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Palaeoenvironmental changes of lower and middle Cenomanian sediments (Slenfeh formation) in the southern part of AL Sahyleh chain (Syria)

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Abstract
A quantitative study of Slenfeh formation sediments (Lower- Middle Cenomanian) by using the palaeoecological indicators calcareous nannofossils was done in AlNasera and Safita sections in the southern part of costal chain. The results of this study showed that the abundance changes of some species have the same trends in the studied sections. The lower part of Cenomanian were characterized with high values of relative abundance for the species *W. barnasae*, and *R.asper*, wherever these values were decreased in the upper part of middle Cenomanian. On the other hand, the relativity abundance of *B.constans*,and *Z.erectus* were gradually increased from lower to middle Cenomanian. Principal Component Analyzes (PCA) were identified two factors that affecting on the abundance of calcareous nannofossils. The first factor is the increase of seawater temperature during the middle Cenomanian, associated with the increase of warm water species abundance such as, *W. barnasae*, *R. asper*. The second factor can be related to the change in the fluctuation of organic matter during the lower Cenomanian as result of increase the abundance of high-productivity species such as (*B .constans*, *Z.erectus*).
The results showed that Autotrophic conditions were dominated in the lower Cenomanian and associated with increase in the organic matter fluctuation. In addition, low biological productivity conditions during the middle Cenomanian were associated with an increase the depth of the sedimentation environment in the two studied sections.

Key words: Calcareous nannofossils, Cenomanian, Relative abundance, Principal Component Analyzes, Sedimentary environment.

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التغيرات البيئية القديمة لرسوبات السينومانيان الأدنى– الأوسط (تشكيلة صلنفة) في القسم الجنوبي من السلسلة الساحلية (سوريا)

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الملخص

تم إجراء دراسة كمية للرسوبات المتكشفة العائدة لتشكيلة صلنفة (سينومانيان أدنى–أوسط) باستخدام بعض الأنواع الدالة مناخيا للنانوفوسيل الكلسية في مقطعي الناصرة وصافيتا في القسم الجنوبي من السلسلة الساحلية. تظهر معالجة النتائج الإحصائية نفس الاتجاه العام لتغير غزارة الأنواع خلال الفترة المدروسة في مقطعي الدراسة. يبدأ السينومانيان الأدنى بقيم مرتفعة للغزارة النسبية للنوعين *W. barnasae, R.asper* . تبدأ هذه القيم بالتناقص التدريجي باتجاه أعلى السينومانيان الأوسط. بشكل معاكس لما سبق تزداد غزارة النوعين *B.constans, Z.erectus* تدريجيا اعتبارا من رسوبات السينومانيان الأدنى باتجاه السينومانيان الأوسط. تشير تحاليل المكونات الأساسية لوجود عاملين يؤثران على تغير غزارة أنواع النانوفوسيل الكلسية، العامل الأول هو تزايد درجة حرارة مياه البحر بالانتقال إلى السينومانيان الأوسط والمرتبط بتزايد في غزارة أنواع المياه الدافئة *W. barnasae, R.asper* ، والعامل الثاني تغير في تدفق المواد العضوية خلال السينومانيان الأدنى من خلال تزايد غزارة أنواع الإنتاجية العالية (*B.constans, Z.erectus*). تسيطر شروط التغذية الذاتية خلال السينومانيان الأدنى مرتبطة بتزايد في تدفق المواد العضوية وشروط إنتاجية بيولوجية ضعيفة خلال السينومانيان الأوسط متعلقة بتزايد في عمق بيئة الترسيب في مقطعي الدراسة.

الكلمات المفتاحية: النانوفوسيل الكلسية، السينومانيان، الغزارة النسبية، المكونات الأساسية، بيئة الترسيب

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1. Introduction

The upper Cretaceous presents very remarkable paleoclimates variations characterized by the greenhouse climate (Jenkyns, 2003), and the highest sea level in the Cenozoic Era (Haq et al., 1988).
Many studies interprets this greenhouse climate in the Upper Cretaceous to the volcanic activates which liberated high concentration of CO2 released atmosphere which caused such warm climate (Wilson et al., 2002; Jenkyns et al., 2004; Voigt et al., 2004). In fact, the late Cenomanian is characterized by anoxic events, which is considered the most remarkable palaeooceanographic variations in the Cenozoic oceans (Schlanger and Jenkyns., 1976).
This anoxic event is noticed in the perturbation of Carbone curve with negative values related to the perturbation in the fluctuation of Carbone cycle in the Late Cenomanian (Schlanger and Jenkyns, 1976; Arthur et al., 1987; Kuypers et al., 2002; Linnert et al., 2010; Pavlishina et al., 2012).
Two anoxic events were registered in the Cenomanian stage; the first is located in the base of this stage, while the second in the middle of Cenomanian.
In Syria, the Cenomanian was studied by many researchers (Dubertret, 1937., Mouty, 2003., Ghaneem and Kuss., 2013). This stage had been subdivided to nine formations in Syria (Dubertret, 1937).
Recently, Alithological, biostratigraphical and geochemical studies which have been done on the Albian – Cenomanoan interval in costal range showed two anoxic events in the Cenomanian interval (Ghanem et al., 2013).
The more recent studies using mathematics methods of planktonic and benthic foraminifera indicate that increase in the abundance of the foraminifera species from the base to the somite part of Cenomanian stage (Shama et al., 2019).
The first attempt to produce a global Cretaceous biozonation of Calcareous nannofossils by using geographically widespread sites, including many DSDP (Deep Sea Drilling Project) sites was prepared by Thierstein (1976). Later Manivit et al., 1977) proposed a biozonation for the 'Middle' Cretaceous. Verbeek (1976a, b, 1977) produced his biozonation for the 'Middle' and Upper Cretaceous where he investigated the nannofloras of Tunisia, southern Spain and France, including the stratotype sections. He was one of the first to illustrate, the attempt to integrate nannofossils and planktonic foraminiferal bioevents.
Sissingh (1977) used different sites as a mixture of onshore stage- stratotype (western European), (French, Tunisian) sections, spot samples of well from the North Sea region, and from Oman, Turkey sections to construct his schema of Calcareous nannofossils biozonation of upper Cretaceous. This work is used as a reference of calcareous nannofossils biozones for upper Cretaceous in many latter studies. In 1977, Sissingh studied the biostratigraphic correlation where he used planktonic foraminifera datums, to reinterpreted the stratigraphic positions of Calcareous nannofossils bioevents.
Roth (1978) prepared a comparable biozonation using similar bioevents to those used by Sissingh by analyzes DSDP materials, and thereby proving the correlation potential of nannofossils biostratigraphy from onshore to oceanic sequences.
The works of Crux's (1980, 1982) can be considered the most complete Cenomanian to Campanian sequences in the world, by using the biostratigraphic correlation with macro fauna zones to determine the stratigraphical position of calcareous nannofossils bioevents, which allows identifying the synchronism or dichroism of these bioevents.
The present research aims to reconstruct the palaeo-ecological changes in Cenomanian stage by using four indicators species of calcareous nannofossils, and to identify the principal’s factors that control the variation in the relative abundance of calcareous nannofossils.

2. Geological setting of the section

Two sections (AL Nasera: N 34° 45′ 46,2″ E 36° 15′ 48,8) and (Safita N.34° 46 11,5 E.36 04 46,3) were selected to investigate the Cenomanian sediments. These sections are located in the southern part of AL Sahyleh chains northwest of Syria (figure. 1).

The studied region is characterizing by grand thickness of Cretaceous sediments located above the Jurassic sediments. Unconformity surface separates between these sediments formations (Mouty, 1976).

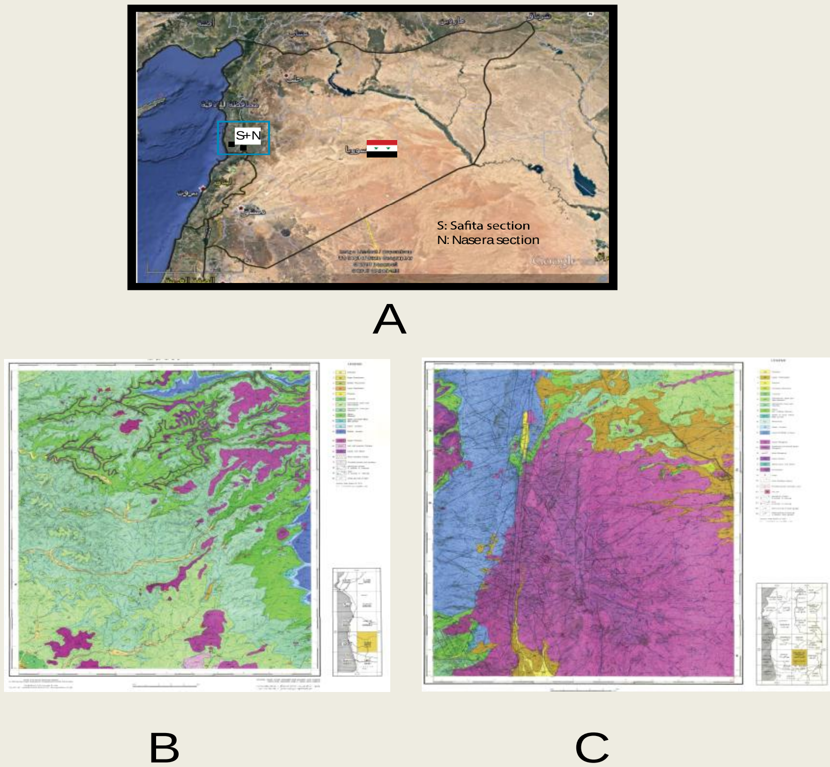

Figure. 1. A: The geographical position of A Nasera and Safita sections.
B: Geological map of Safita region.
C: Geological map of Al Nasera region

This region was located in the southern part of margin of Neo-Tethys during the Upper Cretaceous. A high compression force affected at the studied region due to the convergence of the African and Eurasian plates.

2.1. **AL Nasera section (N 34° 45′ 46,2″ E 36° 15′ 48,8)**

The lower Cenomanian sediments (Slenfeh formation) have 147 m of thickness. In this section, four successive sedimentary unites were observed. The first one extend from the base of this section (bed N100 to N106) composing of massive limestone beds (about 2m of thickness) separating by thin marl beds. The second unite begin from the bed N107 to the bed N141 (figure. 2). In this unite, there is a decrease in the thickness of limestone beds, where marle beds show slight increase where it can be considered as mark of this unite (figure. 2).

The third unite is marked by thin limestone beds that contain the geodes of silica in the bed N143 becoming in the beds N145, N146 marly limestones. The last sedimentary unite correspond the domination of limestones beds from N147 to N158 beds composed of massive limestone beds separating by thins marl and limestones beds (figure. 2).

2.2. Safita section (N.34° 46 11, 5   E.36 04 46, 3)

This section is locating 10 km south- west of Safita city. The sedimentary system of this section is composing from Limestone, dolomite, marly limestone – marl alternation with 85 m of thickness (figure. 2).

Three sedimentary unites were noticed in this section. The first sedimentary unite is composing of massive limestone beds in the base of this section (Y1to Y5 bed) (figure. 2).

In the second unite, the sedimentary system characterized by thin beds of limestones, where marl layers separate between limestone beds from (S1- S7).

The third unite occupies the upper part of Safita section characterized by the increase the thickness of Limestone beds and marl beds. The increase in most thickness coincide high richness in the average of argil in Limestone beds (figure. 2). Large geodes (10 cm of diameter) were found in the bed S7.

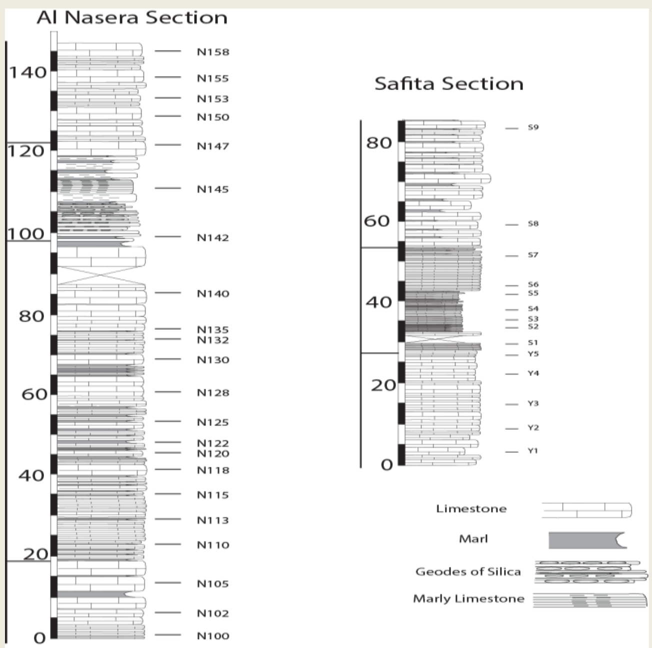

Figure. 2. Stratigraphical alternation of Al Nasera and Safita sections

3. **Material and methods**

Thirty six Samples were studied in the two sections to identify the calcareous nannofossils, (22 samples in Al Nasera section , 14 in Safita section). Samples were systematically taken from adjacent marl-limestone couplets. Sample spacing was quite stable (every three meters) from the base to the top of section. The slideswere prepared according to Beaufort method (Random Setting Technique) described by Beaufort (1991) and modified by Geisen et al. (1999). The method followed in this work contain many stapes: 1- Change the samples into powder. 2- This powder is mixing with alkaline water in the tube to avoid the dissolution of calcareous nannofossils test. 3- The mixing contents are vibrating to have a homogenous powder in water. 4- Small part was deposited in thins slats that had been drayed by using a high temperature. The slats are glued to the hot slides using Rhodopas resin. The slides were studied by optical microscope.

The interval biozones were used to date the sediments of Cenomanian in the region study. The first Occurrence (FO) and Last Occurrence (LO) of index species identify these biozones

4. Results

4. 1. Assemblage of Calcareous nannofossils.

Safita section

Some indicators species have been used to reconstruct the palaeoenvironments changes for the Cenomanian stage. Four abundances curves have been obtained from the treatment of calcareous nannofossils data. High values of *Biscutum constans* (20-25 forms) have been found in the lower part of Cenomanian (figure. 3), whereas these values gradually decrease toward the lower part of middle Cenomanian where 5 forms are found in the sample S2.

A trend of decrease in the curve has been noticed between the samples S3-S6. The interval extending between the samples S6-S9 is characterized by a little increase in the curve of assemblage from S6 and S8 before the decrease in the curve to S9 in the top of Safita section (figure. 3).

We see the same trend for the curve of *Zeugrohabdus erectus* with high values from the sample Y1 in the base of section to the sample S1 at the boundary between the lower and middle Cenomanian.

The lower part of middle Cenomanian was characterized by the diminution in the values (0-5) of this specie in the samples S2, S3

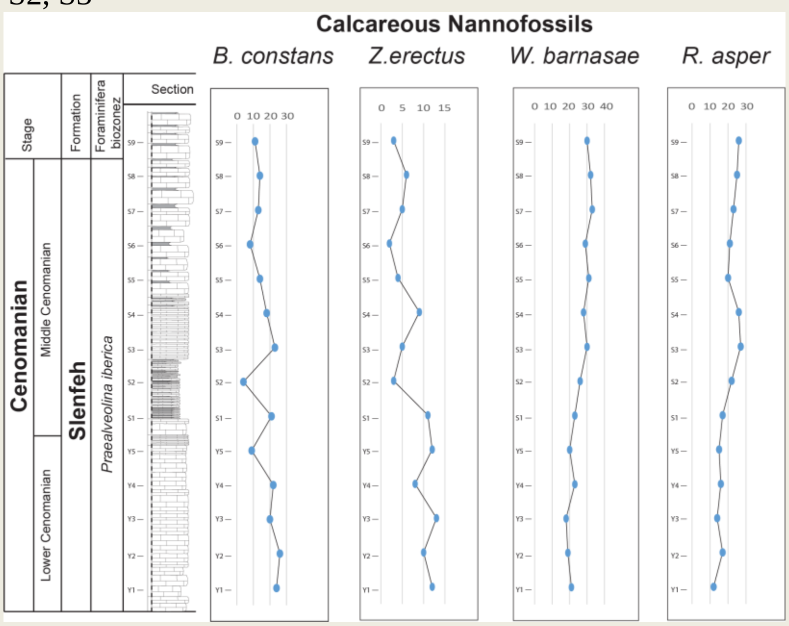

Figure. 3. Assemblage of some indicators species of palaeoenvironments in Safita section

A gradual decrease in the abundance curve of *Z.erectus* has been observed in the sample S4 to the top of Safita section (sample S9) (figure. 3).

Different behaviors for the species of *Watznaueria barnasae* and *Rhagodiscus asper* were noticed corresponding low values in the lower Cenomanian. About 20 forms of *W.barnasae* and 15 for *R.sper* in the samples Y1-Y5 have been recorded (figure. 3). The abundance of *W.barnasae* and *R.sper* show increase trend from the boundary between lower- middle Cenomanian (sample S1) and the top of section (sample S9). About 30 form have been recorded for the first specie, while the second one has been recorded only 25 forms (figure. 3).

The interval between the samples S3-S4 shown the highest value for *R.sper* (about 30 forms) (figure. 3).

In Al Nasera section, the abundance curves were characterized by high values between 20 to 30 forms of *B.constans* in the Lower Cenomanian in the samples (N100 – N120). A gradually diminution in the abundance curve remarked in the sample N120 to N158 with values generally less than 10 forms corresponding the middle - Upper Cenomanian.

The same trend was observed in the abundance curve of *Z. erectus* with a high values ranged between 20-30 forms in the samples (N100- N122). On the other hand, the abundance of *Z. erectus* decrease toward the top of the section (figure. 4).

General increase in the relative assemblage of *W.barnasae* from the base to the top of this section. The abundance of this specie is about 10 in the lower Cenomanian, starting to increase to 40 in the sample N153.

The fluctuation of *R.asper* is characterized by low values in the samples (N100 to N122) before increasing above the sample (N122) to the sample (N150). A gradually decrease was noticed for this specie in the interval between the samples (N153 and N158).

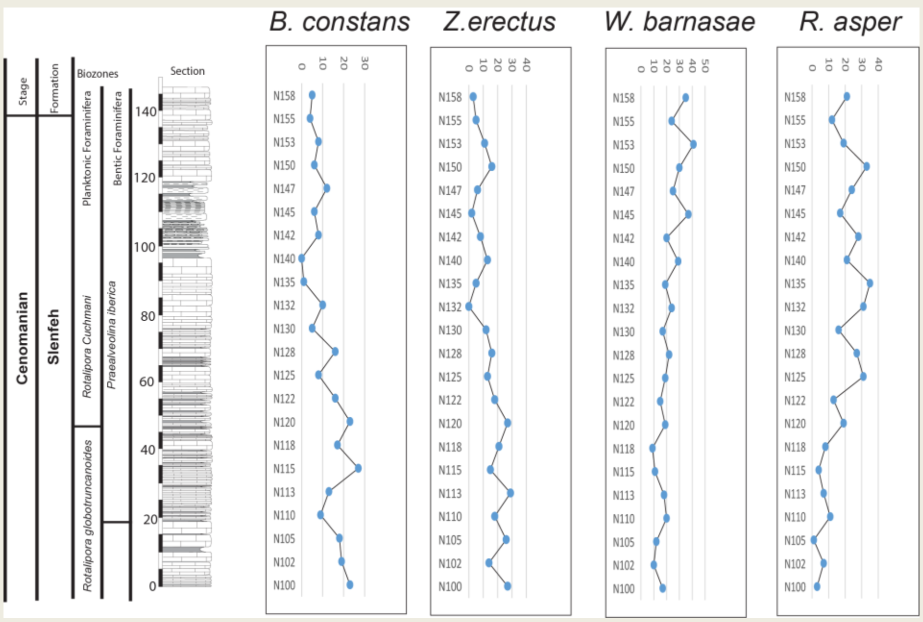

Figure. 4. Abundance of some indicators species of palaeoenvironments in AlNasera section

5. Discussion

5. 1. PCA of calcareous nannofossils

The treatment of palaeoenvironmental indicators species of calcareous nannofossils data was prepared by using the quantitative program (Past) to identify the main factors that controlling the variation of calcareous nannofossil assemblages by using the principal component analyzes (PCA) in the studied sections.

The results of last operation is showed in (figure. 5). The positive values for *W.barnasae* and *R.asper* between 5-15 and negative values (-5 and -10) for the *B.constans* and *Z.erectus* are corresponding the first factor.

Many studies described *W.barnasae* and *R.asper* as a species of warm water such (Mutterlose, 1991, 1992), so the high values of these species and the negative values of *B.constans* considering of cold water comparing with the first factor. This factor correspond the changes in the temperature of water which play the main reason in the variation of calcareous nannofossils assemblage in the lower and middle Cenomanian.

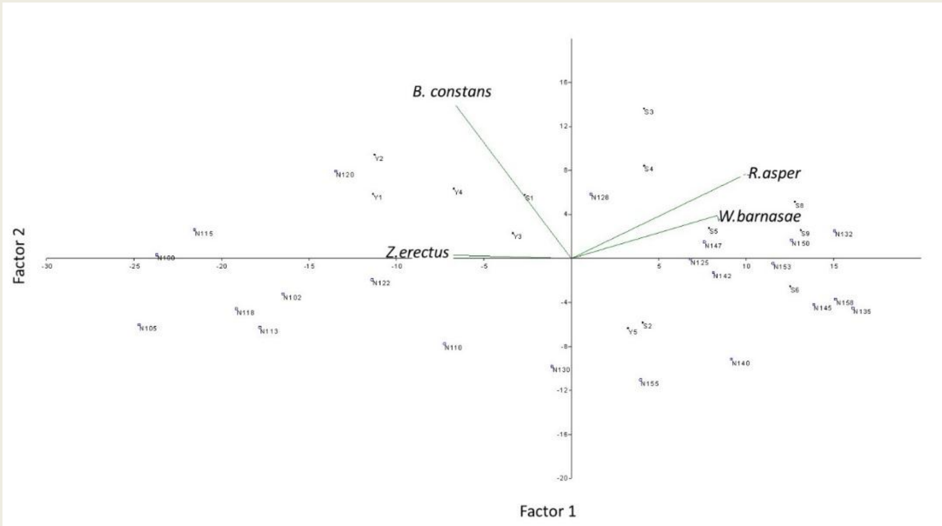

Figure. 5. Principal component analyzes of calcareous nannofossils

The highest values of the second factor corresponds *B.constans* (about 15) (figure. 5). This specie is favorable to high nutriment supply, many studies explain the existence of relation between the high assemblages of *B.constans* with the cold water (Roth and Bowdler, 1981; Roth and Krumbach, 1986; Erba et al., 1992; Linnert et al., 2010). In this study, we interpret the second factor as the change in the nutriment supply in agreement with the new works that consider this specie is the high fertility indicator

5. 2. Reconstruction of palaeoecological changes in Lower- middle Cenomanian

The interpretation of calcareous nannofossils data using the paleo ecological indicators species gives a general idea for the palaeogeographical changes in the lower- middle Cenomanian in the costal changes.

The increase in the temperature of seawater is noticed from the lower Cenomanian to the middle where this increase is related to the increase in the relative abundance of *W.barnasae*, *R. asper* (warm species) (Mutterlose, 1991, 1992) in the sediments of middle Cenomanian, in additional to the decrease in the assemblage of *B.constans* (cold specie) to the middle Cenomanian.

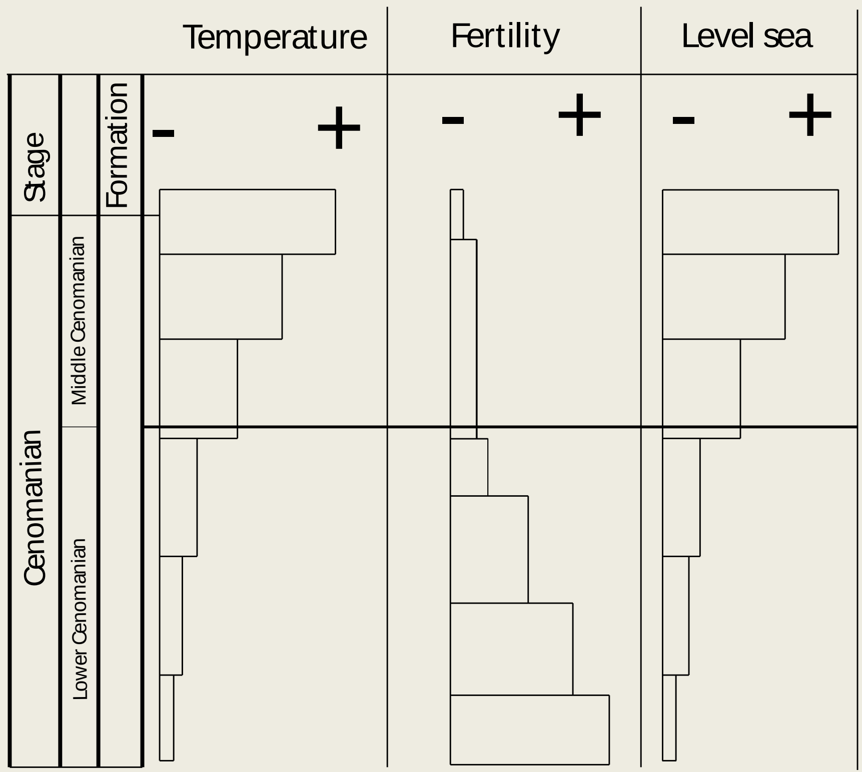

Figure. 6. Palaeoecological changes in the Lower- Middle Cenomanian

The increase in the temperature coincide with the high level of seawater from the lower to the middle of Cenomanian (figure. 6). This result is related to many criteria, the first is the diminution in the assemblage curve of *Z.erectus* specie is favorable to the high supply of nutriment (Roth and Bowdler, 1981; Roth and Krumbach, 1986; Erba et al., 1992; Linnert et al., 2010). This information suggest the increase in the depth of marine environment to the lower –middle Cenomanian boundary proposing a sections more distal and low supply of nutriment in the middle of Cenomanian. The second criteria is related to the increase in the warm species *W.barnasae*, *R. asper* (warm species), and a decrease in the abundance of cold specie (*B.constans*) to the middle Cenomanian.

6. **Conclusion and perspective**

The calcareous nannofossils were used to reconstruct the paleo-ecological conditions during the lower/middle Cenomanian (Slenfeh formation) in two sections (Al Nasera, Safita) in the southern part of costal chain.

Four indicators species have been used (*W. barnasae, R.asper, B.constans, Z.erectus*).

A quantitative method was used in this study. High values of relative abundance for *W. barnasae, R.asper* were recorded in the lower Cenomanian. These values begin to decrease to the upper part of middle Cenomanian. At the contrast, a gradually increase are observed in the abundance of *B.constans, Z.erectus* from the sediments of lower to the middle of Cenomanian. The Principal Component Analyzes method indicate the presence of two factors. The first presents the increase of seawater temperature to the middle Cenomanian, associated with an increase in the abundance of warm water species *W. barnasae, R. asper* toward the middle Cenomanian. The second factor is interpreting as the change in the fluctuation of organic matter during the lower Cenomanian related to the increase the abundance of high-productivity species (*B .constans, Z.erectus*).

Autotrophic conditions dominate in the lower Cenomanian associated with the increase in the organic matter fluctuation, and low biological productivity conditions in middle Cenomanian related to increase the depth of the sedimentation environment in the studied sections.
The increase in the temperature coincide with the high level of seawater from the lower to the middle of Cenomanian.
This studied period need a geochemical analyzes to reconstruct a hard correlation with the data of calcareous nannofossils and foraminifera.

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