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EVIDENCE OF A PALYNOLOGICAL BIOEVENT MARKING THE CRETACEOUS-PALEOGENE (K-PG) BOUNDARY IN THE OFFSHORE BASIN OF CÔTE D'IVOIRE (WEST AFRICA)

Ismaël Ben Ouattara ^{1,*}, Chiaye Larissa Koffi épouse Coulibaly ², Blandine Akissi Egoran ³ and Zeli Bruno Digbehi ¹

¹ Department of Geosciences, Laboratory of Geology, Mineral Resources, and Energy, Felix Houphouët-Boigny University, Côte D'Ivoire.

² Department of Mines and Reservoirs, Geological and Mining Sciences Training and Research Unit, University of Man, Man, Côte D'Ivoire.

³ Department of Coastal Sciences, Faculty of Marine Sciences, University of San Pedro.

* Corresponding Author

ORCID Details

Ouattara Ismaël Ben: <https://orcid.org/0009-0004-1300-6409>

Chiaye Larissa Koffi épouse Coulibaly: <https://orcid.org/0000-0002-0505-0715>

Blandine Akissi Egoran: <https://orcid.org/0009-0002-2809-681X>

Zeli Bruno Digbehi: <https://orcid.org/0000-0002-9018-3546>

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ABSTRACT

The reliable recognition of the Cretaceous - Paleogene (K-Pg) boundary is a major concern in applied biostratigraphy, especially in petroleum basins where this boundary constrains the calibration of major regional unconformities. This study examines, based on six exploration wells from the offshore Côte d'Ivoire basin (OB-1X, OB-3X, OB-6X, OB-4X, OB-5X and OB-2X, distributed across blocks B4, A7 and C02), the reproducibility of a single palynological bioevent: the joint first downhole occurrence of the dinoflagellates *Cerodinium granulostriatum* and *Andalusiella gabonensis*. This bioevent marks the K-Pg boundary in all six studied wells, consistently bracketed downhole by a characteristic Paleocene assemblage dominated by other dinocyst associations, and, further downhole, by the Maastrichtian *Andalusiella* assemblage sensu lato. A detailed, well-by-well analysis of the palynological succession across this boundary shows remarkable consistency in the taxa involved and their relative order of appearance. This exceptional robustness, discussed in light of the globally non-extinctive but strongly reorganised dinocyst assemblage behaviour documented at international reference K-Pg sections, as well as in light of previous work on the Ivorian margin, gives this bioevent a first-order value for regional correlation and petroleum exploration.

Keywords: Cretaceous-Paleogene boundary; K-Pg; Palynostratigraphy; Dinocysts; *Andalusiella*; *Cerodinium*; Offshore Côte d'Ivoire.

1 INTRODUCTION

The Cretaceous-Paleogene boundary (K-Pg) marks one of the most extensively studied biological and sedimentary events in Earth's history. In sedimentary basins exploited for their hydrocarbon resources, this boundary also carries major operational significance: it separates successions with often very different petrophysical and geochemical properties, and it frequently serves as a reference for calibrating regional unconformities and inter-well correlation schemes.

On the offshore margin of Côte d'Ivoire, recognition of this boundary was documented as early as the micropalaeontological data of [1], and was subsequently confirmed by the biostratigraphic and palaeoenvironmental synthesis of [2] on the Cretaceous deposits off Abidjan. On the palynological side, the regional framework established by [3] for the Senegal and Côte d'Ivoire basins very early highlighted the stratigraphic value of latest Maastrichtian dinoflagellate assemblages, in particular of the genus *Andalusiella*, a West African endemic taxon later revised by [4].

While the stratigraphic value of these taxa for the Maastrichtian is well established, the question of the actual reproducibility, across several independent wells within the same basin, of a specific bioevent marking the K-Pg boundary itself remains rarely quantified systematically in the regional literature. The present study proposes to address this specific point, based on a comparative examination of palynological data from several exploration wells located in the Ivorian offshore basin.

The objective of this article is to show that a single palynological bioevent can consistently mark the K-Pg boundary across all of these wells, and by extension across the basin as a whole, to discuss its robustness with respect to other available biostratigraphic criteria (micropalaeontology, nannostratigraphy), and to assess its significance for regional correlation and petroleum exploration.

The present study is based on six exploration wells (Figure 1) drilled in the Ivorian offshore basin: OB-1X and OB-2X (block A7), OB-3X, OB-4X and OB-5X (block B4), and OB-6X (block C02). These six wells are distributed across three distinct blocks on the Abidjan margin.

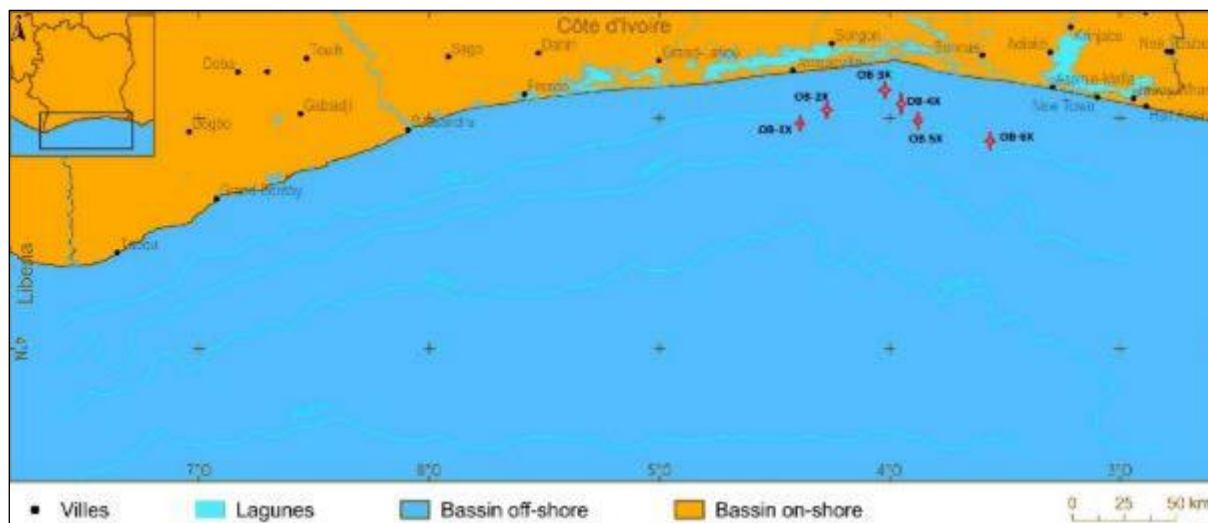


Figure 1: Location of the six wells in the Ivorian basin

2 MATERIAL AND METHODS

The material studied in each well consists of drill-cuttings samples, collected at regular intervals along the well. The number of samples analysed varies from one well to another.

Palynological preparation of the samples (drill cuttings) follows the classic acid-maceration protocol routinely used in the petroleum industry. A mass of approximately 20 g of rock is successively subjected to a *hydrochloric acid attack* (37% HCl) to dissolve carbonates, then to a *hydrofluoric acid attack* (70% HF, 15 hours under a fume hood) to dissolve the silicate fraction, followed by a *second hydrochloric acid attack* intended to remove newly formed fluorosilicate gels; each step is followed by rinsing with distilled water until neutrality is reached. The organic residue is then sieved through a 10 or 15 µm mesh to remove residual mineral particles, then mounted between slide and coverslip using an adhesive called Loctite 358, before finally being observed under transmitted-light microscopy. The taxonomic

determination of the palynomorphs adopted follows the morphographic classification of [5] for spores and pollen grains, and the indexes of [6-7-8] for dinoflagellate cysts. These taxa were compared with those from palynological studies carried out mainly on the Cretaceous and Tertiary of West Africa, and to a lesser extent on the Cretaceous and Tertiary of South America and elsewhere in the world. These studies include those of: [9]; [10]; [11]; [12]; [4]; [3]. The reports of [13], [14], [15] were also used.

3 RESULTS

This section presents, well by well, the palynological succession observed on either side of the K-Pg boundary, followed by a comparative synthesis of the entire dataset.

3.1 Well OB-1X (block A7)

In well OB-1X, the samples analysed for palynology yield, within the Tertiary interval (5110 - 5570 ft), Paleogene palynomorphs composed of the dinocysts *Areoligera coronata*, *Cordosphaeridium fibrospinosum*, *Fibrocysta lapacea* and *Lejeunecysta hyalina* (at 5330 ft), together with *Adnatosphaeridium multispinosum* and *Kallosphaeridium yorubaensis* (at 5360 ft), in association with the spores and pollen grains of *Verrucatosporites usmensis* (at 5330 ft). This assemblage, entirely distinct from the Maastrichtian assemblage described below, is indicative of a Paleogene age and contains no representative of the genus *Andalusiella* nor of *Cerodinium granulostriatum*.

The K-Pg boundary is placed at 5570 ft, the position at which the joint first downhole occurrence of *Cerodinium granulostriatum* and *Andalusiella gabonensis* is recorded. This attribution is confirmed by the continued downhole enrichment of the *Andalusiella* assemblage: F.D.O. of *Andalusiella mauthei* at 5720 ft, followed by the F.D.O. of *Andalusiella ivoirensis* and *Andalusiella polymorpha* at 5750 ft. No isolated or contradictory occurrence of Maastrichtian taxa was recorded above 5570 ft in this well.

3.2 Well OB-3X (block B4)

Well OB-3X constitutes a special case within the dataset: the Paleocene interval it crosses (1150 - 1240 m), dated by other disciplines, was not subject to any palynological sampling (0 samples analysed for palynology over this interval), so that the Tertiary assemblage overlying the K-Pg boundary could not be characterised palynologically here. The K-Pg boundary is nevertheless positioned at 1240 m, based solely on the first downhole occurrence, at this same depth, of *Andalusiella gabonensis* and *Cerodinium granulostriatum*, which mark the top of the palynological coverage available in this well.

This attribution is supported by the downhole confirmation of the Maastrichtian assemblage: F.D.O. of *Andalusiella ivoirensis* at 1350 m, followed by the F.D.O. of *Andalusiella mauthei* and *Andalusiella mauthei aegyptica* at 1370 m. The consistency of the order of appearance of these taxa (first the *Cerodinium granulostriatum* / *Andalusiella gabonensis* pair, then *A. ivoirensis*, then *A. mauthei* and *A. mauthei aegyptica*) faithfully reproduces the sequence observed in the other wells of the dataset, despite the lack of control on the overlying assemblage.

3.3 Well OB-6X (block C02)

In well OB-6X, the palynomorphs recorded in the first analysed sample of the Tertiary interval (4540 ft) down to 4570 ft are very rare: only two specimens of the dinocyst *Cleistophaeridium diversispinosum* and two specimens of the miospore *Cyathidites minor* were observed, which does not allow a precise age attribution on the basis of this sample alone. The base of the Tertiary interval is nevertheless placed at 4600 ft, based on the first downhole occurrence, at this depth, of the Maastrichtian dinocyst markers.

The top of the Maastrichtian strata is thus placed at 4600 ft by the F.D.O. of *Cerodinium granulostriatum*; in this well, the companion species *Andalusiella gabonensis* is not recorded at this same depth, but the *Andalusiella* assemblage develops rapidly downhole: penetration into the lower Maastrichtian section is indicated as early as 4780 ft by the first downhole occurrence of *Andalusiella ivoirensis* and *Andalusiella mauthei aegyptica*, in association with other Maastrichtian species (*A. gabonensis*, *A. mauthei*, *Dinogymnium acuminatum*, *Senegalinium bicavatum*, *Senegalinium obscurum*, *A. rhomboids*).

3.4 Well OB-5X (block B4)

In well OB-5X, the Paleocene interval (5500 - 5785 ft) yields a dinocyst assemblage composed of *Tectatodinium rugulatum*, *Cordosphaeridium fibrospinosum* and *Adnatosphaeridium multispinosum* (at 5500 ft), with no significant associated miospore. This assemblage, dominated by genera different from those of the Maastrichtian assemblage, is indicative of a Paleocene age and contains no representative of the genus *Andalusiella*.

The Paleocene sediments rest on the Maastrichtian section at the interpreted position of the K-Pg boundary at 5785 ft, marked by the first appearance of the Maastrichtian index taxa: the joint F.D.O. of *Cerodinium granulostriatum* and *Andalusiella gabonensis*. This attribution is reinforced by the F.D.O. of *Andalusiella mauthei* at 5920 ft, immediately below.

3.5 Well OB-4X (block B4)

In well OB-4X, the Tertiary interval (4440 - 4480 ft) yields a dinocyst assemblage composed of *Muratodinium fimbriatum* (at 4440 ft), then *Phelodinium magnificatum*, *Apectodinium homomorphum* and *Paleocystodinium golzowense* (at 4460 ft), indicative of a Paleocene age. As in the other wells, this assemblage is entirely devoid of representatives of the genus *Andalusiella* and of *Cerodinium granulostriatum*.

The top of the Maastrichtian sediments (K-Pg boundary) is placed at 4520 ft, at the highest joint occurrence of *Andalusiella gabonensis* and *Cerodinium granulostriatum*. This attribution is confirmed by the F.D.O. of *Andalusiella mauthei* at 4700 ft, then by the F.D.O. of *Palaeocystodinium australinum* and *Andalusiella ivoirensis* at 5310 ft.

3.6 Well OB-2X (block A7)

Well OB-2X is the most richly sampled. The palynomorph assemblages recorded in the first analysed sample of the Tertiary interval (3040 m) are entirely composed of dinocyst specimens, including *Homotryblium tenuispinosum*, *Adnatosphaeridium multispinosum*, *Diphyes colligerum* and *Muratodinium fimbriatum*, indicative of an age no younger than the Eocene. The occurrence, in the next sample, of the species *Damassadinium mutabilis* at 3100 m is suggestive of the penetration of Paleocene sediments at this depth; it should be noted that the genus *Damassadinium* is also recognised internationally as a characteristic marker of the lowest Danian at the El Kef reference section, Tunisia [16], which constitutes an interesting convergence with the signal recorded here on the Ivorian margin.

The dinocysts recorded in the interval 3040 - 3190 m are common to abundant and show a regular distribution, in association with rare miospores, represented only by specimens of a single species. The presence of Maastrichtian dinocysts at 3220 m suggests the base of the Danian interval, that is, the K-Pg boundary, at this depth. The top of the Maastrichtian strata is indeed indicated, at this same depth of 3220 m, by the first downhole occurrence of the dinocyst *Cerodinium granulostriatum*. This attribution is confirmed by the F.D.O. of *Andalusiella gabonensis* and *Palaeocystodinium australinum* at 3250 m, only slightly deeper, these index taxa being associated with other non-diagnostic palynomorphs including a few rare miospores.

3.7 Comparative synthesis

In all six wells studied, the K-Pg boundary is marked by the joint or near-joint first downhole occurrence of the dinoflagellates *Cerodinium granulostriatum* and *Andalusiella gabonensis*. This bioevent is systematically preceded, uphole, by a Tertiary assemblage dominated by distinct dinocysts and devoid of any representative of the genus *Andalusiella* (in the five wells where this assemblage could be characterised palynologically), and systematically followed, downhole, by the progressive enrichment of the Maastrichtian assemblage of the genus *Andalusiella* sensu lato, including, depending on the well, *A. ivoirensis*, *A. mauthei*, *A. mauthei aegyptica*, *A. dubia* and *A. polymorpha*. Table 1 summarises this expression for each of the six wells.

Table 1: Palynological expression of the K-Pg boundary in the six wells studied.

Well	Block	Depth of the K-Pg boundary	Taxon(a) marking the F.D.O. at the boundary	Overlying assemblage	Paleocene	Underlying Maastrichtian confirmation
OB-1X	block A7	5570 ft	<i>Cerodinium granulostriatum</i> + <i>Andalusiella gabonensis</i>	<i>Areoligera coronata</i> , <i>Cordosphaeridium fibrospinosum</i> , etc.		<i>A. mauthei</i> (5720 ft), <i>A. ivoirensis</i> , <i>A. polymorpha</i> (5750 ft)
OB-3X	block B4	1240 m	<i>Andalusiella gabonensis</i> + <i>Cerodinium granulostriatum</i>	Not sampled (0 palynological sample)		<i>A. ivoirensis</i> (1350 m), <i>A. mauthei</i> , <i>A. mauthei aegyptica</i> (1370 m)
OB-6X	block C02	4600 ft	<i>Cerodinium granulostriatum</i>	Very poor, non-diagnostic assemblage (2 specimens)		<i>A. ivoirensis</i> , <i>A. mauthei aegyptica</i> (4780 ft)

OB-5X	block B4	5785 - 5840 ft	<i>Cerodinium granulostriatum</i> + <i>Andalusiella gabonensis</i>	<i>Tectatodinium rugulatum</i> , <i>Cordosphaeridium fibrospinosum</i> , <i>Adnatosphaeridium multispinosum</i>	<i>A. mauthei</i> (5920 ft)
OB-4X	block B4	4520 ft	<i>Andalusiella gabonensis</i> + <i>Cerodinium granulostriatum</i>	<i>Muratodinium fimbriatum</i> , <i>Phelodinium magnificatum</i> , <i>Apectodinium homomorphum</i>	<i>A. mauthei</i> (4700 ft), <i>A. ivoirensis</i> (5310 ft)
OB-2X	block A7	3220 m	<i>Cerodinium granulostriatum</i>	<i>Homotryblium tenuispinosum</i> , <i>Damassadinium mutabilis</i> , etc.	<i>A. gabonensis</i> , <i>Palaeocystodinium australinum</i> (3250 m)

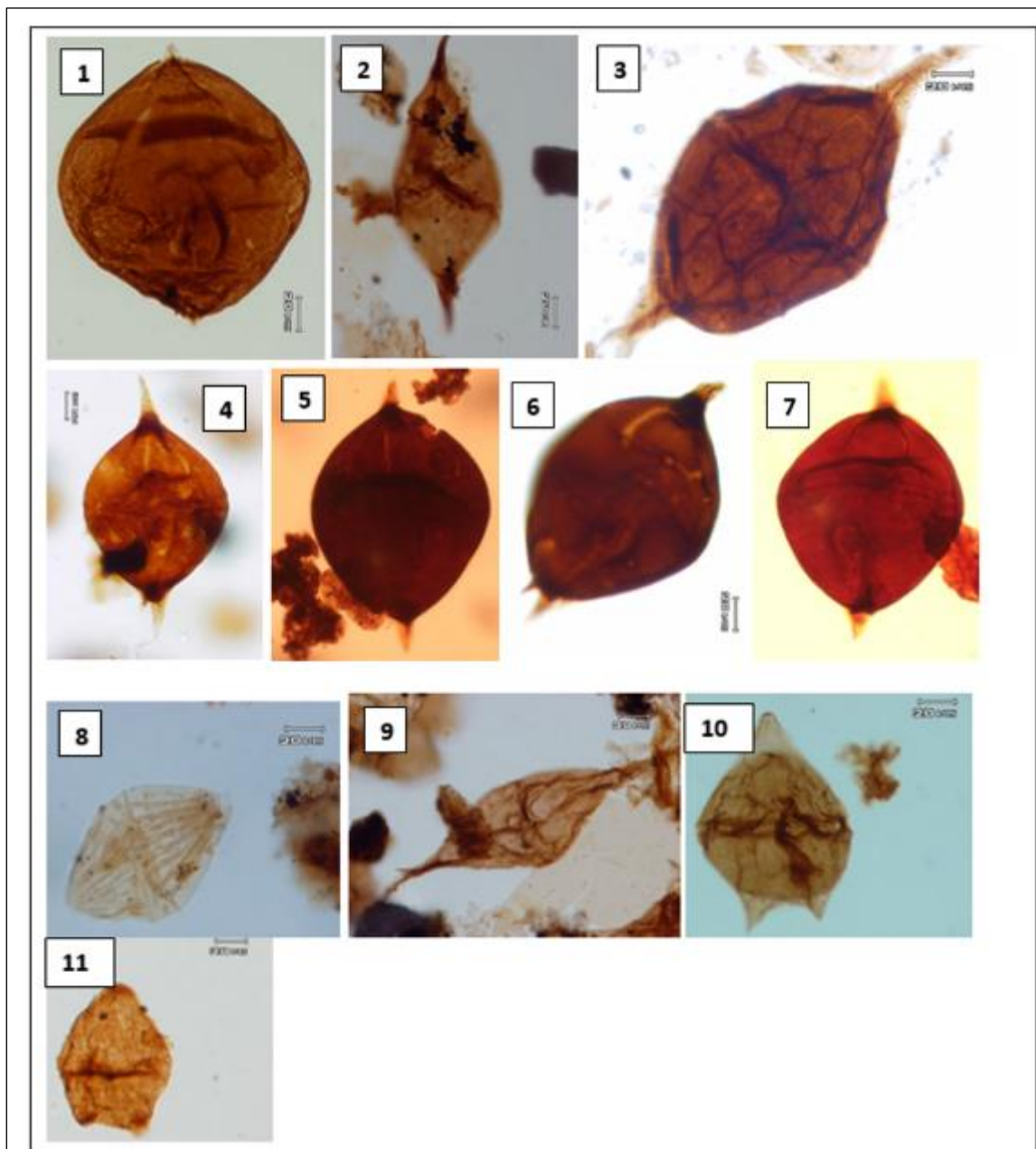


Figure 1: Maastrichtian assemblage

1-*Andalusiella Dubia*, 2-*Andalusiella gabonensis*, 3- *Andalusiella ivoirensis*, 4-*Andalusiella Mauthei*, 5-*Andalusiella Mauthei* subsp. *Aegyptica*, 6-*Andalusiella Plymorma*, 7- *Andalusiella Rhomboïdes*, 8- *Dinogymnium acuminatum*, 9- *Palaeocystodinium australinum*, 10- *Senegalinium bicavatum*, 11- *Senegalinium obscurum*,

No major exception or stratigraphic ambiguity was found across the entire dataset: the selected bioevent was never absent, duplicated, or inconsistently positioned relative to the other Maastrichtian or Paleocene markers available in each well. Across the six wells examined, the reproducibility of this bioevent, based solely on palynological data, therefore reaches 100%, a result rarely observed for a single biostratigraphic marker applied to a set of independent industrial wells. It should be noted that this reproducibility is observed despite considerable variability in the absolute depth of the boundary (from 1240 m in OB-3X to more than 5785 ft in OB-5X) and despite an uneven density of palynological sampling from one well to another, two factors that, had they played a dominant role in the recognition of the bioevent, should have introduced more inconsistencies into the dataset.

A second level of consistency, complementary to the mere presence/absence of the index taxa, deserves to be highlighted: in the wells where the overlying Paleocene assemblage could be characterised (OB-1X, OB-6X, OB-5X, OB-4X, OB-2X), it is systematically dominated by chorate dinocysts with well-developed ornamentation, associated with rare miospores, with none of these wells reporting the persistence, even residual, of a single representative of the Maastrichtian *Andalusiella* assemblage above the proposed boundary. This sharp break in assemblage composition, rather than a simple gradual change in dominance, is consistent with the globally synchronous character of dinocyst assemblage turnover described internationally at this same.

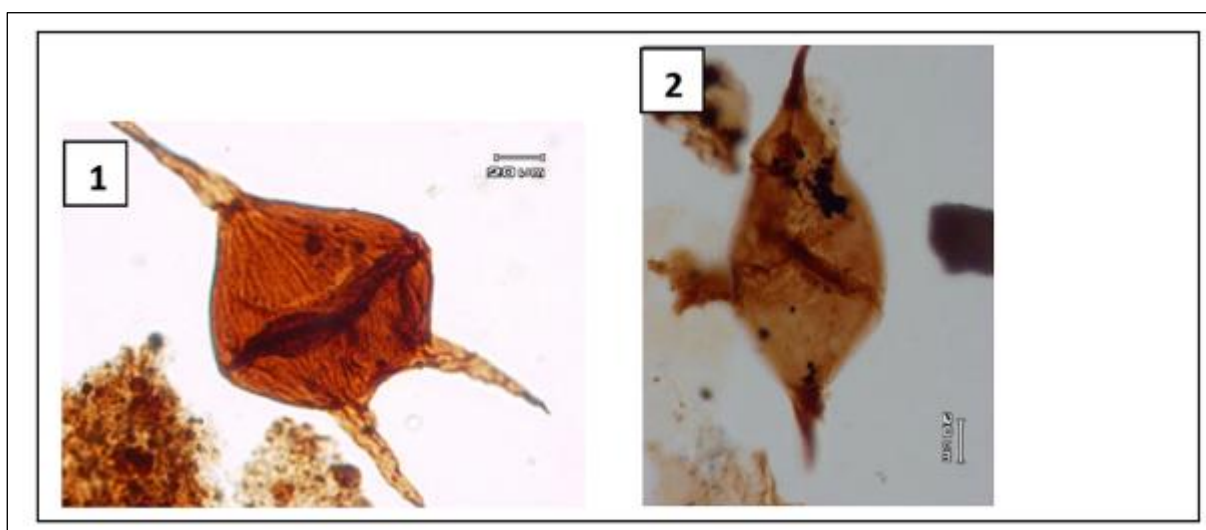


Figure 2: Index taxa of the K-Pg boundary

1-*Cerodinium granulostriatum*, 2- *Andalusiella gabonensis*,

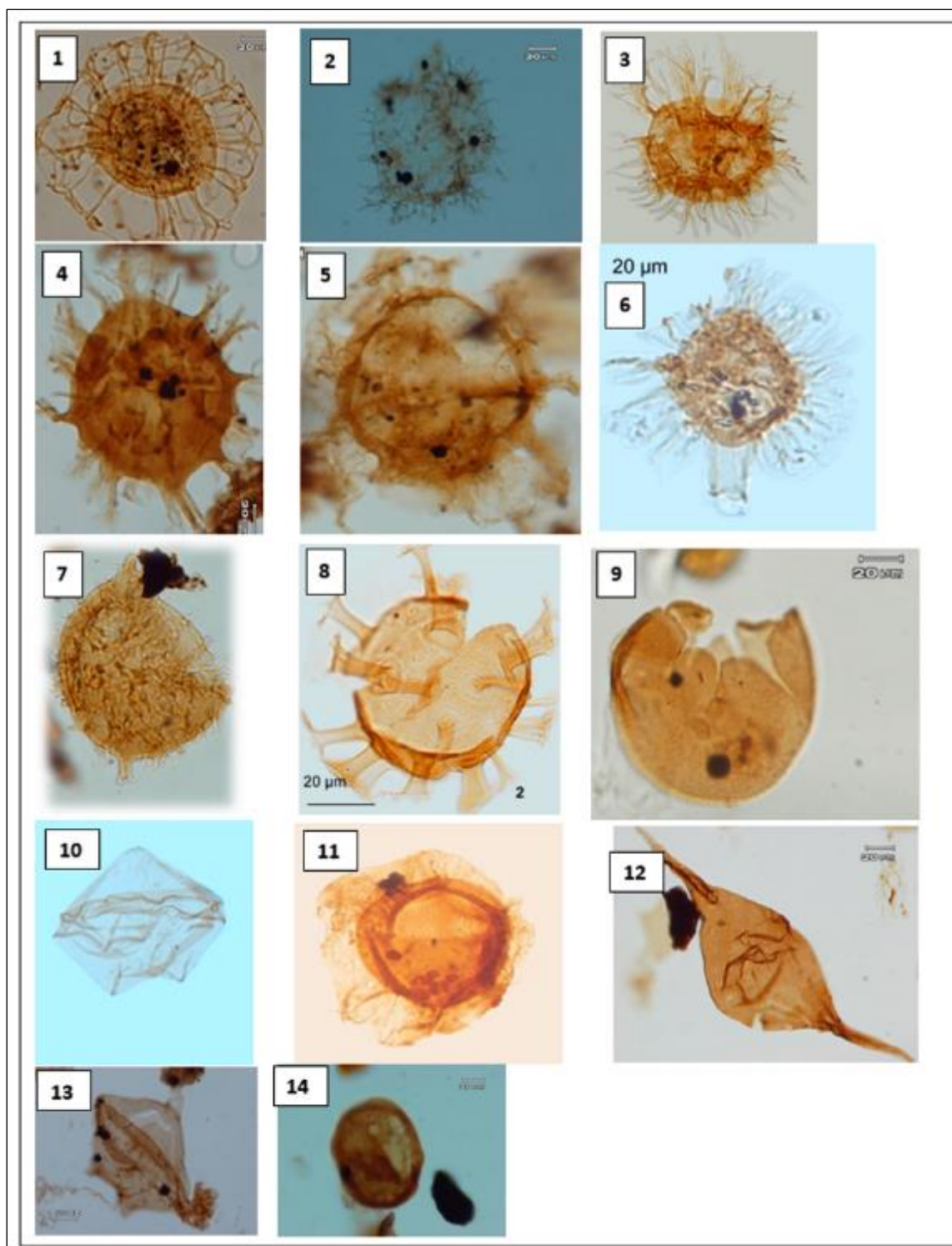


Figure 3: Paleocene assemblage

1-Adnato3phaeridium multispinosum, 2- Apectodinium homomorphum 3- Areoligera coronata, 4- Cordosphaeridium inodes, 5- Damassadinium mutabilis, 6- Diphyes colligerum, 7- Fibrocysta lapacea, 8- Homotryblum tenuispinosum, 9- Kallosphaeridium yorubaensis, 10- Lejeunecysta lata, 11- Muratodinium fimbriatum, 12- Paleocystodinium golzowense, 12- Phelodinium magnificatum, 13- Tectatodinium rugulatum.

4 DISCUSSION

The 100% reproducibility demonstrated here for the joint F.D.O. of *Cerodinium granulostratum* and *Andalusiella gabonensis* in the six wells studied fits within an already relatively dense body of regional work on the Ivorian margin and the Gulf of Guinea, whose conclusions it extends, refines and sometimes nuances.

On the Ivorian side alone, the micropalaeontological data of [1] and the biostratigraphic and palaeoenvironmental synthesis of [2] had already described the Cretaceous-Tertiary boundary off Abidjan as sharp and well expressed. The present study confirms this observation, but shifts it from a qualitative to a quantitative level: these two earlier studies did not involve a multi-well dataset subjected to a systematic reproducibility test, whereas the present article establishes that this sharpness holds strictly identically across six independent wells, distributed over three distinct blocks. No substantive divergence is noted between these earlier studies and ours; the difference is essentially methodological, our study offering a more extensive statistical test of what these authors had already sensed locally.

The stratigraphic value of the genus *Andalusiella* for the top of the Maastrichtian, as established by [4] from type material from the Ivorian basin, is also fully confirmed: the species *A. gabonensis*, at the core of the bioevent studied here, as well as *A. ivoirensis*, systematically associated downhole, are found in all six wells. Our study adds to this founding taxonomic work an operational dimension that it did not aim for: the demonstration that this stratigraphic value remains stable and reproducible when applied to data from independent industrial wells, rather than to the reference type material alone.

The most direct comparison, however, remains with the recent study by [17] on the academic “12 Frères” borehole at Fresco, in the southwestern sector of the Ivorian basin. This independent study, based on the systematic analysis of 76 dinocyst species, precisely identifies *Cerodinium granulostriatum* and *Andalusiella ivoirensis*, alongside *Odontochitina operculata* and the genus *Dinogymnium*, among the marker events of the Cretaceous-Paleogene transition. The similarity with our results is striking and concerns the two central taxa of our study; it differs, however, in the range of secondary taxa mobilised (*Odontochitina operculata*, *Dinogymnium* spp.), which are absent or not systematically reported in our six wells, suggesting that these additional markers could usefully enrich the recognition protocol proposed here rather than contradict it. The fact that two entirely independent datasets, one academic and taxonomically highly resolved, the other industrial and covering a distinct sector of the basin, converge on the same index taxa constitutes a strong argument in favour of the primary nature of the signal, and suggests a potentially broader significance than blocks B4, A7 and C02 alone.

On the same margin but in a more distal setting, the study [18] on early Paleogene dinocysts from ODP Site 959D (Côte d’Ivoire-Ghana transform margin) confirms the regional presence of species of the same West African tropical affinity, including *Andalusiella gabonensis*, but places greater emphasis, in characterising the transition to the Paleogene, on *Cerodinium diebelii* and *Damassadinium californicum* rather than on *C. granulostriatum*. This difference in taxonomic emphasis, rather than a contradiction, could reflect local palaeoenvironmental control: the ODP Site 959D occupies a more distal and more oceanic position than the six platform wells examined here, which could favour different species within the same regional assemblage. This same study also highlights the West African tropical affinity shared by *Andalusiella gabonensis* with the Niger Delta assemblages in Nigeria, which broadens the palaeobiogeographic significance of the signal studied here to the scale of the Gulf of Guinea.

At the international scale, finally, the general principle highlighted here, a clearly expressed but non-extinctive turnover of dinocyst assemblages at the K-Pg boundary, agrees with the observations made at the reference section (GSSP) of El Kef, Tunisia [16], and at Ouled Haddou, Morocco [19]. The major difference with these two North African sections lies in the nature of the taxa involved: cosmopolitan markers (*Damassadinium californicum*, *Carpatella cornuta*) define the base of the Danian there, whereas the Ivorian basin has a local and redundant pair of markers (*Cerodinium granulostriatum* / *Andalusiella gabonensis*), reflecting the palaeobiogeographic endemism specific to the West African margin. This regional specificity, far from weakening the comparison, constitutes a practical asset for correlation at the scale of the Ivorian basin itself.

Taken together, these comparisons reveal no major contradiction between our results and the existing literature, whether Ivorian, West African or international; on the contrary, they show a remarkable convergence, each study contributing a complementary level of resolution (taxonomic, spatial or palaeoenvironmental) to the same underlying signal.

5 CONCLUSION

The joint first downhole occurrence of the dinoflagellates *Cerodinium granulostriatum* and *Andalusiella gabonensis* marks the Cretaceous-Paleogene (K-Pg) boundary in all six exploration wells examined in this study, distributed across three distinct blocks of the Côte d’Ivoire offshore basin. This 100% reproducibility makes this bioevent the most robust palynological marker ever identified in this basin. This result extends and quantifies previous qualitative observations on the sharpness of this boundary in the Ivorian basin, and provides a correlation tool directly applicable to regional petroleum exploration.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

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Disclosure of conflict of interest

The authors declare no conflicts of interest regarding this manuscript.

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