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A model of dinoflagellate cyst distribution around the K/Pg boundary and its paleoenvironmental implications (Eastern Alps)

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Abstract

A new model was developed for the paleogeographic distribution of dinoflagellate cysts across the Cretaceous/Paleogene (K/Pg) boundary. Four sections in the Eastern Alps were studied. The Knappengraben and Gamsbach sections are located in the Gosau Basin of Gams, Austria. They are continuous across the boundary and represent a bathyal environment. The Waidach section north of Salzburg (Austria) contains neritic deposits of the Helvetic unit but shows a hiatus at the boundary. The Goppling section between Teisendorf and Oberteisendorf (Bavaria, Germany) belongs to a turbidite-rich, deep-water system (Ultrahelvetic unit), and is considered to be continuous across the boundary.

The occurrence and distribution of dinoflagellate cysts in these sections suggests that *Trabeculidinium*, *Adnatosphaeridium*, *Spiniferites*, *Pterodinium*, *Impagidinium*, *Achomosphaera* and *Codoniella* are restricted to bathyal environments, whereas *Areoligera*, *Manumiella* and *Trithyrodinium* are restricted to the neritic environment. The abundance of *Manumiella* and *Trithyrodinium* indicate a high nutrient supply. *Hystrichosphaeridium*-dominated assemblages have been recorded in both neritic and bathyal environments. Two *Manumiella* spikes were recorded only at Waidach and interpreted to reflect slight coolings of oceanic surface waters. In the Danian, acme of *Spongodinium delitiense* are recorded ~1 m above the K/Pg boundary in the neritic and bathyal environments. These acmes could reflect a slight cooling of surface waters in the earliest Danian.

The palynofacies analysis in the Gams Basin reveals a high abundance of amorphous organic matter in the Maastrichtian, and black phytoclasts in the Danian, which indicates intensified terrigenous run-off in the Danian with higher sea-floor oxygenation. In the Waidach section, palynomorphs are much more abundant, indicating a shelf to basin transitional area with dysoxic-anoxic conditions at the sea-floor.

1. Introduction

A large number of studies exist that aim to establish biostratigraphic zonations and to reconstruct paleoenvironmental conditions using dinoflagellate cysts. Still, for a thorough understanding of dinoflagellate cyst distribution in time and space, additional studies, field examinations, and paleogeographical analyses are needed, especially in the northwestern Tethys. In the light of the previous dinoflagellate cyst data in Egger and Mohamed (2010), Mohamed (2010) and Mohamed et al. (2012, 2013), the first model of dinoflagellate cyst distribution of the Cretaceous/Paleogene (K/Pg) boundary succession in the Eastern Alps was constructed herein, aiming to increase the paleogeographic database of dinoflagellate cysts in the Tethys. This model includes palynological data from four sections representing different paleoenvironments. Knappengraben and Gamsbach sections comprise bathyal sediments of the Upper Gosau subgroup in the Gams Basin. The Waidach section located in north of Salzburg contains shallow water (neritic) sediments of the Helvetic Zone. The Goppling section between Teisendorf and Oberteisendorf (Bavaria) belongs to a turbidite-rich deep-water system (Fig. 1). All studied sections comprise calcareous nannoplankton Zone CC26 (*Nephrolithus frequens* Zone) of latest Cretaceous age and part of the lowermost Paleocene Zone NP1 (*Markalius inversus* Zone), while section Goppling reaches up to NP11 (Egger and Mohamed, 2010).

2. Geologic background and setting

Five K/Pg boundary sections in the Eastern Alps have been described so far: the Wasserfallgraben section in the Lattengebirge, Bavaria (Herm et al., 1981), the Elendgraben section near the village of Gosau, Austria (Preisinger et al., 1986; Stradner et al., 1987), the Rotwandgraben section near the village of Gosau, about 2.5 km to the southeast of the Elendgraben section (Peryt et al., 1993; 1997), the Knappengraben section at Gams (Stradner et al., 1987), and the Gamsbach section in the valley of the Gamsbach ~1.25 km west of the Knappengraben site (Egger et al., 2009). Other sections containing upper Maastrichtian and lower Danian sediments are located in the Helvetic unit, north of Salzburg.

The depositional area of the Gosau Group was part of the northwestern Tethys realm during the Late Cretaceous and Paleogene (e.g., Stampfli et al., 2002). Paleomagnetic data and general plate tectonic reconstructions for these deposits suggest a paleolatitude of 20° to 30° N (Haubold et al., 1999; Pueyo et al., 2007). The transgression of the Gosau Group was the result of transtension, followed by rapid subsidence into bathyal paleodepths due to subduction-driven tectonic erosion at the front of the Austro-Alpine microplate (Wagreich, 1993). The deep-water facies of the Upper Gosau Subgroup comprises hemipelagic pelitic deposits alternating with turbidites and slump deposits. Both, hemipelagites and mass flow deposits are incorporated into the Nierental Formation (Egger et al., 2009). Foraminifers of the Knappengraben section (Rögl in Egger et al., 2004) indicate a middle bathyal environment between 600 and 1,000 m for the uppermost Maastrichtian to lowermost Danian (P0-Pα planktic foraminiferal zones). The lower Danian deposits (P1a) were probably deposited in lower bathyal depths between 1,000 m and 2,000 m. The top of zone P1a corresponds to the top of calcareous nannoplankton zone NP1. The duration of zone NP1 has been estimated at about 700 ka. (Berggren et al., 2000; Gradstein et al., 2004). During this interval 805 cm of turbidites, slumps, and hemipelagites were deposited at the Knappengraben section (Lahodynsky, 1988). This suggests a sedimentation rate of 11 mm/ka for the earliest Paleocene (Egger et al., 2009).

The K/Pg boundary section at Waidach is located at the northern slope of the Haunsberg close to the hamlet Waidach, some 15 km N of the town of Salzburg. In the Haunsberg area, detached shelf deposits of the southern part of the European Plate form an imbricated pile of small tectonic slices (Traub, 1953). These slices are part of the south-Helvetic thrust unit, which is a detached part of the southern shelf of the European plate. Derived from paleogeographic reconstructions for the sedimentation area of the Waidach section a paleolatitude of about 30° N can be estimated (e.g., Stampfli and Kozur, 2006). At Waidach, the minimum sedimentation rate is ~30 mm/ka.

The 7.5 m long Gamsbach section is composed mainly of pelitic rocks. Below the K/Pg boundary, 3.5 m of light to medium grey marlstones and marly limestones occur, which are interbedded with thin (<15 cm) sandstone turbidites. Dark grey mottles due to bioturbation are present especially in more indurated marly limestone beds. The top of the Maastrichtian consists of a 50 cm thick, well indurated, bioturbated marly limestone. Above this surface, 0.2–0.4 cm of yellowish clay mark the base of the Paleocene (Ir-rich boundary clay with maximum Ir-values of about 6 ppb; Egger et al., 2009).

At the 9.3 m long Knappengraben section (Lahodynsky, 1988), the K/Pg boundary layer is a white-gray soft marly clay (3–7 mm). It contains significantly higher values of Ir, Cr, Co, Ni, MgO, Al_2O_3 and TiO_2 as the layers below and above. Lahodynsky (1988) pointed at the intensive bioturbation of the uppermost 4–5 cm of sediment below the K/Pg boundary clay. Generally, the Knappengraben section is composed of 230 cm upper Maastrichtian sediments and 700 cm lower Danian sediments.

A ca. 320 m thick composite section (Goppling section) of a turbidite-rich deep-water system outcropping between Teisendorf and Oberteisendorf (Bavaria) encompasses the upper Maastrichtian to Ypresian (calcareous nannoplankton Zones CC25 to NP11). These deposits conformably overlie red clayey marlstone (Buntmergelserie). The whole succession is part of the Ultrahelvetic thrust unit, which is a detached part of the continental margin of the southern European Plate.

Additional information on, and detailed descriptions of, these

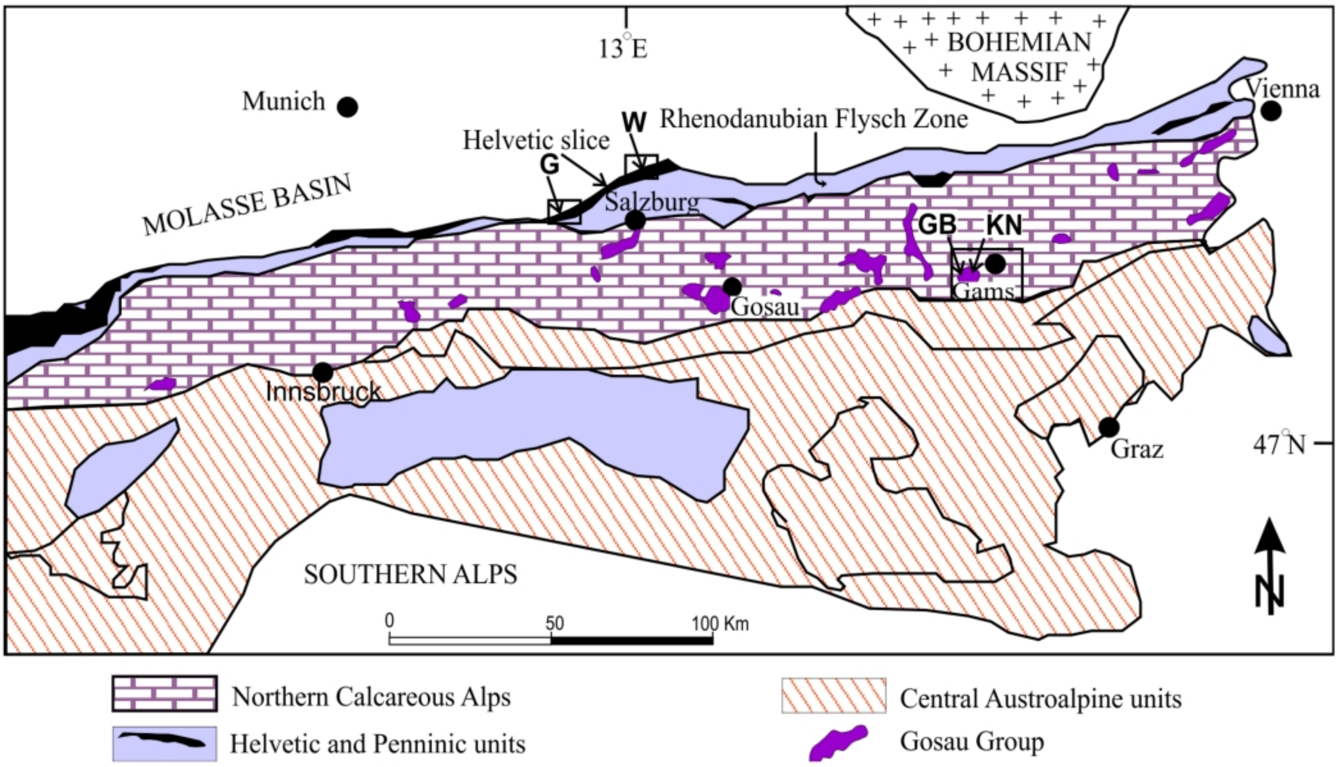

Figure 1: Simplified geological map of the Eastern Alps (after Faupl and Wagreich, 2000). GB = Gamsbach section, KN = Knappengraben section, W = Waidach section and G = Goppling section.

sections, their lithology and correlation of strata as well as on the vertical and horizontal distribution of dinoflagellate cysts can be found in Mohamed (2010), Egger and Mohamed (2010), and Mohamed et al. (2012, 2013).

3. Material and Methods

The studied samples were collected from the Knappengraben section (E 14º52'98", N 47º39'78"), Gamsbach section (E 14º51'50", N 47º39'51"), Waidach section (E 13°00´ 27˝, N 47° 56´34˝) and Goppling section (E 12°47´42", N 47°50´51"). Twenty to 100 g of dry sediment were crushed and treated with cold 35% HCl for one day in order to remove carbonates. Adding water and subsequent decantation was carried out two times with a minimum interval of six hours. Then, the samples were treated with 38% HF for 1–2 days to remove silicates. Adding water and decantation for two times with a minimum interval of seven hours followed the HF reaction. A small amount of 35% HCl was added again to the samples to remove gel which may have formed during the previous step. Water was added to samples for the last time and the samples were put in an ultrasonic device for 10–40 s and then sieved over a 10 µm nylon sieve. A part of the residue was mounted in glycerin jelly on two or three microscope slides after extensive mixing to obtain homogeneity and then covered by a slide cover (20x40 mm). The slides are stored at the Institute of Earth Sciences, Graz University, Graz, Austria.

Percentage data of all species present in four or more samples were analyzed by cluster analysis using Ward's method with the program PAST (Hammer et al., 2001). The peridinioid/gonyaulacoid ratio (P/G = nP/(nP+nG)) (e.g. Guasti et al., 2005) has been calculated to estimate sea surface productivity. For a detailed paleoenvironmental study based on palynofacies, a quantification of the kerogen content and composition was carried out.

At least 500 particles were counted in each sample, differentiating three groups [amorphous organic matter (AOM), phytoclasts and palynomorphs]. To assess the distribution of palynofacies qualitative and quantitative analyses of dispersed organic constituents were undertaken for each section (Fig. 2). All counted samples are plotted in AOM-Phytoclasts-Palynomorphs ternary diagrams after Tyson (1995).

4. Model description and dinoflagellate distributions

The palynological investigations (Egger and Mohamed, 2010; Mohamed, 2010) yielded a moderately abundant palynomorph assemblage, mainly represented by dinoflagellate cysts in Knappengraben, Gamsbach and Goppling sections. In the Waidach section all samples yielded very rich and well preser-

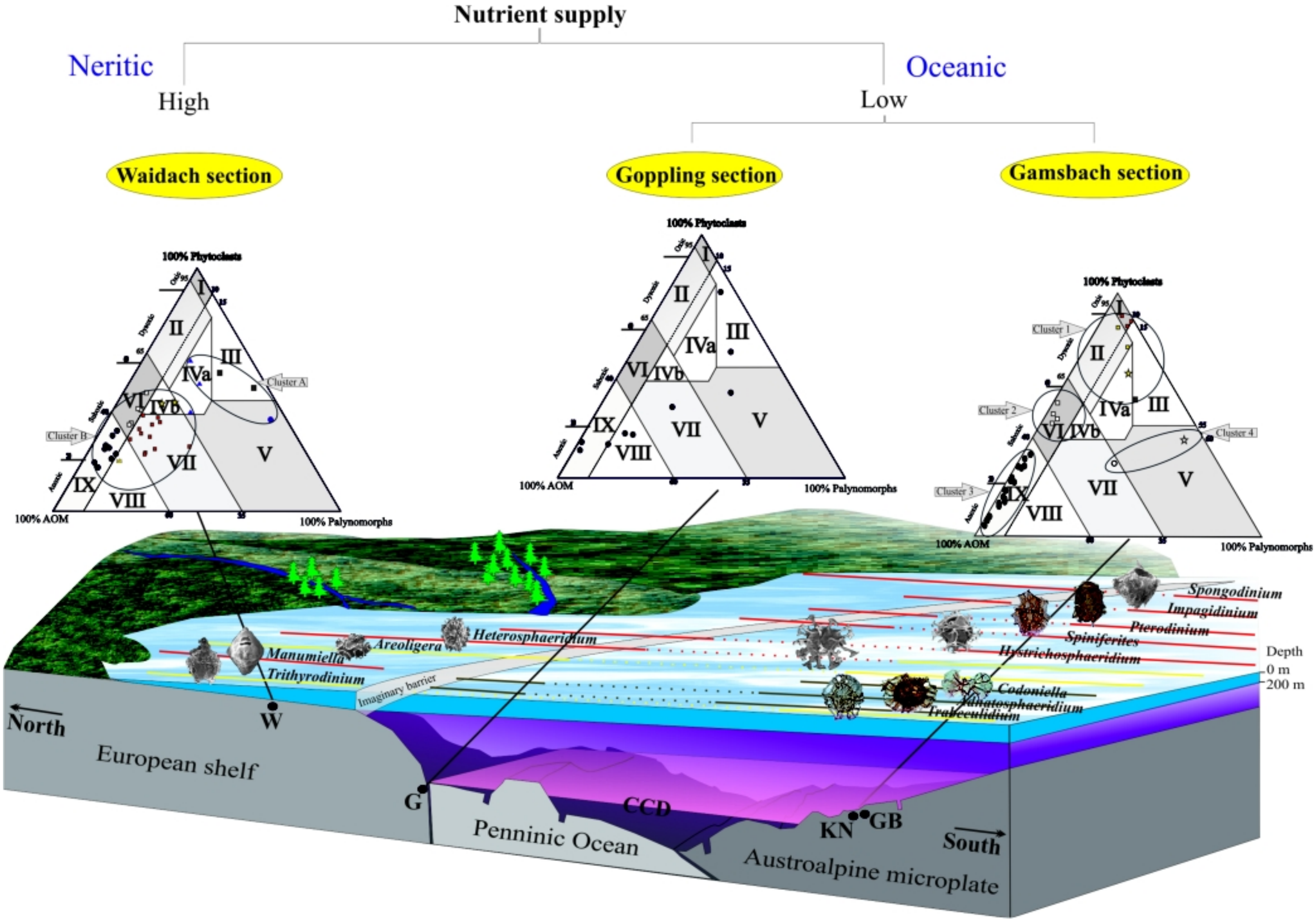

Figure 2: A model of lateral distribution for the Upper Cretaceous-lower Paleogene dinoflagellate cysts with palynofacies analysis in the Penninic Ocean. W = Waidach section, G = Goppling section, KN = Knappengraben section, GB = Gamsbach section and CCD = Calcite Compensation Depth.

ved dinocysts possibly due to high nutrient supply, high sedimentation rate (≥30 mm/ka) and/or low bottom water oxygenation. Terrestrial palynomorphs are very rare in all sections. Most samples show a moderate to high diversity (species per sample). Reworking of Cretaceous dinoflagellate cysts during the Danian is recorded in all sections, with higher amounts in Knappengraben and Gamsbach sections, reflected by the occurrences of *Chatangiella* spp., *Cannosphaeropsis utinensis* and *Coronifera oceanica* subsp. *hebospina*. The dinoflagellates did not suffer from a significant extinction at the K/Pg boundary in any of the studied sections. In fact, dinocyst diversity is slightly increased due to the onset of enhanced nutrient supply above the boundary in the Knappengraben, Gamsbach and Waidach sections. Only in the Goppling section the dinocyst diversity is higher in the uppermost Maastrichtian due to selective preservation (Egger and Mohamed, 2010: 122). The cluster analysis yielded six dinoflagellate cyst assemblages in the Gams Basin (Knappengraben and Gamsbach sections), and five dinoflagellate cyst assemblages in the Waidach section (see Fig. 2; Mohamed, 2010; Mohamed et al., 2012, 2013).

In the model (Fig. 2), three major tectonic units with different types of sedimentary basins and basement units can be distinguished within the Cretaceous Alps; they are from north to south: (1) the Helvetic s.l. European shelf units, platforms and basins on continental crust, forming the northernmost thrust complexes of the orogen today and partly continuing into autochthonous successions of the North Alpine foreland; (2) the Penninic units, partly overthrust onto Helvetic units s.l. and exposed as large tectonic windows below overthrusting units of more internal derivation; and (3) the Austroalpine and the Southern Alpine units which originated from the northern margin of the Adriatic plate (Haubold et al. 1999; Wagreich et al., 2008).

The K/Pg succession in the Knappengraben and Gamsbach sections (Gams Basin) was deposited on the Austroalpine microplate in the bathyal environment above the carbonate compensation depth (CCD) (Krenmayr, 1996). In the marine environments, the proximal-distal trend is one of the principal controls on kerogen distribution. Therefore the palynofacies observations can be used for a detailed paleoenvironmental analyses (Carvalho et al., 2013; Tabără and Slimani, 2017). According to the palynofacies observations by Mohamed (2010) and Mohamed et al. (2012) in the Gams Basin, a clear difference exists between the Maastrichtian and Danian. The Cretaceous part is highly dominated by AOM (cluster 3). In contrast, in the Danian the amount of black phytoclasts is much higher (clusters 1, 2, 4). The high relative abundance of translucent particles (e.g. woody tissues) in ancient marine deposits is known to indicate strong terrestrial influx, with deposition in proximal, nearshore settings (Tyson, 1995; Carvalho et al., 2013). In contrast, large amounts of phytoclasts can also occur in deep waters via turbidity currents (Habib,

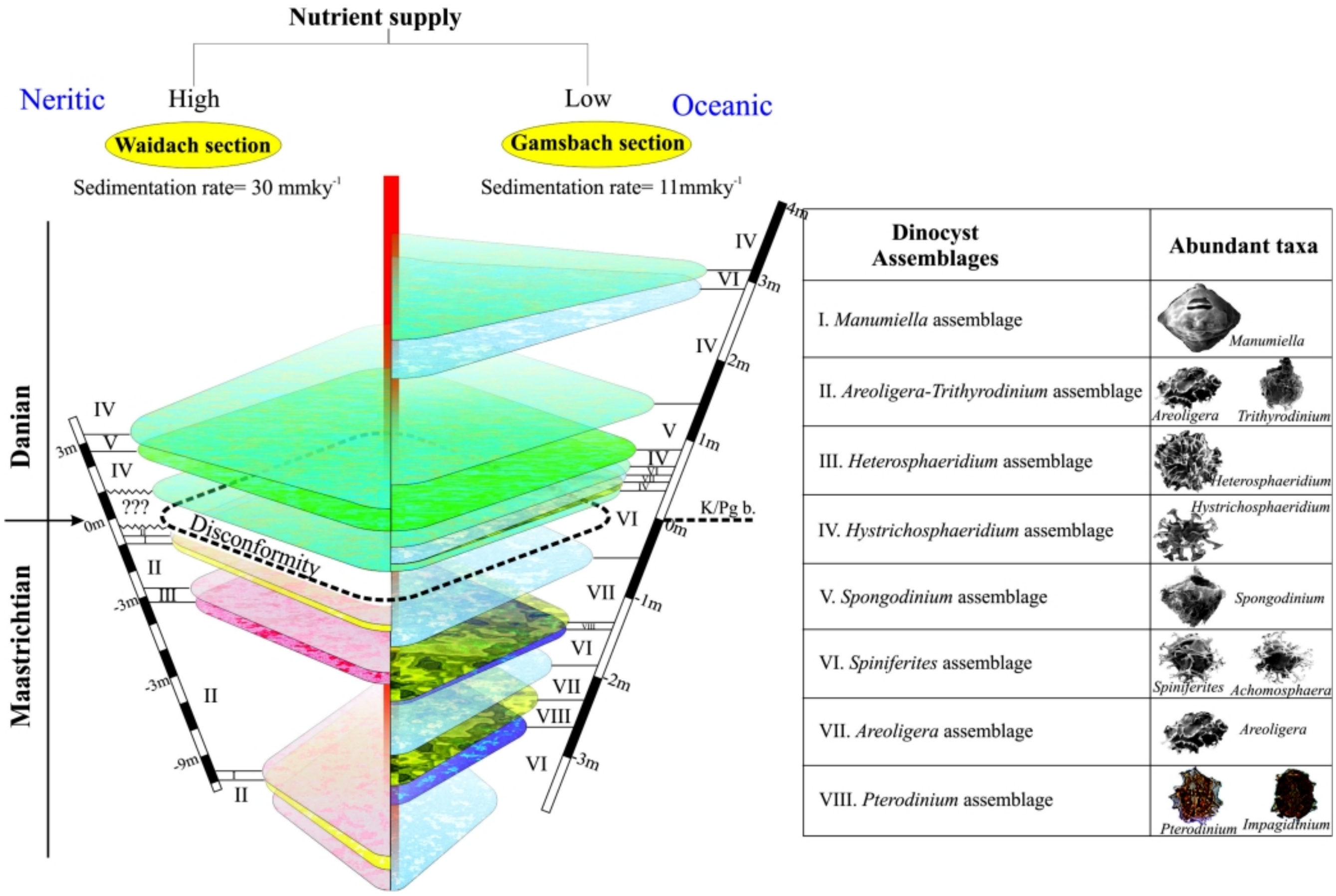

Figure 3: A model of vertical distribution of the dinocyst assemblages in the Waidach and Gamsbach sections.

1982; Carvalho et al., 2013; Tabără and Slimani, 2017). In the Gams Basin, the higher amount of black phytoclasts points to an intensified terrigenous run-off (Mohamed et al., 2012). These data are in good coincidence with the lithological development in the sections, which shows a coarse grain size and higher frequency of beds due to gravity-induced transport in the Danian part of the section. The K/Pg succession in the Goppling section was deposited on the southern part of the European Plate below the CCD. Most samples are characterized by a high abundance of AOM and a low abundance of palynomorphs. The K/Pg succession at the Waidach section was deposited in the neritic environment on the southern shelf of the European Plate. In the Waidach section, the amount of palynomorphs was much higher than in the Gams Basin. The palynofacies analysis yielded two different palynofacies assemblages. The majority of the samples belong to the AOM/Phytoclast palynofacies (cluster B) which indicates a shelf to basin transitional area with suboxic-anoxic conditions at the sea-floor. Only a few samples of the upper Maastrichtian belong to the Phytoclast/Palynomorph assemblage (cluster A) indicate a shelf to basin transitional area with dysoxic-suboxic conditions at the sea-floor.

The lateral distribution of dinoflagellate cysts in this model shows that *Trabeculidinium*, *Adnatosphaeridium* and *Codoniella* are restricted to the oceanic environment whereas *Manumiella* is restricted to the neritic environment.

Q-mode cluster analysis by Mohamed et al. (2012) revealed six dinocyst assemblages in the Gams Basin (Fig. 3), three of them are dominant and show a high species diversity: (VI) *Spiniferites* assemblage is characterized by a high abundance of *Spiniferites* (mainly *S. ramosus*) with an average of (29.8%). The second common genera are *Areoligera* (9.8%) and *Achomosphaera* (8.9%). This assemblage is recorded across the K/Pg boundary in the Gams Basin indicating no significant change in the dinoflagellate cyst assemblage across the boundary. (VII) *Areoligera* (mainly *A. coronata*) assemblage is characterized by a high abundance of *Areoligera* with an average of (22.3%). The next abundant genera are *Spiniferites* (11.5%) and *Achomosphaera* (8.9%). This assemblage is recorded mostly in Maastrichtian samples and only in one Danian (60 cm above the boundary) in the Gamsbach section. These two assemblages are the most frequently occurring assemblages in the Gams Basin. The third assemblage, (IV) *Hystrichosphaeridium* assemblage, is recorded in the Danian and is characterized by a high abundance of *Hystrichosphaeridium* with an average of (21.4%), followed by *Areoligera* (17.8%) and *Spiniferites* (14.2%). The other three assemblages are less common and display low diversity. (V) *Spongodinium delitiense* assemblage is dominated by *S. delitiense* (84.5%) and firstly occurs ~1 m above the K/Pg boundary. (VIII) *Pterodinium cingulatum* assemblage is characterized by a high abundance of *P. cingulatum* (39.4%) but with a very low number of individuals (maximum: 6). This assemblage contains only two samples of the Gamsbach section, characterized by a very low diversity and abundance (7–8 species, 22–25 individuals per sample). The last assemblage (*Areoligera gippingensis-Glaphyrocysta semitecta*) is recorded in two Danian samples (~180 cm and 370 cm, respectively, above the K/Pg boundary) of Gamsbach section, both with a very low diversity (only 3–5 species per sample and a total of 8–11 individuals), therefore this assemblage is not represented in the main study.

In the Waidach section, Q-mode cluster analysis by Mohamed et al. (2013) revealed three dinocyst assemblages in the Maastrichtian: (I) *Manumiella-Areoligera* assemblage is characterized by a high P/G ratio (up to 56) and a high abundance of *Manumiella* (30.6%) and *Areoligera* (34.1%). This assemblage was recorded in two intervals (1 m and 10 m below the K/Pg boundary), (II) the *Areoligera-Trithyrodinium* assemblage is characterized by a high abundance of *Areoligera* with an average of 45.1%, mainly *A. coronata* and *A. senonensis*. The second common genus is *Trithyrodinium* (35.2%). This assemblage is recorded in most Maastrichtian samples. The P/G ratio in this assemblage ranges from 11 to 70 and (III) *Heterosphaeridium* assemblage is present in only one Maastrichtian sample (3.3 m below the K/Pg boundary). This sample is characterized by a high abundance of *H. cordiforme* (32.2%) and a moderate abundance of *Trithyrodinium evittii* (23.2%), *Areoligera* (18.2%) and *Cleistosphaeridium* spp. (14.1%). The P/G ratio is moderate (~25) in this assemblage. The Danian samples comprise two assemblages: (IV) the *Hystrichosphaeridium* assemblage is recorded in almost Danian samples and are characterized by a high abundance (30.4%) of *H. salpingophorum* and *H. tubiferum*. These taxa are followed by *Trithyrodinium* (22.6%) and *Spiniferites* (13.5%). This assemblage is characterized by high diversity (up to 51 species per sample) and moderate P/G ratio (14 to 39) and (V) the *Spongodinium delitiense* is characterized by the dominance of *Spongodinium delitiense* (67.9%) and is recorded in only one Danian sample (1 m above the K/Pg boundary). This sample is characterized by low diversity (23 species per sample) and a low P/G ratio (6.1).

5. Discussion

Dinocyst assemblages show a strong proximal–distal signal according to the general life strategy of organic cyst-forming dinoflagellates (e.g., commonly involving neritic settings), and owing to the adaptation of many species to specific surface water conditions. Hence, the dinocyst assemblages from sediments can be used to reconstruct the influence of inshore waters in a more offshore locality (Brinkhuis, 1994; Sluijs et al., 2005).

In the upper Maastrichtian succession of the Gams Basin, the autotrophic taxa as the *Impagidinium* group (Impagidinium and Pterodinium), the Spiniferites group (*Spiniferites* and *Achomosphaera*) and *Areoligera* are common. This suggests that the sediments were deposited in a deep-water system with low nutrient supply. In contrast, the coeval dinoflagellate cyst assemblages of the Waidach section (Helvetic unit) are dominated by the heterotrophic taxa *Trithyrodinium* and *Manumiella*, which indicates deposition in a shallow-water system with high nutrient supply. Only two *Manumiella* spikes were recorded in the upper Maastrichtian of the Waidach section (~1 m and 10 m below the K/Pg boundary) interpreted to reflect resepctive cooling of oceanic surface waters.

Spongodinium delitiense acmes are recorded in the Gams Basin (from 80 cm to 220 cm above the K/Pg boundary). An acme of the same species is recorded ca. 1 m above the K/Pg boundary in the Waidach section. These acmes suggest a low paleoproductivity and could reflect a slight cooling episode of oceanic surface waters in the lowermost Danian. From a biostratigraphical point of view, the lowest acmes of *S. delitiense* were recorded in almost the same level above the boundary in all studied sections (~ 1 m above the K/Pg boundary). This implies that this lowermost acme of *S. delitiense* can be used as a local stratigraphic marker for the lowermost Danian in the Eastern Alps of Austria.

In the Gams Basin a *Spiniferites*-dominated assemblage (assemblage VI) was recorded across the K/Pg boundary, indicating no significant change across the boundary itself, followed by a *Hystrichosphaeridium*-dominated assemblage (assemblage IV) ca. 70 cm above the boundary. In contrast, in the Waidach section a distinct change occurred from an *Areoligera*- and *Trithyrodinium*-dominated assemblage (assemblage II) in the Maastrichtian to an *Hystrichosphaeridium*-dominated assemblage (assemblage IV) in the Danian. This change may, however, be amplified by the stratigraphic incompleteness of the section owing to tectonic events. Therefore we can expect that assemblage IV appears in the Gams Basin and Waidach section at approximately the same time, and that the lowest occurrences of this assemblage in both areas can be correlated, suggesting that the dinoflagellate cyst assemblages in the lowermost Danian are rather similar in both areas.

As to the hiatus in the Waidach section (Fig. 2), *Carpatella cornuta* is the first typical Danian species recorded 30–36 cm above the K/Pg boundary in the Knappengraben and Gamsbach sections, ca. 35 cm above the K/Pg boundary. But in the Waidach section, *C. cornuta* is recorded in the first Danian sample, confirming a missing part of at least 35 cm of the lowermost Danian in the Gams Basin. According to the variation in the sedimentation rate (11 mm/ka in the Gams Basin and 30 mm/ka in the Waidach section) the expected hiatus in the lowermost Danian of the Waidach section is ~1 m minimum.

6. Conclusions

In the Eastern Alps, the abundance of dinocysts is much higher, and their preservation much better, in the neritic sediments (Helvetic unit) compared to bathyal sediments (Gosau Group and Ultrahelvetic unit). The composition of the dinoflagellate cyst assemblages changes drastically within each section. This can be interpreted as an effect of changing nutrient supply. Abundant occurrences of heterotrophic taxa (*Trithyrodinium* and *Manumiella*) are restricted to the neritic environment and reflect a high productivity. The genera *Trabeculidinium*, *Adnatosphaeridium* and *Codoniella* are restricted to bathyal environments. The *Spongodinium delitiense* acmes represent marker bioevents and reflect a slight cooling episode of oceanic surface waters in the lowermost Danian in the Eastern Alps.

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Artikel/Article: A model of dinoflagellate cyst distribution around the K/Pg boundary and its paleoenvironmental implications (Eastern Alps) 36-42