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Full Length Research Paper

Astronomical Calibration of the Danian Formation of Ndayane: Paleogeographic and Paleoclimatic Implications

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Abstract:

The previous studies of the Formation of Ndayane, that collected a wide set of lithological and biostratigrahic data, as the existing species of benthic and planktonic foraminifera or pelagic index, has been revisited. In fact, he analysis of these data gave general indications on the age of the formation that was dated from Mid to Late Danian. In this work, the available pelagic indices of the Formation of Ndayane are correlated with La2004 numerical solution of eccentricity and insolation. The principle of the correlation is based on the established relation between pelagic index, eccentricity and eustatism. The correlation of eccentricity with insolation is more obvious. The performed correlation allows showing that the pelagic index is well correlated to eccentricity and that the thickness of limestone beds is also correlated to the insolation amplitude. Warmer climate corresponds to thicker limestone beds. Moreover, the method allowed more accurate dating of the Formation of Ndayane, as the first limestone bed at the bottom of the Popenguine cliff can be dated at 64.32 MA.

Keywords: Astronomical Calibration; Formation of Ndayane; Danian, Biostratigraphy; Dating; Pelagic Index; Eccentricity; Insolation

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1. Introduction

The Formation of Ndayane, representing the base of the Paleocene of the Senegalese-Mauritanian basin, has been described through its rarely available outcrops in the Ndayane-Popenguine area (Castellain, 1965). It is formed of a marl-limestone alternation forming the 25 meters height Popenguine cliff. The Formation of Ndayane shows 10 to 90 centimeters thick limestone layers alternating with thin marly laminae. The biostratigraphic study of the Formation from the outcrops of the Popenguine cliff described foraminifera association as *Morozovella pseudobulloides*, *M. cf. trinidadensis*, *M. inconstans* of P1-P2 biozone corresponding to the mid to late Danian (Sarr et *al*, 1998). This age substantiated the previously advocated NP2-NP3 biozone based on the calcareous nannoplankton fossils (Tourmakine et *al*, 1984) and the advocated Danian based on the macrofossils (Tessier, 1952). The ages provided by these studies cover a period ranging from 64.8 to 61 MA basing on P1-P2 biozone and from 64.5 to 62.2 MA basing on NP2-NP3 biozone (Berggren et *al*, 2005). At this step, no radiometric dating study has been carried on the Formation of Ndayane to allow higher resolution dating. The detailed observation of the Formation of Ndayane shows 33 cycles of marl-limestone alternation. The thickness of the limestone layers increases progressively from the bottom to reach a maximum of 90 centimeters in the middle of the cliff. From the middle to the top, the thicknesses decrease again to reach a minimum of 10 centimeters. The thickness of the marly layers varies inversely from the thickness of limestone. These observations motivated the analysis of the formation using astronomical calibration techniques. In fact, astronomical calibration should allow correlating the thickness variation of limestone layers with available earth orbital parameters to unravel whether they govern the deposition of limestone/marl couplets. Moreover, finding such relationship will provide high-resolution dating and useful information on paleographic or paleoclimatic depositional context of the Formation of Ndayane.

2. Material and Method

2.1. Biostratigraphic data

The Paleocene of the Senegalese-Mauritanian basin is transgressive and starts at the Danian with the end of terrigeneous sedimentation and the apparition of the first marl-limestone alternation sequence, deposited in an external platform environment (Roger et *al*., 2009). The rarely known outcrops of the Danian are the marl-limestone alternation forming the Popenguine cliff. Based on the lithology, the cliff is divided into 3 units (table 1). A complete description of foraminifera taxa in the cliff of Popenguine shows 31 benthic and 6 pelagic species of foraminifera (Sarr et *al*, 1998). The benthic foraminifera are less present in the bottom (between 0 and 5 meters) and the top (between 18 and 25 meters) of the formation. The number of benthic species is higher between 5 and 18 meters. The variation of the number of planktonic foraminifera is less important. The peaks of the number of species of benthic and planktonic foraminifera are generally shifted but stay visibly correlated. Based on these data, the pelagic index has been determined along the 25 meters of the Popenguine cliff (Figure 1).

Table 1. Lithologic subdivisions of the Popenguine cliff (Sarr et *al*, 1998, modified)

Unit	Height (meters)	Lithology
I	2.5	Gray clays with marly-limestone lenses crossed by small gypsum veins
II	17.5	15.5 m of limestone beds alternating with yellowish marly limestone crossed by gypsum lenses. The thickness of limestone beds varies from 10 to 40 cm at the base of the unit to 70 to 90 cm at the top of the unit. 2 meters of thin limestone bed of 10 to 20 centimeters thick, alternating with thicker marly beds of 40 to 60 cm
III	7	Lenticular marly-limestone laminae alternating with centimetric to decametric marly bed with calcite rosettes

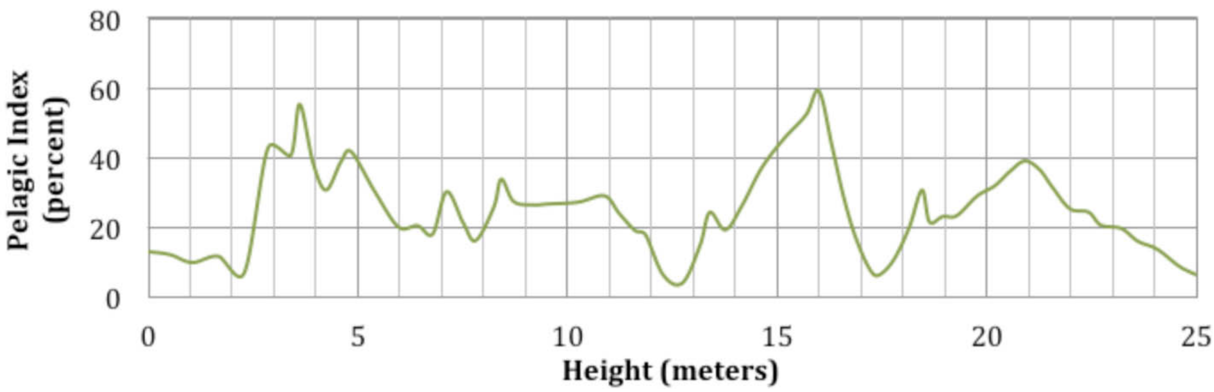

Figure 1. Variations of pelagic index from bottom to top of Popenguine cliff (Sarr, 1995)

2.2. Astronomical data

It has been widely proven, using the Milankovitch theory, that periodic oscillations in Sun/Earth position have induced significant Earth stratigraphic record of climate (Emiliani, 1966; Chappell et al, 1986; Petit, 1999). This motivated the multiple initiatives to search for orbital cycles in stratigraphy back through geologic times using isotopes as well as other climate proxies including facies stratigraphy, percent carbonate, biogenic silica, magnetic susceptibility, wireline logs, and grayscale scans (Hinnov, 2004). From the earth orbital parameters numerical solution La2004 (Laskar et al, 2004), we used the computed earth orbital, eccentricity and insolation quantities for a period ranging from 64.8 to 61 MA with a value every 5000 MA to cover the previously described biostratigraphic age interval (Laskar et al, 2010). The chosen location is at the latitude -14.554° and the longitude 17.112W, based on Popenguine cliff present-day mean geographic coordinates. The obtained eccentricity and insolation curves are shown below (figure 2 and figure 3) :

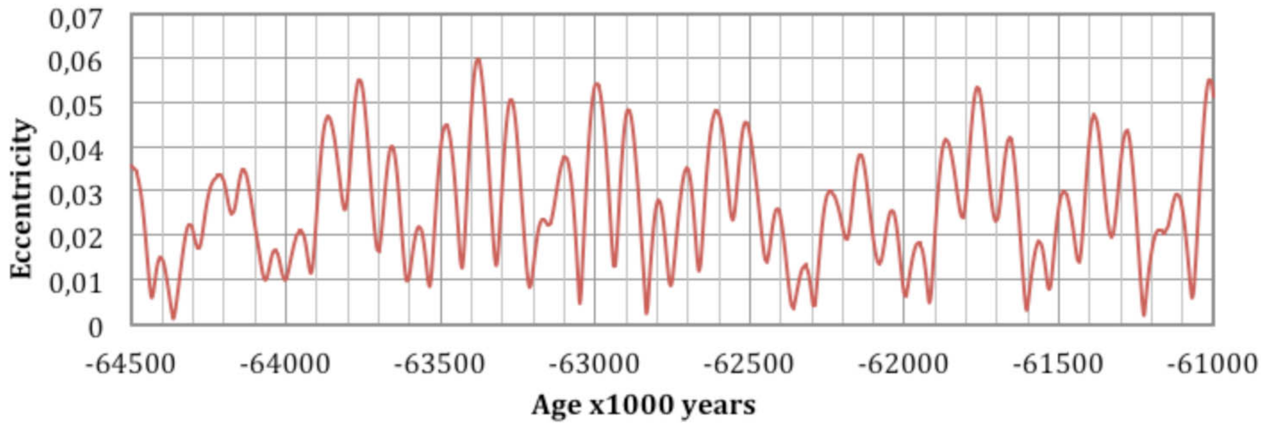

Figure 2. Computed Earth orbital eccentricity using La2004 numerical solution from -64.5 to -61 MA

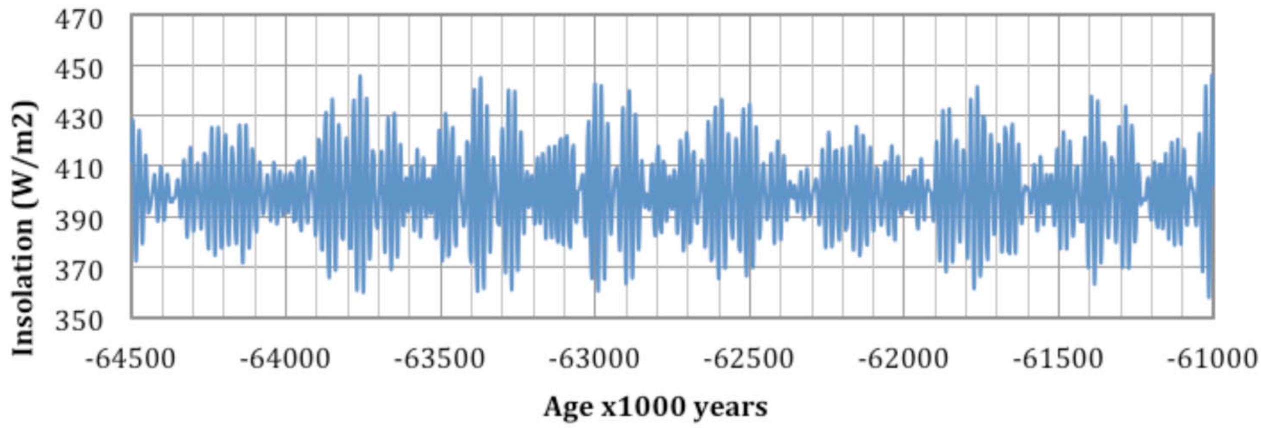

Figure 3. Computed Insolation at Popenguine cliff latitude using La2004 numerical solution from -64.5 to -61MA

A careful observation of the eccentricity curve shows two important events corresponding to the maximum eccentricity at -63400 (i.e. -63.4MA) and the minimum eccentricity at -64450 (i.e. 64.45MA).

2.3. Calibration method

It has been proven that low eccentricity induces low insolation (Krijgsman et *al*, 2001) and that high eccentricity will induce higher sealevels due to ice smelted linked to high insolation (Boulila et *al*, 2010). Also, this relation between eccentricity and insolation can be directly observed comparing computed La2004 curves. It has been also shown that the pelagic index is a proxy of eustatism as high sea levels can be correlated with high pelagic indices (Thiam, 2014).

Based on the relation between the eccentricity and eustatism in one side and between pelagic index and eustatism in the other side, it becomes possible to correlate maximum eccentricity with maximum pelagic index and minimum eccentricity with the minimum pelagic index.

The curve of pelagic index shows three through corresponding to the minima. Based on the relation between eccentricity and pelagic index, the first important decrease of pelagic index can be correlated with the minimum eccentricity. The correlation between pelagic index and eccentricity will allows subsequently the correlation of lithology with eccentricity or insolation. Such correlation should give higher resolution dating of the Popenguine cliff. It is worth to notice that the maximum of pelagic index occurring at 16 meters height will be correlated with the maximum eccentricity occurring at -63.4 MA. In this case the remaining 10 meters of the cliff will not reach -61 MA. In this case, the represented part of the eccentricity curve can be drastically reduced and limited to the interval between -64.5 and -62 MA.

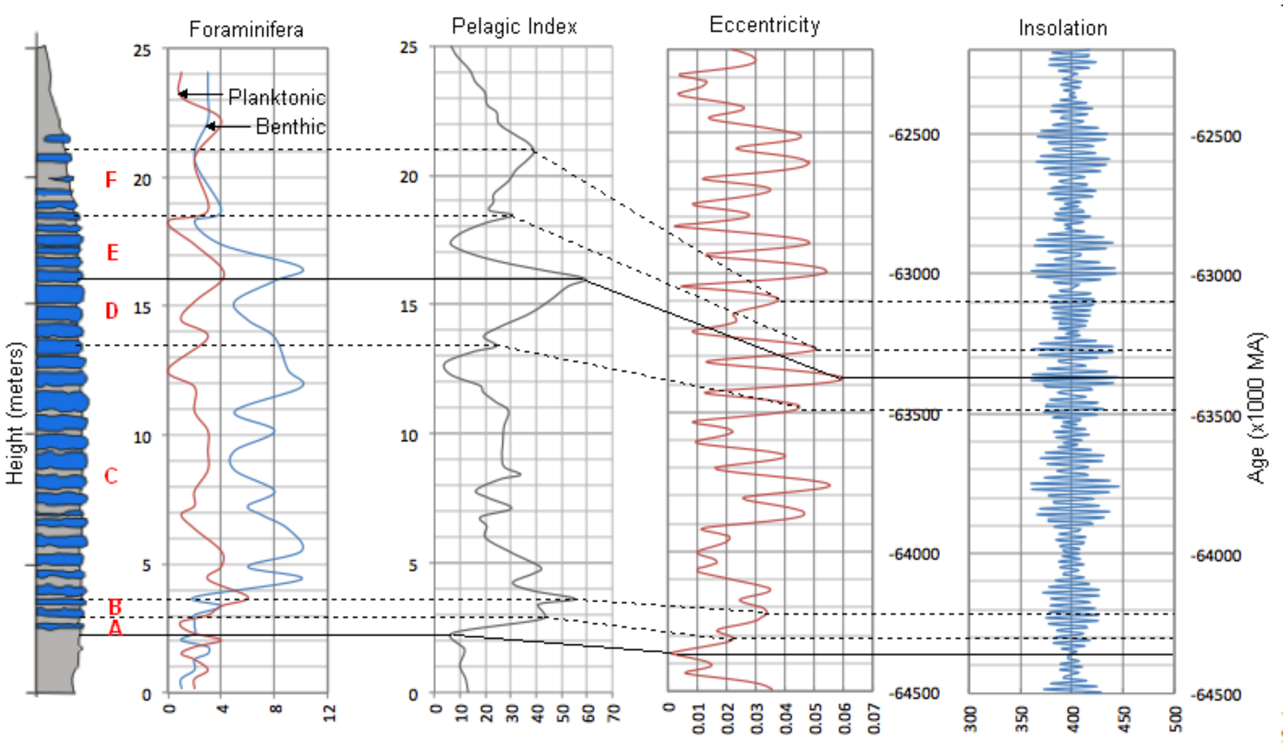

Figure 4. Correlation of pelagic index with orbital eccentricity and insolation

3. Results and discussion

The correlation of the pelagic index with eccentricity and subsequently the correlation of lithologies with insolation allows to unravel that the first limestone bed of the cliff of Popenguine located in the interval A (see figure 4) can be dated between 64.35 and 64.3 MA and more accurately at 64.32 MA. Using the same technique almost all the beds forming the Popenguine cliff can be dated at a high resolution. The quality of the correlation of the maxima and the minima of pelagic index with eccentricity can be verified comparing the two curves. In fact after setting the two controls point, we can observe a match in the trends of eccentricity and pelagic index curves. Moreover, the number of peaks is slightly the same as we count 9 peaks in the pelagic index and 10 peaks in the eccentricity curve. We observe that the insolation peak corresponds to the middle of the limestone bed (see figure 4, interval A). This correspondence between insolation curve and limestone beds can be verified in interval D. In fact the top and bottom correlation lines of the interval D cross the insolation peaks. These two peaks added to the three peaks in the interval making a total of five peaks can be found in the lithological section where correlation lines arrive at the middle of the bottom and the top limestone bed with 3 beds in the interval. This is also the case for interval E. However, this situation cannot be verified for the interval B where one bed is missing and the interval F where more peaks are missing. The relation between the insolation peak and the presence of limestone bed seems to be determined by the amplitude of the peaks. High amplitude peaks give thick limestone bed and low amplitude peaks result in a thin or no limestone bed. A careful comparison of the lithological section and the insolation curve shows that the thickness of the limestone bed and the insolation amplitude are always correlated. In fact, as advanced by other previous authors (Boulila, 2010) the limestone beds represent warmer climates and higher sea-levels and the marls corresponds to colder climates and lower sea-levels. Moreover, the warmer is the climate; the thicker becomes the limestone bed. Inversely, the colder is the climate, the thicker are the marly beds.

4. Conclusion

The astronomical calibration of the Formation of Ndayane shows that the limestone beds have been deposited during a warmer climate session and their thickness is correlated to the insolation. The sea levels determined using foraminifera is emphasized by eccentricity values. Using astronomical calibration can result in more accurate dating of the Formation. However the obtained results could be confirmed using magnetic susceptibility of δO^{18} variations along the cliff of Popenguine. To improve the accuracy of the obtained dating, the stratigraphic log of the Ndayane Formation should be accurately described. Also performing radiochronolgy on foraminifera will allow obtaining more control points and therefore enhance the calibration and the high-resolution dating tool.

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