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**Research Paper**

# Characterization of the Paleoenvironmental and Paleoclimatic changes (palynology) of Tahar section, Western external Rif of Morocco

K.E. Guede[1,*], H. Slimani[2], K.K.K. TOE-Bi[3], M. Chekar[2], A. M'hamdi[4], B.Z. Digbehi[5], A. M'fedal[2]

[1]*UFR of Geological and Mining Sciences, University of Man, BP 20 Man, Côte d'Ivoire*
[2]*Laboratory of Geo-Biodiversity and Natural Patrimony (GEOBIO), Scientific Institute, "Geophysics, Natural Patrimony and Green Chemistry" Research Centre (GEOPAC), Mohammed V University in Rabat, Avenue Ibn Batouta, P.B. 703, 10106, Rabat-Agdal, Morocco*
[3]*Université Péléforo Gon Coulibaly, UFR des Sciences Biologiques, BP 1328 Korhogo, Côte d'Ivoire*
[4]*University of Tunis El Manar, Faculty of Sciences, Department of Geology, Laboratory of Sedimentary Basin and Petroleum Geology: LR 18 ES 07, University Campus, 2092, El Manar II, Tunisia*

***ABSTRACT:*** *The Maastrichtian to Ypresian dated sediments of the Tahar Cut [1, 2], Western Outer Rif (Northwest Morocco), are studied here for paleoenvironmental and paleoclimatic reasons. The results of quantitative and qualitative analyses of dinoflagellate cysts and other palynomorphs of continental origin (spores and pollen) allowed the reconstruction, in ascending order, of twelve different marine depositional environments: (1) outer neritic without productivity and thus without continental influence at the base of the section (Th1-Th3: Upper Maastrichtian); (2) inner neritic without productivity (Th4: Upper Maastrichtian:); (3) shallow outer neritic with low productivity (Th5-Th7: Upper Maastrichtian); (4) inner neritic in a phase of marine regression and widespread cold climatic conditions at the end of the Maastrichtian (Th7a-Th7b': Upper Maastrichtian); (5) outer neritic of very low productivity marking thus a slight marine transgression (Th7c : Danian); (6) inner neritic, reflecting a relative decrease in sea level (Th7d: Danian); (7) outer neritic with very low biological productivity for interval G, reflecting a rise in sea level compared to the previous interval (Th7e-Th7f: Selandian-Thanetian); (8) indeterminate paleoenvironment due to the scarcity of palynomorphs in this interval (Th8: Selandian-Thanetian); (9) marine oceanic without productivity which would result in a marine transgression (Th8a: Selandian-Thanetian); (10) neritic external (Th9: Selandian- Thanetian); (11) neritic internal without productivity for the K interval with a drop in sea level, under relatively warm climatic conditions (Th9a: Ypresian); (12) outer neritic, which would result in a marine transgression (Th10-Th11: Ypresian). These variations in paleoenvironments coincide with global climate changes at the Cretaceous-Paleocene (K-Pg) and Paleocene-Eocene (P-E) boundaries.*

***KEYWORDS:*** *Paleoenvironment, Cretaceous-Paleogene, palynology, dinoflagellate cysts, Morocco.*

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## I. INTRODUCTION

The Cretaceous-Paleogene (K-Pg) boundary is marked by iridium anomalies and mass extinctions of several species, the most famous of which are dinosaurs, belemnites and ammonites. This biological crisis of the K-Pg boundary, which continues to fuel the scientific debate, is the result of several catastrophic events such as eustatism, volcanic activity, and meteorite impacts, especially in Mexico [2-6]. However, for palynomorphs, there are no mass extinctions at this boundary but rather notable changes in relative abundances of taxa, most notably the global peak of *Manumiela sealandica*, indicating cold global climate conditions [2,5,7-9].

In contrast to the K-Pg interval, the P-E (Paleocene-Eocene) transition coincides with the Paleocene-Eocene Global Thermal Maximum (PETM), the most significant period of high heat in the Paleogene [10;11]. The PETM was consistent with large negative carbon isotope excursions (CIEs) recorded in oceanic and continental layers worldwide [12,15]. One of the most important events for dinoflagellate cysts during the

*Corresponding Author: Guédé Koré Elysée
*UFR of Geological and Mining Sciences, University of Man, BP 20 Man, Côte d'Ivoire*

PETM was the global acme of the genus Apectodinium, indicative of warm global climate conditions [16-20]. In our dinocyst studies, *Manumiella seelandica* and *Apectodinium* peaks corroborate well the global climate changes that prevailed during the K-Pg and P-E transitions, respectively.

The palynostratigraphic study of the Tahar section (located in Arba Ayacha, Larache Province) has contributed to the dating of the Western External Rif Range of northern Morocco, which was previously assigned to Senonian to Lower Eocene ages [21,22]. Thus, [1].and [2] were able to determine Cretaceous-Paleogene and Paleocene-Eocene boundaries for the first time in the Tahar section on the basis of dinoflagellate cysts.

Changes in the relative abundance of palynomorph species or species groups are commonly used to interpret sedimentary environments, particularly sea level changes. The present study was conducted on the same samples as the study by [1].and [2] in order to characterize the depositional environments and climatic changes that prevailed during sediment deposition.

## II. GENERALITIES ON THE GEOLOGY OF THE RIF CHAIN

Located in northern Morocco, the Rif Range (Fig. 1) forms an arc-shaped mountain edifice open to the Mediterranean Sea that has its history spanning from the Triassic to the Late Miocene [23-25]. The Rif (Figure 1) constitutes the western termination of an alpine chain derived from the Tethys. It is part of a Betic-Rifo-Tellian structural ensemble around the western Mediterranean and connects to the Apennines through Sicily [26]. The Rif is subdivided into three main areas: the Internal Areas, the Flysch Nappes and the External Areas. (Figure. 1 and 2). The Tahar section being located in the external domain, we will study it in more detail.

Representing the Tethyan margin of the African plate, the Outer Rif is very large and variable. It is covered, in places, by secondary and tertiary allochthonous terrain called the Rif nappes [21,27-28]. It is subdivided into three major parts, from north to south: the Intrarif, Mesorif, and Pre-Rif.

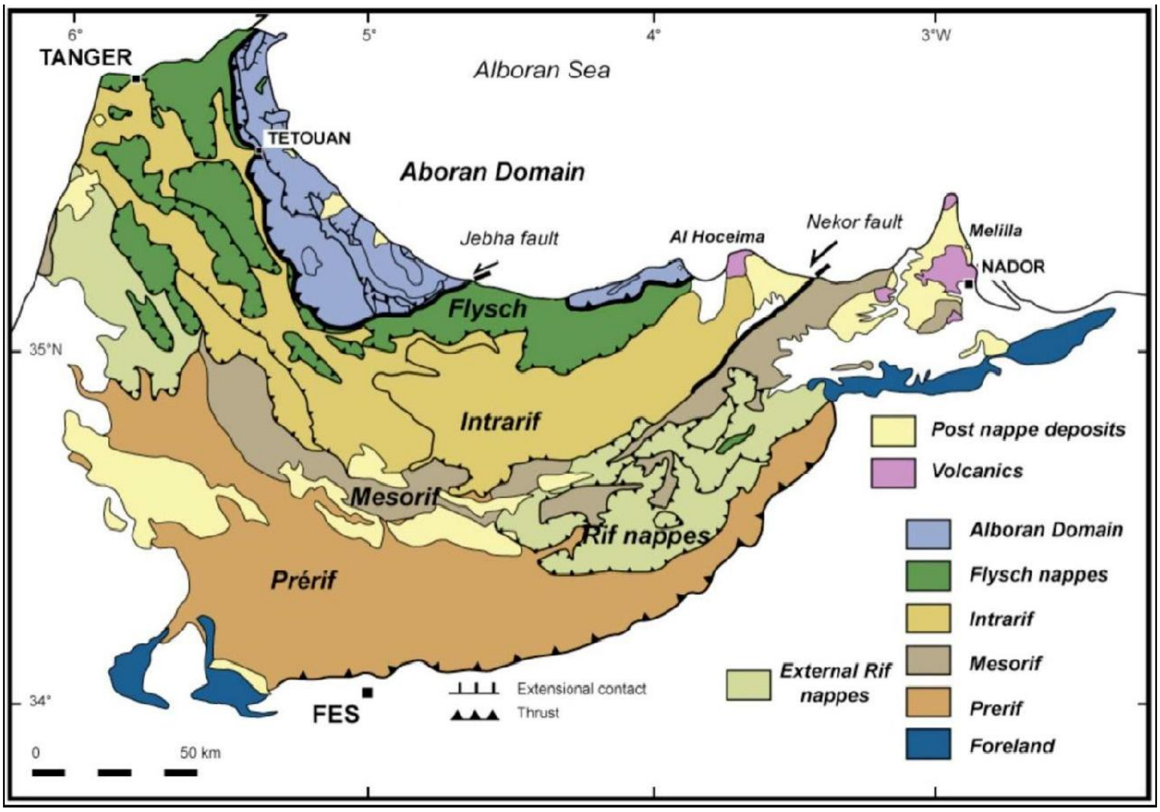


**Figure 1:** Structural map of the Rif Mountains (modified by [29] after [30].

### 2.1 The Intrarif

It is composed of three units:

– The Ketama unit, which outcrops only in the central Rif [31], is a parautochthonous and epi-metamorphic unit with schisto-quarzite material of Liassic to Lower Cretaceous age [31-33].

– The unit of Tangier, little deformed, it is considered to be the cover of the unit of Ketama, with a stratigraphic series that goes from the Albo-Aptian to the lower Miocene.

It is, however, overrepresented by Upper Cretaceous clayey marls [25,32].

– The Loukkos unit is a zone of tectonic scales that outcrops in the western Rif. It has a facies dominated by calcareous marls of Albo-Aptian to Eocene age [33,34].

## 2.2. The Meso-rif

It is formed by terrains of age ranging from the Lias to the Upper Cretaceous, surmounted by the transgressive Lower Miocene. The Meso-rif is characterized by Callovo-Oxfordian sandy-clay deposits [35] and by Middle Miocene calcarenites [36].

### 2.3. The Pre-rif

The Pre-rif is the southernmost part of the Rif Range with a facies dominated by marly clays. It is subdivided into the inner Pre-Rif and the outer Pre-Rif [23,35].

– The inner Pre-rif is formed by scales probably rooted under the Meso-rif. It contains Lias and Doggerian carbonates forming the "sof" also called "Mrayt sandstone" [37] and Kimmeridgian and Tithonian platform carbonates.

– The outer Pre-rif is mostly represented as a chaotically structured gravity nappe (pre-rific nappe) [36,38]. This nappe has a facies of sandy marl of upper Miocene age where elements of variable size are packed [34] resulting from the destruction of the nappe fronts that move outwards.

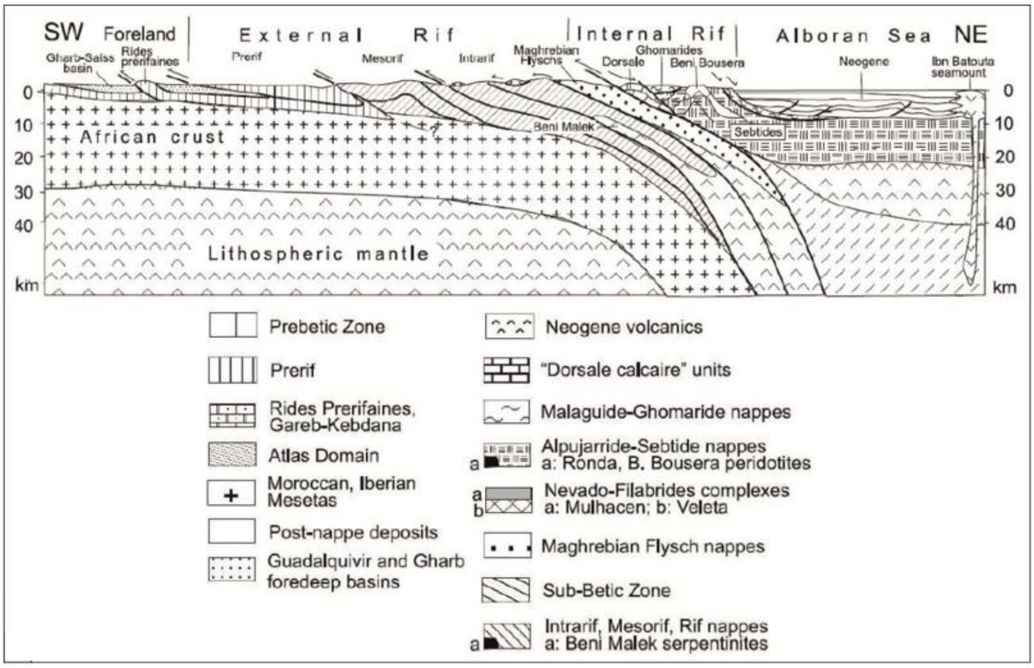


**Figure 2:** Simplified section of the Rif [39]

## III. Materials and Methods

### 3.1 Materials

The Tahar section that is the subject of this study is located in the Western External Rif, in the Arba Ayacha region (Figure 3). Its geographical coordinates are 35° 22' 28" N and 5° 53' 12" W. According to previous studies [21,22,40], this section comprises whitish marls of Eocene age overlying grey to blackish marls of Upper Cretaceous age.

The material used in this study consists of 22 samples from the Tahar cut.

Control samples of this section are kept at the Department of Earth Sciences of the Scientific Institute in Rabat for possible future studies

### 3.2 Methods

The preparation of palynological slides in the laboratory is done in three steps as described by [1,41]: (1) sampling and physical treatment, (2) chemical attacks (HCl 10%, HF 40%) to dissolve the mineral matter

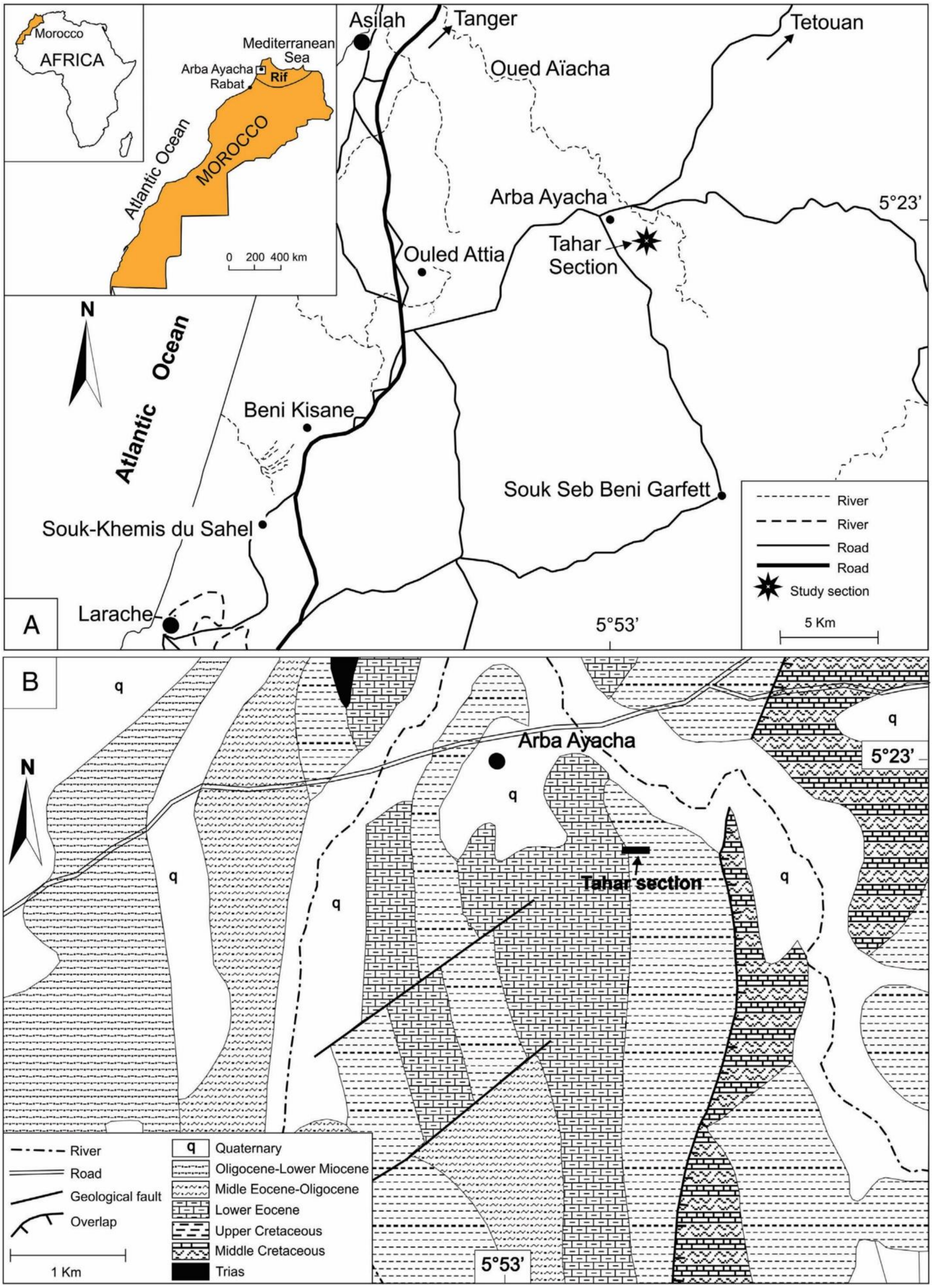


**Figure 3:** Geographic (A) and geological (B) location maps of the Tahar section (Arba Ayacha, Western External Rif, Northern Morocco); B, adapted from the 1/500,000 geological map of the Rif [21].

and preserve the organic matter contained in the sediments, (3) mounting the collected organic matter between slide and coverslip for microscopic study.

The determination of the paleoenvironment in this study is based on the relative proportions of dinokysts (marine organisms) to spores and pollen grains (continental organisms) in the palynological assemblage [42]. Thus, the S/D ratio indicates the continental influence on the depositional environment. It is also calculated with the formula of Versteegh [43] ratio sporomorphs (spores and pollens) / dinokysts (dinokysts and acritarchs) (S/D),

(S/D = nS/(nD + nS) with n= number.

Thus, we will qualify as a continental paleoenvironment, any environment whose sedimentary deposit contains a palynological assemblage consisting solely of spores, pollen grains and organic matter (wood debris).

On the other hand, if the palynological assemblage contains dinokysts and chitinous internal tests of microforaminifera in much higher proportions than the spores and pollen grains, with the presence of amorphous organic matter, we will say that this Paleoenvironment is marine.

When the proportions of dinokysts (marine organisms), spores and pollen grains (continental organisms) are more or less equal, we speak of deposition in a lacustrine or estuarine environment. However, the slight dominance of one species in proportion shows a continental or marine influence.

The depositional environment can also be determined based on the relative proportions of certain intraspecific groups of dinokysts that have a distribution preference along a neritic to oceanic transect.

The ratio of autotrophic to heterotrophic dinocysts or peridinioides/gonyaulacoides (P/G) ratio (P/G = nP/(nP + nG) sensu Versteegh [43] provides information on the productivity of the sea surface.

The ratio between the number of dinocysts characterizing the internal neritic environments (IN) and the number of dinocysts characterizing the external neritic environments (ON) or IN/ON ratio is calculated according to the formula: IN/ON = nIN/(nIN + nON) [43,44]. It provides information on the paleo-depth.

Other curves have been developed based on certain dinokyst groups that characterize a particular depositional environment, including:

- *Areoligera* Group: It includes dorsoventrally compressed gonyaulacoides skolochorates taxa, such as *Areoligera* spp. and *Glaphyrocysta* spp. It characterizes inland and coastal neritic depositional environments [4,6,44-47,].

- The *Spiniferites* Group consists of proximochorate and cosmopolitan gonyaulacoid cysts including *Spiniferites* spp. and *Achomosphaera* spp. It characterizes an outer neritic environment; [5,6,44-46,48-54,74,75].

- The *Senegalinium* Group includes cornucavate peridinioid cysts, such as *Cerodinium* spp., *Palaeocystodinium* spp., *Spinidinium* spp., *Senegalinium* spp., *Isabelidinium* spp. and *Deflandrea* spp. that are heterotrophic cysts marking a neritic to oceanic depositional environment. This group is associated with nutrient and high productivity levels [44-46,55,56].

- The *Fibrocysta* Group consists of fibrous, proximate, chorate gonyaulacoid cysts such as *Fibrocysta* spp., *Kenleyia* spp., *Cordosphaeridium* spp., *Operculodinium* spp., *Carpatella* spp, *Damassadinium californicum*, and *Cribroperidinium* spp. This group generally characterizes an inner neritic depositional environment [6,44,47,51,57-59].

- The *Lejeunecysta* Group is composed of cornucavate proto-peridinoid cysts with proximate acavate and characterizes areas of high productivity [6,44,50,53,60-62].

- *Impagidinium* spp. is instead composed of proximochorate gonyaulacoid cysts that are typical of oceanic marine environments [6,44,45,53,54,58,63-66].

- *Palaeohystrichophora* spp. consists of the peridinian cysts *Palaeohystrichophora infusorioides* and *Palaeohystrichophora palaeoinfusa.* It characterizes an external neritic environment [6,52].

- *Odontochitina* spp. consists of the *Odontochitina costata, Odontochitina operculata, Odontochitina porifera,* and *Odontochitina tabulata* cysts. It characterizes an external neritic environment [6,52,66].

## IV. RESULTS AND DISCUSSIONS

Quantitative palynological analysis of the Tahar section sediments revealed significant variations in the relative abundance of dinoflagellate cyst groups, sporomorphs, and in IN/ON, P/G and S/D ratios (Figure 4). These variations, which probably reflect changes in paleoenvironments and paleoclimates, revealed twelve (12) intervals, from A to L, that follow each other from the bottom to the top of the Tahar section:

### 4.1. A Interval (Th1-Th3)

A Interval (Th1-Th3) contains Upper Maastrichtian sediments. It is marked by a diversified palynological material (up to 46 species at TH2), abundant and dominated by species of the *Spiniferites* group (*Spiniferites* spp. and *Achomosphaera* spp.) with a relative frequency of 33% at Th1 and 40% at Th2, generating low IN/ON ratios of the order of 0.1. The *Areoligera* and *Fibrocysta* groups are present with low frequencies of about 11% at Th1 and 6% at Th2 respectively. We note the presence of the *Senegalinium* group in low proportion in this interval (12% at Th2) implying a low P/G ratio (0.02).

The preponderance of the *Spiniferites* group (40%) marking an outer neritic depositional environment[4,6,44-47,52,74,75] over the *Areoligera* and *Fibrocysta* groups characterizing inner neritic environments, as well as the low IN/ON (0.1) and P/G (0.02) ratios, allow us to suggest, for the A interval, an outer neritic marine environment without productivity, given the low proportions of the *Lejeunecysta* and *Senegalinium* groups

The absence of continental *sporomorphs* (0%) confirms the suggestion of an outer neritic environment without productivity and thus without continental influence for the A interval.

**4.2. Interval B (Th4)**

This interval corresponds to the Th4 sample of Maastrichtian age. Deposits in this interval show an increase in the relative frequency of the *Fibrocysta* and *Areoligera* groups, indicative of inner neritic environments [4,6,44,47,51,57-59], from 15% (at Th3) to 33% (at Th4) and from 0% (at Th3) to 7% (at Th4) respectively. The *Spiniferites* group, which characterizes the outer neritic environments, shows a slight increase in its relative frequency but does not exceed that of the *Fibrocysta* and *Areoligera* groups, which results in an average IN/ON=0.51 ratio. Because of the absence of peridinoid dinoflagellates and sporomorphs in the B interval, the P/G and S/D ratios are zero (0).

The preponderance of the *Fibrocysta* and *Areoligera* groups over the *Spiniferites* group and its mean IN/ON ratio coupled with the low P/G and S/D ratios indicate a non-productive inner neritic depositional environment in interval B (Th4), which could be explained by a slight drop in sea level from the previous interval (interval A).

**4.3. C interval (Th5-Th7)**

The C interval starts from sample Th5 to Th7 (Upper Maastrichtian). It is dominated by the *Spiniferites* group (up to 40% at Th5) which characterizes the outer neritic environments, followed by the *Fibrocysta* and *Areoligera* groups with relative frequencies of 19% (Th6) and 12% (Th5) respectively which implies low IN/ON ratios (0.2 at Th6). There is also an increase in the proportions of the *Senegalinium* group from Th6 (18%) to Th7 (27%), resulting in a slight increase in the P/G ratio in this interval (0.2 to 0.3). The absence of continental sporomorphs in this interval implies a zero S/D ratio, thus a distance from the shore.

The slight preponderance of the *Spiniferites* group over the *Fibrocysta* and *Areoligera* groups, coupled with low IN/ON, P/G and S/D ratios suggest a shallow outer neritic environment with low productivity for the C interval. This would be reflected in a slight rise in sea level.

**4.4. D interval (Th7a-Th7b')**

Interval D, from Th7a to Th7b' (Upper Maastrichtian) is dominated by marker species of inner neritic environments with the acme of *Manumiella seelandica* at Th7b' (84%) and the abundance of the *Fibrocysta* group (up to 52% at Th7a and 16% at Th7b) which results in a high IN/ON ratio (0.9 at Th7b'). In this interval, there is a strong increase in the P/G ratio from 0.01 (at Th7a) to 0.9 (at Th7b'), which reflects an increased productivity at Th7b'. There is also a considerable decrease in species diversity from 54 species in the previous C interval (Th6) to 16 species at Th7b. This change, very important in the biodiversity and in the relative abundance of dinoflagellate taxa, could be explained by the major crisis of the end of the Cretaceous.

The acme of *M. seelandica* is considered indicative of low salinity or even brackish conditions [7,8], but also of shallow depths and cold climatic conditions [5,8,67,68].

The low representativeness of the *Spiniferites* group (4%) at Th7b' and *Impagidinium* spp. (0.5%) in the D interval, coupled with peaks of *Manumiella seelandica* (84%) at Th7b' and the *Fibrocysta* group (52%) at Th7a suggest an inner neritic environment at Th7b' during a phase of marine regression and widespread cold climatic conditions at the end of the Maastrichtian.

**4.5. E interval (Th7c)**

Interval E consists of the Danian Th7c sample. It is characterized by a slight dominance of the *Spiniferites* group (>3%) which characterizes the outer neritic environments over the *Fibrocysta* (2%) and *Areoligera* (less than 1%) groups which characterize the inner neritic environments.

The proportion of the *Senegalinium* group (12%) is low and results in a low P/G ratio (0.1), thus no productivity [44-46,55,56]. The absence of sporomorphs also leads to a zero S/D ratio.

The slight preponderance of the *Spiniferites* group (>3%) over the *Fibrocysta* (2%) and *Areoligera* (less than 1%) groups associated with very low P/G (0.1) and S/D (0) ratios suggest an outer neritic environment of very low productivity marking a slight marine transgression.

**4.6. F interval (Th7d)**

Dated from the Danian, the F interval is dominated by the *Fibrocysta* group (31%) which characterizes inner neritic environments, followed by the *Spiniferites* group (20%) characterizing outer neritic environments and the *Senegalinium* group (15%) associated with productivity [44-46,55,56]. The weak presence of peridinoid dinokysts (*Senegalinium* group) in this interval leads to a low P/G ratio (0.1), thus no productivity.

The preponderance of the *Fibrocysta* group (31%) over the *Spiniferites* group (20%) favoring a high IN/ON=0.6 ratio, as well as the low P/G ratio (0.1) suggest an inner neritic environment, reflecting a relative decrease in sea level

**4.7. G interval (Th7e-Th7f)**

The G interval, which includes Th7e and Th7F samples, is dated to the Sélandien-Thanétien. It is characterized by a dominance of the *Spiniferites* group (33%) at Th7e over the Fibrocysta (2%) and Areoligera (<1%) groups with a low IN/ON ratio (0.3) at Th7f. Low P/G (0.06) and S/D (0.05) ratios imply lack of productivity and a depositional environment far from shore.

The preponderance of the S*piniferites* group (33%) over the *Fibrocysta* (2%) and *Areoligera* (less than 1%) groups associated with very low IN/ON (0.3), P/G (0.06) and S/D (0.05) ratios suggest an outer neritic environment with very low biological productivity for the G interval, reflecting a rise in sea level compared to the previous interval.

**4.8. H Interval (Th8)**

The H interval (Sélandien-Thanétien) is marked by an extreme rarity of dinoflagellate and continental sporomorph cysts (non-saccate spores and pollen). Only 14 bissacates and 1 specimen of *Spiniferella cornuta* were observed in this sample, whereas it is known that bissacates can be deposited very far from their formation environment. This results in zero S/D, P/G and IN/ON ratios, making it difficult to determine the paleoenvironment in this interval. In addition, the brownish or golden color of the marls in this interval may indicate that the palynological material could be more or less oxidized.

**4.9. I Interval (Th8a)**

Interval I, framing sample Th8a (Selandian-Thanetian) is dominated by *Impagidinium* spp. (24%) which characterizes oceanic marine environments [44,53,54,58,66], followed by the *Fibrocysta* (17%), *Areoligera* (13%), and *Spiniferites* groups (14%). The absence of continental sporomorphs in this interval results in a zero S/D ratio and thus no continental influence. The P/G ratio remains low (0.01).

The slight preponderance of *Impagidinium* spp. (24%) over the *Fibrocysta* (17%), *Areoligera* (13%) and *Spiniferites* (14%) groups, combined with the low P/G and S/D ratios suggests for interval I, a marine oceanic environment without productivity that would result in a marine transgression.

**4.10. J interval (Th9)**

This interval frames the Th9 sample of Sélandien-Thanétien age. Deposits in this interval are marked by the disappearance of *Impagidinium* spp. (0%) in favor of the *Spiniferites* group (6%), which characterizes outer neritic environments, and the *Senegalinium* group (7%), associated with nutrient and high productivity levels. The *Fibrocysta* (4%) and *Areoligera* (<1%) groups, indicators of inner neritic environments, are represented in low proportions, resulting in a low IN/ON ratio (0.4). The low P/G (0.09) and S/D (0) ratios imply that there is no productivity and very little continental influence in the J interval.

The preponderance of the *Spiniferites* Group (6%) over the *Fibrocysta* (4%) and *Areoligera* (<1%) groups and the low IN/ON (0.4), P/G (0.09), and S/D (0) ratios indicate, for the B interval, an outer neritic depositional environment.

**4.11. K interval (Th9a)**

Dated Ypresian, the K interval is dominated by the *Fibrocysta* group (43%) which characterizes inner neritic environments [6,44,47,51,57-59], followed by *Apectodinium* spp. (17%) which is related to warm conditions [51,64,73], and the *Spiniferites* group (16%) which characterizes external neritic environments. The high proportion of the *Fibrocysta* group (43%) results in a high IN/ON ratio (0.7). The low P/G (0.007) and zero S/D (0) ratios imply that there is no productivity and that the continental influence is very weak. Note that the highest concentration of calcium carbonate $CaCO_3$ (33%) was observed in the Tahar section in the K interval.

The global peak of the genus *Apectodinium* was recorded between the end of the Thanetian and the base of the Ypresian (NP9b-baseNP10 calcareous nannoplankton zones), in the interval of the Paleocene-

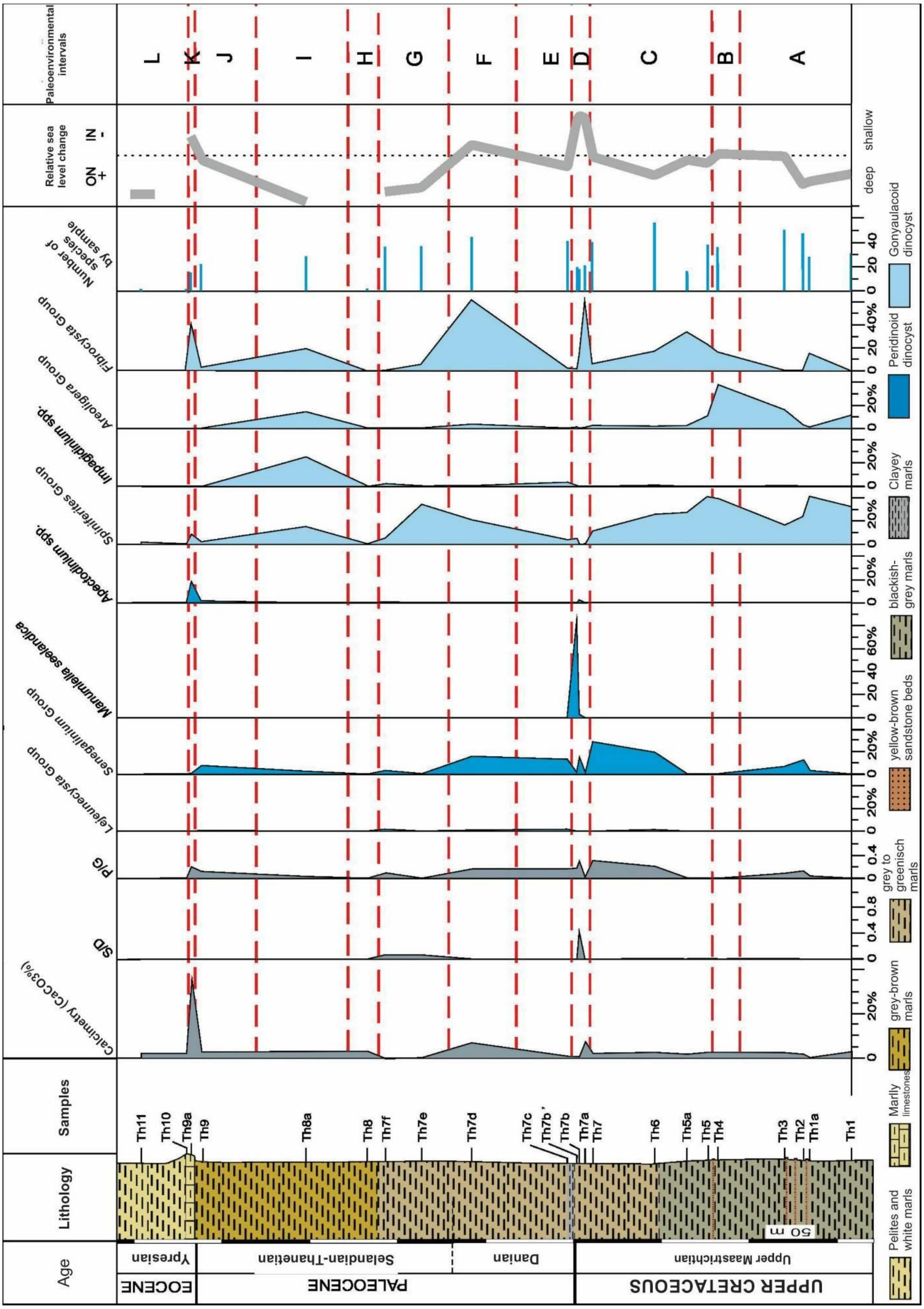

**Figure 4:** Tahar section: calcimetry curve; Sporomorph to Dinoflagellate ratio curve; Peridinoid to Gonyaulacoid ratio curve (productivity); relative abundances of morphologically and ecologically related dinoflagellate cysts; species diversity per sample; relative sea level change curve (IN/ON) and palynological intervals

Eocene Thermal Maximum (PETM) [16-20,64,69-72]. In the Tahar section, the oldest *Apectodinium* acme is moderate (16%). This acme is represented primarily by *A. quinquelatum* in the K interval, but is associated with Eocene dinokyst species there. Thus, the oldest *Apectodinium* acme (Upper Thanetian) is missed (sediments not sampled) in the Tahar section [6].

The preponderance of the *Fibrocysta* group (43%) over the *Spiniferites* group (16%) with its corrolary of high IN/ON ratio (0.7), as well as the low P/G (0.007) and S/D (0) ratios suggest an inner neritic environment without productivity for the K interval with a drop in sea level, under relatively warm climatic conditions.

**4.12. Interval L (Th10-Th11)**

This interval is Ypresian in age and marked by a scarcity of dinokysts. The *Spiniferites* group is represented up to 41% in sample Th11 with only 5 specimens, while sample Th10 is completely azoic. This implies zero IN/ON, P/G and S/D ratios for this interval. This scarcity of palynomorphs could be due to unsuitable fossilization conditions.

The presence of the *Spiniferites* group (41%) in this interval allows us to attribute an outer neritic depositional environment, which would reflect a marine transgression.

## V. CONCLUSION

Qualitative and quantitative analysis of the palynological content of the Tahar section, shows important changes in the relative abundance of morphologically and ecologically related dinokyst groups, reflecting variations in the paleoenvironment and Paleoclimate.

This analysis indicates that the Upper Cretaceous deposits of the Tahar section in Morocco were deposited in a marine environment of external neritic type, under a transgressive regime accompanied by a cooling period at the end of the Maastrichtian. This interpretation is based on the preponderance of the *Spiniferites* group that characterizes an outer neritic environment over the *Fibrocysta* and *Areoligera* groups characterizing inner neritic environments, hence the high IN/ON ratios and the abundance of the species *Manumiella seelandica* at the end of the Maastrichtian. The acme of *M. seelandica* is considered indicative of low salinity or even brackish conditions, but also of shallow depths and cold climatic conditions.

The transition from Maastrichtian to Danian is marked here by a slight preponderance of the *Spiniferites* group over the *Fibrocysta* and *Areoligera* groups resulting in a slight marine transgression.

The Paleogene is marked by a generalized transgression from the Danian to the Sélandien, then a regression at the end of the Thanetian followed by a transgression in the Ypresian.

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