A Cyclostratigraphic Analysis of the Mid-Cenomanian Event, Avacelli and Furlo, Italy

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Abstract

Spectral analysis on the mid-Cenomanian Event (MCE, prelude to the second Cretaceous oceanic-anoxic event) recorded in the Scaglia Bianca formation at Avacelli, the Umbria-Marche region of Italy reveal multiple cycles with periods that correlate with the theoretical orbital cycles calculated by Laskar et al. (2004). Fast Fourier Transforms (FFT) and bandpass filters yielded a constant sedimentation rate of 1.07 cm/ky and an age of 96.00 Ma to 98.48 Ma. Monte Carlo simulation of FFT shows Milankovitch cycles as statistically significant within the stratigraphic section. Sliding window shows little climatic shift, allowing the assumption of a constant sedimentary rate. The low frequency eccentricity cycle envelopes both of the higher frequency obliquity and precession cycles, proving these cycles as truly results of Milankovitch orbital forcing. The OAE 2 is controlled by astronomical variations given the orbital control over the cyclic deposition of the OAE 2 within the formation. Similarly, we hypothesize that the mid-Cenomanian Event's cyclic deposition is orbitally controlled even while going through the beginning of a large-scale oceanic structure and palaeoclimate change that leads up to the OAE 2.

Keywords: Milankovich cycles, mid-Cenomanian Event, Scaglia Bianca, Avacelli, pelagic, spectral analysis

Introduction

The mid-Cretaceous (Barremian to Turonian, 127-89 Ma) went through several breaks in the carbon cycle, known as Oceanic Anoxic Events (OAEs). They cause extensive organic carbon-rich marine sediment depositions as well as marine biota fluctuations (Coccioni and Galeotti, 2003), ultimately depositing black shales with at least 15% organic carbon content and 1.5 – 2% in positive carbon isotope excursion (Schlanger and Jenkyns, 1976; Arthur and Schlanger, 1979; Jenkyns and Hallam, 1980; Arthur and Premoli Silca, 1982; Bralower et al., 1993; Arthur and Sageman, 1994; M'Ban, 1996). During this time, inner-Earth dynamics such as the rifting of Pangaea (Anderson, 1994) or a superplume event (Larson, 1991) possibly had an effect on characteristics such as a stable magnetic field with warm global climates, as well as elevated sea levels and volcanic activity during the mid-Cretaceous (Mitchel et al., 2007).

Oceanic Anoxic Events can be observed in the rock records in the Umbria-Marche Basin, usually leaving a higher frequency of organic-rich beds. The Bonarelli level represents the climax of a black shale deposition cycle that lasted 2 My, and begun abruptly and prominently in the mid-Cenomanian foraminiferal Rotalipora cushmani zone; this event is named by Coccioni and Galeotti as the mid-Cenomanian Event (MCE), marked by changes in the biotic and abiotic records. Moreover, the MCE caused carbon and oxygen isotope changes which correlates with a major sea-level fall, associating itself to large-scale changes in the oceanic structure and paleoclimate (Coccioni et al., 1987, 1989, 1992, 2003).

Mitchel et al. (2007) did a stratigraphic study of the previously mentioned 2 Ma black shale deposition leading up the Bonarelli level. His study shows that the section he analyzed indicated three oscillating oxygenation and productivity level caused by orbital influence after comparing with the orbital variations theoretical curves calculated by Laskar et al. (2004).

Since the climate change is recorded and part of the pelagic rock records both in Umbria-Marche Basin and the Cenomanian Lower Chalk Formation in Southeastern England (Coccioni, 2003), it may be possible for these regions to show paleoclimate forcing. The OAE 1 and OAE 2 have been analyzed for evidence of Milankovitch cycle forcing. The OAE 2 section analyzed by Mitchel et al. (2007) shows a stronger correlation to Laskar's theoretical eccentricity curve as opposed to obliquity or precessional. The orbitally-controlled lithologic rhythms of oscillations between dsyoxic and anoxic conditions are well recorded in the mid-Cretaceous outcrop in the Umbria-Marche Basin region, reflecting oscillation rhythms (Arthur and Premoli Silva, 1982; de Boer, 1986; Herbert and Fischer, 1986; Herbert et al., 1986; Pratt and King, 1986; Gale et al., 1993; Arthur and Sageman, 1994; Sageman et al., 1997; Grippo et al., 2004).

In this study, I conducted a cyclostratigraphic study of the mid-Cenomanian event, a continuation of Mitchel et al.'s (2007) study in attempt to complete the cyclostratigraphic analysis record of the region. The oscillations suggest that the mid-Cenomanian Event was influenced by orbital cycle climate variation forcing, allowing for potential correlation to the theoretical predicted orbital variations calculated by La2004.

Background

Milankovitch cycles are discovered as the cycles of the variation in earth's orbit in relation to the sun by a Serbian civil engineer, mathematician, climatologist and astrophysicist Milutin Milanković (1941). The three orbital cycles described are eccentricity – earth's orbital shape, obliquity – earth's tilt angle, and precession – earth's axial wobble. These three orbital cycles affect climate on earth by varying the distribution of energy from the sun at a time over a certain area (insolation, measured in W/m^2) at different latitudes. Hays et al. (1976) tested and proved Milanković's hypothesis on the relationship between Milankovitch cycles and climate variations (Brown, 2006).

The eccentricity cycle completes one cycle every 95 to 123 ky. This cycle affects the variation in distance between the earth and the sun, therefore the amount of energy by the varying elliptical and oval shape of its orbit. Although not directly, this cycle affects climate variations by controlling the effects of the precession cycle. The obliquity cycle (41 ky) is the change in the earth's tilt angle, which changes between 22° and 24°. The change in tilt angle changes the insolation, causing lower seasonality during lower tilt angles and vice versa, affecting the North and Southern Hemispheres simultaneously. The precession cycle (19 -23 ky) alternates the angle of insolation, causing the North and Southern Hemisphere to alternate having mild seasonality and extreme seasonality on a yearly basis. While it is hard to say which one of these causes a greater variability in insolation, they are all responsible for changes in surface temperature, seasonal length, extremity of yearly seasons, oceanic circulation and biological activity.

Stratigraphic and Geologic Setting

The outcrop studied is a road cut in Avacelli, a small town in the comune Arcevia, located in the Province of Ancona of the region of Marche, Italy (Fig. 1, 2). This location is a classic location for Cretaceous pelagic succession containing several anoxic events. The outcrop is a section within the Scaglia Bianca formation, situated below the Bonarelli level and the Scaglia Rossa formation and above the Marne a Fucoidi formation (Fig. 3). Since the boundaries between the Scaglia Bianca and Scaglia Rossa as well as Fucoidi are gradational, it is difficult to precisely locate the transitions between formations at the outcrop.

The predominant lithology consists of alternating layers of well bedded limestones and cherts, with the occasional marls (Fig. 3) deposited at a paleolatitude of 25°N throughout the Umbra-Marche Basin (Dercourt et al., 1993). The Scaglia Bianca was deposited at a deep bathyal bathymetric position. At 1500 to 2000 m water depth, above the calcite compensation depth, the lithification of nannofossil-planktonic foraminiferal ooze causes the high (>70%) carbonate content in the formation (Authur and Premoli Silva, 1982; Kuhnt, 1990). The base of the targeted outcrop begins at the boundary between marly limestone and limestone with chert, which is the end of the Marne a Fucoidi formation. It ends at the second to last black chert bed within the Scaglia Bianca formation, overlapping approximately 2 m with Mitchel et al's section (2007). This 27 m stratigraphic section is mainly composed of well bedded pelagic limestones that are white, grey, yellow, or pink in color. The black, white, and pink cherts occasionally lie within the limestone beds, which are not always apparent. Though

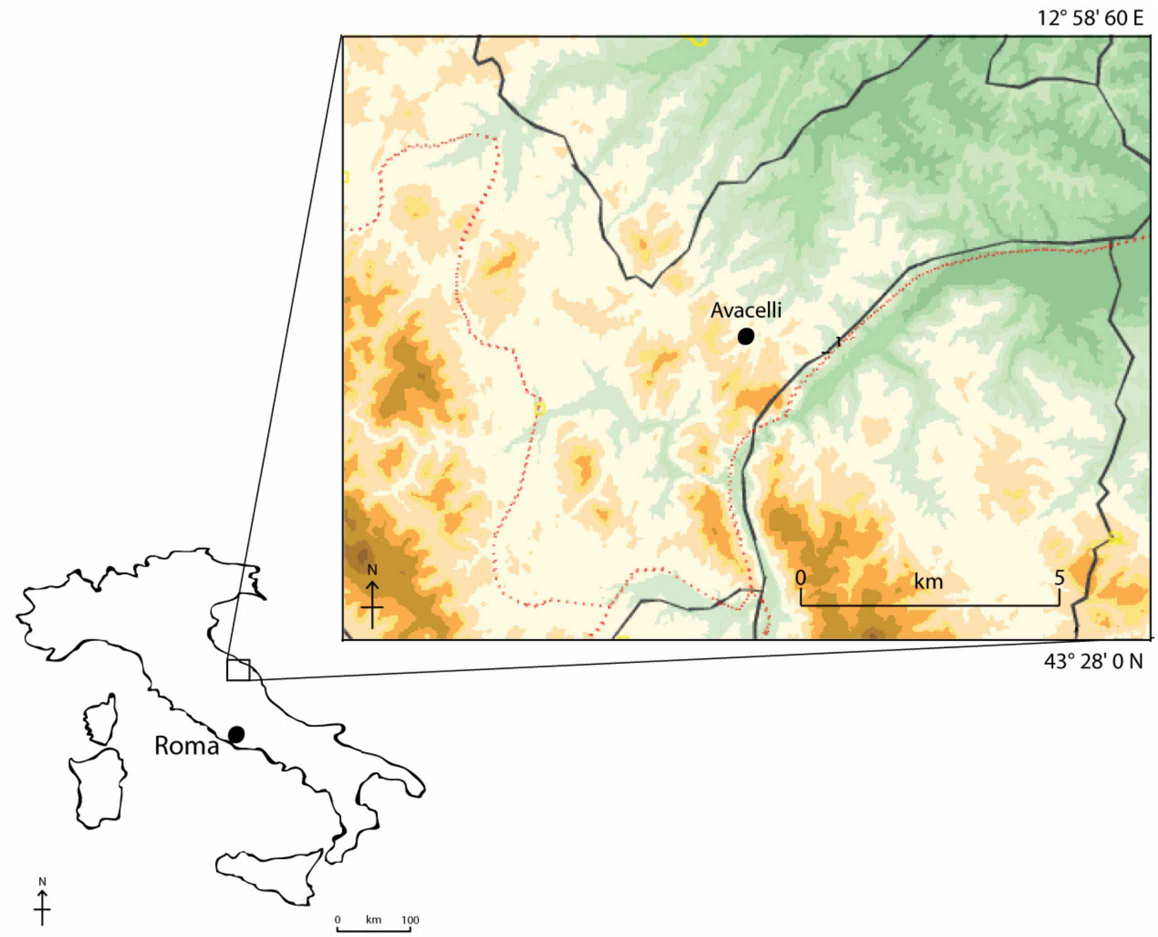

Figure 1. Location map of Avacelli. Topographic map in the upper right courtesy of Falling Rain Genomics, Inc.

Figure 2. The 27 m outcrop. Arrow indicating the younging direction. The marker on the left indicates the top of the mid-Cenomanian Event section, hammer for scale. A

dextral fault displaces the beds, which has been corrected and accounted for in making of the litholog. The marker on the left indicates the base of the stratigraphic section, as well as the end of the Marne a Fucoidi formation.

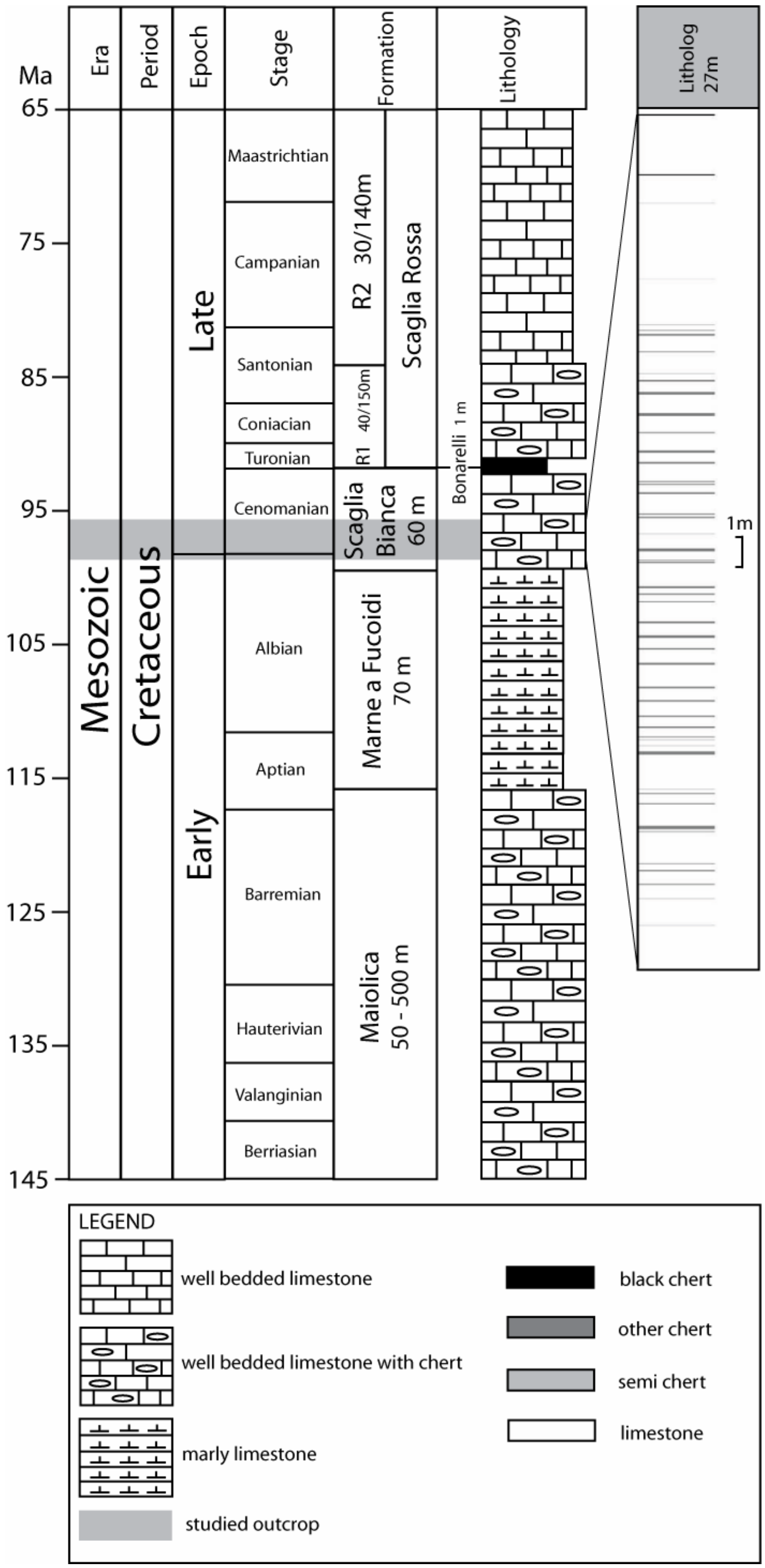

Figure 3. The Umbria-Marche Succession with the stratigraphic litholog of this study.

rare, this section contains a few thin marly limestone layers, especially towards the Fucoidi formation that is mainly composed of marly limestones.

Coccioni and Galeotti (2003) consider the MCE as a possible precursor of the Bonarelli event and Mitchel et al. (2007) considers the OAE 2 as the prelude to the Bonarelli event. Moreover, the MCE is nestled between two discrete members within the Scaglia Bianca formation, W3 and W4 (Coccioni, 1996). In other words, the MCE combines both the yellow-grey limestone with nodular greenish-grey chert of W3, and the grey limestone with dark grey and black chert nodules of W4. Lack of faulting, synsedimentary slumping and turbidite activity, as well as the uniform thickness of the Marne a Fucoidi and Scaglia Bianca formations throughout the Umbria-Marche Basin suggests that the thinned continental margin of Adria has been tectonically inactive during the Aptian throughout the Turonian (Montanari et al., 1989; Montanari and Koeberl, 2000).

Previous Work

There has been some resistance towards the validity of cyclostratigraphic analysis, doubting the strength of orbital signal or the presence of evidence for Milankovitch cycles within the Scaglia Bianca formation (Grippo et al., 2004; Gale et al., 1995). However, other studies have advocated the existence of Milankovitch cycles within the formation (de Boer, 1986; Claps and Masetti, 1994; Schwarzacher, 1994; Beaudoin et al., 1996). Most notably is Schwarzacher's (1994) study on spectrally analyzing the Scaglia Bianca formation using lithology thickness index, resulting in the finding of an eccentricity cycle signal.

More recently, Mitchel et al.'s (2007) intensive study of the OAE 2 meticulously investigated the correlation between Laskar's mathematically derived curves and the lithologic cycles in Furlo, as well as its connection with the overlying Bonarelli level by spectrally analyzing the respectively assigned grayscale values of different lithologies to determine the cyclicity of the OAE 2. M'ban (1996) has shown that the color of limestone and chert has a positive correlation with the total organic carbon (TOC) content. Moreover, Coccioni and Luciani (2005) suggest that a correlation between chert's radiolarian concentration and high surface waters nutritional levels. Therefore the relative grayscale value method is a viable approach to determining the nutrient influx to surface waters in addition to the TOC, possibly caused by Milankovitch cycle's affect on climate as well as biological productivity.

Field and Spectral Analysis Methods

Data Collection

The mid-Cenomanian Event section of the Scaglia Bianca was logged by measuring the thickness of each bed starting from the second to last black chert layer down section towards the Marne a Fucoidi formation. There are two reasons for doing so. Since the section logged by Mitchel et al. (2007) began from the last black chert layer, by starting our log at the second to black chert layer, a slight overlap can assure a proper link up of the two separate lithologs for future analysis if necessary. Moreover, the section was logged down section due to the gradational boundary between the Scaglia Bianca and the Fucoidi formations; it is difficult to decide on a precise starting marker bed as the beginning of the Scaglia Bianca formation. An average of the thickness measurements were taken and rounded to the nearest centimeter for ease of building the litholog of the section. The lithology, color, and anything unusual were recorded as well.

This approach was chosen over using a photograph because weathering, shadows, vegetation coverage, and oftentimes obscured lithology (e.g. faint chert nodules in limestone) make working from a photo problematic, possibly missing important layers.

Litholog Creation

The litholog was created by assigning a numerical value for three lithologies – limestone, black chert and other cherts. The respective grayscale values used to construct the litholog are 0% for limestone, 100% for black chert and 50% for other cherts. The numerical values after converting these grayscale values are 0 for limestone, 127 for other cherts and 255 for black cherts. These values are arbitrarily chosen, and other values can be used and still achieve the same spectral analysis results as long as the ratio of the values remain the same.

Only these three lithologies have been used in order to eliminate “noise” so that the end result is a clean, simple and continuous dataset. Marls have been eliminated for the same reason, however, due to their rare, thin and oftentimes obscure occurrences (<1cm), they have minimal effects on the analysis results. In addition to these advantages, using this numerical coding approach realistically accounts for the abrupt lithologic changes possibly related to diagenesis or the climate changed abruptly, eliminating the possibility of recording any gradational facies. The dataset created by this approach is a square, non-sinusoidal waveform. This generates some small “fake” peaks that are multiples of the fundamental frequency (Fig. 4); however, these overtones are relatively weak and insignificant in comparison (Mitchel et al., 2007).

Spectral Methods

Spectral analysis was performed in Matlab 7.0.1 with algorithms modified by Muller and MacDonald (2000). Fast Fourier Transforms (FFTs) were performed on the numerical data of the litholog in order to acquire a set of spectral peaks of cycles measured by the complex conjugate (z^*) normalized to unit mean power of the Fourier coefficients (Muller and MacDonald, 2000). The sedimentary rate for this FFT had been set as 1 cm/ky, inspired Coccioni and Galeotti’s (2003) calculation by comparing Hardenbol et al.’s (1998) timescale of the Cenomanian rock accumulation rate of the Bottaccione Gorge section with Umbria-Marche succession’s microfossil biostratigraphy. A Monte Carlo simulation of this FFT was used in order to identify significant peaks. This is done by generating 1000 truly random false data sets that have similar structure of our data, running FFTs on all of them, and then analyzing the power at each frequency to find the 95% confidence level. Spectral peaks that do not rise above the 95% confidence level are ascribed to random noise. Bandpass Filters were run on Laskar’s astronomical curves (2004) with the band-widths of the filters chosen to acquire the theoretical eccentricity, obliquity and precession cycles’ values. Another FFT was run with an adjusted sedimentary rate. An evolutionary spectral (sliding-window) analysis was run in

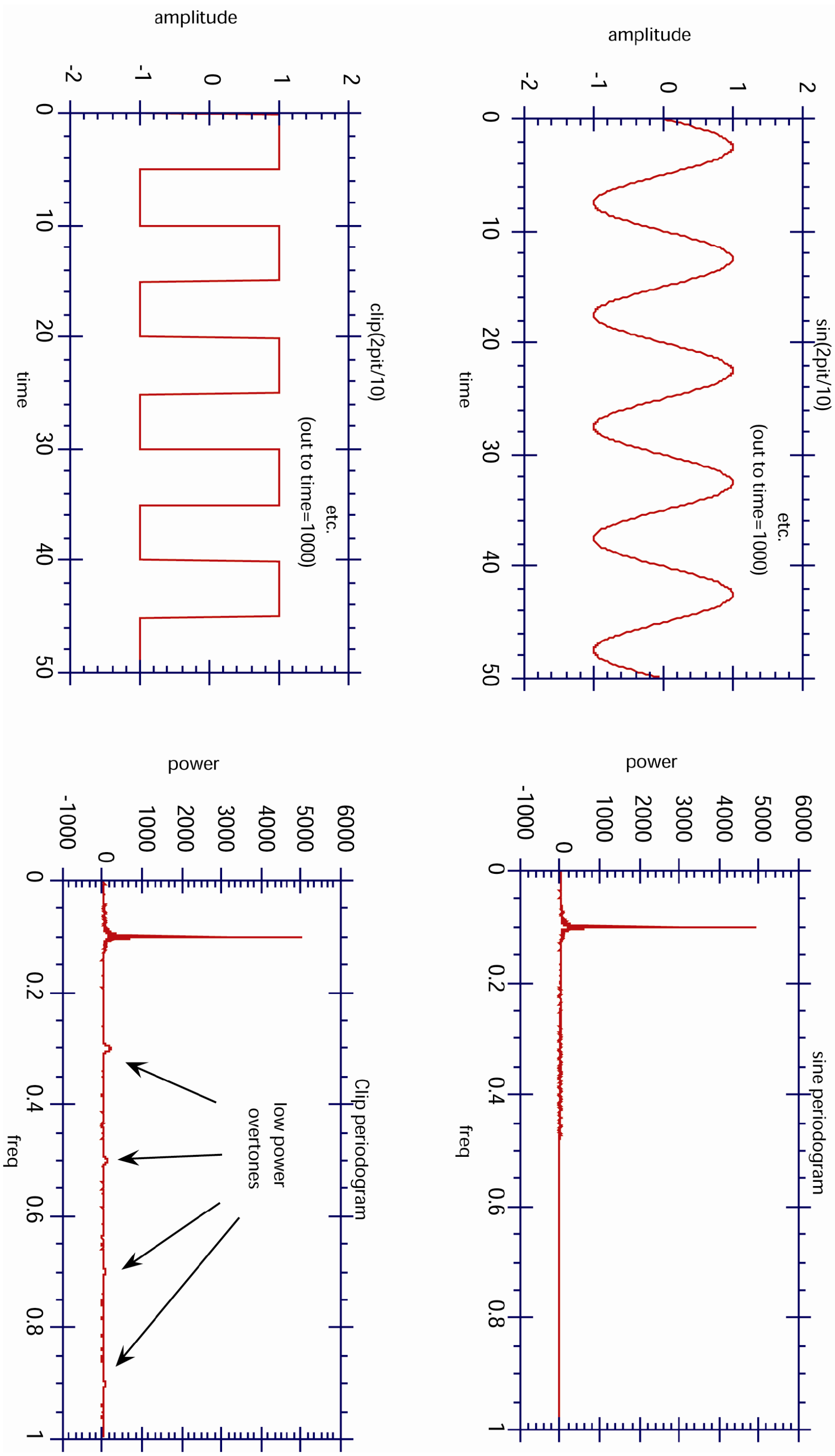

Figure 4. An example of "fake" peaks, low power overtones at multiples of the fundamental frequency generated by square waves on Fast Fourier Transforms. Figure courtesy of Professor Linda Hinnov from Johns Hopkins University.

order to confirm the constant sedimentation rate and persistence of the spectral cycles (Cleveland et al., 2002) in addition to the cycle and sedimentation stability. The eccentricity, obliquity and precession cycles calculated by Laskar et al. (2004) were combined by standardizing and stacking time series to create an ETP (eccentricity, tilt, precession) curve (Imbrie et al., 1984). This combined curve is used in addition to the individual curves to test for correlation with our stratigraphic section's curves. A Hilbert transform was run to test the presence of Milankovitch cycles by inspecting amplitude modulation relationships between eccentricity and precession. Finally the bandpass filtering results were compared to Laskar's calculated curves (2004) for possible correlation between the three cycles, ultimately utilized to astronomically date the logged Scaglia Bianca section in Avacelli.

Results

The initial FFT with a sedimentation rate of 1.0 cm/ky of the Scaglia Bianca shows multiple strong cycles, especially the eccentricity cycle. The 108 ky, 40.28 ky and 22.45 ky cycles has been regarded as the eccentricity, obliquity and precession cycles. Other prominent cycles are 53.25 ky, 35.15 ky, 27.48 ky, 23.11 ky, 20.73 ky and 18.63 ky (Fig. 5). Weaker signals are 62.27 ky, 45.71 ky and 33.08 ky. None of these spectral peaks are due the "false" peaks caused by the low power overtones due to the square waves. The Monte Carlo simulation was used to provide the 95% confidence level for in addition to the FFT to ensure that the previous mentioned peaks are statistically

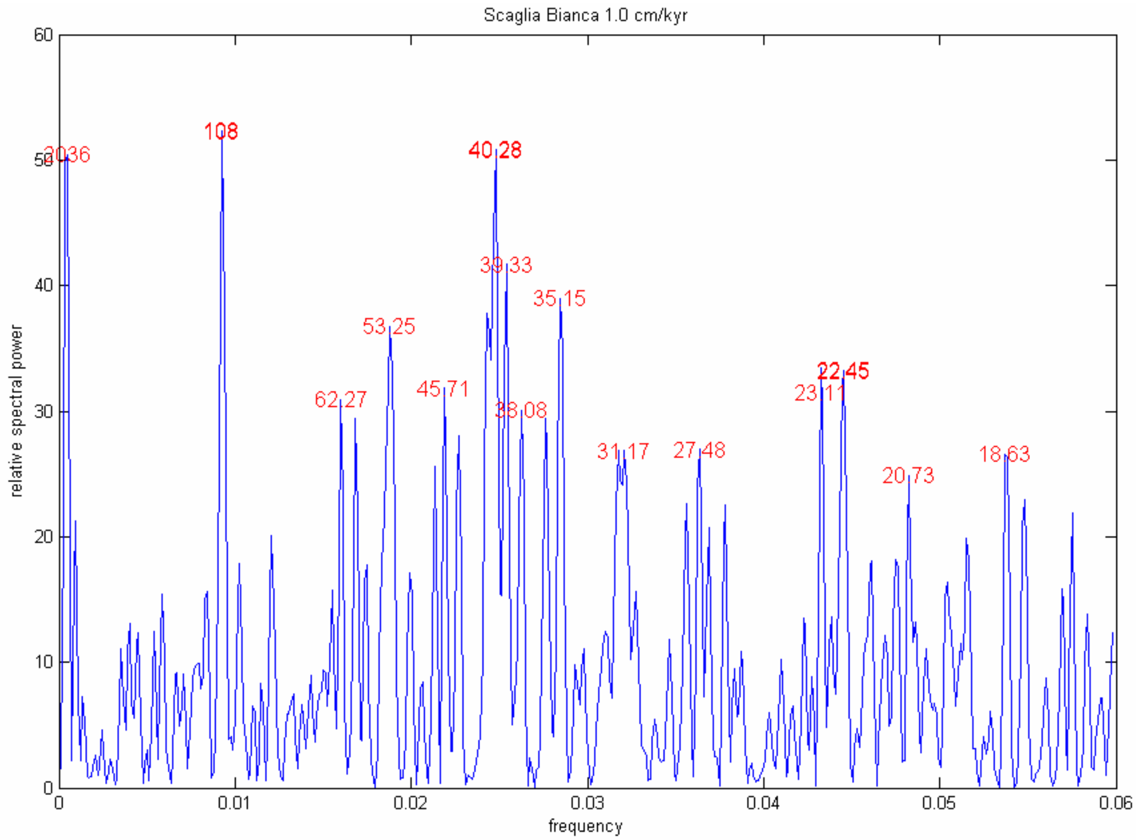

Figure 5. FFT with sedimentation rate of 1.0 cm/ky. Eccentricity, obliquity and precession cycles are all present and rise above surrounding "noise".

significant and not due to noise related to low climate variation, sedimentation chatter or bioturbation (Fig. 6).

The bandpass filters on Laskar's calculated values revealed 403.9 ky, 100.2 ky and 95.74 ky cycles for eccentricity, 37.71 ky cycle for obliquity and 22.58 ky, 21.36 ky and a weaker 18.42 ky cycle for precession (Fig 7). These cycle values are utilized to fine tune the sedimentation rate. While there are other statistically significant peaks, it is difficult to know the precise cause for lower peaks.

A corrected FFT with a sedimentation rate of 1.07 cm/ky was carried out, showing 100.6 ky for eccentricity, 37.76 for obliquity and 21.61 for precession (Fig. 8). These cycle values are extremely comparable to the cycle values revealed by the bandpass filter mentioned above and are most likely caused by Milankovitch cycles. Some other cycles that are statistically significant as shown by the Monte Carlo simulation are 58.43 ky, 49.66 ky, 32.88 ky, 25.67 ky, 17.4 ky etc. Due to the strong correlation between eccentricity, obliquity and precession with Laskar's theoretical values confirms that a sedimentation rate of 1.07 cm/ky is the best fitted rate for this stratigraphic section. Using this sedimentation rate and the previously determined age of the Bonarelli, we calculated and dated our section, giving it an age of 96.0 Ma to 98.5 Ma.

The sliding window analysis shows a relatively constant rate of sedimentation because of the prominent cycles remain steady and constant throughout the section, without signs of shifting (Fig. 9). A larger window sized was used in order to observe all three Milankovitch cycles, the 100.2 ky, 37.88 ky and the 21.04 ky cycles. There is a prominent 49.79 ky cycle that was not observed previously in the FFTs.

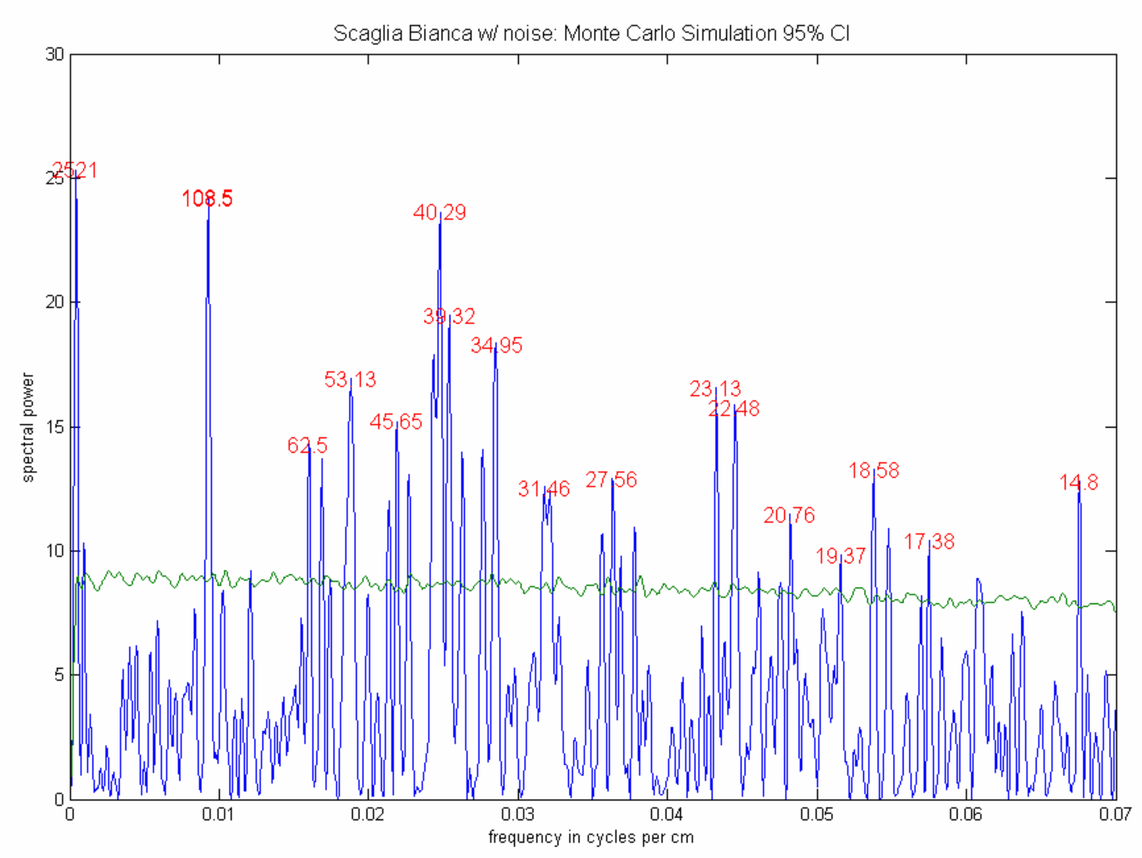

Figure 6. Monte Carlo simulation providing a 95% confidence level (2 standard deviations) with a sedimentation rate of 1.0 cm/ky, showing eccentricity, obliquity and precession cycles as significant.

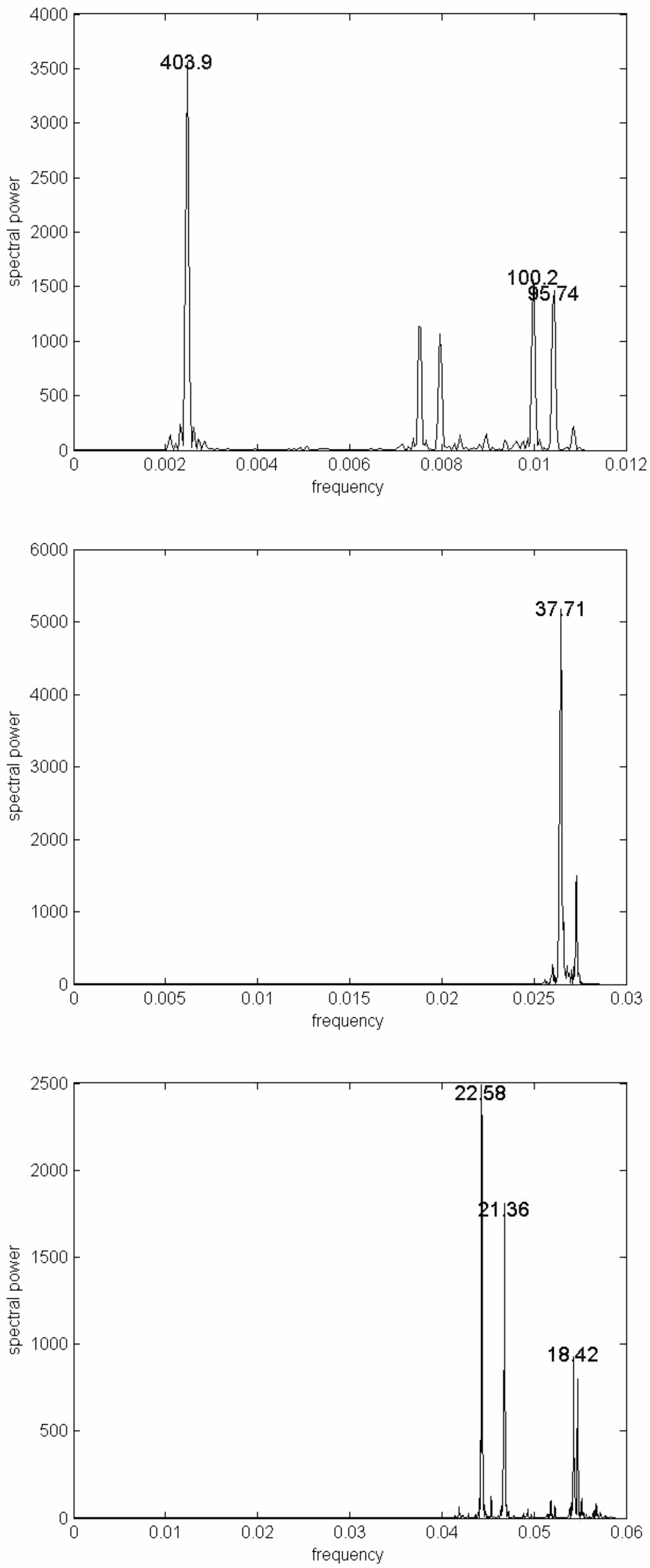

Figure 7. Bandpass filters on Laskar's theoretical curves. Top is eccentricity, middle is obliquity and bottom is precession.

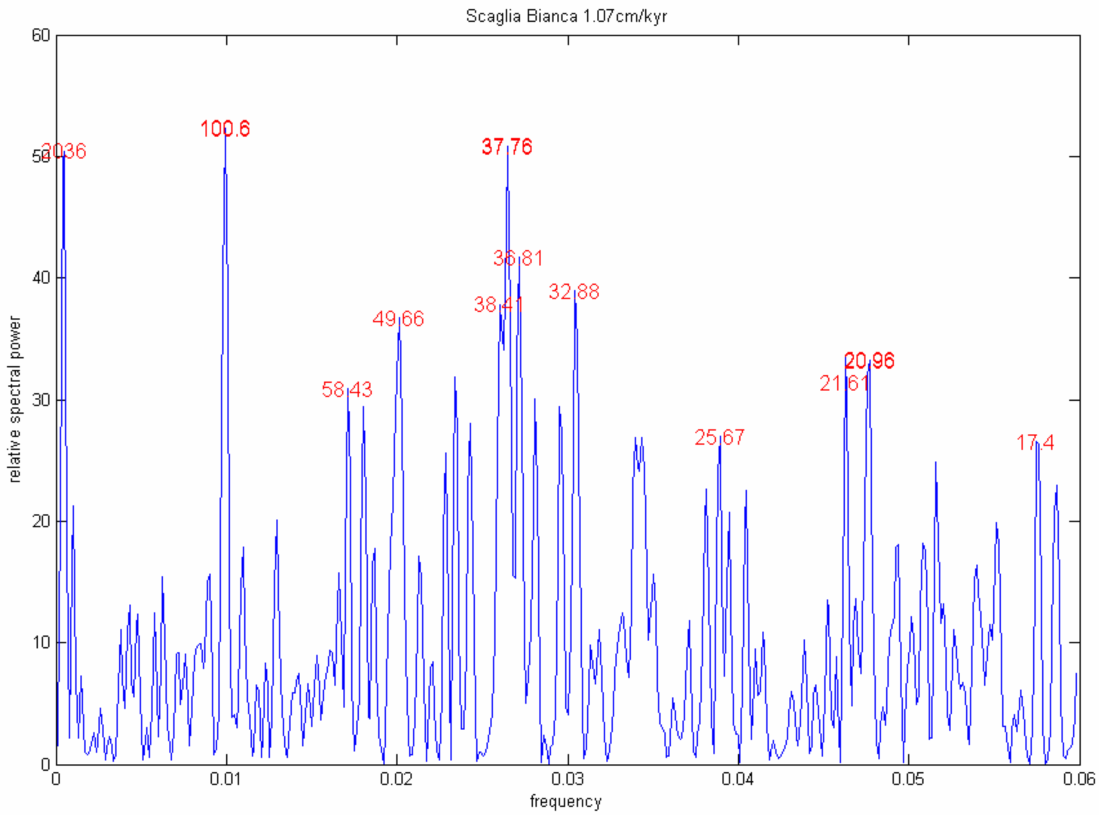

Figure 8. FFT with sedimentation rate of 1.07 cm/ky. Significant peaks are labeled. Eccentricity and obliquity match exceedingly well with Laskar's theoretical values (2004).

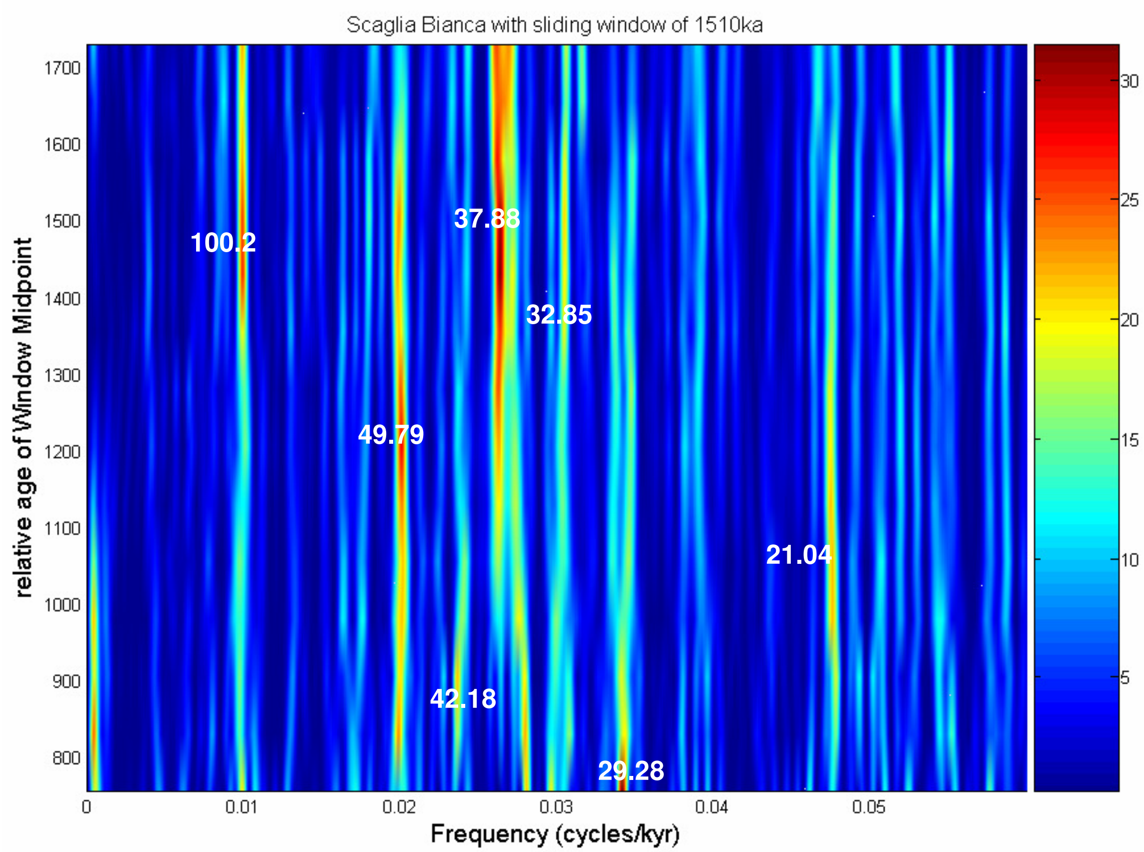

Figure 9. Evolutionary spectral analysis with a 1510 ky window size, revealing changes in spectral power over time. The frequency is measured in cycles/ky.

The ETP curve was generated in order to compare with the results of the bandpass filtering and La2004 eccentricity, obliquity and precession curves respectively for possible correlation (Fig 10, 11, 12, 13). This is done by visually investigating the swells, nodes and general shape in La2004 curves, the stratigraphic analysis curves as well as the ETP curve. The result shows that correlation exists in all three cycles. Finally the Hilbert transform confirms the astronomical parameter relationship of low-frequency bandpass of eccentricity enveloping high-frequency bandpass of precession.

Discussion

The main purpose of this study is to complete the missing section that has not been logged and spectrally analyzed in the Scaglia Bianca formation. While it is not surprising that the mid-Cenomanian Event shows orbital forcing signals, such a strong correlation with Laskar's theoretical values (2004) were unexpected. With the adjusted sedimentation rate of 1.07 cm/ky the eccentricity and obliquity cycles completely match up with the values acquired by bandpass filtering. Moreover, the Monte Carlo simulation confirms that the observed peaks in the FFT are statistically significant. The sliding window shows all three cycles and due to the lack of drift in spectral power over time, confirms the relatively constant sedimentation rate in the stratigraphic section. The fact that the two higher frequency obliquity and precessional cycles are enveloped by the lower frequency eccentricity as shown in the Hilbert transform (Fig. 14) further confirms that the stratigraphic section's lithologic variations were orbitally forced. All of the spectral analysis methods conclude that not only is the Scaglia Bianca a great case study

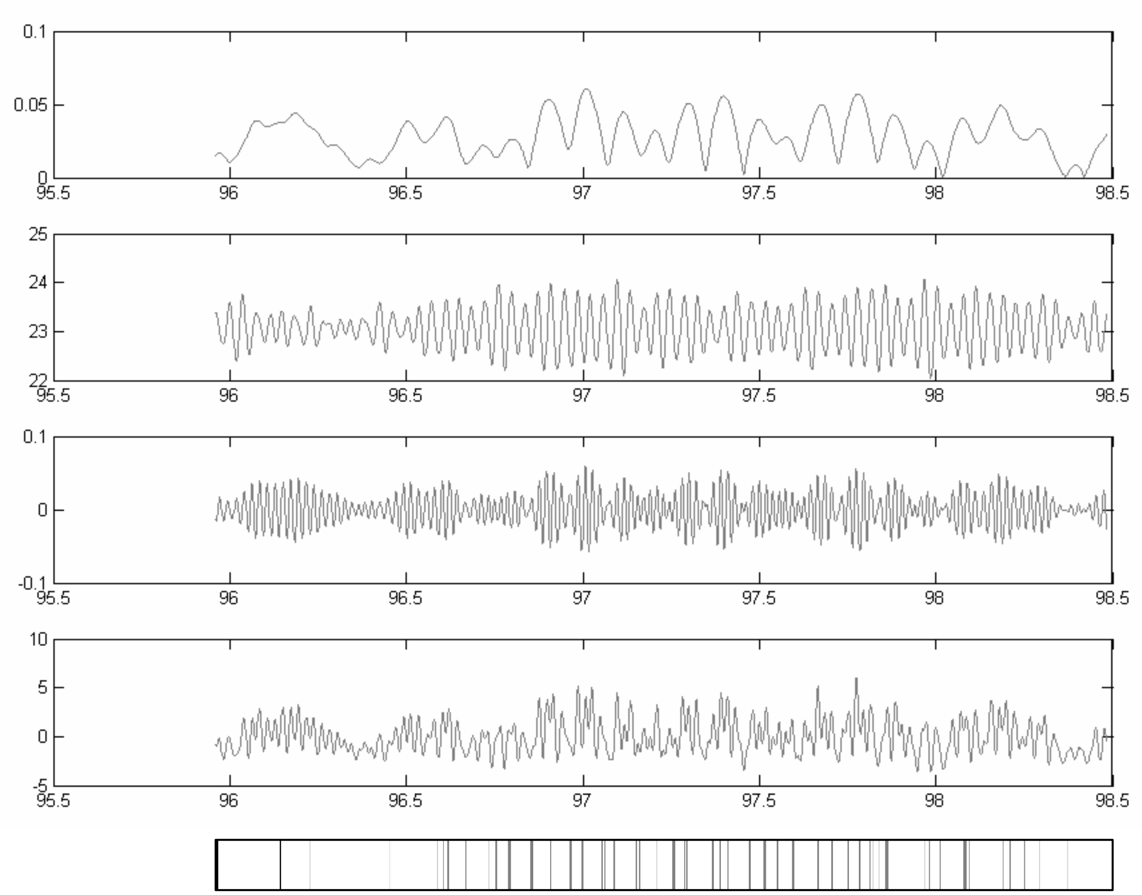

Figure 10. Focusing on the 96.0 – 98.5 Ma section, Laskar's (2004) calculated eccentricity curve (top, y-axis is eccentricity parameter) combined with obliquity (second down, y-axis is obliquity angle) and precession (third down, y-axis is precession parameter), contributing equally to create the ETP curve (bottom, y-axis is standardized units). Litholog at botton for reference and comparison.

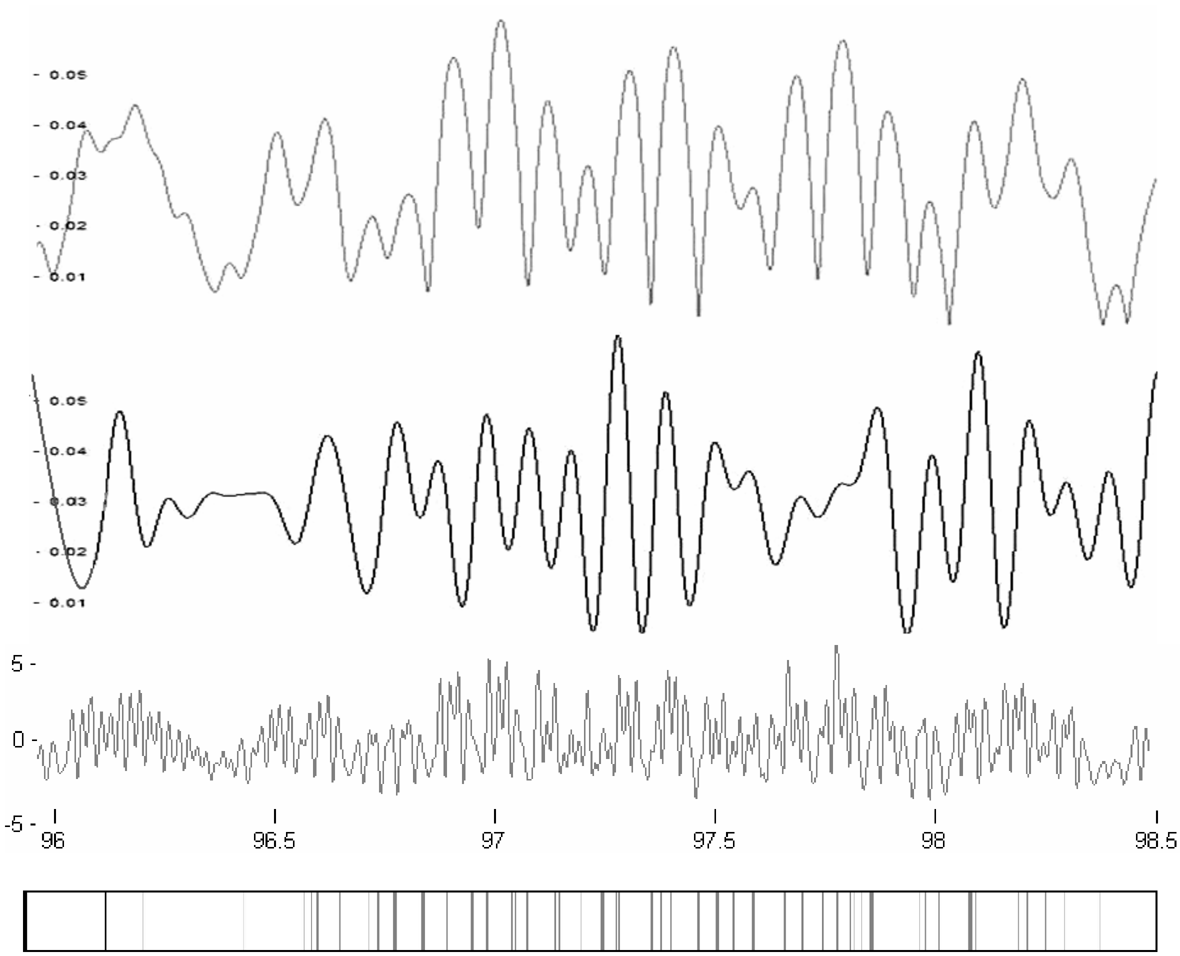

Figure 11. 0 – 27 m stratigraphic section bandpass 96-98 Mya with a sedimentation rate of 1.07cm/ky. Laskar's calculated eccentricity curve (top), compared to eccentricity curve of stratigraphic section (below) with the ETP curve (third down) and litholog (bottom) for reference and comparison.

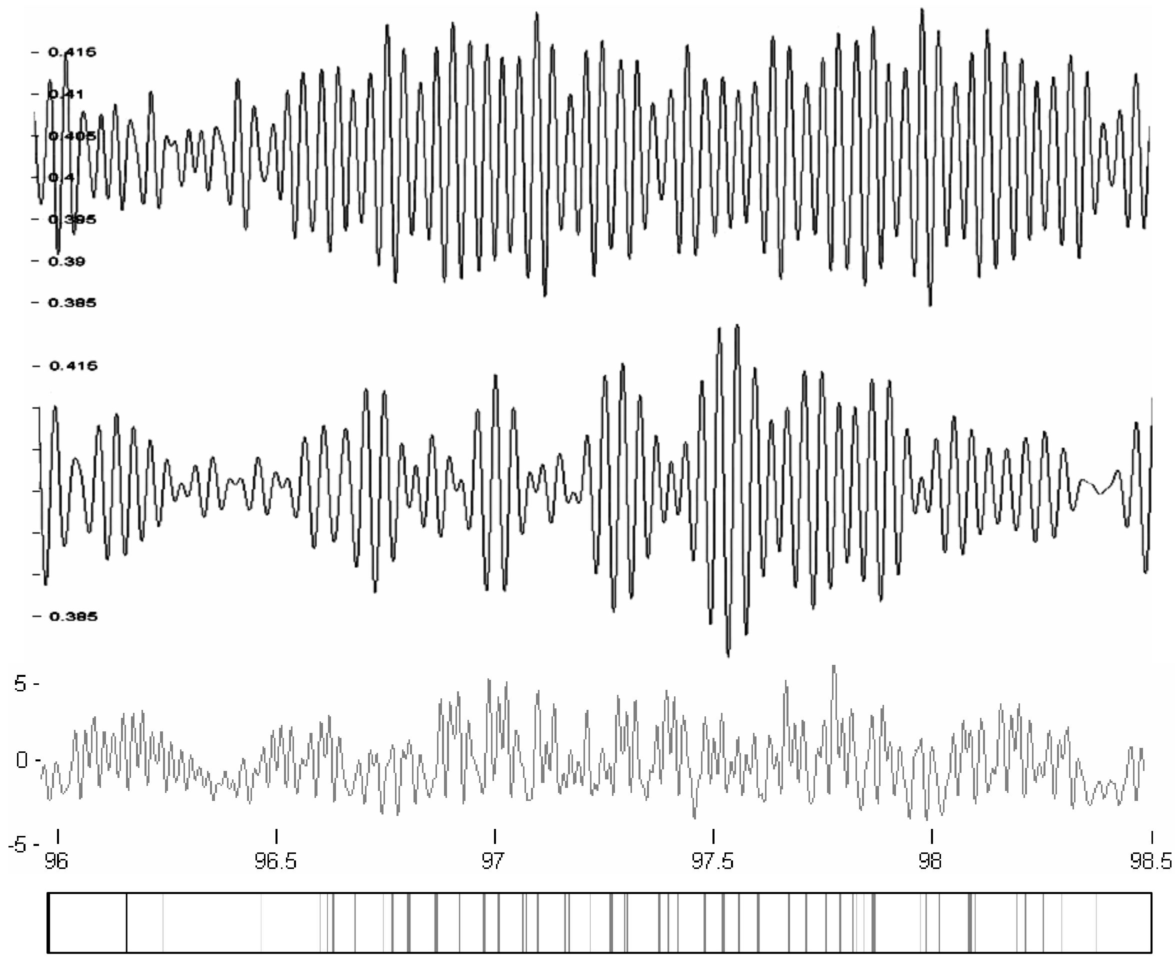

Figure 12. 0 – 27 m stratigraphic section bandpass 35-50 ky with a sedimentation rate of 1.07cm/ky. Laskar's calculated obliquity curve (top), compared to obliquity curve of stratigraphic section (below) with the ETP curve (third down) and litholog (bottom) for reference and comparison.

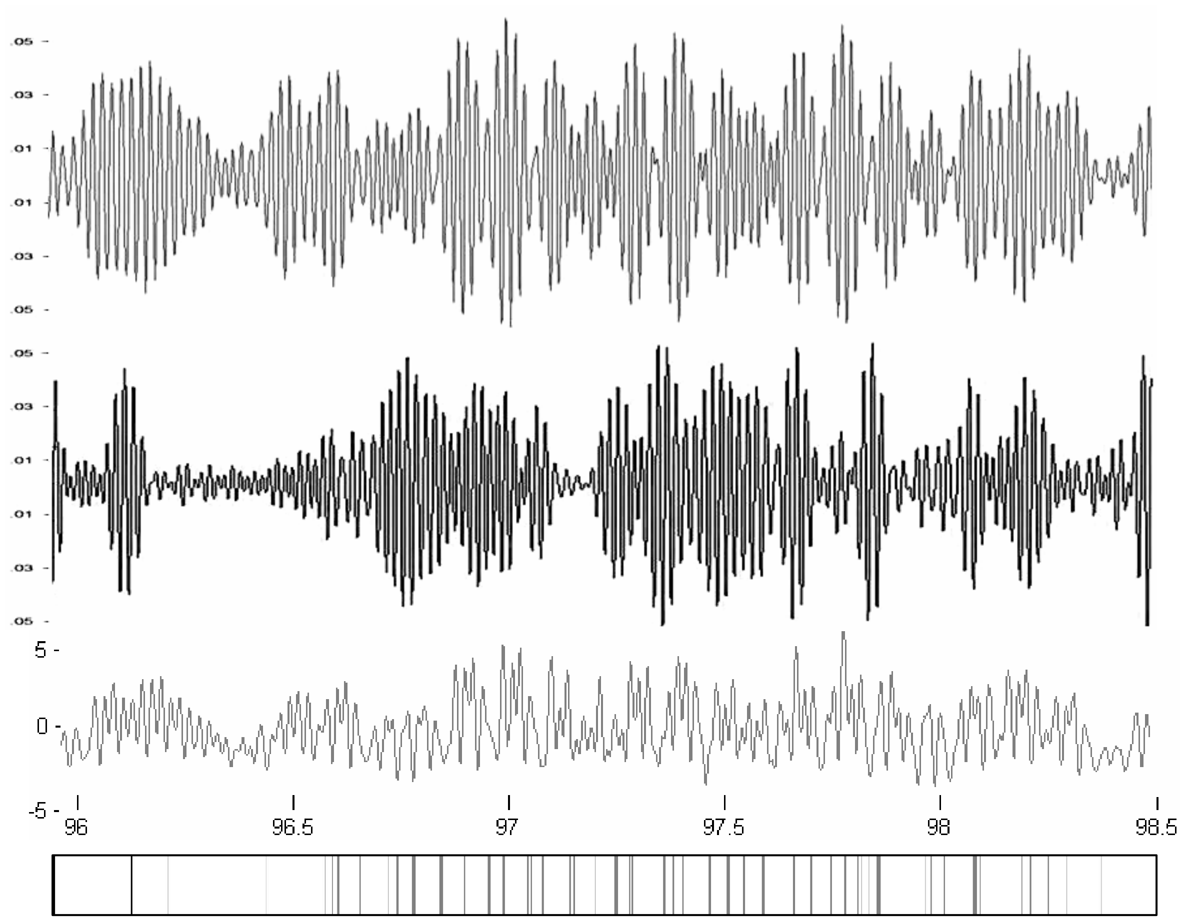

Figure 13. 0 – 27 m stratigraphic section bandpass 96-98 mya with a sedimentation rate of 1.07cm/ky. Laskar's calculated precession curve (top), compared to precession curve of stratigraphic section (below) with the ETP curve (third down) and litholog (bottom) for reference and comparison.

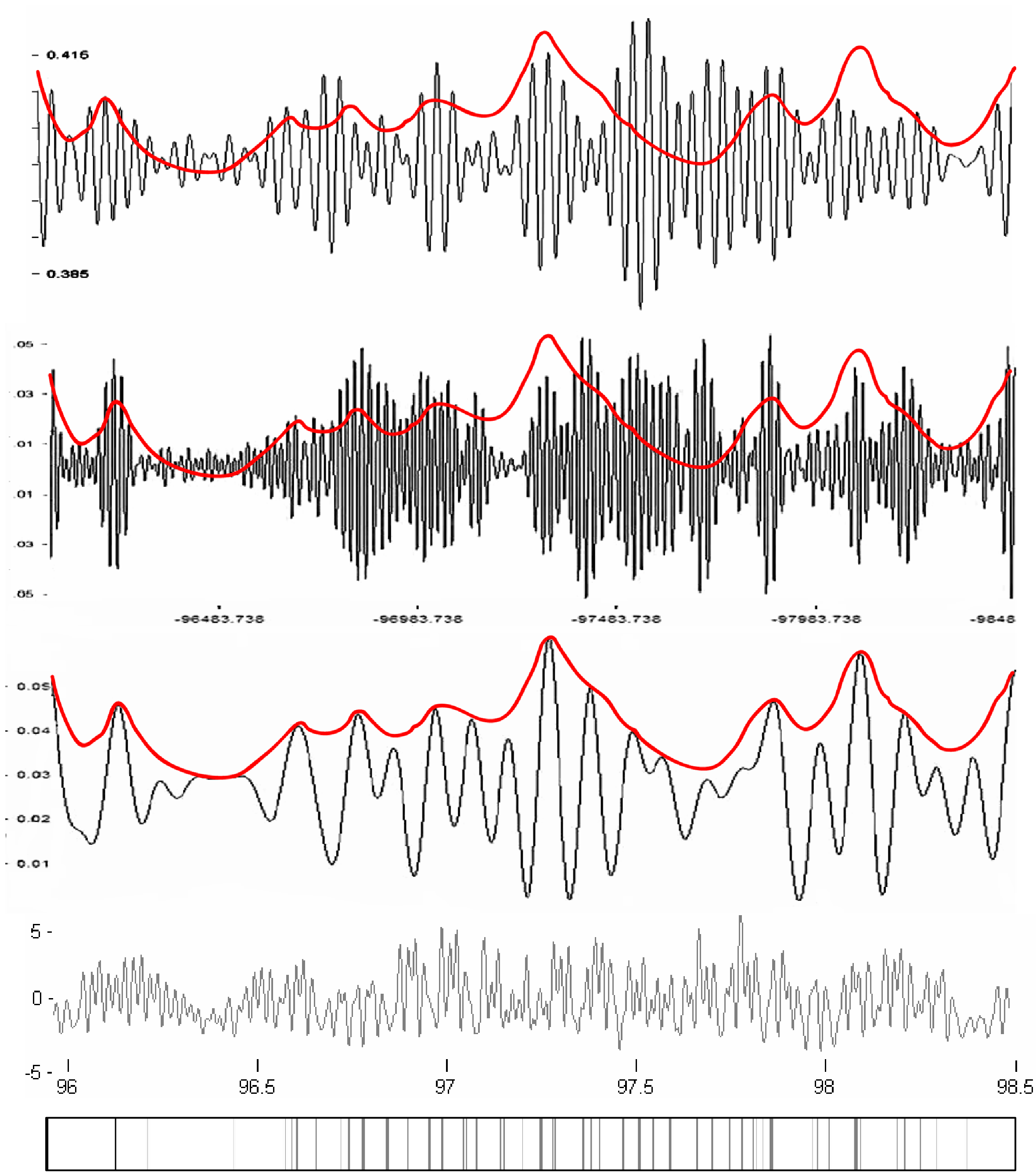

Figure 14. Hilbert transform. The obliquity cycle (above) as well as the precession (second down) is enveloped by the eccentricity cycle (third down) as shown above with the red line. ETP curve (third down) and litholog (bottom) for reference and comparison.

for cyclical palaeoceanographic, climate changes and forcing, the MCE section at least in Avacelli records Milankovitch cycles exceptionally well.

Despite ignoring marl layers as well as the presence of unexpected but statistically significant peaks possibly due to the complex interactions between the three cycles, my results show that similar to Mitchel et al's study of the OAE 2 along with other previous studies done on the Scaglia Bianca (Schwarzacher, 1994; Claps and Masetti, 1994), the mid-Cenomanian Event's lithologic variations in the deposition of the Scaglia Bianca formation at Avacelli matches with Milankovitch cycles. This shows evidence of climate variations influenced strongly by all three orbit cycles. Even though we see evidence for precessional, obliquity and eccentricity cycles, eccentricity and obliquity are relatively stronger than the precessional cycle. This differs from Mitchel et al.'s observation of a weak eccentricity frequency in the OAE 2 stratigraphic section.

Mitchel et al. (2004) noted the atypical presence of the high latitude obliquity cycle in the Scaglia Bianca, due to the lack of ice during the mid- to Late Cretaceous, in addition to the subtropical locality of this Tethys region. It may be possible that small polar ice sheets were present in the Cretaceous, amplifying and spreading obliquity signal ocean wide to lower latitudes through an ice-albedo feedback mechanism to regions such as ours as well as the Western Interior Seaway (Grippo et al., 1997, Stoll and Schrag, 2000; Miller et al., 2005). This is worth mentioning because while the obliquity cycle has the weakest signal out of all three signals I analyzed, it is still fairly significant. Another explanation for this could be that warm waters were expanding into high latitudes during the MCE, as suggested by the geographical distribution of planktonic foraminifera (Coccioni and Galeotti, 2003).

Conclusion

The spectral analysis of the lower Cenomanian section of the Scaglia Bianca formation shows various cycles that are statistically significant. Among these are three dominant cycles strongly correlated to Milankovitch cycles – eccentricity, obliquity and precession. The FFTs with the Monte Carlo simulation, bandpass filters, sliding window and Hilbert Transforms all provide evidence that not only Milankovitch cycles are present in the Scaglia Bianca formation, it shows that sedimentological and biotic records changes of the MCE were strongly influenced by climate, which was forced by Milankovitch cycles. Ultimately the relationships between the cycles obey the mathematical relationships between cycles, existing geochronological constraints and orbital theory predictions.

However, the correlation is not perfect as seen both in the statistically significant but origin unclear peaks (Fig. 8) as well as the eccentricity cycle's envelope at approximately between 97.5 to 97.8 Ma (Fig. 12). During this time the eccentricity does not envelope the other two higher frequency cycles. It could be due to an incomplete eccentricity cycle record in the stratigraphic section at this particular outcrop since both obliquity and precession shows the same general swell during that time period.

Despite the fact that this study's purpose is to complete the litholog of the Scaglia Bianca formation, a spectral analysis on the entire formation from the MCE through the onset of the Bonarelli event has not been done. Moreover, a section of the Scaglia Rossa, which is above the Bonarelli has been logged but not analyzed. These future projects will provide an exciting complete stratigraphical record spanning a significant portion of the late Cretaceous.

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Appendix

A list of Matlab 7.0.1 scripts used for spectral analysis of this study. Algorithms are modified from Muller and Macdonald (2000).

ETP curve

```
clear;
load ETP90_100new.dat; %input data file
t=ETP90_100new(:,1); %time in ka
ecc=ETP90_100new(:,2); %La2004 eccentricity
ob=ETP90_100new(:,3); %La2004 tilt angle
p=ETP90_100new(:,4); %La2004 precession parameter


es=(ecc-mean(ecc))/0.013447;
os=(ob-mean(ob))/0.4627;
ps=(p-mean(p))/0.022242;
etp=es+os+ps;


t=t/1000;

figure(1); plot(t,etp);
figure(2);subplot(4,1,1); plot(t,ecc);
subplot(4,1,2): plot(t,ob);subplot(4,1,3); plot(t,p);
subplot(4,1,4); plot(t,etp);
```

Bandpass filter

```
% This performs a band-pass filter on data in order to isolate
% variability contained in certain frequency bands

% data file: column 1= data series; column 2= meter level (cm);

clear;
load avaquat27.dat; % input data file
t=avaquat27(:,2);   % define the second column as the stratigraphic height vector,
in cm
w=avaquat27(:,1);   % define the first column as the data vector

% plot the data series (data vs. meter level)
figure(1);
plot(t,w);
xlabel('stratigraphic height (cm)')
```

```
ylabel('pixel density')

% convert meter level to time, using assumed sedimentation rate
t=t*1/1.07;     % denominator is the sedimentation rate in cm/kyr

% plot the data vs time
figure(2);
plot(t,w);
xlabel('age (kyr)')
ylabel('pixel density')
axis tight;

%interpolation to evenly spaced ages
a=linspace(min(t),max(t),2*length(t));
h=interp1(t,w,a);

%subtract the mean
h=h-mean(h);

% bandpass filter to remove noise

%first define the range of frequencies to keep, between f1 and f2
f1=1/25;    % denominator is the period (longer)
f2=1/19;    % denominator is the period (shorter)
n=length(a);
ft=fft(h);
Nyquist=abs(0.5/(a(2)-a(1)));
fre=linspace(0,2*Nyquist,n)';
[m,k1]=min(abs(fre-f1));
[m,k2]=min(abs(fre-f2));
k3=n-k2+2;
k4=n-k1+2;
% zero all but the desired band
ft(1:k1)=zeros(k1,1);
ft(k2:k3)=zeros(k3-k2+1,1);
ft(k4:n)=zeros(k1-1,1);
%take inverse FFT; remove the imaginary part
hnew=real(ifft(ft));

figure (3);
plot(a,hnew);
xlabel('age (kyr)')
title('0-27m bandpass Obliquity 17-25 kyr 1.07cm/kyr')

%calculate FFT and Power after padding of the filtered data
npt=2^16;
```

```
H=fft(hnew,npt);
P=H.*conj(H);
%calculate frequency array
f=linspace(0,Nyquist,npt/2);
%normalize to unit mean power
P=P/mean(P(1:npt/2));
%plot
fmax=f2;
num=round(npt/2*fmax/Nyquist);

save prec_data.out hnew -ASCII

figure (4);
plot(f(1:num),P(1:num))
XLABEL('frequency')
YLABEL('spectral power')
mark1x

%save the bandpassed data (hnew) in a file called 'datafile'
%so you can plot it in another application
hnew=hnew';
save datafile.txt hnew -ASCII
```

Fast Fourier Transform

```
% This analyzes the data from FDR 05, and shows cycles in terms of time

clear;
load AVAquat27.dat; %input data file
h=AVAquat27(:,1); %name the data vector h (gray value)
t=AVAquat27(:,2); %name the time vector t (thickness)

t=t*1/1.00 % denominator is sedimentation rate (cm/ka)


%t=(26.54*(m/100)); % 26.54=inverse sed rate -- kyr/m

%interpolation to evenly spaced ages
a=linspace(min(t),max(t),2*length(t));
h=interp1(t,h,a);


%subtract the mean then plot
h=h-mean(h);
figure(2);
```

```
plot(a,h);
%zoom on;

%calculate FFT and Power after padding
npt=2^14;
H=fft(h,npt);
P=H.*conj(H);
%calculate frequency array
Nyquist=abs(0.5/(a(2)-a(1)));
f=linspace(0,Nyquist,npt/2);
%normalize to unit mean power
P=P/mean(P(1:npt/2));
%plot
fmax=0.06;
num=round(npt/2*fmax/Nyquist);
figure(4);
plot(f(1:num),P(1:num));
XLABEL('frequency')
YLABEL('relative spectral power')
TITLE('Scaglia Bianca 1.0 cm/kyr')
mark1xx
```

Sliding window

```
% this routine loads the data, and then performs a fft with a sliding time window
clear;
load AVAquat27.dat;
t= AVAquat27 (:,2);
h= AVAquat27 (:,1);
t=t*1/1.07;% sedimentation rate (cm/ka)

%interpolation to evenly spaced ages


a=t;
h_interp=h;
%define size of sliding window and the offset
fract=.5; %window as a fraction of the whole dataset
wdw=floor(length(a)*fract); %size of window
shft=20; %fraction of window length by which it is shifted
shift=floor(wdw/shft); %amt by which window is shifted
last=length(a)-wdw; %position where windowing ends
%calculate frequency array
Nyquist=abs(0.5/(a(2)-a(1)));
npt=2^14;
f=linspace(0,Nyquist,npt/2);
```

```
fmax=.06;
num=round(npt/2*fmax/Nyquist);
%misc steps before iteration
steps=floor(last/shift);
Power=zeros(num,steps);
h_sub=zeros(wdw+1,1);
w=0;
for i=1:shift:last
   w=w+1;
   h_sub=h_interp(i:(i+wdw));
   h_sub=h_sub-mean(h_sub);
   %calculate FFT and Power after padding
   H=fft(h_sub,npt);
   P=H.*conj(H);
   %normalize to unit mean power
   P=P/mean(P(1:npt/2));
   Power(:,w)=P(1:num);
   freq=f(1:num);
   age(w)=a(i+round(wdw/2));
end
wndow=round((max(t)-min(t))*fract); %size of window in kyr
Power=Power';
%Power=log(Power);
figure(2);
pcolor(freq,age,Power)
%axis([0 .015 93 96])
colorbar
shading interp
title(['Scaglia Bianca with sliding window of
',num2str(wndow),'ka'],'FontSize',12)
XLABEL('Frequency (cycles/kyr)','FontSize',14)
YLABEL('relative age of Window Midpoint','FontSize',14)
mark1xx
```

Monte Carlo simulation

```
% Monte Carlo noise simulation and basic FFT of Scaglia Bianca lithologic
% log in the stratigraphic domain
clear;
load AVAquat27.dat; % the  data set
m=AVAquat27(:,2); % centimeters
c=AVAquat27(:,1); % color, where 255=black chert, 0=white lst, 155=gray lst


figure; plot(m,c);
```

```
% subtract mean
c=c-mean(c);


%convert cm to age in kyr
r=0; % sedimentation rate in cm/kyr
t=m/r; % time or age in kyr
%figure;plot(t,c);




%calculate frequency array
npt=2^14;
Nyquist=0.5/abs((m(2)-m(1)));
f=linspace(0,Nyquist,npt/2);
fmax=.07;
num=round(npt/2*fmax/Nyquist);
freq=f(1:num);


%calculate the noise
%misc steps before iteration
steps=2000; %number of iteration steps
Power=zeros(num,steps); %creates an empty array for the spectral power
w=0; % a counter


mr=[1:2700]; %1850 is the total length in cm of the real section; the random ones
will have the same length


for i=1:steps
   cr=zeros(size(mr));cr=cr+255; % everything gets an initial value of 255 for
white limestone
   b=round(1845*rand(1,27));b=b+1; %there are 27 black cherts in the section
   g=round(1845*rand(1,37));g=g+1; % there are 37 grey cherts in the section
   cr(b)=0;cr(b+2)=0;cr(b+1)=0; % black cherts get a pixel value of 0 and are
given a thickness of 2 cm
   cr(g)=155;cr(g+2)=155;cr(g+1)=155;% gray cherts get a pixel value of 155 and
are given a thickness of 2 cm
   % cr is now a number string that should look a lot like the coded
   % lithologic log
   cr=cr-mean(cr); % subtracts the mean
```

```
   w=w+1; %advances the counter
   %calculate FFT and Power after padding
   H=fft(cr,npt)'; % puts the result into a column vector
   P=H.*conj(H); % gets rid of the imaginary part
   %normalize to unit mean power
   P=P/mean(P(1:npt/2));
   Power(:,w)=P(1:num)'; % loads the Power column into the larger array
end
PQ=mean(Power'); % calculates the mean of each column of the transpose of
Power


PR=std(Power');  % calculates the standard deviation of each column of the
transpose of Power
PS=PQ+PR; % adds 1 std dev to mean
P3S=PQ+PR+PR+PR; % adds 3 standard deviations to the mean  -- not used here
PQ3=3*PQ; % THREE TIMES THE MEAN  -- this is what theoretically gives
you the 95% confidence level



%calculate FFT and Power after padding
npt=2^14;
H1=fft(c,npt);
P1=H1.*conj(H1);


%normalize to unit mean power
P1=P1/mean(P1(1:npt/2));


%plot
figure(2);plot(freq(1:num),P1(1:num),freq,PQ3)
title(['Scaglia Bianca w/ noise: Monte Carlo Simulation 95% CI'],'FontSize',12)
xlabel('frequency in cycles per cm')
ylabel('spectral power')
mark1xx
```