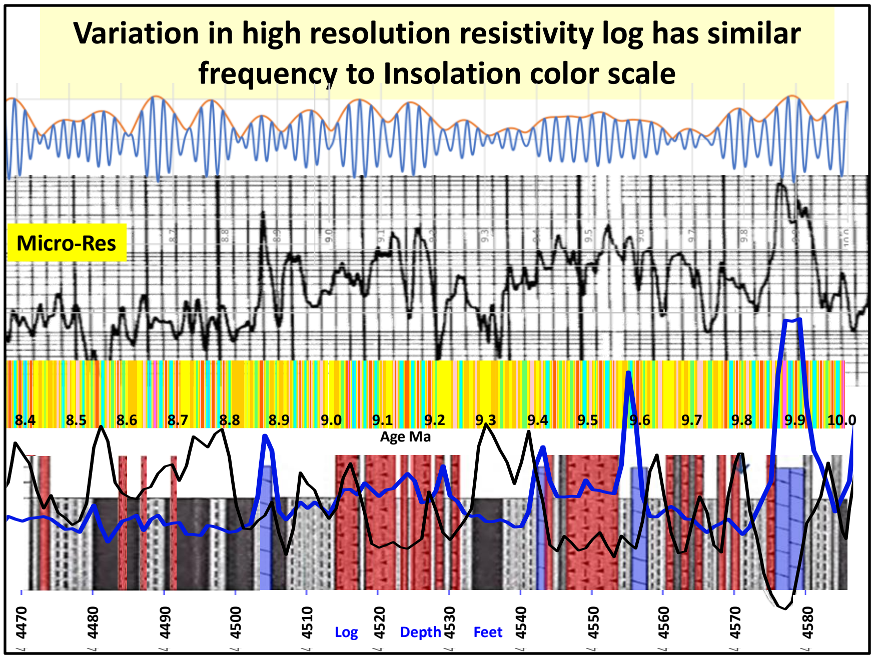
Climatic Precession cycles divide the insolation curve into higher and lower amplitude periods. However, in contrast to the greenhouse conditions of the earlier climatic optimum, conditions were colder and dryer in the Monian. During this stage, high insolation phases seemed to favor siliceous plankton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



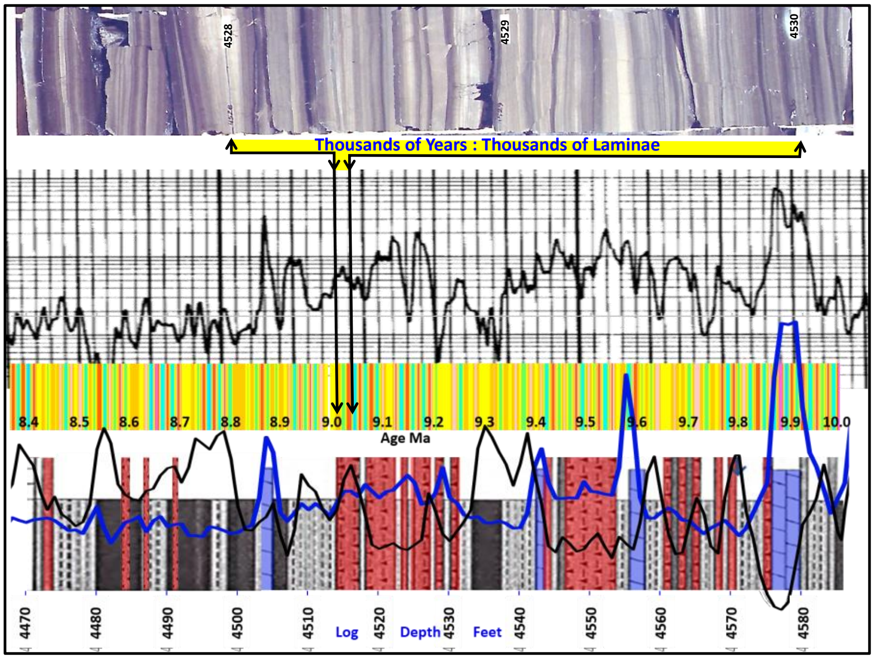
Interpretation is that increased energy is delivered alternately to northern and southern hemispheres during times of high eccentricity, leading to higher wind and current energy in the atmosphere-ocean system, resulting in enhanced upwelling, and more favorable conditions for siliceous plankton. It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



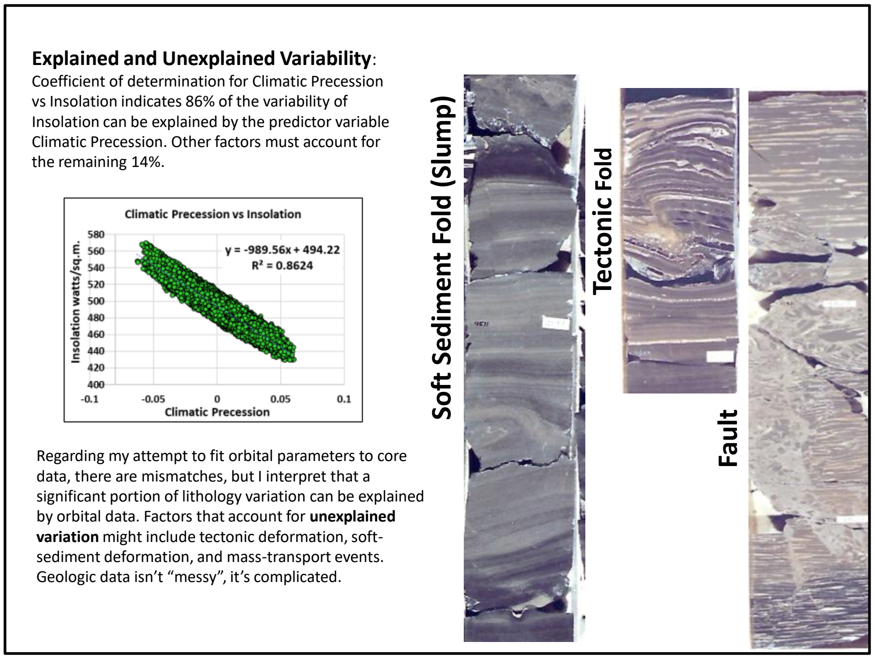
I shifted the obliquity curve down to the color bar. Obliquity cycles during times of high eccentricity appear to control fine-scale interlayering within thicker biogenic units.



Short period variation in resistivity log is similar in wavelength to high frequency precession cycles.



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.

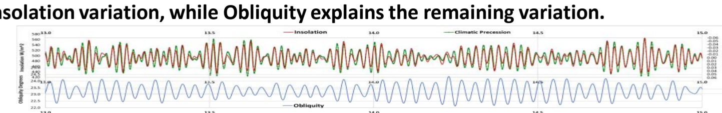


Earlier, we talked about Explained and Unexplained Variability. A close look at my comparisons shows that I can't explain all rock variation by a match to orbital curves. There is an element of unexplained disagreement. Familiar geological processes explain some errors, including tectonic deformation, 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 change. Some people dismiss mismatches by saying that geologic data is messy. I won't make that excuse. Geologic data isn't "messy", but it can be complicated.

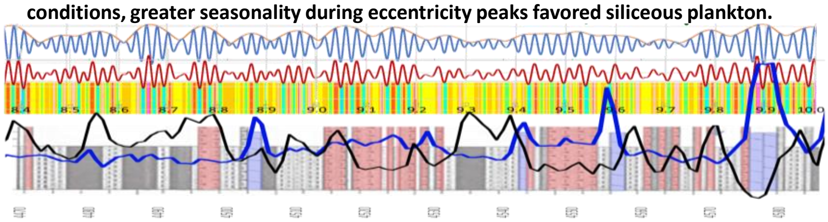
In Summary: I presented for your use a spreadsheet that you can use to display orbital parameters and insolation variation for the past 30 million years.

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

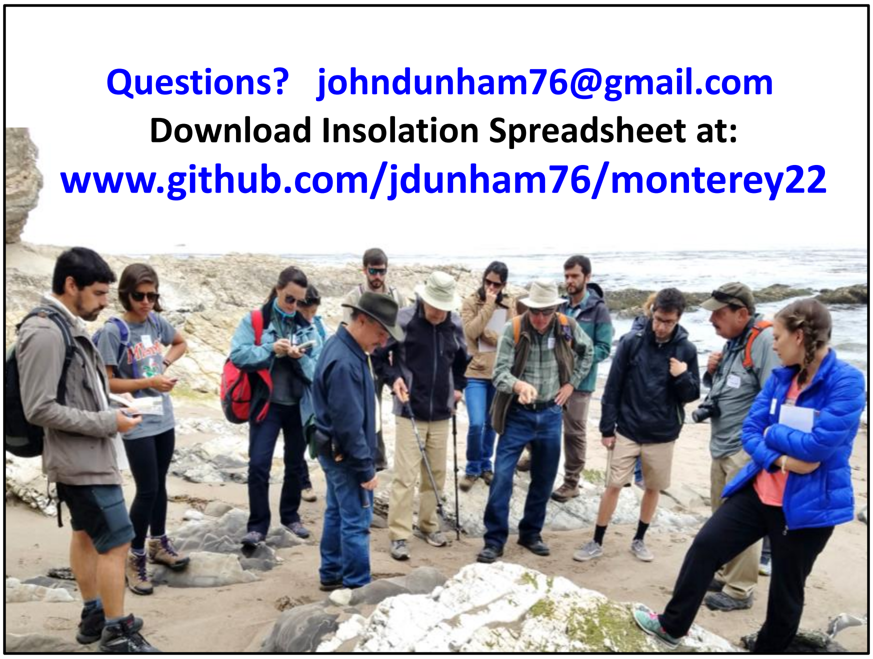
I showed that Climatic Precession (Eccentricity * Sine Precession) explains 86% of Insolation variation, while Obliquity explains the remaining variation.



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.



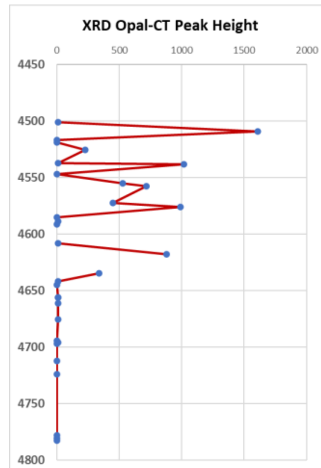
In summary, you can download my spreadsheet to display insolation and orbital data for the past 30 million years. I showed that climatic precession explains 86% of insolation variation, while Obliquity explains the remaining balance. I proposed a model where insolation peaks driven primarily by Climatic 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 model, but through further research, I hope that some of you might successfully assign absolute ages to individual beds in the Monterey Formation.



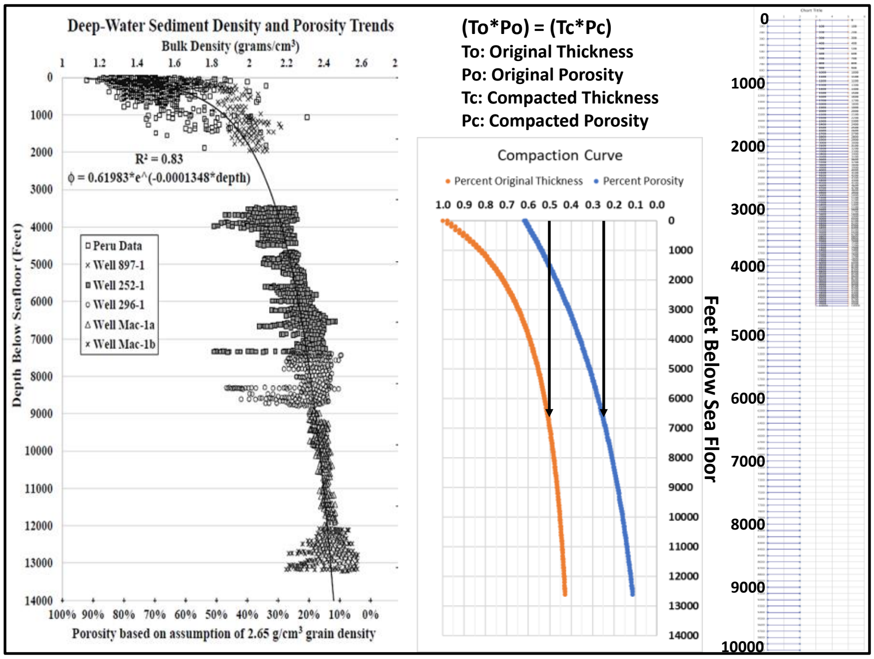
You can download the Insolation Spreadsheet at this web site, along with core photos and a copy of this presentation. Are there any questions?

BACKUP SLIDES

SAMP.	LITH.	POROSITY	EXT.TOC	DETRIT.	BIO.SI.	DOLO.	CALC.
4696.1	PO4 MUD	33.3	21.12	45	6	1	1
4675.3	PO4 MUD	31.9	18.4	40	15	6	2
4778.1	PO4 MUD	30.2	7.79	30	10	20	4
4608.3	PO4 MUD	29.2	18.5	49	16	10	1
4661.1	PO4 MUD	24.5	8.16	25	17	25	6
4546.9	PO4 MUD	24.2	11	36	7	42	2
4501.2	PO4 MUD	23.8	9.65	65	13	4	0
4782.5	PO4 MUD	23.3	8.14	41	16	13	3
4634.6	PO4 MUD	22.9	17.9	29	51	0	0
4655.9	PO4 MUD	22.6	15.1	43	24	3	2
4585	PO4 MUD	22.4	16	64	14	1	0
4597.5	PO4 MUD	21.7	10	59	25	2	0
4537.1	PO4 MUD	20.9	10.5	41	8	34	2
4572.5	PO4 MUD	20.8	8.81	39	23	24	2
4525.6	PO4 MUD	18.4	15.2	57	21	2	0
4645	PO4 MUD	18.2	6.2	24	18	38	6
4519	PO4 MUD	17.2	13.1	65	10	5	0
4641.9	DOL.MUD	25.3	5.65	12	16	58	6
4555.1	DOL.MUD	21.2	1.8	5	26	60	8
4712.5	DOL.MUD	21.2	3.21	6	14	62	11
4509.2	PORC.	22.5	1.73	12	85	0	0
4576	PORC.	14.9	1.44	4	94	0	0
4557.9	PORC.	13.6	1.1	3	95	0	0
4538.1	PORC.	9.8	2.25	8	89	0	0
4618	PORC.	9.8	1.39	5	93	0	0
4694.5	DOLO.	14	1.87	7	2	78	9
4697	DOLO.	12.7	2.39	4	1	81	10
4591.5	DOLO.	8.8	0.1	0	17	71	11
4588.7	DOLO.	5.7	0.21	1	2	91	5
4780.6	DOLO.	5.7	1.37	5	0	79	14
4724.2	DOLO.	5.4	2.02	3	1	85	9
4517.1	DOLO.	4.1	0.07	1	2	89	8
4656.2	DOLO.	3.9	1.46	4	3	77	15
4624.9	CHERT	1.1	0.59	1	98	0	0



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.

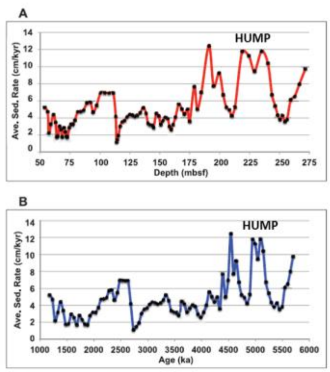
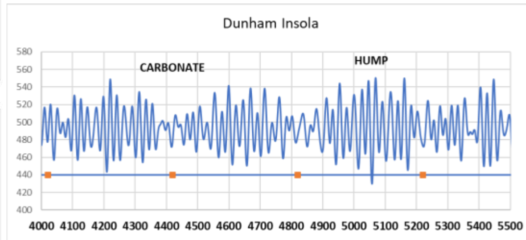


FIG. 9.—A) Sedimentation rates vs. depth (mbsf). B) Sedimentation rates vs. age (ka). Sedimentation rates were calculated from the 83 final tie points (black dots) from the tuning of 1016A (Table 2). Corresponding ages for each interval were calculated by linear interpolation between tie points.

Hill and Behl, 2019: Regionally Correlative "Hump" corresponds to eccentricity and insolation peak. Major carbonate productivity event at 4400-4500 Ka.



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