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DINOFLAGELLATE CYSTS, PALYNOFACIES AND ORGANIC GEOCHEMISTRY OF THE CRETACEOUS-PALAEOGENE (K–Pg) BOUNDARY TRANSITION AT THE ELLÈS SECTION, NORTHEASTERN TUNISIA

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Abstract: A palynofacies study carried out across the Cretaceous–Palaeogene (K–Pg) boundary in the El Haria Formation at Ellès, northeastern Tunisia, revealed the presence of organic matter dominated by marine palynomorphs, mainly dinoflagellate cyst assemblages. Continental palynomorphs (sporomorphs) and amorphous organic matter (AOM) are also present in all samples. The total organic carbon (TOC) content is generally less than 0.7 wt.%. The Rock-Eval S1 parameters vary from 0.01 to 0.3 mgHC/g rock. The Rock-Eval S2 parameters vary from 0.15 to 0.57 mgHC/g rock. The hydrogen index (HI) and oxygen index (OI) values range from 61 to 214 mgHC/g TOC and 149 to 638 mgHC/g TOC, respectively. The Tmax values range from 420 to 440°C. The TOC, Rock-Eval pyrolysis and palynofacies analyses indicate that the El Haria Formation is characterized by immature organic matter type II and III and a low thermal alteration index (TAI). Also, the authors present in this paper the biostratigraphic, palaeoenvironmentl and palaeobiogeographic framework for the dinoflagellate cyst assemblages below and above the Cretaceous–Palaeogene boundary in the Ellès section.

Key words: Cretaceous–Palaeogene (K–Pg) boundary, dinoflagellate cysts; palynofacies, organic matter, Ellès section; Tunisia.

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INTRODUCTION

The Ellès section already has been the subject of several studies, based on mineralogy, geochemistry (Adatte *et al.*, 2002; Stüben *et al.*, 2002), biostratigraphy of planktonic and benthic foraminifera (Said-Benzarti, 1978; Karoui-Yaakoub, 1999; Zaaghbib-Turki *et al.*, 2000, 2001; Karoui-Yaakoub *et al.*, 2002; Coccioni and Marsili, 2007) and calcareous nannofossils (Gardin, 2002). This section has been proposed as a parastratotype and even as a new stratotype of the K–Pg boundary (Zaaghbib-Turki *et al.*, 2000, 2001; Karoui-Yaakoub *et al.*, 2002), since it contains, according to the latter authors, one of the most complete Cretaceous–Palaeogene (K–Pg) boundary transition and is better exposed than the El Kef stratotype section. Recent palynological studies, based on dinoflagellate cyst (dinocyst) assemblages from this section, indicated continuous sedimentation in the K–Pg transition (M'Hamdi *et al.*, 2013a) and permitted palaeoenvironmental and palaeobiogeographical interpretations (M'Hamdi *et al.*, 2013b, in press; M'Hamdi, 2014).

The aim of this paper is to present an analysis of the palynofacies and geochemistry, which combines Rock-Eval pyrolysis and TOC measurements at the K–Pg boundary transition in the Ellès section.

GEOLOGICAL BACKGROUND

The Ellès section is located near the small settlement of Ellès, between the cities of Siliana and Maktar, about 137 km from Tunis, 43 km from El Kef and 65 km from Kalaat Senan (Fig. 1). This section is well exposed in the Ellès Syncline (Pervinquière, 1903), with a complete Cretaceous–Palaeogene transition. The section sampled is oriented NW–SE, between Argoubet el Aïeicha and Jebel Madkour. It is similar to the section, studied by Zaaghbib-Turki *et al.* (2000, 2001). Its Lambert coordinates on the Maktar map (scale 1/50000) are: 426/295.7; 426.5/294.1. Specifically, it has the geographic co- ordinates: N35°56'40.4", E009°04'49.9" (Carthage) and N3 977974, E507310 (UTM coordinates) at an altitude of 725 m.

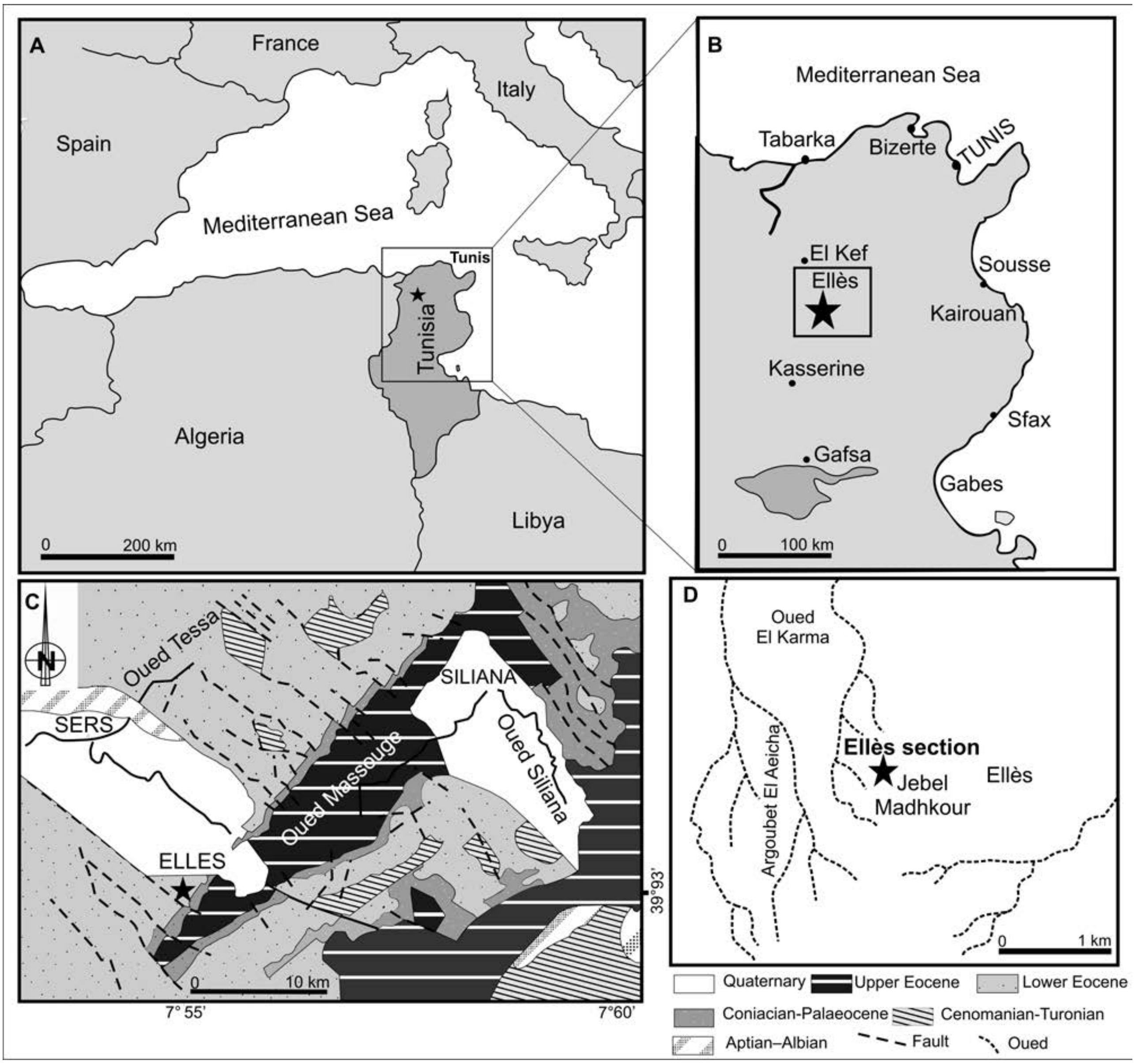

Fig. 1. Location of study area. **A, B.** Geographical location of the Ellès section in northeastern Tunisia. **C.** Geological setting of the section studied. **D.** Detail location of the Ellès area. Adapted from the geological map of Tunisia, 1:500,000 (Ben Haj Ali *et al.*, 1985).

The Ellès section is situated in the Karma Valley, Tunisian Central Atlas. Its palaeogeographic setting is similar to that of the El Kef section. Both localities were situated on the southern margin of the Tethys Ocean, on the African continental shelf. The sediments in this section were deposited at water depths, corresponding to the middle to outer shelf, relatively close to the emerged zone of Kasserine Island (Burollet, 1956; Adatte *et al.*, 2002; Galeotti and Coccioni, 2002; Gardin, 2002; Karoui-Yaakoub *et al.*, 2002; Keller *et al.*, 2002; Coccioni and Marsili, 2007). This section is located in a slightly more proximal position than the El Kef section, with a generally higher terrigenous content and hence a sedimentation rate exceeding that of the El Kef section (Adatte *et al.*, 2002; Stüben *et al.,* 2002). The Ellès section contains one of the most complete K–Pg boundary transitions in Tunisia.

MATERIAL AND METHODS

Sample provenance

This study focuses on only 2 m of marly and clay deposits around the Cretaceous–Palaeogene boundary, exposed at the Ellès section. This interval extends from 92 cm below to 108 cm above the K–Pg boundary and includes the Maastrichtian–Danian transition. Among the twenty-five samples collected, eleven are from the uppermost Maastrichtian marls and fourteen from the Danian clays and marls, with tighter sampling near the K–Pg boundary (Fig. 2).

Palynological preparation

In total, 25 samples from the Ellès section were processed, following standard palynological processing techniques. Processing involved an initial treatment of 50 g of

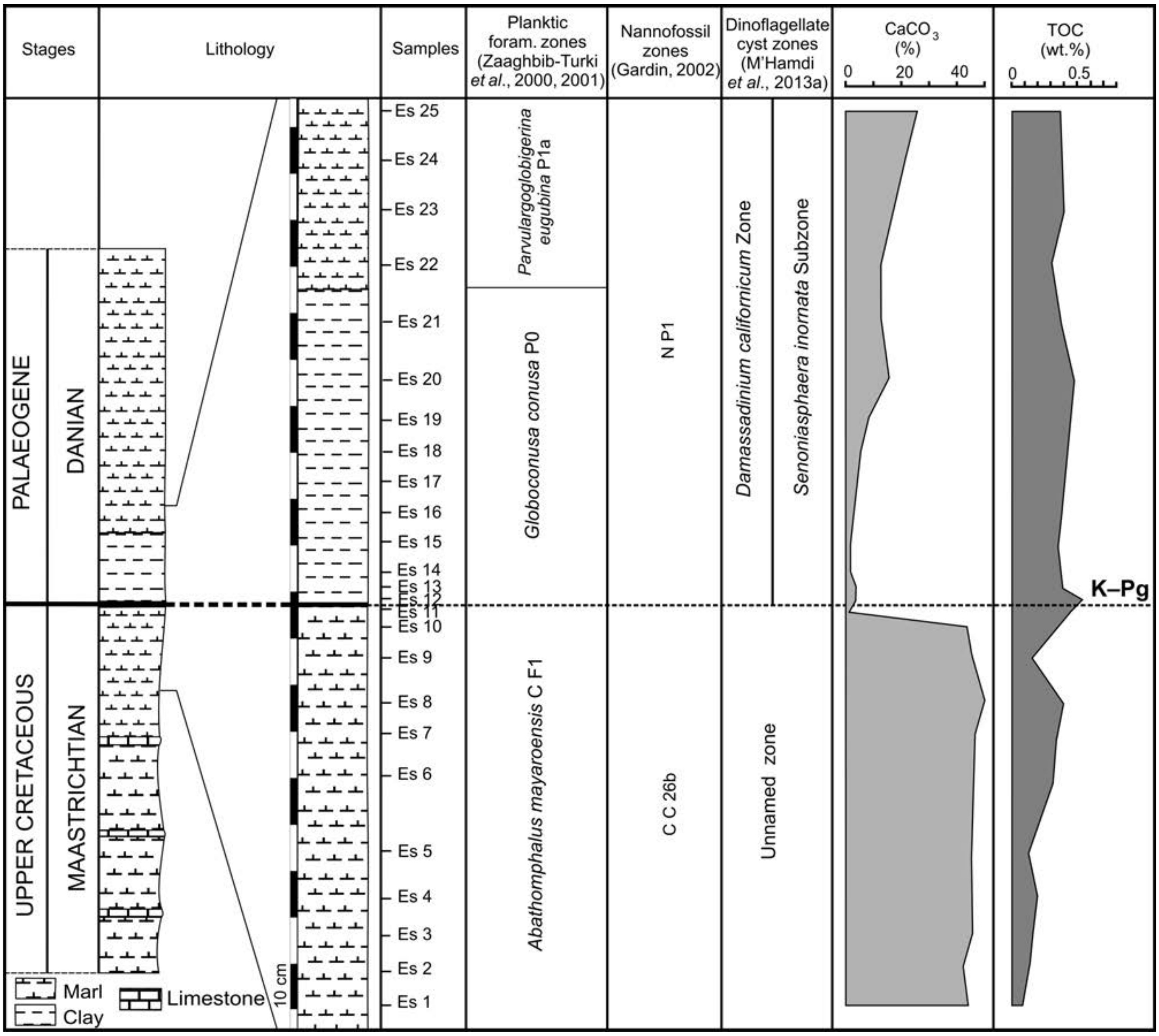

Fig. 2. Lithologic description, calcium carbonate content ($CaCO_3$) and total organic carbon (TOC) of the Cretaceous–Palaeogene boundary transition at the Ellès section, northeastern Tunisia. TOC – total organic carbon.

sediment per sample with cold HCl (20%), followed by digestion in HF (40% at 70°C), to dissolve the carbonates and silicates, respectively. The samples were rinsed with distilled water until neutral between the acid treatments. Silicofluorides were removed in warm HCl (20%). The residues were sieved on a nylon screen with a mesh of 15 µm and mounted in glycerine jelly on microscope slides. Photomicrographs of palynomorphs were taken with a digital Olympus C-400 Zoom camera, mounted on an Olympus BX53 microscope. The taxonomy of the dinoflagellate cyst species is based on Dinoflaj 2 (Fensome *et al.*, 2008) and Slimani *et al.* (2008, 2010, 2012). All samples were prepared at the Department of Geology, Faculty of Sciences, at the University of Tunis (Tunisia), with additional preparation (digestion of silicofluori- des, sieving, slide preparation) at the Laboratory of Geology and Remote Sensing, Scientific Institute of Rabat (Morocco).

For the quantitative analysis, two ratios that are often used as palaeoenvironmental proxies were calculated (Fig. 3). The ratio between numbers of autotrophic and heterotrophic dinocycts or peridinioid/gonyaulacoid (P/G) dinocyst ratio ($P/G = nP/(nP+nG)$ *sensu* Versteegh (1994) provided information about the sea-surface productivity. The sporomorph/dinocyst (S/D) ratio ($S/D = nS/(nD+nS)$ *sensu* Versteegh (1994), with S = number of spores and pollen and D = dinocysts and acritarchs, was used to estimate the continental influence.

The quantification of the kerogen content and composition was carried out in order to analyse the palynofacies. At least 300 particles were counted in each sample, following Tyson (1995), to differentiate three groups: amorphous organic matter (AOM), phytoclasts (black and translucent matter) and palynomorphs (dinocysts, acritarchs, organic linings of foraminiferal tests and spores and pollen grains).

Geochemical procedures

The total organic carbon (TOC) content and Rock-Eval parameters were determined at the Laboratory of Organic

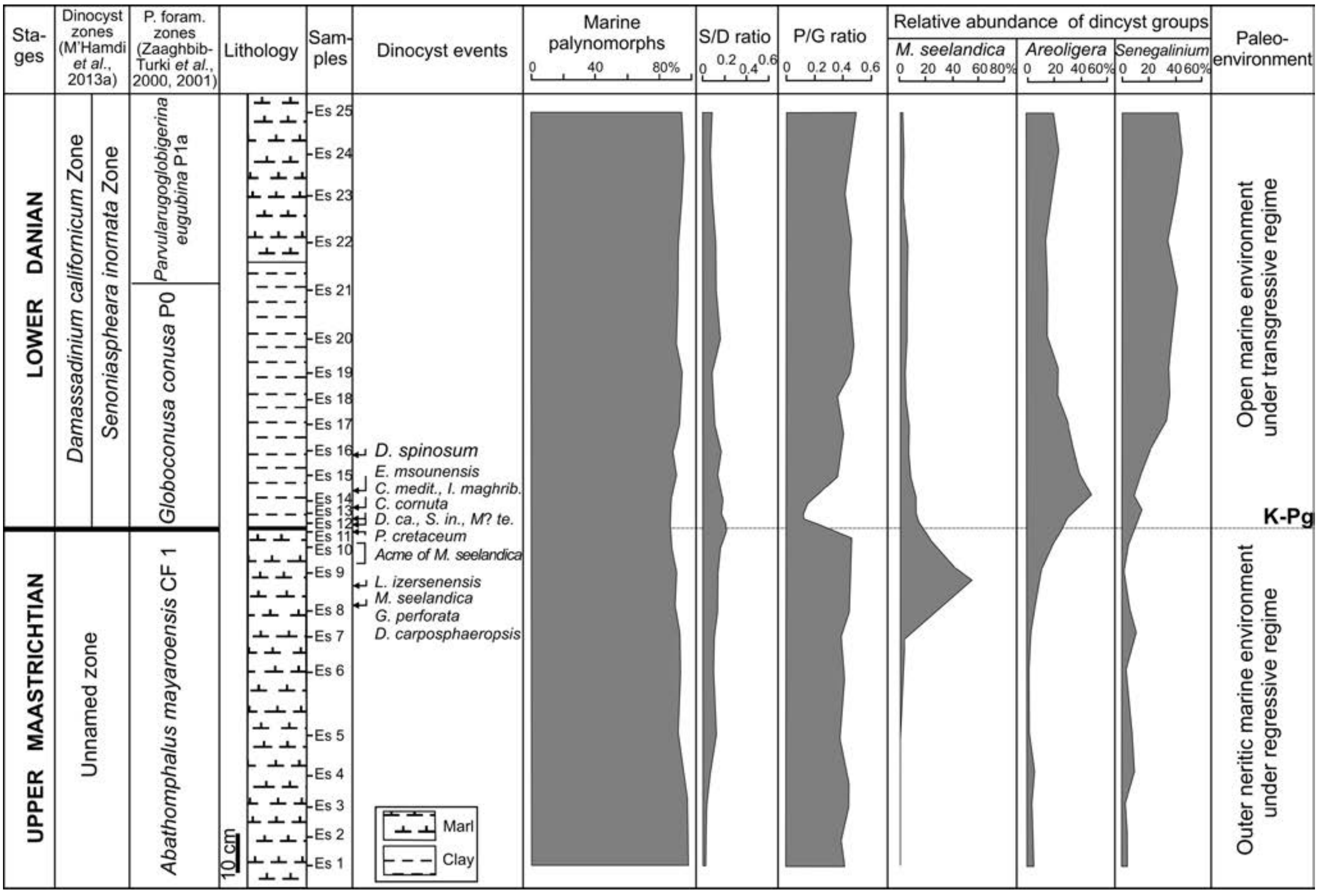

Fig. 3. Relative abundances of selected species and groups of morphologically related species, biozones, bioevents, diversity patterns and palaeoenvironmental changes of dinoflagellate cysts across the Cretaceous–Palaeogene boundary at the Ellès section, northeastern Tunisia. P/G – peridinioid/gonyaulacoid dinocyst ratio *sensu* Versteegh (1994) (P/G = nP/(nP+nG), S/D – sporomorph/dinocyst ratio *sensu* Versteegh (1994) (S/D = nS/(nD+nS), with S – number of spores and pollen and D – dinocysts and acritarchs.

Geochemistry of the Tunisian Oil Company. The Rock-Eval analyses were performed using the instrument Rock-Eval II, following the procedures proposed by Espitalie *et al.* (1977).

STRATIGRAPHIC FRAMEWORK

The subdivision, used here for the Ellès section, follows Zaaghbib-Turki *et al.* (2000, 2001) and Karoui-Yaakoub *et al.* (2002) on lithostratigraphy and planktonic foraminifera, Gardin (2002) and Coccioni and Marsili (2007) on calcareous nannofossils and M'Hamdi *et al.* (2013a) and M'Hamdi (2014) on dinoflagellate cysts.

Lithostratigraphy

The Cretaceous–Palaeogene boundary section of Ellès begins, in the uppermost meters of the Maastrichtian deposits of the El Haria Formation (Burollet, 1956), with gray marls ($CaCO_3$ content 30–60%) containing gypsum and Fe-oxides. These marls end upwards with an iridium-rich layer, marking the fallout from the Chicxulub impact event and the K–Pg boundary. This iridium-rich layer consists of a rusty red layer, 2–3 mm thick and rich in Fe-oxides (Adatte *et al.*, 2002). Cosmic markers, such as an anomalous concentration in Ir, Ni-rich spinels and altered microtektites, are also present in this thin layer (Gardin, 2002). Just above the layer, the Palaeocene succession begins with a boundary clay layer, dark and 50 cm thick ($CaCO_3$ content 10%). In its basal part it is rich in jarosite nodules, Fe-oxides and gypsum, but enriched toward the top in beige nodular carbonate intercalations. This unit is overlain by 5.8 m of gray marls, rich in jarosite concretions. This study focuses on 2 m of deposits around the K–Pg boundary of the Ellès section (Fig. 2).

Biostratigraphy

Most microfossil studies realized in the Ellès section concern foraminifera, nannofossils and dinoflagellate cysts. In the top metres of the uppermost Maastrichtian marls, planktonic and benthic foraminifera are abundant, varied and characterise the planktonic foraminiferal *Abathomphalus mayaroensis* (CF1) Zone. The foraminiferal group undergoes progressive disappearances, already from 4 m below the K–Pg boundary and upwards, and then a mass extinction at the K–Pg boundary. About two-thirds of the species disappeared and a third survived above the boundary. A gradual renewal led to the establishment of the typical associations of the Palaeocene. The basal Palaeocene clays contain a fauna, characteristic of the planktonic foraminiferal *Globoconusa conusa* (P0) Zone. The *Parvularugoglobigerina eugubina* (P1a) Zone begins at the end of the Palaeocene marls, at about 67 cm above the iridium-rich layer (Zaaghbib-Turki *et al.*, 2000, 2001; Karoui-Yaakoub *et al.*, 2002).

The K–Pg interval studied corresponds to the Upper Maastrichtian calcareous nannofossil *Nephrolithus frequens* Zone (*Miculaprinsii* Subzone [CC26b]) and the Lower Danian NP1 Zone (Gardin, 2002).

The dinoflagellate cyst assemblages indicate continuous sedimentation in the interval of the section studied. They permit the K–Pg boundary to be placed just above the uppermost Maastrichtian global marker acme of *Manumiella seelandica* and the highest occurrence of a few Cretaceous taxa, such as *Dinogymnium* spp., *Alisogymnium euclaense* and *Pterodinium cretaceum*, and directly below the lowest occurrence of the basal Danian markers

Damassadinium californicum, *Membranilarnacia*? *tenella*, *Senoniasphaera inornata* and *Carpatella cornuta*. The quantitative analysis of the dinoflagellate cyst associations does not reflect a distinct extinction at the K–Pg boundary, but shows significant changes in the relative abundance of species or groups of species that are morphologically related.

The lithostratigraphy and planktonic foraminiferal (Zaaghbib-Turki *et al.*, 2000, 2001; Karoui-Yaakoub *et al.*, 2002), calcareous nannofossil (Gardin, 2002) and dinoflagellate cyst (M'Hamdi *et al.*, 2013a, b, in press; M'Hamdi, 2014) biostratigraphy together confirm a complete record of the K–Pg boundary transition at Ellès.

PALAEOENVIRONMENTAL AND PALAEOBIOGEOGRAPHIC FRAMEWORK OF DINOFLAGELLATE CYSTS

The Maastrichtian–Danian transition in the Ellès section shows important changes in the relative abundances of morphologically related dinoflagellate cysts, probably reflecting changes in palaeoenvironmental conditions (M'Hamdi *et al.*, 2013b, in press; M'Hamdi, 2014). The Upper Maastrichtian marls contain dinoflagellate cyst assemblages, characterized by a great abundance of the *Cordosphaeridium* and *Glaphyrocysta* groups (Brinkhuis and Zachariasse, 1988; Eshet *et al.*, 1992; Slimani *et al.*, 2010). Both groups thrived in a shallow marine environment. The greatest abundance (50–65%) of *Manumiella seelandica* in the uppermost part of the Upper Maatrichtian (Fig. 3) indicates a deep marine environment under a regressive regime during cool climatic conditions Habib and Saeedi (2007), caused by the astronomical event, recorded at the K–Pg boundary event. A similar acme of *Manumiella seelandica* was observed by Strong *et al.* (1977), Wilson (1978), Firth (1987), Habib and Saeedi (2007), Slimani *et al.* (2010), Slimani and Toufiq (2013) and Mohamed *et al.* (2013).

In the lower Danian sediments, the decrease in abundance of *Manumiella seelandica* and the *Glaphyrocysta* and *Cordosphaeridium* groups and the abrupt relative increase in *Areoligera* spp., especially in the basal Danian, a great relative abundance of *Senegalinium* spp. (Fig. 3) and *Spiniferites* group *sensu* Slimani *et al.* (2010), and the great abundance of dinoflagellate cyst species indicate more open marine conditions under a transgressive regime (Brinkhuis and Zachariasse, 1988; Slimani *et al.*, 2010).

The P/G ratio (peridinoid/gonyaulcoid ratio of dinoflagellate cysts *sensu* Versteegh, 1994) varies between 0.3 and 0.55 in the Upper Maastrichtian, decreases sharply at the K–Pg boundary and subsequently increases in the Danian to achieve values similar to those of the Cretaceous (Fig. 3). The increase of the P/G ratio within the Danian indicates an increase in food and palaeoproductivity (Brinkhuis *et al.*, 1998). The peridinoid group consists of heterotrophic dinoflagellates, such as *Senegalinium* spp., *Palaeocystodinium* spp. and *Andalusiella* spp.

The dinoflagellate cyst assemblages of the Maastrichtian–Danian transition in the Ellès section reflect pronounced provincialism. The dominance of dinoflagellate cyst taxa of the Malloy suite (Lentin and Williams, 1980), such as species of *Lejeunecysta*, *Cerodinium*, *Andalusiella* and *Senegalinium* (Figs 7, 8) indicate deposition in a subtropical to warm- temperate province (M'Hamdi *et al.*, 2013b, in press; M'Hamdi, 2014). Similar assemblages have been observed in other Tethyan areas by Brinkhuis and Zachariasse (1988), De Coninck and Smit (1982), Rauscher and Doubinger (1982), Soncini and Rauscher (1988), Soncini (1990), Slimani *et al.* (2010) and Slimani and Toufiq (2013).

RESULTS

Palynofacies analysis

The distribution of palynofacies in the Ellès section was evaluated on the basis of qualitative and quantitative analyses of dispersed organic constituents. In the majority of the samples, palynomorphs (continental and marine), amorphous organic matter (AOM) and phytoclasts (P) are present. Dinoflagellate cysts dominate the total palynofacies. The chorate and proximate dinoflagellate groups are present throughout the entire section. The abundances of both groups are relatively constant throughout the Maastrichtian and Danian stages.

Acritarchs are present, but rarer than dinoflagellate cysts. The foraminiferal test linings group is present throughout much of the section. Pollen and spores are rare in this section. AOM was recorded constantly throughout the section.

Marine palynomorphs account for more than 80% of the total organic matter. These palynomorphs are good indicators of marine conditions (Tyson, 1995). The presence of the foraminiferal test linings and acritarchs confirm the existence of marine conditions during sedimentation.

All of the organic components counted were plotted in the AOM-Phytoclast-Palynomorph ternary diagram of Tyson (1993) in Figure 4A. Different proportions of the components of this organic matter indicate that the palynofacies is dominated by palynomorphs (65%).

The organic matter observed is very abundant and well preserved. Projection of different proportions of the organic matter components in the palynofacies diagram of Roncaglia and Kuijpers (2006) shows that marine-derived organic

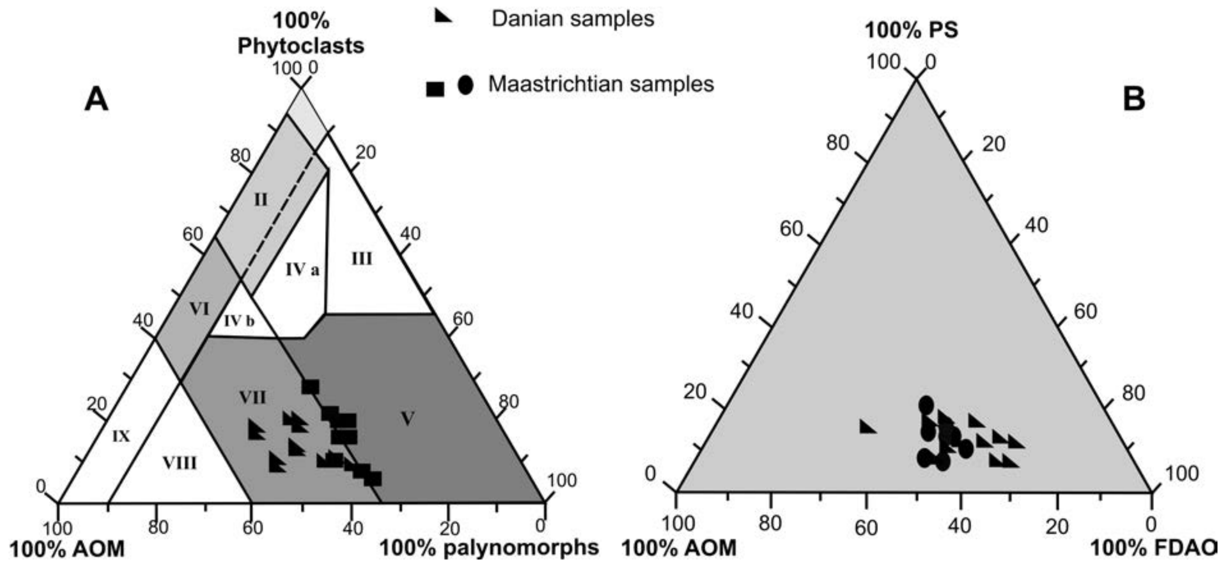

Fig. 4. Palynofacies proportions in samples from the Ellès section as expressed by ternary kerogen and palynomorph plots. **A.** AOM-Phytoclast-Palynomorph plot (Tyson, 1993), field I – kerogen type III, field II – kerogen type III, field III – kerogen type III or IV, field IV – kerogen type III or II, field V – kerogen type III IV, field VI – kerogen type II, field VII- kerogen type II, field VIII – kerogen type II I, field IX - kerogen type II I. **B.** AOM–PS–FDAO (Roncaglia and Kuijpers, 2006). AOM – amorphous organic matter, PS – phytoclasts + sporomorphs, FDAO – foraminifera linings + dinoflagellate cysts + acritarchs + other marine algae.

matter is dominant (Fig. 4B). This is supported by the lithological characteristics and inferred sedimentation, namely for the most part marls and clay, rich in planktonic foraminifera, reflecting a deep marine environment (Gallala, 2010).

The marine organic matter represents 50% to 80% of the total organic matter in the palynofacies, and microplankton represents 70% to 95% of the total palynomorphs. The frequency of spores and pollen grains does not exceed 12%.

The S/D ratio, at the Ellès section is generally low, not exceeding 12%. It reaches its maximum at the K–Pg boundary, showing a continental influence. The maximum enrichment of terrestrial palynomorphs is recorded in sample Es11, just below the K–Pg boundary (Fig. 3). According to Brinkhuis and Zachariasse (1988), this increase in abundance and attainment of peak proportions within the land-derived organic matter is interpreted as a result of a rapidly retreating sea. This regression, occurring at the end of Late Maastrichtian, is also indicated by the acme of *Manumiella seelandica* just below the K–Pg boundary (Es 9–Es10) (M'Hamdi *et al.*, 2013b, in press; M'Hamdi, 2014). The acme of *Manumiella seelandica* recorded below the K–Pg boundary is related to a global cooling (Habib and Saeedi, 2007). In the lower Danian, there is a decrease in the abundance of terrestrial palynomorphs, whereas AOM is still present and the palynofacies is dominated by marine indices. An abundance of dinocysts and foraminiferal test linings points to a rise in sea-level in the Danian. The palynomorphs are dominated by peridinoid dinocyts, such as *Senegalinium* spp., *Lejeunecysta* spp., *Andalusiella* spp., and *Cerodinium* spp. The gonyaulacoid dinocysts are represented by *Areoligera* spp., *Cordosphaeridium* in spp. and *Spiniferites* spp. The predominance of peridinoid dinocysts cited above reflects a period of transgression (Dam *et al.*, 1998) and therefore an increase in sea-surface temperature. This agrees with the return to relatively warm conditions, previously known to have occurred during the Danian (Brinkhuis *et al.*, 1998; Slimani and Toufiq, 2013). The small grain size of the Lower Danian clays reinforces the argument for an increase in sea level and deposition in an environment farther offshore (Keller and Lindinger, 1989).

Total organic carbon (TOC) and Rock-Eval pyrolysis

The geochemical study involved 12 samples from the K–Pg boundary transition in the Ellès section. The results of the TOC and Rock-Eval pyrolysis are given in Figure 5 and Table 1. The TOC content is generally low and varied between 0.07 to 0.53 wt.%, indicating a low organic carbon content (Peters and Cassa, 1994).

The Rock-Eval S1 and S2 parameters varied from 0.02 to 0.31 mgHC/g rock and 0.14 to 0.57 mgHC/g rock, respectively (Fig. 5, Table 1). The Tmax values ranged from 420 to 440°C.The hydrogen index (HI) and oxygen index (OI) values ranged from 61 to 214 mgHC/g TOC and 149 to 638 mgHC/g TOC, respectively. They indicate a marine planktonic organic matter (Type II) altered and/or mixed with a continental organic matter (type III). According to Tissot *et al.* (1977), the low hydrogen index values are probably due to the contribution of organic matter type III and/or the poor preservation of organic matter. The low Tmax values (420–440°C) indicate an immature state of the organic matter.

The petroleum potential (PP) is also low, ranging from 0.14 to 0.57 kg HC/t rock with an average of 0.27 kg HC/t rock. The PP/TOC diagram shows that the El Haria Formation generally has a low overall petroleum potential (Table 1).

The HI/Tmax and PI (production index)/Tmax diagrams indicate that the organic matter is immature. The PP/Tmax diagram shows that the samples are immature in terms of thermal evolution, which does not exceed the Tmax of 440° C (Table 1).

Table 1

Rock-Eval analysis from samples at the Ellès section, northeastern Tunisia

Samples	S1 (meg)	S2 (meg)	S3 (meg)	PI	Tmax (°C)	IH	IO	TOC (%)	PP
Es 19	0.03	0.22	0.96	0.11	432	61	267	0.36	0.22
Es 16	0.09	0.28	1.11	0.25	445	74	292	0.38	0.28
Es 15	0.02	0.25	0.52	0.09	431	71	149	0.35	0.27
Es 13	0.02	0.24	0.55	0.09	427	65	149	0.37	0.26
Es 12	0.06	0.39	0.95	0.13	436	74	179	0.53	0.39
Es 11	0.07	0.32	2.26	0.18	432	73	514	0.44	0.32
Es 9	0.05	0.21	0.67	0.18	435	131	419	0.16	0.21
Es 8	0.31	0.57	0.61	0.35	423	141	156	0.39	0.57
Es 7	0.1	0.23	0.68	0.3	439	70	206	0.33	0.23
Es 6	0.11	0.25	0.56	0.3	431	83	187	0.3	0.25

S1 – free oil, S2 – free oil by cracking, S3 – CO_2 produced during cracking, PI – production index, Tmax – temperature maximum, IH – hydrogen index, IO – oxygen index, TOC – total organic carbon, PP – petroleum potential.

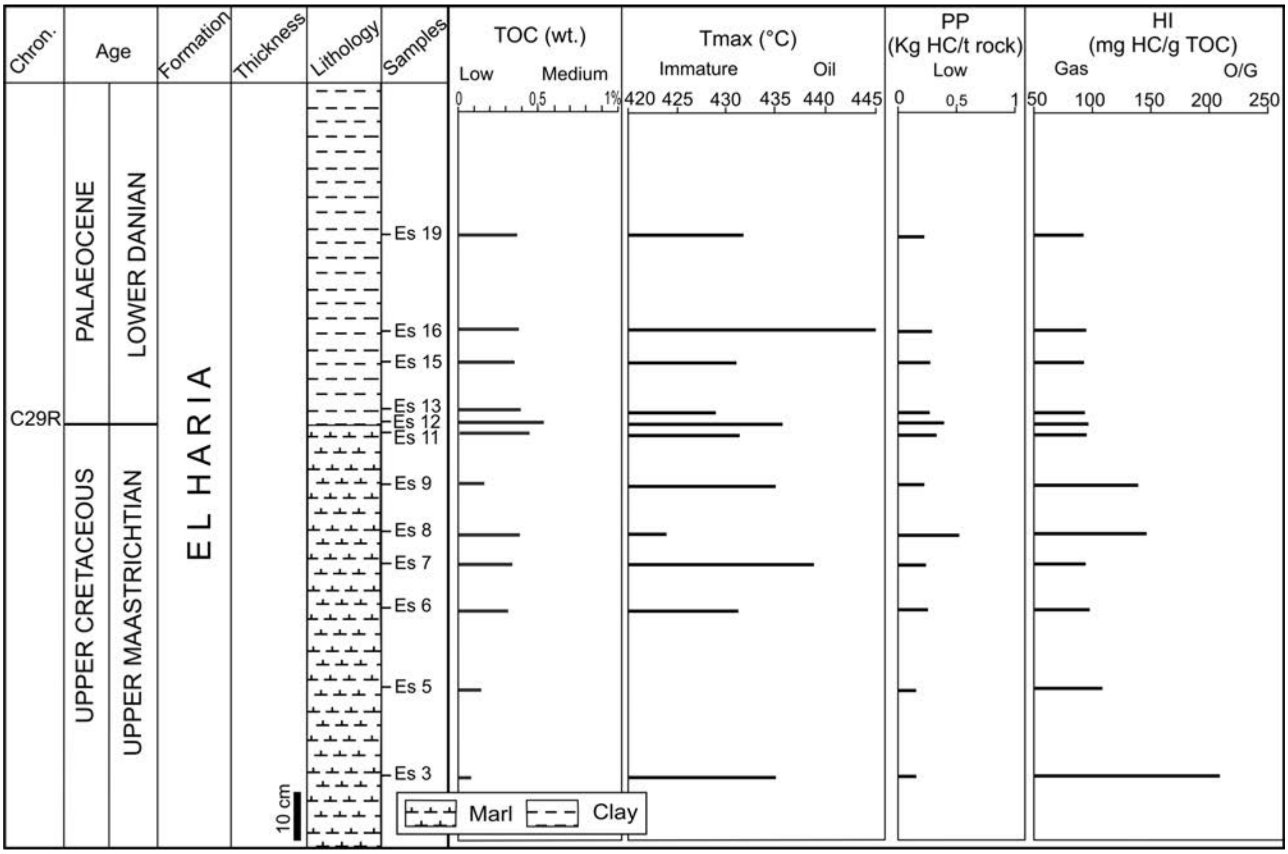

Fig. 5. Quantitative and qualitative characteristics of organic matter from the El Haria Formation at the Ellès section, northeastern Tunisia. TOC – total organic carbon, Tmax – Pyrolysis maximum temperature, PP – petroleum potential, HI – hydrogen index.

Optical methods: spore coloration and thermal alteration index (TAI)

Microscopic studies of organic matter are now widely used for palaeoenvironmental reconstruction, as well as for the evaluation of source rocks and kerogen types (Staplin, 1969; Fisher *et al.*, 1980; Jones and Demaison, 1982; Batten, 1982, 1983; Van Bergen and Kerp, 1990; Bertrand *et al.*, 1994; Tyson, 1995; Pavlus and Skupien, 2014). The results of the study of organic matter maturity and potential hydrocarbons in the Ellès section are reported in Table 2.

The observed samples show well-preserved organic matter. It is generally composed of amorphous matter, palynomorphs including dinocysts, seaweed and algae frag-

Table 2

Kerogen (transmitted light) in samples from the Ellès section, northeastern Tunisia

ELLÈS SECTION									
Substage	Lthology	Formation	Samples	Kerogen type	Spore colour index	S.C.I.	Thermal alteration index (TAI)	Preservation	Maturity
Lower Danian	Marly limestones	El Haria	Es 25	II-III	yellow	1	1	good	Immature
			Es 22				1+		
	Clays		Es 20				1/1+		
			ES 18				1		
			ES 15				1–		
			Es 12				1–		
Upper Maastrichtian	Marly limestones		ES 6				1		
			Es 3				1		
			Es 1				1/1+		

SCI – spore coloration index.

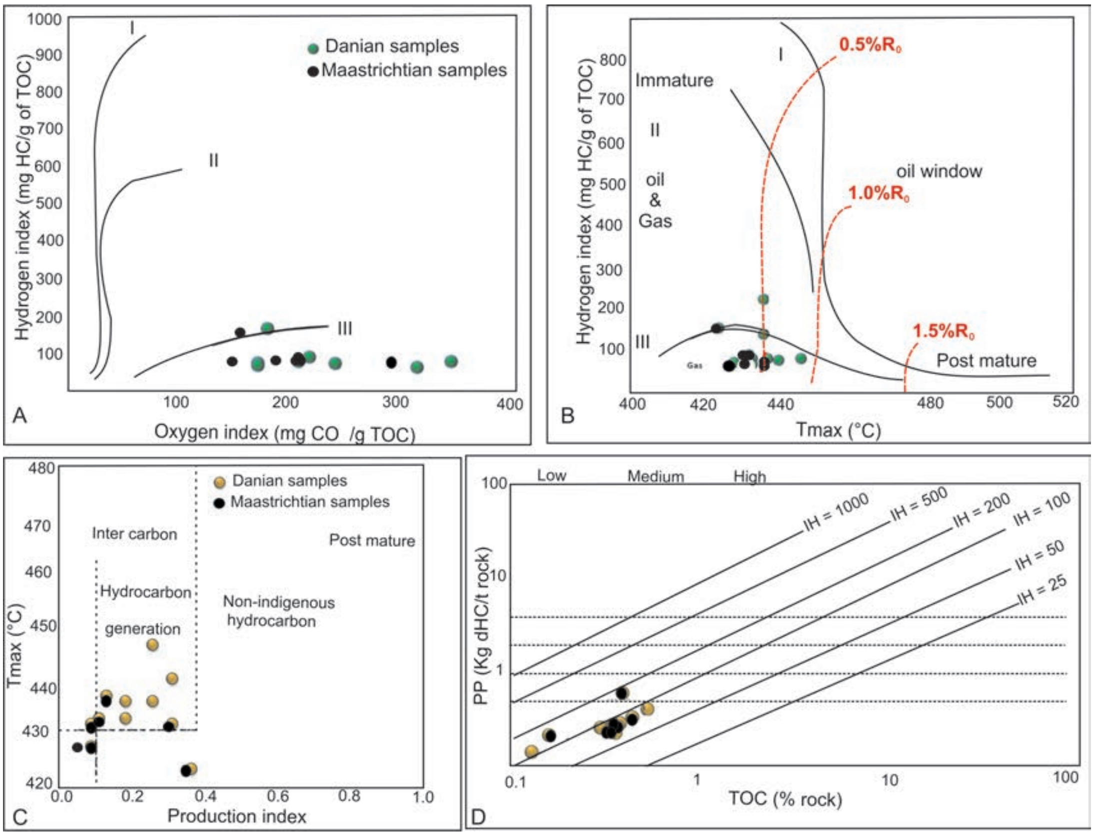

Fig. 6. Geochemical parameters from the K–Pg boundary at Ellès section, northeastern Tunisia.

ments, some spores and pollen and woody debris with angular contours.

The relative percentage of organic fractions is often variable and some are relatively rich in woody debris, reflecting a continental influence. The maturity was assessed on the basis of observation in transmitted light. The spore coloration index (SCI) is in the order of 1, the organic material is considered immature and the spores have a yellow color. The appearance of palynomorphs is fresh and clear and the SCI is low varying between –1 and +1, and the thermal alteration index (TAI) is also low (Batten, 1996). The organic matter (kerogen) is of type II and III. It is immature and can generate only gas. With regard to the results of the samples studied from the Ellès section, the organic matter associated with sediments of the El Haria Formation is well preserved, but immature.

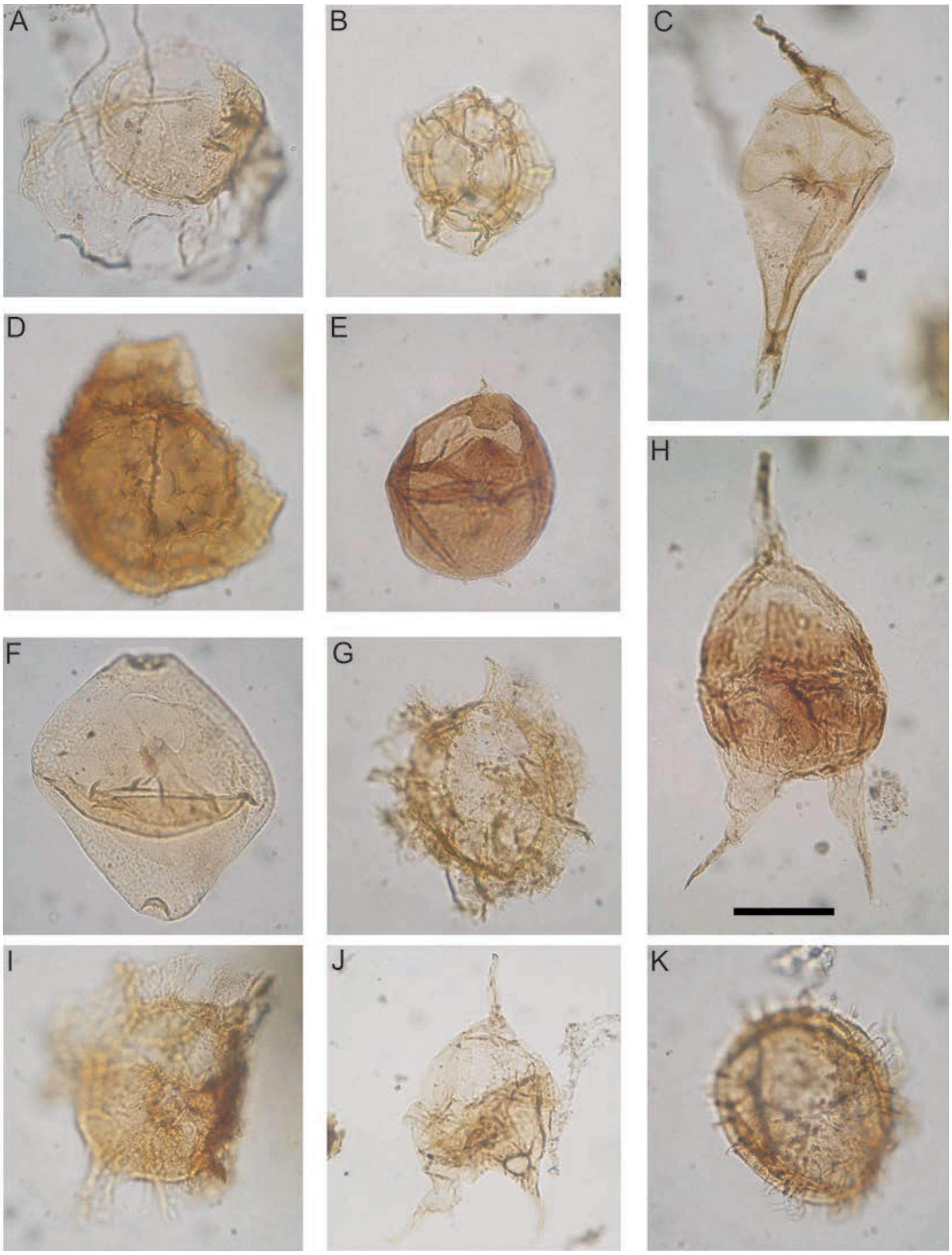

Fig. 7. Photomicrographs of dinoflagellate cysts from the Cretaceous–Palaeogene boundary section at Ellès, northeastern Tunisia. Scale bar represents 40 µm for all specimens. **A.** *Riculacysta amplexa* Kirsch, 1991, sample Es 1, slide 1, EF D44/1. **B.** *Pterodinium cretaceum* Slimani *et al.*, 2008, sample Es 7, slide 3, EF N65/4. **C.** *Andalusiella mauthei* subsp. *punctata* (Jain and Millepied, 1973) Masure *et al.*, 1996, sample Es 7, slide 3, EF G49/3. **D.** *Cribroperidinium septatum* Hultberg, 1985, - sample Es 7, slide 3, EF R34/3. **E.** *Trithyrodinium evittii* Drugg, 1967, sample Es14, slide 2, EF Q29. **F.** *Manumiella seelandica* (Lange, 1969) Bujak and Davies, 1983, sample Es 10, slide 2, EF W36. **G.** *Cordosphaeridium fibrospinosum* (Hultberg, 1985) Fensome *et al.*, 1993, sample Es 1, slide 6, EF C36/4. **H.** *Phelodinium pentagonale* Corradini, 1973, sample Es12, slide 3, EF U31/3. **I.** *Damassadinium californicum* (Drugg, 1967) Fensome *et al.*, 1993, sample Es 7, slide 3, EF U31/2. **J.** *Deflandrea obliquipes* (Deflandre and Cookson, 1955), sample Es 1, slide 1, EF C36/4 X40. **K.** *Operculodinium israelianum* (Rossignol, 1962) Wall, 1967, sample Es 7, slide 2, EF K27/2.

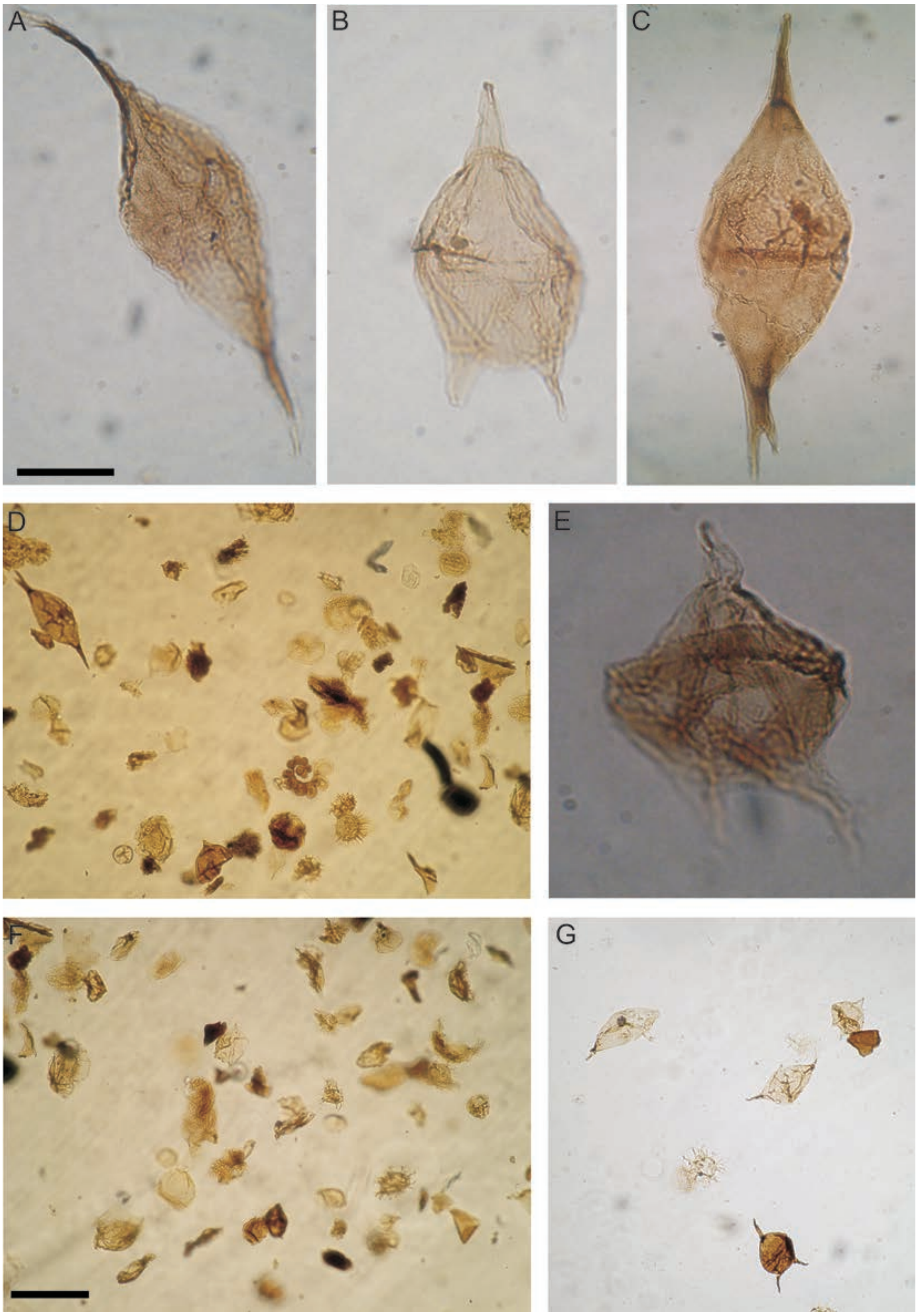

Fig. 8. Photomicrographs of dinoflagellate cysts and palynofacies from the Cretaceous–Palaeogene boundary section at Ellès, north-eastern Tunisia. Scale bar in (A) represents 40 µm for specimens (A–C, E), scale bar in (F) represents 200 µm for D, F, G. **A.** *Palaeocystodinium golzowense* Alberti, 1961 – sample Es 7, slide 2, EF H41/2. **B.** *Cerodinium pannaceum* (Stanley, 1965) Lentin and Williams, 1987. sample Es 7, slide 3, EF X34/4. **C.** *Andalusiella mauthei* Riegel, 1974 subsp. *punctata* Jain and Millepied, 1973, sample E1, slide 6, EF Y39. **D.** Palynofacies assemblages, abundance of peridinoid cyst, sample Es 15. **E.** *Cerodinium mediterraneum* Slimani *et al.*, 2008 – sample Es 7, slide 3 EF V46/2. **F.** Palynofacies assemblages, sample Es 20.G. Abundance of peridinoid cysts, sample Es 14.

CONCLUSIONS

The palynofacies study of the Cretaceous–Palaeogene transition deposits of the El Haria Formation at Ellès, northern Tunisia, revealed the presence of organic matter, dominated by marine palynomorphs, continental palynomorphs (sporomorphs) and amorphous organic matter. The palynomorphs are dominated by dinoflagellate cysts, which are diversified and well preserved. The dinoflagellate cysts allowed biostratigraphic, palaeoenvironmental and palaeobiogeographic interpretations of the K–Pg transition at Ellès (M'Hamdi *et al.*, 2013a, b, in press; M'Hamdi, 2014).

The distribution of the palynofacies is evaluated on the basis of qualitative and quantitative analyses of the dispersed organic constituents in the Ellès section. The palynomorphs are dominanted by dinoflagellate cysts; however, sporomorphs are rare. In the AOM- Phytoclast- Palynomorph ternary diagrams of Tyson (1993), the different proportions of components of this organic matter indicate that the palynofacies is dominated by palynomorphs with higher proportions of 65%. Projections on the palynofacies diagram of Roncaglia and Kuijpers (2006) show that different proportions of the components of the organic matter are dominated by marine-derived organic matter, such as dinoflagellate cysts, acritarchs and foraminiferal test linings. In terms of palynofacies, this association is characterised by the dominance of marine organic matter, the proportion of which varies between 50 and 80%, and palynomorphs are dominated by microplankton. The palynofacies analysis suggests a regression at the end of the Late Maastrichtian, just below the K–Pg boundary, related to a global cooling, and a transgression, related to a return to relatively warm conditions in the Danian.

The geochemical data from the Ellès section permit the characterisation of the organic matter. The kerogen has low TOC contents (<7 wt.%) and is predominantly characterised by marine organic matter and marine palynomorphs, preserved in a marine environment. The results (low values of TOC, S2 and HI) show that the El Haria Formation at the Ellès section contains kerogens type II and type III. The maturity indicators (Tmax) indicate an immature stage of the organic matter.

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