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Interactive comment on "A ~400 ka supra-Milankovitch cycle in the Na, Mg, Pb, Ni, and Co records of a ferromanganese crust from the Vityaz fracture zone, central Indian ridge" byR. Banerjee et al.

Anonymous Referee #2
Received and published: 11 August 2010

Dear Sir,

Referee's specific comments are in black and our replies are given in blue as following:

In this manuscript the authors present major and trace element time series obtained by EMPA analyses of a hydrogenous ferromanganese crust from the central Indian Ocean. The records were dated by a combination of 230Thex dating in the uppermost part of the crust and Co-constant flux modeling. The authors claim that there is a ~400 kyr cycle in the records of certain elements which they ascribe to astronomical forcing of past environmental conditions in the Indian Ocean.

Newly generated paleochemical time series data and have been produced and previously unidentified cyclicities in metal abundances in ferromanganese crusts including important implications have been found that should in my opinion be made accessible to the readership of "Climate of the Past".

Thanks for opinion.

The current version of the manuscript is, however, not up to required standards for publication and requires a major revision. The authors need to significantly improve their interpretations and the amount of background information they provide in many places, as outlined below. In many cases the statements of the authors are not precise or highly speculative and not adequately supported by appropriate references.

The manuscript also definitely needs to be reviewed by at least one specialist on statistical analyses of time series data because I cannot judge the reliability of the statistical approaches performed by the authors!

Also the manuscript urgently requires careful proofreading by a native English speaker and rewriting in most parts because style and grammar are in very bad shape, which sometimes makes it very hard to follow what the authors actually want to say.

Introduction:

The authors need to say clearly since when the 1 mm/yr northward movement of the Indian plate occurred because clearly the emergence of the Himalayas already started about 35 million years ago. What does this exactly have to do with the Capricorn Plate?

After examining the details, we felt that that the statement is improper, and therefore we omitted it in the revised version, and relevant reasons are given in the text in introduction.

In mentioning previous occurrences of Milankovitch cyclicities in the Indian Ocean, the authors need to precisely say which paleoenvironmental factors varied at which frequencies. It is clear that the benthic oxygen isotope record varied due to ice volume (not even mentioned in the introduction!) but other than that I am mainly aware of paleo SSTs and terrigeneous inputs (dust) which for example vary on precessional time scales together with the monsoon cyclicity.

During previous occurrences of Milankovitch cyclicities in the Indian Ocean, in addition to planktonic foraminiferal oxygen isotope record, paleo SSTs (Hays et al. 1976; Gupta et al., 1996) and terrigeneous inputs (deMenocal, 2004), "Monsoonal productivity" also varied at the precession (23-k) and eccentricity (100-ka) cycles (Bassinot et al., 1994; Beaufort et al. 1997). These details are included in the revised version at appropriate places. In addition, following new references have been introduced in the revision to support the records of higher paleo-productivity during last few million years in this region as following:

i) .

<table>
<tr>
<td>Bassinot, F.C., Beaufort, L., Vincent, E., Labeyrie, L.D., Rostek, F., Miiller, P.J., Quidelleur, X., Lancelot, Y. (1994): Paleoceanogr. v. 9, 4, pp 579-600

Bassinot et al. (1994) studied composite coarse fraction index in sediment cores MD900938, 940, and 963 showing precession (23- and 19-ka) and the 100-ka cycles, and attributed to changes in surface water productivity associated with monsoonal changes during last ~2-Ma around Maldives area as depicted in their fig.17 as shown in right panel.</td>
<td>

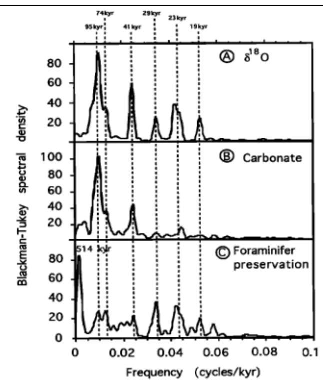
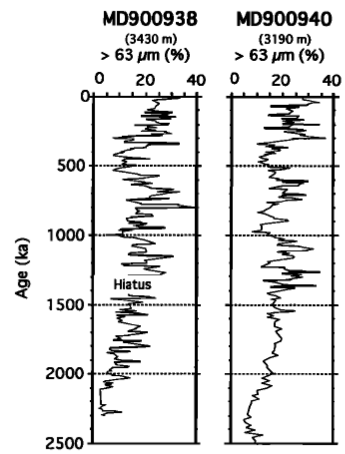


Figure 17. Blackman-Tukey spectral density of δ18O, carbonate content, and foraminiferal preservation records in core MD900963.

</td>
<td>



</td>
</tr>
</table>

ii)

deMenocal, P.B.(2004): African climate change and faunal evolution during the Pliocene-Pleistocene, Earth and Planetary Science Letters, v. 220, p. 3-24.

deMenocal, P.B.(2004) studied **African eolian desert dust** content in the **Arabian Sea** cores and reported dust pulses derived by monsoonal winds (NE) at the eccentricity cycles in the last **3.5 Ma**. A relevant part of their fig.5 is shown in right panel.

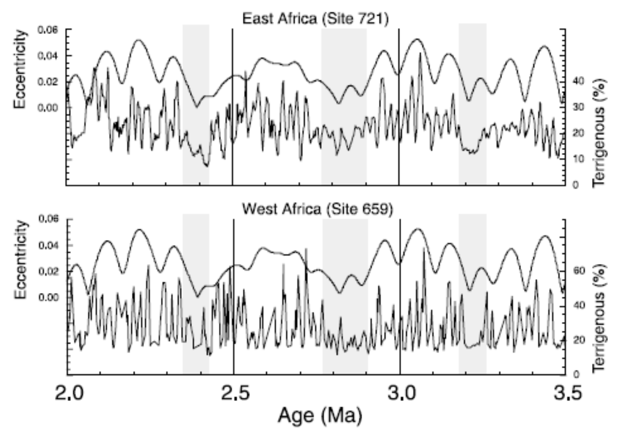
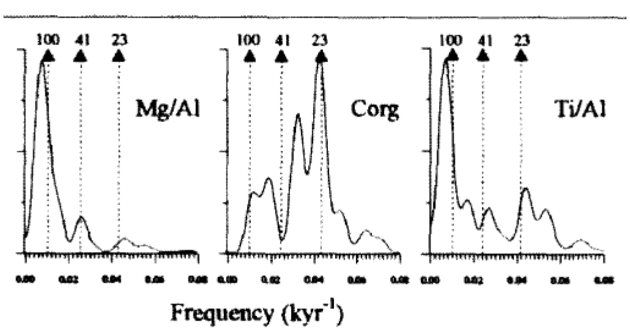


Fig. 5. Evidence for high- and low-amplitude African climate 'variability packets' from West and East African Sites 659 and 721/722 [15,30]. African paleoclimate variability over this

iii)

Reichart, G.J., den Dulk, M-D., Visser, .J., Cornelis H., van der W., and Zachariasse, W.J., (1997) Palaeogeography, Palaeoclimatology, Palaeoecology, v 134, p. 149 169

Change in the **Mg/A1** ratio at δ^{18}O stages 6 and 2 reflected flooding of the Persian Gulf **during deglaciation, cutting off the main source of airborne dolomite**. The suggested relationship between glacio-eustatic sea level change and the **Mg/AI ratio is reflected in the spectrum by a strong 100 kyr eccentricity cycle** in their fig. 9B shown in right panel.



Spectra of the MAR and Mg/Al are dominated by 100 kyr periodicity.

The authors need to say precisely which parameters changed on 400 kyr time scales in previous studies.

We specifically mentioned that coccolithphore production in SW Indian Ocean has responded to changes at 100 and 400-ka eccentricity cycles **(**please see page 8, lines 14-22 of the older version and reproduced as following):

"Rickaby et al. (2007) studied periods of high Sr/Ca and high bloom production of *Gephyrocapsa caribbeanica* and *Emiliania huxleyi* in the SW Indian Ocean. They found the marked periods of high coccolithophore production are inversely correlated with the low amplitude 100- and 400-ka eccentricity cycles, and suggested a link between the production of coccolithophore blooms and eccentricity due to orbital control of silica leakage from the Southern Ocean. They further opined that the orbitally defined inverse correlation between insolation and growing season length result into the asymptotic growth response, and proposed a possible mechanism to account for the secular coccolithophore production cycles linked with the 400-ka eccentricity forcing."

Also, which parameters changed on Milankovitch periodicities in the previous Han et al. (2003) study on a ferromanganese encrustation and which forcing factors were responsible for these changes.

Han et al. (2003) reported cyclic changes in the µm level micro-layer thickness in the variations in Al, Fe, and Fe/Mn ratio, and the spectral results (in their fig. 5, are summarized in their table 4), suggesting the growth laminae bands varied at 407-ka, 91-ka, and 100-ka cycles of the eccentricity, while Fe, and Al varied at precession (23-ka) and tilt (41-ka) cycles, and Mn varied at 41-ka cycle only. They correlated the Fe-Mn changes at precession and tilt cycles with the intensity of biological productivity of surface waters.

Sample and methodology:

P. 1313, line 26-27: The sentence does not make any sense.

We omitted it.

P. 1314, line 14-15: If I understand correctly, the authors measured their elemental data at a resolution of 100 µm. Then for a reason that I don't understand they averaged the data over a mm. Why was that done? Actually, if the authors want to extract a 400 kyr cyclicity in their records, then the higher the resolution the better and 100 µm would correspond to about µ10 kyr.

Averaging of 10 data slices of 100 µm each to mm level was primarily done due to following reason:

(i) The ferromanganese growth laminae were not uniform in thickness through out the crust.

(ii) Often there were detrital material, tiny voids, or fragmented foraminifers or siliceous plankton tests along the path of the line of scan, resulting to unsatisfactory total of data.

These two reasons obviously prompted us to average our data at the mm level.

Also, were the data with totals below 40% omitted (holes in the section) and what was the water correction? Were analyses that obviously hit detrital grains omitted? What is the precision of all the elemental analyses and was the precision the same for all elements.

All totals below 40% were omitted and moisture correction was also incorporated in the ZAF program. Precision in all the data generated were within 1 σ error limit. Details of the EPMA analysis are included in method section in the text.

In table 1 with the elemental data, for all data points below 1 % abundance, the numbers need to be given with two digits after the comma.

We put two digit data in the revised Table 1 as suggested**.**

P. 1315, line 8: Co concentration below 0.8 %!

OK, it is included in the revised manuscript.

P. 1315, line 14: Which limitations do the authors mean? Be precise!

The limitations are already described in the "Co-chronometer" section of the manuscript. However, we again repeat those as follows**:** "ferromanganese crusts of deeper water (>3000 m water depth), having a lower Co concentration of <0.8%, and of relatively younger age (<10 Ma) **(**Frank et al., 1999, O'Nions and Frank, 2000; Klemm et al., 2005)" only are suitable for dating by Co-chronometry method.

P. 1315, line 15: Importantly, the bottom age: : : This is strong support for the chronology the authors present!

Thanks for concurrence on Age model agreement for bottom most age based on biostratigraphy**.**

P. 1316, first paragraph: The authors did not measure the 234U activity for each 230Th measurement, but only the average. This is not very reliable, in particular in the older part of the dated section of the crust (2-8 mm).

Agreed. As ^{230}Th decay dating is most reliable to last 400k, and then its reliability goes wayward. As suggested by the reviewer, in the revised version we restricted ^{230}Th chronometry till 0-3 mm level and removed the dependence on 3-8 mm. Accordingly, we corrected our figure 2, and the discussion is modified subsequently in the "age-depth section" of our revised manuscript**.**

P. 1316, line 2: : : :is the seawater-derived portion of the 230Th: : :

Yes, it is the seawater-derived portion of the ^{230}Th.

P. 5, 16, line 14-15: This statement is completely wrong and needs to be omitted.

Omitted, as suggested**.**

The implication that only 6 % of the 230Th water column inventory is incorporated into the crust is clearly not that the crust grew episodically but simply that most of the water column-derived 230Th is adsorbed to particles and is deposited in the pelagic sediments and not in crusts.

We agree with the reviewer and the statement is modified in the revised version of the manuscript accordingly.

P.5, 6: From the inset in Fig. 1 I calculate a growth rate of _14 mm/Myr for the section between 2 and 8 mm depth, which makes sense also for the development of the growth rate in the rest of the crust. 72 mm is clearly far too high!

As suggested by the reviewer, dependence of ^{230}Th measured in 3-8 mm section of the crust is omitted in the revision, as mentioned above, and so the calculated age of 14mm/Ma is ineffective and deleted from the revised version. Instead, we depended upon Co chronometry in the 3-32 mm section of the crust. In the 0-3 mm section, ^{230}Th record is used to ensure that the younger record in the crust is intact.

P. 5, 6: The authors need to provide the Co-age equation they finally applied. In table 2 the digits after the comma for the data need to be adjusted. At the maximum 1 digit makes sense in view of the precision of the data. Are these 1 or 2 sigma errors? The 210Pb data are not discussed in the ms. and need to be omitted.

Growth rates of the crust microlayers were calculated following the equation suggested by Manheim (1986) and Manheim and Lane – Bostwick (1988):

growth rate (mm/Ma) = $6.8 \times 10^{-1} / (w^{n}Co)^{1.67}$

where $w^{n}Co = wCo \times 50/w(Fe+Mn)$

wCo= wt% Co in sample; wFe= wt% Fe in sample; wMn= wt% Mn in sample

We included in the revised text the above mentioned Co-age equation, and in table 2 made 1 digit data, as suggested by the reviewer. The data is within 1 sigma error, and as suggested by the reviewer we omitted ^{210}Pb data in table 2 in the revised version.

Results and discussion:

P. 5, 7: The Co shows a 400 kyr cyclicity, which means that the growth rate varied on a 400 kyr cycle, which points to a change in supply of Mn and/or Fe. How could that be caused?

As suggested by the reviewer, we have analyzed growth rate time series and it shows a cycle of ~400-ka in Co chronometric growth rate also**.** Yin and Guo, (2008) (and references therein) have described records of strong summer monsoon with a cyclicity of ~400 ka in the equatorial Indian ocean. The detritus derived from the monsoonal river run-off and/or dust flux carried by the varying trade winds / easterlies, strongly blowing over Australian desert, across the Indian Ocean, may be the major the sources of Fe, Mn, Co and Pb to the site where this ferromanganese crust has formed in the Indian Ocean.

..

P. 1317: It is in my opinion in no way possible to extract a 400 kyr cycle from a 1 million year record!

Our record is of ~3.5 Ma (and not 1 Ma as mentioned by the reviewer) based on Co-Chronometry, which agreed with published biostratigraphic dates, on which reviewer has earlier consented that they are in good agreement.

P. 1317: Again, as far as I can see, all those 400 kyr cyclicities are a consequence of changes in detrital inputs, so are the observed variations related to productivity and thus possibly fertilization effects of the surface waters?

Yes. That is why we related the geochemical variations in the crust, which were mainly brought to the sea floor by the higher detrital/fecal material fluxes at the times of high oceanic productivity, which is reported to vary at ~100- (Beaufort et al., 1997) and ~400-ka (Ricaby et al., 2007). Thus, this process of variations in productivity is probably a consequence of changes in the detrital inputs and thus fertilization effects of the surface waters .

P. 1318: Why would the Mg content in the crust vary with cholorophyll production? This does not make any sense at all. If you wanted to look for a potential indicator of productivity, in my opinion this could only be Ba content, or more precisely Ba flux (Ba/Co).

As suggested by the reviewer, as a measure of productivity, MTM spectral analyses of Ba/Co ratio, i.e. Ba flux (a), and growth rate (b) are performed, and both exhibits a ~400-ka cycle, as discussed in the revised version of the paper. We produce this figure (Fig. 8) as below.

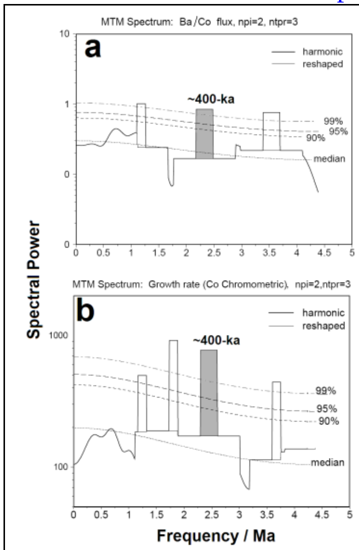


Fig.8. The MTM spectral analysis of Ba/Co ratio as flux measurement of productyivity (a), and Co chronometric growth rate (b), both showing the ~400-ka cycle (99% significant) (see ref.) .

But even then it will be difficult to relate the metal variability to particular environmental factors as for example shown by Wen et al. (1997).

Frank et al., (1999) in agreement with Wen et al., (1997) suggested that the variations in major element compositions (e.g. Mn and Fe) in ferromanganese crusts have mainly been caused by variations of local water mass chemistry and depositional conditions. Now, we suggest that this local water mass chemistry and depositional conditions could be influenced by surface water productivity, which is again influenced by a ~400 ka cycle of detrital flux through dust or through monsoonal detrital discharge or both, in the Indian ocean.

Also the Mg and Na content of the crusts can not have derived from any variability in the seawater concentrations because these have definitely been constant for the past 10 million years! The variations must be dilution effects caused for example by variations in detrital fluxes.

We produce below a figure for ready reference supporting that Na (and for that matter Mg also) has changed with time, and were not constant for last 10 Ma. Please refer figure 2 of Lorius et al. (1991) exhibiting cyclic changes in sea-salt (Na) contents in the Vostok ice core (Legrand et al. 1988) showing variation in climate, dust, sea salt (Na), and acidity changes in sea water for last 150-ka.

Lorius et al. 1991

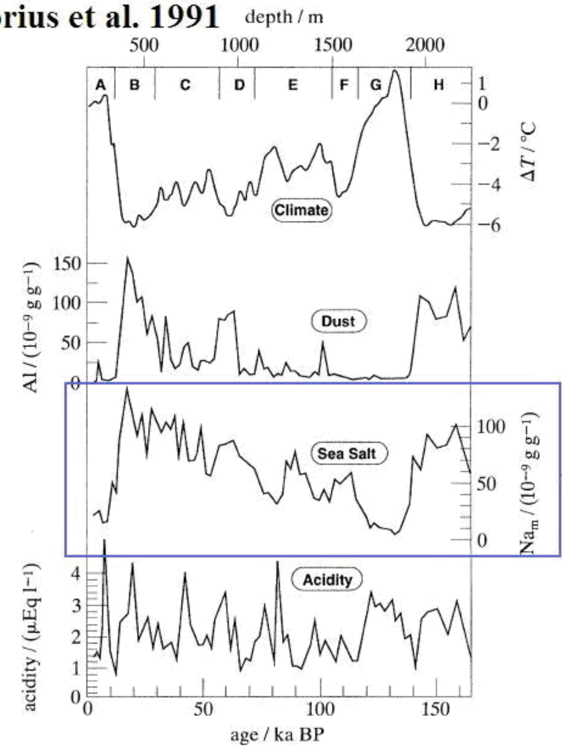


Figure 2. Time series along the Vostok core of: the atmospheric temperature record (adapted from Jouzel *et al.* (1987)); the aluminium content (adapted from De Angelis *et al.* (1987)); the sodium content (labelled sea salt and adapted from Legrand *et al.* (1988*a*)); the acidity (adapted from Legrand *et al.* (1988*a*)).

Phil. Trans. R. Soc. Lond. B (1992) [29]

You can in no way distinguish cosmic supply of the mentioned elements (line 27) because their cosmic supply is far too small compared with the weathering supply from the continents. This is complete nonsense.

As suggested by the reviewer, we omitted it in the revised text.

P. 1319: All the considerations of the time series analyses have to be reviewed by a specialist, which I am not! In addition, what do the authors mean by aliasing effect?

Aliasing effect means the spurious low frequency cycles due to large sampling interval (δt) in a time series of high frequency climate signal.
We have answered related questions in the text as well as in editor's initial comment before uploading the text in CP-discussion. Also the specific comments on the related topic by the reviewer #1 have been duly replied and uploaded earlier.

P. 1320: Is the amplitude or variance of the 400 kyr cycle one 10th of the 100 kyr or the 41 kyr cycle?

Amplitude of power in 400-ka cycles (100) is one tenth of the 41-ka cycles (1000) in the differential insolation monsoon index as evident from Fig. 6a (in older version of manuscript).

Conclusions:

In the conclusions the age model needs to be discussed first and then the implications of the data.

OK, done as suggested.

Additional comment:

There are two high resolution elemental time series from nearby locations in the Indian Ocean (Frank et al., 1999) that the authors could perform their time series analyses on in order to support their conclusions by more than one record.

Frank et al.'s (1999) elemental data from crust SS-663 located at 12°579S 76°069E is from a 67 mm thick crust yielding growth arte of 2.8 mm/Ma, which dates back to 26 Ma. The crust 109D-C 27°589S 60°489E is having thickness 30 mm, growth rate 1.6 mm/Ma and dates back to 24Ma. Data of both these crusts are not at high resolution, and compared to our crust the published data are at a very coarse time interval (and also are not at a regularly spaced interval), and so can not be computed by our method, as suggested by the reviewer. Therefore, these crust data are not suitable for the time series analyses for following reasons as depicted in the figure below:

Showing a part of fig. 2 f and g from Frank et al. (1999) at p. 1694.

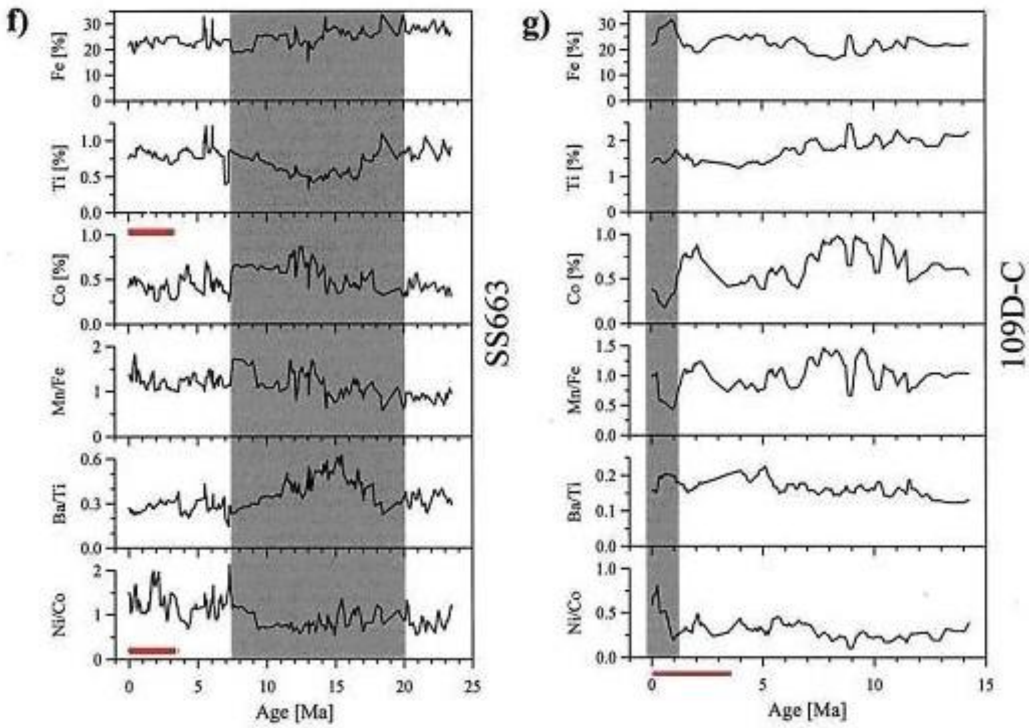


Fig. 2. Time series of the concentrations of selected major elements and element ratios versus age for: (f) and (g) Indian Ocean crusts 109D-C and SS663. The shaded period between 0 and 1.2 Ma on the plot of 109D-C marks a major change in the major element composition and the shaded period on the plot of SS663 marks the period between 20 and 7.4 Ma which was interpreted to represent maximum Himalayan exhumation and erosion rates deduced from the 208Pb/206Pb profile in this crust (Frank and O'Nions, 1998). All data represent five times running averages.

Sampling interval is irregular, and larger (< 20 samples in 3 .5 Ma records) in these two crusts than our crust.

We have 32 data points for 3.5 Ma crust records, whereas SS663 and 109-D-C have <20 data points in 3.5 Ma records.

Therefore data is not comparable, and does not qualify the time series analyses criterion as performed at 0.11 Ma time interval in our crust.

Moreover, their objective was not a time series analyses to search climatic cycles, but to find out qualitative oceanographic changes preseved in last 15-24 Ma record.

Even in a later study of SS663 crust is limited to 7 data points in last 25 Ma records as shown in following table.

We do not find this data suitable for time series analyses and to compare our results.

Seven data points in last 25 Ma

V.K. Banakar, J.R. Hein, **2000, p. 534**

Table 1

Compositional variation with depth in SS663 crust

Depth (mm)	Res.[a] (%)	Si (%)	Al (%)	Si/Al	Mn (%)	Fe (%)	Mn/Fe	Co (%)	Ni (%)	Cu (%)	Ba (%)
00–20	07	3.20	0.97	3.3	19.5	17.8	1.1	0.26	0.30	0.09	0.10
20–32	11	4.39	1.47	3.0	18.4	17.7	1.0	0.27	0.29	0.11	0.11
32–44	15	5.42	1.64	3.3	15.5	21.2	0.7	0.27	0.22	0.14	0.13
44–47	15	5.47	1.93	2.8	14.3	22.3	0.6	0.23	0.19	0.15	0.14
47–72	20	6.97	2.75	2.5	12.0	21.9	0.5	0.20	0.18	0.13	0.12
18–21[c]	12	5.10	1.43	3.6	18.0	17.7	1.0	0.25	0.23	0.14	0.12
47–60[c]	18	6.55	2.70	2.4	11.7	21.7	0.5	0.17	0.15	0.15	0.12

There are 7 data points in 24 Ma at irregular sampling interval (3mm to 20 mm) in crust SSS-663, and therefore not suitable for time series analyses.

536 *V.K. Banakar, J.R. Hein / Marine Geology 162 (2000) 529–540*

Additional reference:

Wen X., De Carlo E.H., and Li Y.H. (1997) Interelement relationships in ferromanganese crusts from the central Pacific Ocean: Their implications for crust genesis. Mar. Geol. 136, 277-297.

This reference is included in the revised text at appropriate place.

Reply to First reviewer on Spectral analyses being on 32 data point:

Spectral Analyses results of elemental data at 1 mm yielding the 32 data points presented in original submission is taken with reservation of the limitation of being less than hundred by the reviwer #1.

We present an exercise to answer his concern using three data sets.

(i) the sunspot numbers for the last 257 (Fig. 1A), 30 years (Fig. B) and its 4 monthly interpolation (Fig. C),

(ii) The eccentricity (Varadi et al., 2003) at 0.034 Ma with 1029 data points (Fig. D), at 0.111 Ma with 32 data points (Fig. E) and at 0.003 Ma with 118 data points (Fig. F)

(iii) our elemental data interpolated at 0.03 Ma (Fig. G-K) as following:

Interpolation

We used piece-wise cubic spline (hermit) interpolation method in MATLAB for interpolating data 30000 years interval, and thereby increasing 31 years sunspot data to 104 data point and the elemental data size from 32 to 114 (0.111-3.52 Ma) followings:

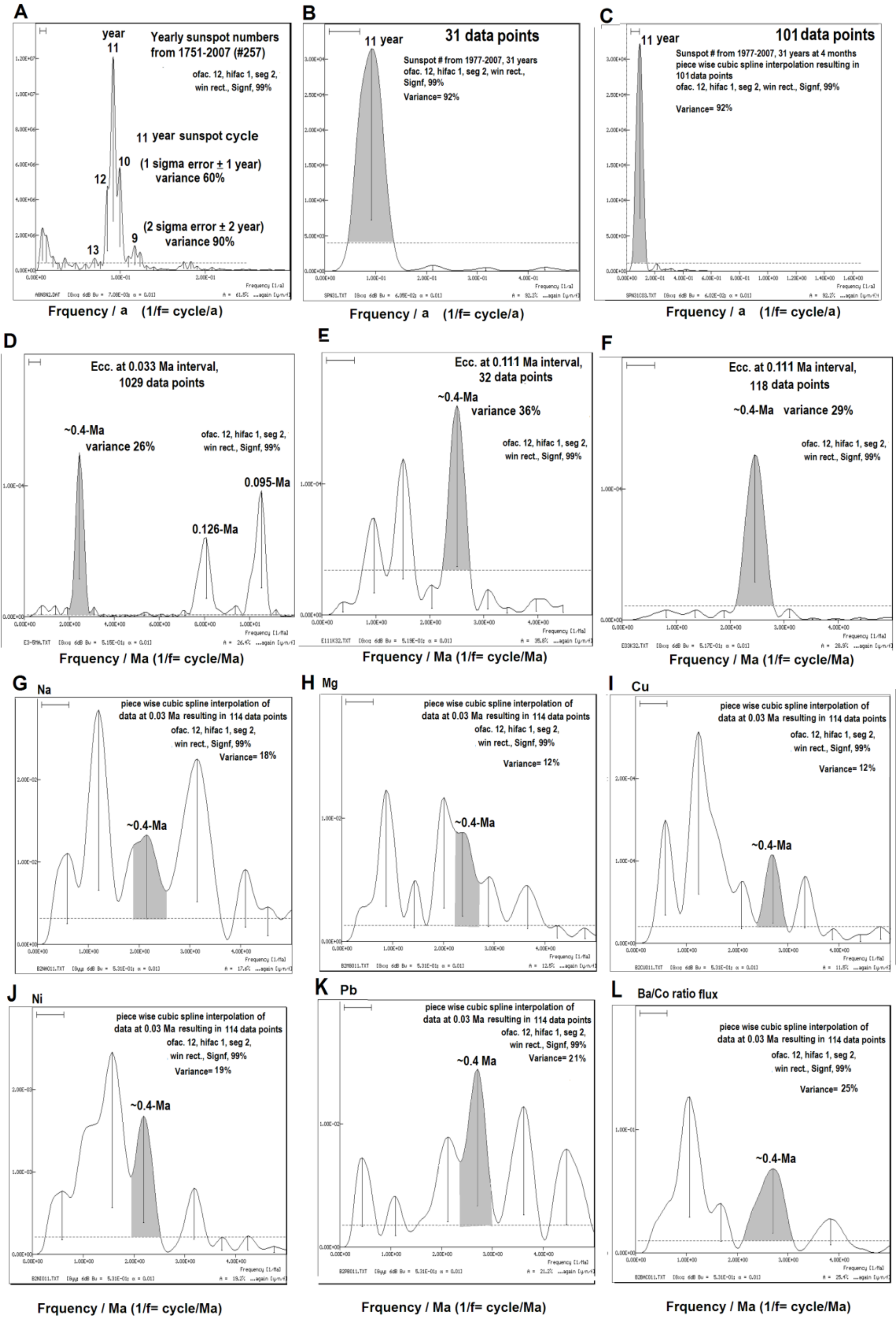
```
% load age data to interpolate
load age.dat
x= age;
% step increment to interpolate with in the range
xi= 0.111:.03:3.5;
xi'
% load elemental data to interpolate
load Ni.txt
y=ni;
yi= pchip(x,y,xi)
yi'
% idata is interpolated elemental data
```

SPECTRUM analyses

As the above set of interpolated data is equally spaced at $\delta t=4$ months resulting in 104 sunspot data points, and at 0.03 Ma in elemental data, we used SPECTRUM program of Schulz nd Sttattegar (1997) for spectral analyses of 114 data points.

We used ofac 12, hifac 1, segment 2, detrending, significance level 0.01 (99%), performed spectral analyses and results are presented in figure accompanying below. The exercise resulted in NO DEVIATION from our ~400-ka (99-90% significane) cycles reported in original submission. Therefore, we retain our figure 3-7 as such.

Reference: Varadi, F., Runnegar, B. and Ghil, M. (2003) Successive refinements in long term integration of planetary orbits. Astrophys. J., v. 592, pp. 620–630.


A
year
11
Yearly sunspot numbers
from 1751-2007 (#257)
ofac. 12, hifac 1, seg 2,
win rect., Signf, 99%
11 year sunspot cycle
10
12
(1 sigma error ± 1 year)
variance 60%
(2 sigma error ± 2 year)
variance 90%
9
13
Frquency / a (1/f= cycle/a)
B
11 year
31 data points
Sunspot # from 1977-2007, 31 years
ofac. 12, hifac 1, seg 2, win rect.,
Signf, 99%
Variance= 92%
Frquency / a (1/f= cycle/a)
C
11 year
101 data points
Sunspot # from 1977-2007, 31 years at 4 months
piece wise cubic spline interpolation resulting in
101 data points
ofac. 12, hifac 1, seg 2, win rect., Signf, 99%
Variance= 92%
Frquency / a (1/f= cycle/a)
D
Ecc. at 0.033 Ma interval,
1029 data points
~0.4-Ma
variance 26%
ofac. 12, hifac 1, seg 2,
win rect., Signf, 99%
0.095-Ma
0.126-Ma
Frquency / Ma (1/f= cycle/Ma)
E
Ecc. at 0.111 Ma interval,
32 data points
~0.4-Ma
variance 36%
ofac. 12, hifac 1, seg 2,
win rect., Signf, 99%
Frquency / Ma (1/f= cycle/Ma)
F
Ecc. at 0.111 Ma interval,
118 data points
~0.4-Ma variance 29%
ofac. 12, hifac 1, seg 2,
win rect., Signf, 99%
Frquency / Ma (1/f= cycle/Ma)
G Na
piece wise cubic spline interpolation of
data at 0.03 Ma resulting in 114 data points
ofac. 12, hifac 1, seg 2,
win rect., Signf, 99%
Variance= 18%
~0.4-Ma
H Mg
piece wise cubic spline interpolation of
data at 0.03 Ma resulting in 114 data points
ofac. 12, hifac 1, seg 2,
win rect., Signf, 99%
Variance= 12%
~0.4-Ma
I Cu
piece wise cubic spline interpolation of
data at 0.03 Ma resulting in 114 data points
ofac. 12, hifac 1, seg 2,
win rect., Signf, 99%
Variance= 12%
~0.4-Ma
J Ni
piece wise cubic spline interpolation of
data at 0.03 Ma resulting in 114 data points
ofac. 12, hifac 1, seg 2,
win rect., Signf, 99%
Variance= 19%
~0.4-Ma
Frquency / Ma (1/f= cycle/Ma)
K Pb
piece wise cubic spline interpolation of
data at 0.03 Ma resulting in 114 data points
ofac. 12, hifac 1, seg 2,
win rect., Signf, 99%
~0.4 Ma
Variance= 21%
Frquency / Ma (1/f= cycle/Ma)
L Ba/Co ratio flux
piece wise cubic spline interpolation of
data at 0.03 Ma resulting in 114 data points
ofac. 12, hifac 1, seg 2,
win rect., Signf, 99%
Variance= 25%
~0.4-Ma
Frquency / Ma (1/f= cycle/Ma)