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Facies development along the tide-influenced shelf of the Burdigalian Seaway: An example from the Ottnangian stratotype (Early Miocene, middle Burdigalian)

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ABSTRACT

Herein, we report quantitative micropaleontological (benthic foraminifers, dinoflagellate cysts, calcareous nannoplankton), sedimentological (grain-size analysis) and geophysical (background gamma radiation) analyses from Ottnang–Schanze, the stratotype for the regional Ottnangian stage (Central Paratethys; Lower Miocene, middle Burdigalian). The revealed trends in bathymetry, primary productivity, bottom-water oxygenation and water energy allow exemplary insights into the paleoenvironment of the terminal Burdigalian Seaway. Several facies of a eutrophic environment are distinguished that reflect a transition from a suboxic outer neritic to upper bathyal towards a better oxygenated middle neritic setting under the influence of storm events and currents.

A comparison with available data from Upper Austria and Bavaria consistently shows the regressive trend during the late early Ottnangian. In Upper Austria, the deep-water facies from the lower part of the stratotype represents the most distal sediments. The upper part together with localities closer to the northern coast records inner to middle neritic environments that are heavily affected by tidal currents. The facies distribution results from the progradation of a tide-influenced environment along the northern shelf of the North Alpine Foreland Basin, heralding the closure of the Burdigalian Seaway. The available age estimate for the stratotype constrains the onset of the regressive phase to 18 Ma.

1. Introduction

The North Alpine Foreland Basin (NAFB) represents one of the major sedimentary basins of the Central Paratethys Sea from Oligocene to Early Miocene (Lemcke, 1988; Rögl, 1998a; Wagner, 1998; Kuhlemann and Kempf, 2002). Via the Rhône Basin in the West it acted as the marine gateway between the Western Mediterranean/Atlantic realm and the Central Paratethys (Fig. 1a; Rögl, 1998a; Kuhlemann and Kempf, 2002). The connection was only interrupted during late Chattian and Aquitanian, when the gateway was temporarily blocked and freshwater environments developed in the west (Berger, 1996). A major transgression re-established basin-wide marine conditions during the early Burdigalian, initiating a wave of faunal immigration from the Atlantic and Mediterranean into the Central Paratethys (Vavra, 1979; Berger, 1996; Schlunegger et al., 1997; Rögl, 1998a; Kroh and Harzhauser, 1999; Mandic and Steininger, 2003; Kroh and Menkveld-Gfeller, 2006). This newly established gateway is commonly referred to as the Burdigalian Seaway (Allen et al., 1985). In contrast to the wide and deep-marine Oligocene foreland basin, the Burdigalian Seaway was a strait with extensive shelf areas narrowed by the advancing Alpine thrust front. Deep-water environments were limited to the remnants of the up-filled Puchkirchen Basin and the easternmost part of the NAFB along the steep escarpment of the Bohemian Massif (Wenger, 1987; Rögl, 1998a; Wagner, 1998; Kuhlemann and Kempf, 2002; Rupp and Haunold-Jenke, 2003; Roetzel et al., 2006; Grunert et al., 2010a). The narrowing of the basin resulted in amplified currents that are linked to increased tides. The widespread tidal deposits along the northern shelf have become a prominent example for sedimentation under meso- and macrotidal control and complex interacting current patterns have been discussed in a number of sedimentological and modeling studies (Homewood and Allen, 1981; Allen and Homewood, 1984; Allen et al., 1985; Faupl and Roetzel, 1987, 1990; Keller, 1989; Tessier and Gigot, 1989; Lesueur et al., 1990; Krenmayr, 1991; Schaad et al., 1992; Martel et al., 1994; Sztanó, 1994, 1995; Sztanó and De Boer, 1995; Uchmann and Krenmayr, 1995, 2004; Krenmayr et al., 1996; Salvermoser, 1999; Bieg, 2005; Heimann et al., 2009; Grunert et al., 2010a). Marine sedimentation in the NAFB finally

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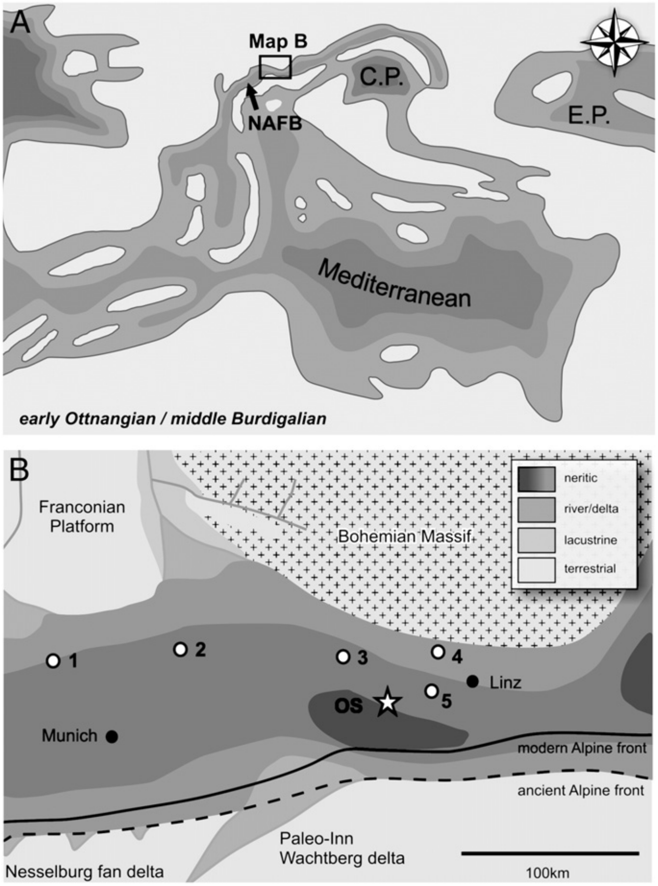

Fig. 1. Early Ottnangian (middle Burdigalian) paleogeography of (A) the Central Paratethys and Mediterranean seas and (B) the study area in the North Alpine Foreland Basin (NAFB). The maps follow Rögl (1998a), Kuhlemann and Kempf (2002), Brügel et al. (2003), Harzhauser and Piller (2007) and Grunert et al. (2010b). OS = stratotype Ottnang–Schanze. 1–5 = early Ottnangian localities in Upper Austria and eastern Bavaria that are compared to the stratotype: 1 = drill-sites Schrobenhausen and Stockhausen, Neuhofen Beds (Pippèrr, 2011); 2 = drill-site Altdorf, Neuhofen Beds (Pippèrr and Reichenbacher, 2010); 3 = outcrops Höhenmühle, Neuhofen and Oberschwärzenbach, Neuhofen Beds (Pippèrr and Reichenbacher, 2010; Pippèrr, 2011); 4 = S margin of Bohemian Massif, Atzbach Fm. (Faupl and Roetzel, 1987); 5 = Wels area, Atzbach and Ottnang Fms. (Rupp and Haunold-Jenke, 2003).

ceased due to its constant upfill during the middle Burdigalian, marking the onset of a major paleogeographic reorganization of the Central Paratethys (Berger, 1996; Rögl, 1998a; Harzhauser and Piller, 2007).

In the present study, we provide a detailed facies analysis of the section Ottnang–Schanze which represents the stratotype for the regional Ottnangian stage (Lower Miocene, middle Burdigalian; Figs. 2, 3). Since its initial description in the 19th century and the designation as holostratotype by Rögl et al. (1973) only few data on the section have been published (e.g., Rupp et al., 1991; Rupp and van Husen, 2007; Rupp et al., 2008). The facies of the outcrop is commonly summarized as a euhaline sublittoral environment (Rögl et al., 1973; Zorn, 1995; Janz and Vennemann, 2005; Rupp and van Husen, 2007; Rupp et al., 2008). However, this interpretation is based on a small number of samples and no information on their relative position within the outcrop is given in any publication. The lack of detailed paleoenvironmental information is all the more surprising as the lithology of the section indicates various depositional environments (Fig. 3; Grunert et al., 2010b).

The herein presented analyses of microfossil assemblages (benthic foraminifers, dinoflagellate cysts, calcareous nannoplankton), grain-size and background gamma radiation is based on new sample material and allows a detailed evaluation of the paleoenvironment. Facies types will be discussed with respect to the paleoecological key-parameters water depth, water energy, primary productivity, organic matter flux and bottom water oxygenation, and the revealed facies development will exemplarily document the dynamic paleoenvironment of the terminal Burdigalian Seaway.

2. Regional setting

The studied section Ottnang–Schanze has been chosen as the stratotype for the regional Ottnangian stage by Rögl et al. (1973). The regional stratigraphic concept for the Central Paratethys originates from its complex paleogeographic history that is reflected in distinct biogeographic patterns (for details see e.g., Harzhauser and Piller, 2007). The concept paralleling global Oligocene–Miocene stratigraphy has been established over 40 years ago mainly on the basis of endemic fossil assemblages and has been applied to the Central Paratethys since then (Cicha et al., 1967; Steininger and Seneš, 1971; Papp et al., 1973, 1974, 1978, 1985; Baldí and Seneš, 1975; Stevanović et al., 1990). For each of the regional stages a holostratotype and several faciostratotypes have been selected (Piller et al., 2007). As they represent characteristic facies of regional importance these sections do not follow the GSSP concept of the International Commission for Stratigraphy introduced by Hedberg (1976). More recently, larger data-sets and new stratigraphic approaches allow an improved calibration of the regional stages to the international chronostratigraphic framework (e.g., Rögl, 1998a; Piller et al., 2007; Lirer et al., 2009; de Leeuw et al., 2010; Grunert et al., 2010b; Vasiliev et al., 2010). According to Piller et al. (2007), the Ottnangian corresponds to the middle Burdigalian Bur 3-cycle (Abreu and Haddad, 1998; Fig. 4).

The study area is located in the NAFB of Upper Austria (Fig. 2). The Ottnangian sediments in the region are summarized in the Innviertel Group (Fig. 4; Papp and Cicha, 1973; Rupp et al., 2008; Grunert et al., 2010b). While the lower and middle Ottnangian silts and sands originate from transgressive and highstand phases, the brackish-fluvial *Oncophora* Beds represent the regressive facies of the upper Ottnangian. The sediments of the stratotype section belong to the lower Ottnangian Ottnang Formation that summarizes the pelitic basinal deposits in the area (Rupp et al., 2008; Grunert et al., 2010b). The average thickness of the Ottnang Fm. is reported with 80–100 m and shows considerable lateral variations (Bürgl, 1949; Aberer, 1958; Kaltbeitzer, 1988; Wagner, 1998). The Ottnang Fm. overlies the Atzbach Fm., the Kletzenmarkt-Glaukonit Fm. and the Plesching Fm. and partly interfingers with these units. It is followed up by the middle Ottnangian Ried and Reith Fms. and the Enzenkirchen Sands (Rupp and van Husen, 2007; Rupp et al., 2008). Detailed information on the geological setting can be found on the Austrian geological maps ÖK 200 "Upper Austria" (Krenmayr and Schnabel, 2006) and ÖK 47 "Ried im Innkreis" (Rupp et al., 2008).

The section Ottnang–Schanze is located in the Vöcklabruck district, c. 700 m SSW Wolfsegg and 500 m N of the village Ottnang in Upper Austria (Fig. 2). It is part of an abandoned clay pit near a memorial to the Peasant Wars (called "Schanze") and has been declared a natural heritage site and geotop (Rögl et al., 1973; Reiter, 1989).

At the outcrop and its surroundings the Ottnang Fm. overlies the Atzbach Fm. The contact between the two formations is not exposed at the outcrop but the Atzbach Fm. has been reported from the close-by village of Nieder-Ottnang (Rögl et al., 1973, p. 142; Roetzel and Rupp, 1991). Based on geological maps and information from drill-sites in the vicinity of the stratotype, most of the Innviertel Group in the study area is made up by the Vöckla and Atzbach Fms. (Aberer, 1958; Schläger, 1988; personal communication R. Hinsch, RAG). The Ottnang Fm. is represented with a thickness of 40–60 m. Its top is eroded and covered by late Miocene and Pleistocene deposits (Rögl et al., 1973; Schläger, 1988; Rupp et al., 2008).

The age of the section and the Ottnang Fm. in general has been discussed since the 19th century (see Rögl et al., 1973; Rupp et al., 2008; Grunert et al., 2010b for summaries). Recently, Grunert et al. (2010b) presented a conclusive calibration of the stratotype to an absolute age of 18.06–17.95 Ma by using a combination of bio- and magnetostratigraphy.

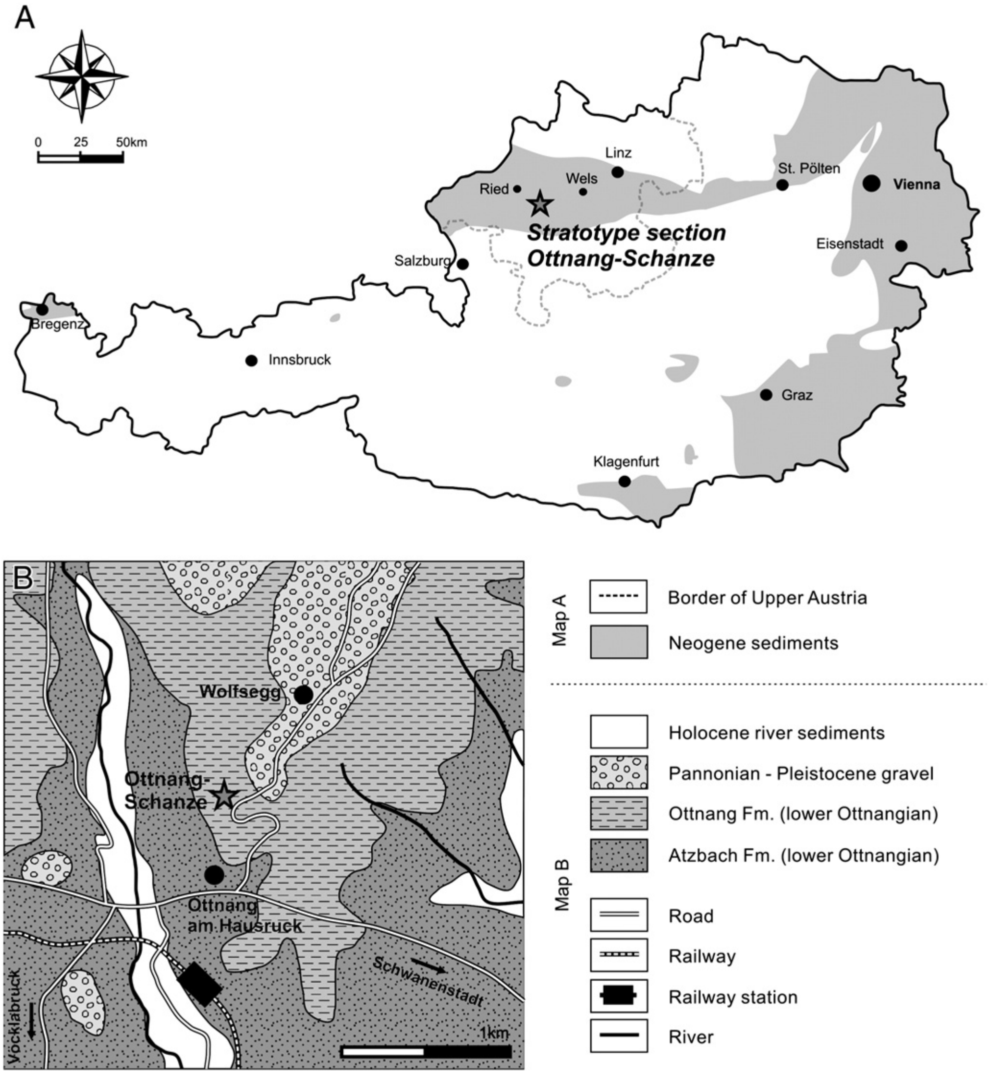

Fig. 2. (A) Location of the stratotype section in the Austrian part of the NAFB. (B) Geography and geology of the study area based on Krenmayr and Schnabel (2006) and Rupp et al. (2008). Adopted from Grunert et al. (2010b).

3. Material and methods

3.1. Lithology

A detailed lithological log of the succession and 24 samples (OS 1–24) were taken in 2007 (Fig. 3). Grain-size analysis of the sample material was conducted by wet sieving and using a Sedigraph for grain-sizes <0.063 mm at the Geological Survey of Austria. Background gamma radiation was measured with a portable scintillation counter (Heger-Breitband-Gammasonde).

3.2. Micropaleontology

All 24 samples were included in micropaleontological analyses. For foraminiferal analysis, 100 g of each sample was treated with diluted H_2O_2 for several hours and wet sieved under running tap water. Dried samples were split using a splitting device described in Rupp (1986) and at least 200 specimens were counted from size fractions >150 µm. Foraminiferal species have been identified based on Wenger (1987), Cicha et al. (1998) and Rupp and Haunold-Jenke (2003). For paleoenvironmental analyses, benthic foraminifers were grouped according to their bathymetric distribution, organic matter flux, microhabitat and oxygen dependency (Tables 1, 2 and references therein). The nomenclature for oxygen levels refers to Kaiho (1994): high oxic (3.0–6.0 mL/L), low oxic (1.5–3.0 mL/L), suboxic (0.3–1.5 mL/L) and dysoxic (0.1–0.3 mL/L).

For dinoflagellate cyst analysis, a standard palynological technique for the extraction of organic-walled microfossils from sediments has been applied with slight modifications following Green (2001). 20–30 g of sediment were treated with 100 mL of HCl (35%) and then macerated in 30–50 mL of cold concentrated HF (48%) overnight to remove any carbonates and silicates. Before sieving (mesh-sizes: 125 µm, 20 µm), the residues were treated for 30 s in an ultrasonic bath and stained with red Safranin "O". Two slides of each sample were prepared by using glycerine jelly as a mounting media and sealed with nail varnish. Dinoflagellate cysts were determined and documented using a Zeiss microscope (Axioplan 2) fitted with a Leica digital camera. 250 dinoflagellate cysts were counted in every sample; the remainder of the slide(s) was then scanned for rare specimens. Taxonomy follows Fensome et al. (1993, 2008). The observed taxa are listed in Table 3.

Smear slides for nannoplankton investigations were prepared using standard methods and examined with a light microscope (cross and parallel nicols) with 1000× magnification. At least 300 specimens were counted from each sample. A further 100 view squares were checked for paleoecologically important nannoplankton taxa. The encountered taxa are listed in Table 4.

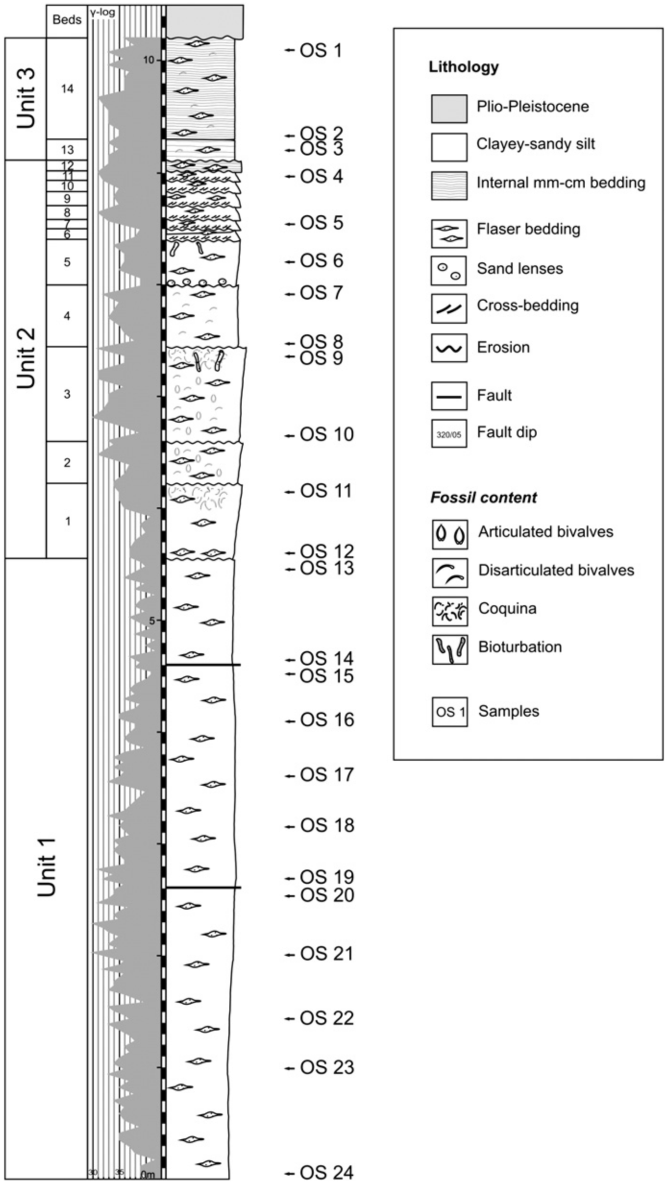

Fig. 3. Lithological units, background gamma radiation and lithology of the stratotype Ottnang–Schanze. Modified from Grunert et al. (2010b).

Statistical analysis was carried out by using the software PAST (version 2.08; Hammer et al., 2001). Diversity of the individual microfossil groups is expressed by the total number of taxa (S) and the Fisher alpha index (α), the distribution of species within an assemblage is reflected by dominance (D) and equitability (J) (Hammer and Harper, 2006). Cluster analysis (Ward's method) and non-metric multidimensional scaling (NMDS; Bray–Curtis similarity) were applied to the combined data-sets of all three microfossil groups to define distinct microfossil assemblages (Hammer et al., 2001). A similarity percentage analysis (SIMPER; Bray–Curtis similarity) was performed to evaluate the contribution of the individual taxa to the differences between the defined assemblages (Clarke, 1993). Rare taxa (<2% in all samples) and undetermined specimens were excluded from statistical analysis.

4. Results

4.1. Lithology

The exposed section is 10.2 m thick and disturbed by two tectonic faults (Fig. 3). Sedimentation shows distinct changes allowing the subdivision of the section into three lithological units:

Unit 1 (0–5.5 m) shows rather homogeneous greenish-brown sediments of clayey silts and clayey–sandy silts with sand-lenses and flaser bedding. The sand lenses have a lateral extrusion of up to 30 cm and often contain plant debris. Sediments show no bedding and are heavily bioturbated.

Unit 2 (5.5–9.1 m) shows an overall coarsening upward trend and is subdivided into 12 beds separated by erosional surfaces. The succession starts with clayey–sandy silts and flaser bedding similar to Unit 1 and soon passes into mollusk-rich pelitic sediments. Each bed shows internal gradation: beds 1–5 reflect coarsening-upward cycles and beds 6–12 fining-upward cycles. Beds with coarsening-upward cycles show indistinct dm-layering and articulated bivalves at the base, passing into bioturbated sediments with bivalve coquinas. Fining-upward cycles (max. thickness: 10 cm) start with ripple-cross-bedded silty sands passing into sandy silts.

Unit 3 (9.1–10.2 m) shows two beds with an increased thickness of clayey–sandy silts compared to beds 6–12 with a distinct lamination, flaser-bedding, and disarticulated bivalve shells enriched in sand-lenses.

Gamma logging and grain-size analysis both reflect the three lithologic units recognized in the outcrop during field-work (Table 5; Figs. 3, 5). From the base up to OS 16, the mean grain-size distribution of Unit 1 shows a slight increase (coarsening upward) from clayey silts towards clayey–sandy silts which results from an increase in the fine-sand fractions. In the uppermost part of Unit 1 (OS 15–OS 13) the pelitic component increases. This trend is also reflected by the gamma log record.

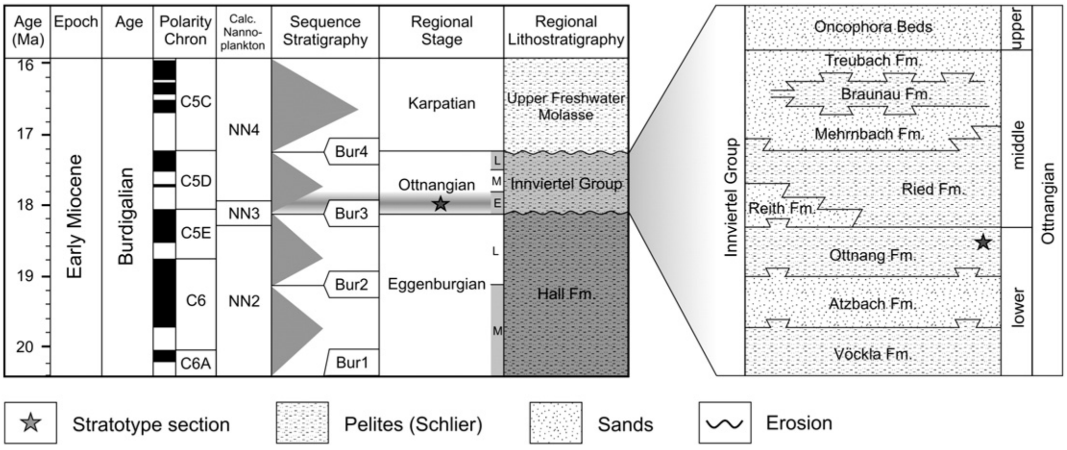

Fig. 4. Global and regional stratigraphy of the Burdigalian according to Piller et al. (2007). Correlation of the stratotype with the international time-scale (Lourens et al., 2004) is based on Grunert et al. (2010b). Regional lithostratigraphy according to Rupp and van Husen (2007), Rupp et al. (2008) and Grunert et al. (2010b).

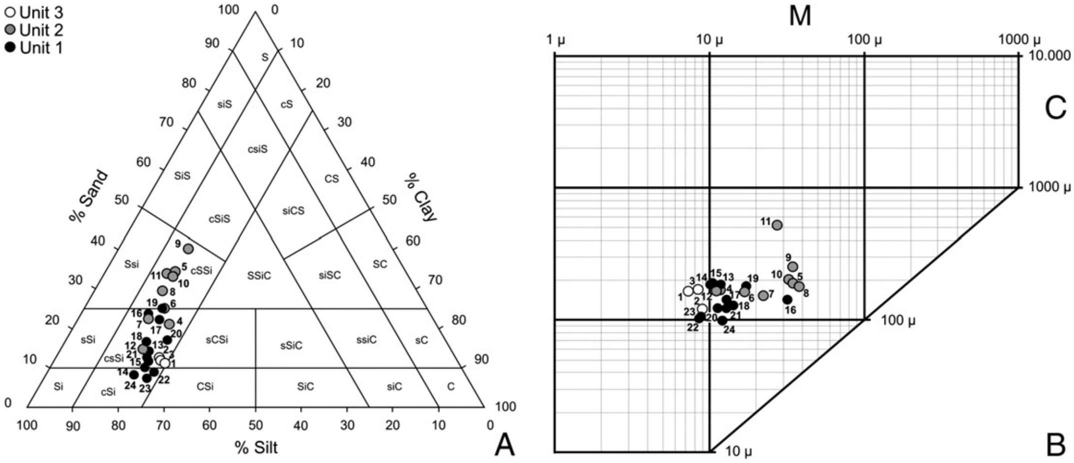

Fig. 5. (A) Nomenclature of sediments from the stratotype samples based on grain-size analysis following Füchtbauer (1959) and Müller (1961). (B) CM-diagram for the samples from the stratotype (Passega, 1957).

Unit 2 starts with clayey–sandy silts comparable with Unit 1 (OS 12) which passes into clayey sand–silts (OS 11–OS 8, OS 5). The latter is continuously interrupted by slightly finer clayey–sandy silts (OS 7, OS 6, OS 4). The coarsening trend is also documented in a lowered mean grain-size value (6.2 Phi; standard deviation = σ = 0.4) and a strongly positive skewness (0.6–1.1). Accordingly, gamma log values are distinctively lower than in Unit 1 reflecting higher sand content.

The clayey–sandy silts of Unit 3 (OS 3–OS 1) show an increasing silt and clay content with mean values of more than 7 Phi. Gamma log values show only a small difference to Unit 2 which may be caused by the extensive flaser bedding in this part of the section.

In the CM-diagram (Passega, 1957, 1964; Passega and Byramjee, 1969), in which C is the one-percentile and M is the median of the grain-size distribution, the majority of the samples plots in segment RS that indicates transport in uniform suspension (Fig. 5b). Besides a prominent silt-content, sediments from Ottnang–Schanze are characterized by high portions of fine sand and considerable clay-portions. According to Passega (1977) such sediments were deposited by currents where bottom turbulence is not competent to support suspended particles coarser than fine sand. These currents may also include interflows and surface currents. Variation in the CM-diagram mainly occurs along M indicating highest bottom turbulence for samples OS 16, OS 11–8 and OS 5.

4.2. Microfossil abundance and diversity

4.2.1. Benthic foraminifers

Moderately to well preserved tests of 117 benthic foraminiferal taxa have been identified (Table 1). Those with hyaline tests are dominating the samples (mean = A = 85%, σ = 10%; Fig. 6). Miliolids show a mean abundance of 10% (σ = 4%) mostly represented by *Sigmoilinita tenuis* and *Sigmoilopsis ottnangensis*. Agglutinated taxa occur rarely (A = 6%, σ = 7%) with the exception of samples OS 17 and OS 11–10 (A = 22%, σ = 5%) which show peaks of *Spiroplectammina pectinata*.

Fisher alpha diversity values range between 3.8 and 13. Unit 1 has an average diversity of 9.9 (σ = 2.5) with highest values in its lower part (OS 24–17) and lower numbers with a positive peak in OS 14 at the top. Unit 2 reveals a lower average value of 6.1 (σ = 2) and peaks in OS 12, OS 9 and OS 4. Finally, Unit 3 has an average diversity of 6.9 (σ = 2.5) with a positive peak in OS 3. Dominance is generally low in the samples of Unit 1 (A = 0.09, σ = 0.02) with a trend towards higher values in Units 2 and 3 ($A_{\text{Unit 2}} = 0.15$, $\sigma_{\text{Unit 2}} = 0.07$; $A_{\text{Unit 3}} = 0.21$, $\sigma_{\text{Unit 3}} = 0.12$). Conversely, equitability is high for Unit 1 (A = 0.86, σ = 0.03) and changes towards lower values in Units 2 and 3 ($A_{\text{Unit 2}} = 0.72$, $\sigma_{\text{Unit 2}} = 0.09$; $A_{\text{Unit 3}} = 0.68$, $\sigma_{\text{Unit 3}} = 0.16$) with a positive peak in OS 2.

Foraminiferal taxa characteristic for outer neritic–upper bathyal settings show high abundances in Unit 1 and the lower part of Unit 2 (OS 24–12; A = 32%, σ = 12%) and a sharp decrease in samples OS 11–1 (A = 8%, σ = 4%). Conversely, inner neritic taxa mainly occur in samples OS 7–1 (A = 12%, σ = 8%) from Units 2 and 3 while they are very rare (A = 2%, σ = 2%) in Unit 1 and the lower part of Unit 2 (OS 24–8).

Indicators for elevated nutrient flux show highest abundances in Units 2 and 3 (OS 10–1; A = 17%, σ = 5%) mainly related to the abundance of *Caucasina* spp. While samples OS 18–11 show very low values (A = 2%, σ = 3%), the lower part of Unit 1 revealed average values of 8% (σ = 2%) due to the occurrences of *Praeglobobulimina* spp. and *Caucasina* spp. (OS 24–19).

Epi- and infaunal taxa are distributed almost equally in most samples of Unit 1 and lowermost Unit 2 (OS 24–12; $A_{\text{epi}} = 41\%$, $\sigma_{\text{epi}} = 8\%$; $A_{\text{inf}} = 39\%$, $\sigma_{\text{inf}} = 7\%$). Deep infaunal taxa occur in samples OS 16–13 (A = 4%, σ = 2%) and OS 24–21 (A = 8%, σ = 1%). Units 2 and 3 show a general increase in epifaunal taxa ($A_{\text{epi}} = 53\%$, $\sigma_{\text{epi}} = 6\%$; $A_{\text{inf}} = 25\%$, $\sigma_{\text{inf}} = 8\%$) and absence of deep infaunal taxa. The high abundance of epifaunal taxa primarily results from an average increase of 20% in the abundance of *Lenticulina inornata* in the upper part of the section. Peak abundances of epifaunal taxa are documented for OS 11–8, OS 4, OS 3 and OS 1.

Index taxa for sub- and dysoxic bottom waters dominate foraminiferal assemblages throughout the section (A = 78%, σ = 7%). Suboxic taxa dominate over dysoxic taxa, the later being restricted to samples OS 24–21 and OS 16–13 of Unit 1. The abundance of oxyphilic taxa is very low (A = 6%, σ = 4%) with peaks in samples OS 18, OS 15 and OS 10–11.

4.2.2. Dinoflagellate cysts

64 taxa of dinoflagellate cysts have been identified (Table 3). Most taxa show low abundances with less than 5%, only *Apteodinium* spp., *Achomosphaera*/*Spiniferites* spp., *Exochosphaeridium insigne*, *Lingulodinium machaerophorum*, *Operculodinium centrocarpum*, *Spiniferites* spp. and round brown cysts occur commonly.

The total number of taxa (A = 31, σ = 4) as well as diversity values (A = 9.1; σ = 1.5) show no clear trends (Fig. 7). Dominance is low with lower values for Unit 1 and the lower part of Unit 2 (OS 24–10; A = 0.14, σ = 0.04) than for the upper part of Unit 2 and Unit 3 (OS 9–1; A = 0.3, σ = 0.07). Accordingly, equitability shows high values in Unit 1 and the lower part of Unit 2 (OS 24–10; A = 0.74, σ = 0.05) and lower values in samples OS 9–1 (A = 0.57, σ = 0.04).

The abundance of oceanic dinoflagellate cysts is low (A = 4%, σ = 2%) and shows highest abundances in the lower part of Unit 1 (OS 24–19; Fig. 7). Dinoflagellate cysts associated with coastal environments show a

Table 1
Benthic foraminifers from the stratotype.

	OS 1	OS 2	OS 3	OS 4	OS 5	OS 6	OS 7	OS 8	OS 9	OS 10	OS 11	OS 12	OS 13	OS 14	OS 15	OS 16	OS 17	OS 18	OS 19	OS 20	OS 21	OS 22	OS 23	OS 24
Alabamina tangentialis (Clodius)	12	10	47	68	224	36	88	64	44	24	16	0	0	2	0	0	1	1	0	2	0	3	3	0
Ammonia beccarii (Linné) gr.	8	16	23	34	32	20	8	0	4	16	0	0	0	0	0	3	0	1	2	1	3	0	1	1
Amphicoryna ottnangiensis (Toula)	4	4	7	4	16	13	40	1	10	148	125	40	5	7	0	4	8	12	15	23	30	13	20	28
?*Amphicoryna* sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0
Astacolus crepidulus (Fichtel & Moll)	0	0	0	0	8	0	0	0	0	0	0	6	0	2	0	0	0	0	1	0	1	0	0	0
Asterigerinata planorbis (D'Orbigny)	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Astrononion perfossum (Clodius)	16	0	16	34	88	112	64	80	27	56	0	0	0	0	0	1	0	2	1	7	0	0	0	0
Astrononion cf. *perfossum* (Clodius)	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	3	1	0	0	0
Aubignyna cf. *brixi* Rögl	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
?*Aubignyna* sp.	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
?*Biapertorbis biaperturatus* Pokorny	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bolivina concinna (Knipscheer & Martin)	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bolivina cf. *budensis* (Hantken)	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bulimina elongata D'Orbigny	0	4	0	0	0	0	8	0	0	8	16	0	0	0	0	0	0	0	1	0	1	1	0	0
Bulimina sp.	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Caucasina cylindrica Zapletalova	84	38	141	116	336	172	192	176	52	328	80	0	0	0	0	0	0	1	6	6	2	0	1	0
Caucasina subulata (Cushman & Parker)	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	1	0	0	0
Chilostomella ovoidea Reuss	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2	0
Chilostomella sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
?*Chilostomella* sp.	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cibicidoides austriacus (D'Orbigny)	1	0	1	0	0	0	0	3	1	4	1	0	0	0	0	0	0	0	0	2	1	0	0	0
Cibicidoides lopjanicus (Myatlyuk)	0	8	34	2	0	0	0	1	2	0	9	0	0	0	0	0	0	0	1	0	0	0	0	0
Cibicidoides ornatus (Cicha & Zapletalova)	0	0	0	0	8	0	0	0	1	0	0	2	0	1	0	2	0	0	0	0	2	0	1	1
Cibicidoides pseudoungerianus (Cushman)	12	0	0	8	24	24	8	8	20	128	80	0	4	3	0	1	1	2	0	4	0	4	2	0
Cibicidoides ungerianus ungerianus (D'Orbigny)	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	1	3	1	1
Cibicidoides spp.	4	0	1	6	0	4	24	9	1	0	0	0	0	0	0	0	0	0	0	1	0	0	2	0
Dentalina cf. *acuta* D'Orbigny	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	4	0
Dentalina sp.	0	0	0	0	0	0	0	0	0	0	4	0	0	6	0	0	0	0	1	0	0	1	0	0
?*Dentalinoides aproximata* (Reuss)	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0
?*Elphidiella* sp.	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Elphidium angulatum (Egger)	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Elphidium crispum (Linné)	0	0	0	0	8	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Elphidium fichtelianum (D'Orbigny)	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Elphidium glabratum Cushman	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Elphidium hauerinum (D'Orbigny)	0	0	5	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Elphidium karpaticum Myatlyuk	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Elphidium matzenense Papp	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Elphidium ortenburgense (Egger)	0	0	3	0	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Elphidium reussi Marks	0	0	0	4	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Elphidium rugulosum Cushman & Wickenden	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Elphidium subtypicum Papp	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Elphidium spp.	0	0	0	4	0	4	0	0	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0
Elphidiidea indet.	4	4	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fursenkoina acuta (D'Orbigny)	12	6	19	16	72	68	88	72	16	56	32	0	0	0	0	1	1	1	0	2	1	0	0	0
Glandulina ovula D'Orbigny	0	0	0	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
?*Glandulina* sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Globocassidulina oblonga (Reuss)	0	0	0	0	8	4	16	0	1	0	0	1	4	0	0	0	1	2	0	0	0	0	0	0
Globocassidulina cf. *globosa* (Hantken)	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Globulina gibba D'Orbigny	0	0	2	0	0	0	0	0	1	0	1	2	0	0	0	0	0	0	1	0	0	1	1	0
Gyroidinoides octocameratus (Cushman & Hanna)	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Gyroidinoides cf. *octocameratus* (Cushman & Hanna)	0	0	0	0	0	0	0	0	0	0	32	0	0	0	0	0	0	0	0	0	0	0	0	0

Gyroidinoides parvus (Cushman & Renz)	0	0	0	4	0	0	0	0	0	24	0	26	24	16	0	2	1	4	5	19	11	9	16	0
Hansenisca soldanii (D'Orbigny)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Hanzawaia boueana (D'Orbigny)	4	10	10	16	24	12	16	0	10	24	0	0	0	0	0	0	0	0	1	1	1	1	1	0
Hanzawaia cf. *boueana* (D'Orbigny)	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hemirobulina glabra (D'Orbigny)	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hemirobulina cf. *pediformis* (Bornemann)	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0
Heterolepa dutemplei (D'Orbigny)	4	2	2	2	0	0	1	9	4	0	1	0	0	1	1	0	1	0	0	0	1	1	1	0
Laevidentalina cf. *boueana* (D'Orbigny)	0	0	0	2	8	0	0	0	0	8	0	32	20	17	4	15	1	10	6	15	12	9	0	1
Laevidentalina communis (D'Orbigny)	4	2	5	4	32	0	0	0	5	8	32	4	8	2	1	0	0	1	2	2	3	6	1	0
Laevidentalina elegans (D'Orbigny)	0	0	0	0	8	0	0	0	5	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Laevidentalina sp.	0	0	0	0	0	4	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Lagena gracilicosta Reuss	0	0	5	2	0	0	0	0	0	0	0	2	4	2	0	0	1	0	1	0	1	1	0	1
Lagena striata (D'Orbigny)	0	0	1	4	8	0	0	8	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1
Lagena sp.	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
?*Lagena* sp.	0	0	0	0	0	0	0	0	0	3	4	1	0	1	0	0	0	1	0	0	0	0	0	0
Lenticulina calcar (Linné)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Lenticulina inornata (D'Orbigny)	309	11	274	133	350	156	275	539	542	407	241	19	11	14	6	5	5	9	8	4	13	18	31	8
Lenticulina gibba (D'Orbigny)	1	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	1	2	0	0	0
Lobatula lobatula (Walker & Jacob)	4	6	5	6	16	12	8	0	2	16	0	0	0	0	0	0	1	1	0	2	0	0	0	0
?*Lobatula lobatula* (Walker & Jacob)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Marginulina hirsuta D'Orbigny	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	4	7	13	6
Marginulina wengeri Rupp & Haunold-Yenke	0	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Melonis pompilioides (Fichtel & Moll)	0	0	4	2	0	0	0	0	1	8	0	0	0	0	0	0	0	0	1	0	0	0	1	0
Melonis sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	3	0	0
Myllostomella advena (Cushman & Laiming)	0	0	0	0	0	0	0	0	0	0	0	3	0	1	0	0	0	0	0	0	0	0	0	1
Myllostomella recta (Palmer & Bermudez)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Nonion commune (D'Orbigny)	14	28	35	34	96	44	24	49	23	118	7	9	4	2	3	4	3	1	2	12	15	7	8	9
Nonionidae indet.	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0
Oridorsalis umbonatus (Reuss)	0	0	0	4	0	0	0	0	1	8	48	10	16	9	1	5	1	5	10	9	21	22	17	10
?*Porosononion* sp.	4	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Praeglobobulimina pyrula-pupoides gr.	0	0	0	0	0	0	0	0	0	0	0	0	9	4	0	0	0	0	0	1	16	19	14	9
Praeglobobulimina sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
?*Protelphidium roemeri* (Cushman)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0
Pullenia bulloides (D'Orbigny)	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pullenia quinqueloba (Reuss)	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pullenia sp.	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Quadrimorphina petrolei (Andreae)	0	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Saracenaria arcuata (D'Orbigny)	0	0	0	2	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	1	0	0
?*Stilostomellidae* indet.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Vaginulinopsis cf. *hauerina* (D'Orbigny)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Vaginulinopsis sp.	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Valvulineria complanata (D'Orbigny)	0	0	2	4	0	0	0	0	1	8	0	11	16	16	0	10	0	2	2	18	26	29	25	7
Hyaline indet.	20	8	27	62	48	28	26	48	15	80	97	21	12	22	3	11	3	8	10	31	25	19	16	19
Cycloforina cf. *ludwigi* (Reuss)	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	1	1	1	0	0	0	0	0	0
?*Cycloforina* sp.	0	0	0	6	0	4	0	8	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pyrgo cf. *lucernula* Schwager	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0
Pyrgo lunula (D'Orbigny)	0	0	1	2	8	0	0	0	1	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pyrgo simplex (D'Orbigny)	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Quinqueloculina buchiana D'Orbigny	0	0	0	0	11	4	0	7	15	19	19	1	0	6	0	3	0	0	1	0	0	0	10	0
Quinqueloculina cf. *buchiana* D'Orbigny	0	0	0	0	32	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	5	0	0
Quinqueloculina sp.	0	0	0	0	1	0	0	0	1	0	1	0	0	1	0	0	0	1	1	0	8	1	0	1
Sigmoilinita tenuis (Czjzek)	0	0	0	4	16	0	0	32	6	136	96	1	0	0	0	0	2	7	2	7	3	4	6	1
Sigmoilopsis ottnangiensis Cicha, Ctyroka & Zapletalova	10	0	1	0	3	20	21	79	63	102	93	5	14	5	1	0	2	6	5	15	7	14	14	3

(*continued on next page*)

Table 1 (*continued*)

	OS 1	OS 2	OS 3	OS 4	OS 5	OS 6	OS 7	OS 8	OS 9	OS 10	OS 11	OS 12	OS 13	OS 14	OS 15	OS 16	OS 17	OS 18	OS 19	OS 20	OS 21	OS 22	OS 23	OS 24
Sigmoilopsis cf. *ottnangiensis* Cicha, Ctyroka & Zapletalova	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spiroloculina canalilucuta D'Orbigny	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spiroloculina lamposa Hussey	12	14	15	94	56	44	24	8	7	88	0	6	0	3	0	0	0	0	0	1	0	0	1	0
Spiroloculina sp.	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Miliolidae indet.	0	0	1	0	0	0	0	0	2	0	18	0	4	2	0	0	1	0	0	0	0	0	0	0
Martinotiella communis (D'Orbigny)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0
Spiroplectammina pectinata (Reuss)	2	0	8	4	74	28	8	38	90	461	415	2	0	3	1	3	8	4	9	15	5	7	11	3
Textularia gramen D'Orbigny	0	0	0	2	0	0	0	0	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Textularia cf. *gramen* D'Orbigny	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Textularia sp.	0	0	0	0	8	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Hyaline	529	165	681	587	1430	725	902	1091	797	1496	826	195	144	138	22	66	29	66	81	174	204	179	187	104
Miliolid	22	14	22	108	127	72	45	134	95	374	243	14	18	17	1	4	6	15	9	24	18	24	31	5
Agglutinated	2	0	8	6	82	28	8	40	91	463	416	3	0	3	1	3	8	4	9	15	8	7	11	3
Total	553	179	711	701	1639	825	955	1265	983	2333	1485	212	162	158	24	73	43	85	99	213	230	210	229	112
Number of taxa	24	20	42	39	31	24	21	26	41	35	25	27	18	30	11	18	19	25	28	34	35	28	33	20
Diversity (Fisher alpha)	5.1	5.8	9.8	8.9	5.4	4.6	3.8	4.6	8.6	5.8	4.5	8.2	5.2	11.0	7.9	7.6	13.0	11.9	13.0	11.4	11.5	8.7	10.6	7.1
Dominance	0.34	0.10	0.20	0.11	0.12	0.12	0.15	0.22	0.32	0.11	0.13	0.10	0.08	0.07	0.14	0.11	0.10	0.08	0.07	0.07	0.07	0.07	0.07	0.13
Equitability	0.56	0.86	0.61	0.73	0.75	0.79	0.76	0.65	0.51	0.73	0.75	0.80	0.91	0.86	0.90	0.87	0.88	0.87	0.87	0.83	0.83	0.86	0.83	0.80
Inner neritic taxa (%)	5	25	9	22	7	11	6	1	2	5	0	3	0	2	0	4	0	2	3	2	2	0	1	1
Outer neritic–bathyal taxa (%)	3	8	8	13	17	5	9	5	6	4	9	41	52	41	29	44	9	27	25	31	34	38	28	16
Epifauna (%)	66	31	51	44	39	38	41	59	79	62	71	36	44	41	50	32	53	48	43	39	35	42	50	26
Infauna (%)	20	32	28	23	30	33	36	21	10	25	20	46	41	41	25	42	28	35	39	34	44	43	37	48
Deep infauna (%)	0	0	0	0	0	0	0	0	0	0	0	0	6	3	4	1	0	0	0	0	8	9	7	8
Oxic indicators (%)	4	7	7	5	3	4	4	5	4	11	13	3	2	4	13	4	9	12	4	7	5	6	6	3
Suboxic indicators (%)	86	66	82	65	82	81	87	87	91	77	77	78	82	70	75	70	74	71	81	76	76	78	75	73
Dysoxic indicators (%)	0	0	0	0	0	0	0	0	0	0	0	0	6	3	4	1	0	0	0	0	8	9	7	8
High nutrient-flux ndicators (%)	16	23	20	17	21	21	21	14	5	15	6	0	6	3	0	1	0	1	10	4	10	11	7	8

high abundance throughout the samples with an increasing trend from Unit 1 ($A=43\%$, $\sigma=10\%$) to Units 2 and 3 ($A=73\%$, $\sigma=8\%$).

High abundances of indicators for surface water productivity (heterotrophic protoperidinoid cysts, autotrophic *L. machaerophorum*) are documented for Unit 1 ($A=22\%$, $\sigma=5\%$) with highest abundances in samples OS 24–21 and OS 15–13. For Units 2 and 3 a sudden drop of productivity indicators is documented ($A=10\%$, $\sigma=4\%$) mainly related to diminishing numbers of *L. machaerophorum*.

4.2.3. Calcareous nannoplankton

A total of 43 autochthonous, 27 Paleogene and 27 Cretaceous nannoplankton taxa have been determined. They are well preserved and occur commonly throughout the section.

Table 2

Bathymetric distribution (IN = inner neritic, MN = middle neritic, ON = outer neritic, B = bathyal), microhabitat (E = epifaunal, I = infaunal, DI = deep infaunal), oxygen dependency (O = oxic, S = suboxic, D = dysoxic) and dependence on high organic matter flux (H = high OM flux) for benthic foraminifers from the stratotype.

	Depth	Habitat	Oxygen	Productivity	References
Alabamina tangentialis	ON–B	E/I	S		1.2
Ammonia spp.	IN	E/SI	O/S		3,4,5,6
Amphicoryna spp.	MN–B	I	S		1,2,7,8
Astacolus crepidulus	IN				9
Asterigerinata spp.	IN–MN	E	O		4,10
Astrononion spp.	IN–B	E/I	S		4,6,11,12
Aubignyna spp.	IN	?I			4
Biapertorbis biaperturatus	ON–B	E	?S		7,8
Bolivina spp.	IN–B	I/DI	D		4,5,13
Bulimina elongata	IN–B	I	S/D	H	4,13,14
Caucasina spp.	IN–B	I	S/D		4,13,14
Chilostomella spp.	ON–B	DI	D		4,6
Cibicidoides spp.	MN–B	E	O		1,2,3,7
Dentalina spp.	IN–B	I	S/D		1,2,4,6,15
Elphidiella spp.	IN–ON	?I			4
Elphidium spp. (keeled)	IN	E	O		3,4,16
Elphidium spp. (non-keeled)	IN	I	O		4
Fursenkoina acuta	IN–B	I	S/D		4,7,14,17
Glandulina spp.	MN–B	I	S		9,10
Globocassidulina spp.	MN–B	I	O/S		4,6
Globulina gibba	IN–B		O		2,22
Gyroidinoides spp.	B	E	S		18,19
Hansenisca soldanii	B	E	S		9,10,18
Hanzawaia boueana	IN	E	S		4,11,12
Hemirobulina spp.	IN–B	?I			20
Heterolepa dutemplei	IN–B	E	O		2,4,17
Laevidentalina spp.	ON–B	I	S/D		2,8
Lagena spp.	IN–B	I	S		1,2,8,11
Lenticulina spp.	MN–B	E	S		1,3,8,11,17
Lobatula lobatula	IN–MN	E	O		2,15,22
Marginulina spp.	IN–B	?I	?O		8,19
Melonis spp.	MN–B	I	S/D	H	1,4,15
Myllostomella advena	MN–B	I	S/D		19,21
Myllostomella recta	MN–B	I	S/D		19,21
Nonion commune	MN–B	I/E	S		2,3,15
Oridorsalis umbonatus	B	E	S		1,4,10
Porosononion spp.	IN–MN				2
Praeglobobulimina spp.	MN–B	DI	D	H	1,2,3,4,16
Protelphidium roemeri	?IN–ON				22
Pullenia spp.	ON–B	I	S		1,4,11,12
Pyrgo spp.	IN–B	E	O/S		1,4
Quadrimorphina petrolei	B	I	S		1,4,22
Saracenaria arcuata	ON–B	I			2,8
Vaginulinopsis spp.	MN–B	I			2,8,9
Valvulineria complanata	ON–B	I	S		1,4,6
Cycloforina spp.		E			
Pyrgo spp.	IN–B	E			4
Quinqueloculina spp.	IN–ON	E	O/S		4
Sigmoilinita tenuis	MN–B	E	O		10,22
Sigmoilopsis ottnangiensis	MN–B	E	?S		7,22
Spiroloculina spp.	IN	E	O/S		4,6
Martinotiella communis	ON–B	E	O		10,15
Spiroplectamina pectinata	MN–B	E	S		7,22
Textularia spp.	IN–B	E	O/S		4,10

References
1 Kaiho (1994).
2 Hohenegger (2005).
3 Rögl and Spezzaferri (2003).
4 Murray (2006).
5 Barmawidjaja et al. (1992).
6 Bernhard and Sen Gupta (2002).
7 Pippèrr and Reichenbacher (2010).
8 Reolid et al. (2008).
9 Jones (1994).
10 Pezelj et al. (2007).
11 Kouwenhoven and Van der Zwaan (2006).
12 Den Dulk et al. (2000).
13 Van Hinsbergen et al. (2005).
14 Spezzaferri et al. (2002).
15 Spezzaferri and Tamburini (2007).
16 Martins et al. (2007).
17 Báldi (2006).
18 Corliss (1991).
19 Roetzel et al. (2006).
20 Leckie and Olson (2003).
21 Grunert et al. (2010a).
22 Wenger (1987).

The autochthonous assemblages are dominated by *Coccolithus pelagicus* with mean abundances of 50% ($\sigma=6\%$) throughout the section. Its abundance increases slightly from the bottom to the top of the section ($A_{\text{Unit 1}}=47\%$, $\sigma_{\text{Unit 1}}=6\%$; $A_{\text{Unit 2}}=55\%$, $\sigma_{\text{Unit 2}}=4\%$; $A_{\text{Unit 3}}=51\%$, $\sigma_{\text{Unit 3}}=5\%$) reaching highest values in samples OS 8–4 and OS 3 (Fig. 8). Besides *C. pelagicus*, only few taxa (*Helicosphaera ampliaperta*, *Cyclicargolithus floridianus* and reticulofenestrids) occur frequently. Other nannoplankton taxa like the stratigraphically important group of sphenoliths are very scarce or missing.

Reticulofenestrids are mainly represented by *Reticulofenestra excavata* and *Reticulofenestra minuta* ($A=12\%$, $\sigma=6\%$). Values of *R. minuta* show two peaks, one at the base of Unit 1 (OS 24–22; $A=25\%$, $\sigma=2\%$) and one at the top of Unit 1 and at the base of Unit 2 (OS 14–12; $A=19\%$, $\sigma=2\%$). In Units 2 and 3 values drop ($A=9\%$, $\sigma=4\%$). *R. excavata* shows highest abundances in the lower portion of Unit 1 (OS 24–16; $A=16\%$, $\sigma=3\%$) and then passes into lower values for the rest of the section. Helicosphaerids are mainly represented by *H. ampliaperta* which increases in abundance from the bottom to the top of the section ($A_{\text{Unit 1}}=11\%$, $\sigma_{\text{Unit 1}}=4\%$; $A_{\text{Unit 2}}=14\%$, $\sigma_{\text{Unit 2}}=3\%$; $A_{\text{Unit 3}}=15\%$, $\sigma_{\text{Unit 3}}=4\%$).

The total number of autochthonous species varies between 10 and 20 ($A=15$, $\sigma=3$) showing highest numbers in Unit 3 (OS 3–1; Fig. 8). Diversity is low and varies between 2.0 and 4.7 ($A=3.4$, $\sigma=0.7$) with highest values in Unit 3. Variations in dominance ($A=0.31$, $\sigma=0.04$) and equitability ($A=0.59$, $\sigma=0.04$) are minimal and without trends.

Reworked coccoliths are predominantly composed of Cretaceous taxa (dominated by *Watznaueria barnesae*) and to a lesser degree of Paleogene taxa. They occur frequently ($A=14\%$, $\sigma=4\%$) with highest abundances in two intervals in Units 2 and 3 (OS 8–1) and in the middle part of Unit 1 (OS 21–16).

4.3. Microfossil assemblages

Cluster analysis and non-metric multidimensional scaling performed on the combined data-sets of the studied microfossil groups allow the identification of four microfossil assemblages (Fig. 9). Cluster analysis and nMDS were additionally performed for the individual microfossil groups. The results show that the four assemblages are primarily determined by benthic foraminifers and dinoflagellate cysts, while calcareous nannoplankton mainly contributes to the distinction of assemblages 1 and 2–4. SIMPER analysis shows that within each microfossil group the abundances of only a few taxa are responsible for the differences between the assemblages: (1) the ratio between outer neritic to upper bathyal and inner to middle neritic foraminifers, (2) the ratio between the dinoflagellate cysts *Apteodinium* spp., *Polysphaeridium zoharyi*,

Table 3
Dinoflagellate cysts from the stratotype.

	OS 1	OS 2	OS 3	OS 4	OS 5	OS 6	OS 7	OS 8	OS 9	OS 10	OS 11	OS 12	OS 13	OS 14	OS 15	OS 16	OS 17	OS 18	OS 19	OS 20	OS 21	OS 22	OS 23	OS 24
Apteodinium spiridoides Benedek	30	168	149	100	70	98	35	152	146	97	70	65	49	42	27	59	38	83	30	71	29	45	28	91
Achomosphaera/Spiniferites spp.	21	12	19	18	9	21	18	19	21	30	31	58	39	53	47	62	108	43	67	42	92	59	51	34
Apteodinium australiense (Deflandre & Cookson) Williams	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Apteodinium spp.	132	12	10	5	0	1	1	3	0	0	1	0	1	1	2	2	2	3	10	2	0	3	8	1
Batiacasphaera sphaerica Stover	2	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	1	1	0	0	0	0
Cerebrocysta poulsenii De Verteuil & Norris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
Cleistosphaeridium placacanthum/ ancyreum	7	0	4	3	20	25	6	15	7	6	9	9	14	11	12	4	16	9	14	6	10	19	8	4
Cordosphaeridium cantharellus (Brosius) Gocht	0	1	1	0	0	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0	1	3	0	0
Cousteaudinium aubryae De Verteuil & Norris	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cribroperidinium giuseppei (Morgenroth) Helenes	4	1	4	1	1	0	2	6	6	9	38	5	39	35	27	7	1	18	12	6	6	5	9	6
Cribroperidinium tenuitabulatum (Gerlach) Helenes	1	2	1	4	3	1	0	3	6	4	35	27	8	12	9	3	1	13	0	3	1	5	1	4
Dapsilidinium pseudocolligerum/ pastielsii	0	1	4	5	2	1	3	3	1	0	5	4	2	6	2	3	3	5	6	1	5	4	7	0
Deflandrea phosphoritica Eisenack	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0
Distatodinium cavatum Zevenboom & Santarelli	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Distatodinium paradoxum (Brosius) Eaton	0	2	8	2	2	2	7	0	1	1	1	0	0	3	0	0	1	1	3	1	1	0	1	0
Exochosphaeridium insigne De Verteuil & Norris	3	7	14	6	5	7	3	10	8	36	12	15	11	3	8	8	10	11	10	24	6	15	16	5
Glaphyrocysta reticulosa (Gerlach) Stover & Evitt s.l.	4	5	2	3	1	0	1	0	1	0	0	1	0	1	0	0	1	0	0	0	0	0	0	0
Glaphyrocysta spp.	13	14	4	16	1	0	1	0	1	1	0	1	1	2	1	0	3	0	1	1	1	1	0	1
Heteraulacacysta sp. A Costa & Downie	0	0	0	0	1	0	0	0	0	1	1	4	7	0	4	0	1	2	1	6	1	5	2	0
Homotryblium tenuispinosum Davey & Williams	0	1	0	0	0	0	1	0	0	0	1	1	0	0	0	0	1	0	0	0	1	1	0	0
Hystrichokolpoma cinctum Klumpp	0	0	0	1	0	0	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0
Hystrichokolpoma denticulatum Matsuoka	0	1	1	1	1	0	1	0	1	1	0	4	1	0	0	0	0	0	0	0	0	0	0	0
Hystrichokolpoma rigaudiae Deflandre & Cookson	0	2	3	1	1	1	0	0	0	1	3	1	0	1	1	0	1	0	0	1	2	0	2	1
Hystrichokolpoma truncatum Biffi & Manum	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Hystrichokolpoma spp.	0	4	0	2	3	3	0	3	0	4	1	1	3	3	1	1	2	2	3	0	1	1	5	1
Hystrichosphaeropsis obscura Habib	0	0	1	0	0	0	1	0	1	0	2	1	0	1	0	0	0	1	0	2	0	1	0	1
Impagidinium paradoxum (Wall) Stover & Evitt	0	0	1	1	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Lejeunecysta brassensis Biffi & Grignani	0	0	0	1	0	0	0	0	1	0	0	0	1	3	1	1	1	0	1	2	0	0	1	0
Lejeunecysta communis Biffi & Grignani	0	0	0	1	2	1	0	0	0	0	0	1	0	0	1	0	0	0	0	0	2	1	0	0
Lejeunecysta convexa Matsuoka & Bujak	0	0	1	0	1	1	1	1	1	1	0	0	0	0	0	0	1	1	1	0	1	1	1	0
Lejeunecysta diversiforma (Bradford) Artzner & Dörhöfer	1	0	2	2	1	0	2	3	1	1	0	0	0	0	1	0	1	1	0	0	2	0	0	2
Lejeunecysta spp.	0	4	1	6	2	3	1	1	3	7	3	1	7	5	14	6	8	1	3	5	9	6	4	13
Lingulodinium machaerophorum (Deflandre & Cookson) Wall	6	1	1	5	1	1	1	2	2	13	5	5	23	26	27	19	11	19	24	18	30	18	27	11
Melitasphaeridium choanophorum (Deflandre & Cookson) Harland & Hill	0	0	1	1	1	1	1	0	2	0	2	0	0	1	1	0	1	1	3	0	4	0	2	0

Membranilarnacia? picena Biffi & Manum	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Membranophoridium sp.	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nematosphaeropsis downieii Brown	1	1	1	1	0	1	1	1	1	1	1	1	4	2	5	4	1	2	4	5	7	3	11	13
Nematosphaeropsis labyrinthus (Ostenfeld) Reid	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Operculodinium centrocarpum (Deflandre & Cookson) Wall	5	3	9	7	2	5	1	3	16	2	4	8	7	8	6	10	3	10	8	12	2	9	9	8
Operculodinium piaseckii Strauss & Lund	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0
Palaeocystodinium miocaenicum Strauss, Lund & Lund-Christensen	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	3	2	0	0	0
Palaeocystodinium powellii Strauss, Lund & Lund-Christensen	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	2	1	3	0	1
Pentadinium laticinctum Gerlach	1	1	1	1	1	0	0	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
Polysphaeridium zoharyi (Rossignol) Bujak	9	4	10	34	110	67	141	0	1	4	1	5	5	3	1	3	0	1	4	4	3	7	2	0
Reticulatosphaera actinocoronata (Benedek) Matsuoka & Bujak	0	2	2	0	2	3	5	2	1	1	4	3	1	3	5	3	8	3	7	4	9	2	6	2
Rounded brown cysts	8	7	2	25	6	7	10	12	12	7	7	12	11	13	8	3	8	9	7	5	7	8	4	17
Selenopemphix armageddonensis De Verteuil & Norris	0	0	0	0	0	1	0	0	1	0	0	1	1	1	3	3	2	0	3	6	5	4	8	9
Selenopemphix brevispinosa Head, Morris & Mudie	1	0	1	1	0	1	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Selenopemphix nephroides Benedek	3	6	2	4	1	1	3	1	0	4	3	1	6	1	7	2	3	1	3	9	2	11	4	19
Selenopemphix quanta (Bradford) Matsuoka	1	0	0	0	0	0	1	0	0	0	0	4	0	3	0	0	1	0	1	0	1	0	1	1
Spiniferites pseudofurcatus (Klumpp) Sarjeant	0	5	0	1	1	1	2	9	11	9	7	7	5	2	14	4	12	3	15	1	2	1	2	1
Spiniferites solidago De Verteuil & Norris	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sumatradinium druggii Lentin, Fensome & Williams	0	0	0	0	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Sumatradinium hispidum (Drugg) Lentin & Williams	0	1	0	0	2	1	1	0	0	4	0	1	0	3	0	1	0	2	0	0	0	0	0	0
Sumatradinium soucouyantiae De Verteuil & Norris	2	2	1	2	1	1	2	1	0	5	2	2	2	3	8	4	2	2	3	3	2	7	0	2
Tectatodinium pellitum Wall	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0
Thalassiphora pelagica (Eisenack) Eisenack & Gocht	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trinovantedinium spp.	0	0	0	0	1	0	0	0	0	0	0	0	1	0	1	4	0	0	3	0	1	1	2	1
Tuberculodinium vancampoae (Rossignol) Wall	1	1	1	1	1	0	0	0	2	0	0	1	1	0	2	0	0	1	1	2	1	0	1	0
Xandarodinium xanthum Reid	0	0	0	1	1	0	0	0	0	0	0	1	0	1	2	2	0	1	1	0	1	0	1	0
Protoperidinium cysts indet.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Dinoflagellate cysts indet.	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	3	0	0	0
Reworked dinocysts	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	1	0	1	1	0	1	0
Total	261	274	267	267	260	257	258	252	257	254	251	253	253	252	251	220	254	252	252	250	256	252	226	251
Number of taxa	27	31	36	37	35	27	32	22	28	28	27	33	29	30	33	26	32	31	32	31	38	31	31	27
Diversity (Fisher alpha)	7.6	9.0	11.2	11.7	10.9	7.6	9.6	5.8	8.0	8.0	7.7	10.1	8.5	8.9	10.2	7.7	9.7	9.3	9.7	9.3	12.3	9.3	9.7	7.7
Dominance	0.28	0.39	0.33	0.18	0.26	0.23	0.33	0.38	0.34	0.19	0.14	0.14	0.11	0.11	0.09	0.17	0.22	0.16	0.11	0.13	0.16	0.11	0.10	0.17
Equitability	0.60	0.53	0.56	0.68	0.56	0.60	0.54	0.55	0.55	0.69	0.73	0.72	0.78	0.77	0.81	0.72	0.65	0.70	0.79	0.75	0.70	0.79	0.80	0.71
Coastal taxa (%)	80	80	78	67	83	79	74	76	75	63	68	55	54	47	38	44	30	59	36	52	23	44	36	48
Restricted marine taxa (%)	4	3	6	15	43	26	56	1	2	2	3	4	3	4	2	3	2	3	4	3	4	6	4	0
Offshore taxa (%)	1	4	3	3	3	3	3	3	2	3	4	4	4	4	5	4	5	3	6	4	7	3	11	7
Protoperidinoid species (%)	6	7	4	16	7	7	9	8	7	12	6	9	12	13	18	12	11	7	10	12	13	15	12	26
Protoperidinoids + *L. machaerophorum* (%)	8	8	4	18	8	7	10	8	8	17	8	11	21	23	29	20	15	15	20	19	25	23	24	30

Table 4
Calcareous nannoplankton from the stratotype.

	OS 1	OS 2	OS 3	OS 4	OS 5	OS 6	OS 7	OS 8	OS 9	OS 10	OS 11	OS 12	OS 13	OS 14	OS 15	OS 16	OS 17	OS 18	OS 19	OS 20	OS 21	OS 22	OS 23	OS 24
Autochthonous species																								
Braarudosphaera bigelowii (Gran & Braarud) Deflandre	0	0	0	0	0	1	0	1	0	2	0	1	1	0	2	2	2	0	0	0	0	3	3	1
Calcidiscus sp.	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
Coccolithus miopelagicus Bukry	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	3	1	0	0	0
Coccolithus pelagicus (Wallich) Schiller	150	158	175	190	170	190	170	150	147	155	167	160	164	170	140	170	150	120	165	190	150	138	120	134
Coronocyclus nitescens (Kamptner) Bramlette & Wilcoxon	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Coronosphaera mediterranea (Lohman) Gaarder	3	0	0	0	1	0	0	1	0	0	1	3	0	0	2	1	0	0	0	0	0	0	0	0
Cyclicargolithus floridanus (Roth & Hay) Bukry	17	32	19	16	18	10	15	13	23	16	11	23	24	12	12	12	20	16	17	18	12	10	11	9
Cricolithus jonesii (Cohen)	0	1	0	0	1	0	2	0	0	2	1	0	0	0	0	1	0	7	0	1	0	1	0	2
Discoaster deflandrei Bramlette & Riedel	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Discoaster sp.	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
Helicosphaera ampliaperta Bramlette & Wilcoxon	61	52	33	50	54	55	48	43	56	30	28	36	28	39	59	35	52	26	46	28	38	20	29	26
Helicosphaera minuta Müller	0	4	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Helicosphaera carteri (Wallich) Kamptner	3	1	3	0	0	2	2	1	3	0	2	1	2	0	0	0	3	1	1	0	5	0	3	1
Helicosphaera euphratis Haq	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	1	1	0	0	0
Helicosphaera intermedia Martini	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Helicosphaera scissura Miller	2	5	12	2	7	5	10	5	4	7	5	4	5	4	3	9	4	4	5	3	6	10	10	7
Helicosphaera sellii (Bukry & Bramlette) Jafar & Martini	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Helicosphaera sp.	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
Holodiscolithus macroporus (Deflandre & Fert) Roth	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lithostromoation sp.	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Pontosphaera multipora (Kamptner) Roth	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	1	0	0	0	0	1	0	0
Pontosphaera sp.	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Reticulofenestra bisecta (Hay) Roth	2	7	6	3	4	4	1	4	0	8	7	6	1	2	5	2	6	2	6	2	5	0	4	4
Reticulofenestra excavata Lehotayova	38	21	33	20	18	32	34	37	20	31	35	39	30	34	25	45	46	69	43	55	56	47	45	42
Reticulofenestra gelida (Geitzenauer) Wise	0	0	0	2	1	3	3	5	6	0	3	0	1	3	0	5	3	4	2	5	0	1	0	0
Reticulofenestra haqii Backman	2	0	0	0	0	0	0	0	1	0	0	1	0	0	4	0	1	0	1	1	0	0	3	0
Reticulofenestra lockeri Müller	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	1
Reticulofenestra minuta Roth	22	28	21	35	47	12	20	17	35	26	20	55	66	63	68	20	26	65	18	3	44	76	84	71
Reticulofenestra pseudoumbilica (Gartner) Gartner	7	3	0	0	4	6	4	1	4	4	2	1	1	2	2	7	6	0	6	11	4	1	4	1
Reticulofenestra sp.	2	4	1	1	0	1	0	2	1	2	2	4	0	0	1	1	3	4	2	0	1	1	0	2
Sphenolithus cf. *belemnos* Bramlette & Wilcoxon	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Sphenolithus capricornutus Bukry & Percival	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Sphenolithus conicus Bukry	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Sphenolithus disbelemnos Fornaciari & Rio	1	0	1	0	1	1	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0
Sphenolithus dissimilis Bukry & Percival	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Sphenolithus moriformis (Bronnimann & Stradner) Bramlette & Wilcoxon	2	1	2	1	0	0	0	1	0	2	0	0	1	0	0	1	0	1	1	0	1	0	0	0
Sphenolithus procerus Maiorano & Monechi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Sphenolithus cf. *tintinnabulum* Maiorano & Monechi	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sphenolithus sp.	1	2	0	0	0	1	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0
Thoracosphaera heimii (Lohmann) Kamptner	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	1	0	0	0	0	0	0	0	1
Thoracosphaera saxea Stradner	1	1	0	0	1	0	1	0	0	2	0	1	0	0	0	0	0	1	1	2	0	1	0	0
Umbilicosphaera sp.	0	1	0	0	0	0	1	0	1	0	0	0	0	0	1	0	0	1	0	0	1	1	0	0
Total autochthonous species	315	325	312	320	327	324	311	283	304	291	286	336	327	331	326	316	323	323	314	324	328	314	316	301
Number of taxa	17	20	18	10	13	15	14	17	15	18	16	15	16	11	15	20	14	15	14	15	17	17	12	14
Diversity (Fisher alpha)	3.8	4.7	4.2	2.0	2.7	3.3	3.0	4.0	3.3	4.2	3.7	3.2	3.5	2.2	3.2	4.7	3.0	3.3	3.0	3.3	3.8	3.9	2.5	3.0
Dominance	0.29	0.27	0.34	0.40	0.33	0.39	0.34	0.33	0.29	0.31	0.37	0.28	0.31	0.33	0.27	0.32	0.27	0.23	0.32	0.39	0.27	0.28	0.25	0.28
Equitability	0.59	0.62	0.57	0.57	0.59	0.53	0.60	0.57	0.60	0.61	0.55	0.61	0.57	0.61	0.61	0.57	0.65	0.65	0.59	0.53	0.60	0.57	0.68	0.62
Reworked from Paleogene																								
Blackites sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0

Chiasmolithus sp.	0	1	0	0	0	1	1	2	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	1
Cribrocentrum reticulatum (Gartner & Smith) Perch-Nielsen	0	1	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cruciplacolithus sp.	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	0	0
Cyclicargolithus abisectus (Müller) Wise	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Cyclicargoithus luminis (Sullivan) Bukry	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Discoaster lodoensis Bramlette & Riedel	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Discoaster taninodifer Bramlette & Riedel	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Discoaster barbardiensis Tan	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
Discoaster saipanensis Bramlette & Riedel	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Discoaster sp.	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ericsonia formosa (Kamptner) Haq	4	1	1	1	2	0	1	0	0	2	0	2	0	2	1	0	1	2	4	1	1	0	0	0
Ericsonia robusta (Bramlette & Sullivan) Edwards & Perch-Nielsen	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0
Heliolithus kleinpellii Sullivan	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Lanternithus minutus Stradner	0	0	0	3	3	0	1	0	0	0	0	1	0	0	2	2	0	1	1	0	1	0	0	0
Tribrachiatus orthostylus (Bramlette & Riedel) Shamrei	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pemma sp.	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pontosphaera duocava (Bramlette & Sullivan) Romein	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Pontosphaera exilis (Bramlette & Sullivan) Romein	1	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0
Prinsius martinii (Perch-Nielsen) HAQ	0	0	0	1	2	1	0	0	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0	0
Reticulofenestra dictyoda (Deflandre & Fert) Stradner	1	1	7	0	0	0	4	2	0	0	0	0	0	1	0	1	1	1	1	4	0	1	0	4
Reticulofenestra hillae Bukry & Percival	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0
Reticulofenestra stavensis (Levin & Joerger) Varol	0	1	1	3	1	0	0	1	0	0	0	3	0	0	1	0	0	1	0	3	1	0	0	0
Reticulofenestra umbilica (Levin) Martini & Ritzkowski	0	0	1	0	0	1	0	1	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	1
Toweius sp.	0	8	5	1	0	0	0	2	1	2	0	6	5	1	2	3	2	0	0	2	1	0	3	2
Zygrhablithus bijugatus (Deflandre) Deflandre	0	0	2	1	1	2	0	3	2	1	0	0	1	0	1	1	1	0	0	0	0	1	1	1
Reworked from Cretaceous																								
Arkhangelskiella cymbiformis Vekshina	0	0	2	0	0	4	1	2	1	1	1	1	1	2	1	1	2	2	0	2	3	3	0	0
Arkhangelskiella maastrichtiana Burnett	0	0	1	0	0	0	0	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Biscutum ellipticum (Górka) Grün	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Broinsonia parca parca (Stradner) Bukry	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
Calculites ovalis (Stradner) Prins & Sissingh	0	0	0	0	0	1	0	0	1	0	0	0	0	0	1	0	0	1	0	0	1	0	0	0
Cribrosphaerella ehrenbergii (Arkhangelsky) Deflandre	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	3	1	2	1	0	0	0
Cyclagelosphaera reinhardtii (Perch-Nielsen) Romein	1	0	0	1	1	4	1	0	4	0	0	1	0	1	1	0	2	3	2	2	0	0	2	0
Eiffellithus gorkae Reinhardt	2	3	2	1	0	2	0	0	0	0	1	1	0	0	2	1	2	0	1	0	0	0	0	1
Eiffellithus turriiseiffelii (Deflandre) Reinhardt	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Lucianorhabdus cayuxii Deflandre	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Microrhabdulus belgicus Hay & Towe	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Microrhabdulus decoratus Deflandre	2	0	1	0	0	0	0	0	1	0	0	2	0	0	0	0	2	0	0	0	0	0	0	0
Micula decussata Vekshina	5	4	4	5	4	11	2	2	2	1	4	2	3	3	2	0	4	1	9	5	2	6	1	1
Nannoconus steinmannii Kamptner	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Placozygus fibuliformis (Reinhardt) Hoffmann	0	0	0	2	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0
Prediscosphaera cretacea (Arkhangelsky) Gartner	2	3	5	1	1	0	1	0	2	1	0	1	1	2	0	0	1	4	2	1	1	1	3	0
Prolatipatela multicarinata Gartner	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Quadrum trifidum (Stradner) Prins & Perch-Nielsen	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Reinhardtites levis Prins & Sissingh	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Retecapsa crenulata (Bramlette & Martini) Grün	1	0	0	3	1	2	0	0	0	0	0	2	0	0	0	1	3	1	0	2	1	0	1	0
Watznaueria barnesae (Black) Perch-Nielsen	40	40	31	27	37	30	34	34	19	19	31	23	17	17	19	37	36	22	30	41	32	15	14	16
Watznaueria biporta Bukry	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Watznaueria britannica (Stradner) Reinhardt	5	1	6	1	1	5	2	0	3	3	3	5	1	1	3	3	4	10	4	3	4	3	5	1
Watznaueria fossacincta (Black) Bown	4	4	1	1	0	1	0	0	0	0	0	5	1	3	1	0	3	1	1	5	3	0	1	0
Watznaueria manivitae Bukry	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
Zeugrhabdotus diplogramus (Deflandre) Burnett	0	0	0	1	2	0	0	0	2	0	0	0	0	0	2	1	0	0	0	0	1	0	0	0
Zeugrhabdotus sp.	1	3	5	1	0	0	1	0	1	0	1	2	0	0	0	0	1	0	0	2	0	0	0	0
Total reworked	71	74	78	57	56	69	51	56	42	33	42	58	37	36	40	55	71	58	59	76	57	33	32	30
Total reworked Paleogene	7	16	18	12	9	7	9	13	4	8	0	13	10	6	8	10	10	9	9	10	5	3	4	10
Total reworked Cretaceous	64	58	60	45	47	62	42	43	38	25	42	45	27	30	32	45	61	49	50	66	52	30	28	20
Total	386	399	390	377	383	393	362	339	346	324	328	394	364	367	366	371	394	381	373	400	385	347	348	331

Table 5
Statistic moments (mean: first moment in Phi; standard deviation (stand.dev): second moment in Phi; skewness: third moment) of the stratotype samples. Sorting is derived from standard deviation (Friedman, 1962).

Sample	Sorting	Mean (Phi)	σ (Phi)	Skewness
OS 1	Extreme badly sorted	7.41	2.83	0.58
OS 2	Extreme badly sorted	7.14	2.78	0.72
OS 3	Extreme badly sorted	7.22	2.83	0.66
OS 4	Extreme badly sorted	6.82	2.90	0.80
OS 5	Extreme badly sorted	5.99	2.84	1.06
OS 6	Extreme badly sorted	6.42	2.80	0.90
OS 7	Extreme badly sorted	6.23	2.68	1.05
OS 8	Extreme badly sorted	5.99	2.81	1.10
OS 9	Extreme badly sorted	5.98	2.87	1.10
OS 10	Extreme badly sorted	6.04	2.79	0.97
OS 11	Extreme badly sorted	5.83	2.63	0.68
OS 12	Very badly sorted	6.71	2.55	0.62
OS 13	Extreme badly sorted	6.80	2.81	0.83
OS 14	Extreme badly sorted	6.95	2.76	0.79
OS 15	Extreme badly sorted	6.95	2.78	0.76
OS 16	Extreme badly sorted	6.14	2.67	1.13
OS 17	Extreme badly sorted	6.58	2.81	0.86
OS 18	Extreme badly sorted	6.59	2.76	0.94
OS 19	Extreme badly sorted	6.38	2.78	0.86
OS 20	Extreme badly sorted	6.90	2.92	0.78
OS 21	Extreme badly sorted	6.78	2.80	0.88
OS 22	Extreme badly sorted	7.18	2.76	0.72
OS 23	Extreme badly sorted	7.19	2.76	0.77
OS 24	Extreme badly sorted	6.82	2.67	0.94

Achomosphaera/*Spiniferites* spp. and *Cribroperidinium* spp., and (3) the ratio between helicosphaerids and reticulofenestrids in the calcareous nannoplankton, in particular the abundance of *R. minuta* (Tables 6, 7).

Assemblage 1 (OS 24–12) corresponds to Unit 1 and lowermost Unit 2. It is mainly composed of infaunal, outer neritic to upper bathyal foraminiferal species (*Amphicoryna ottnangiensis*, *Laevidentalina* spp., *Lenticulina* spp., *Gyroidinoides* spp., *Oridorsalis umbonatus*, *Valvulineria complanata*). Dinoflagellate cysts show approximately equal portions of *Apteodinium* spp. and *Achomosphaera*/*Spiniferites* spp. and elevated abundances of *L. machaerophorum* and *Cribroperidinium* spp. Coccoliths are characterized by highest abundances of reticulofenestrids and lowest abundances of helicosphaerids of all assemblages.

In contrast to assemblages 2–4, cluster analysis suggests three subclusters (1a–c) for assemblage 1 that are mainly determined by changes in the abundance of *A. ottnangiensis*, *Cribroperidinium* spp., *E. insigne*, *R. excavata* and *R. minuta*. However, the bulk of microfossil taxa is equally distributed in clusters 1a–c and the results from nMDS indicate that their internal organization is not very robust. Consequently, the assemblages of all three subclusters are considered parts of one assemblage.

Assemblage 2 (OS 11–10) from the lower part of Unit 2 (beds 1–3) shows a composition intermediate between assemblages 1 and 3–4. Foraminifers reveal highest abundance of *S. pectinata* of all samples together with increased occurrences of *L. inornata*, *Caucasina* spp., *Cibicidoides* spp. and *S. tenuis*. Except for *L. inornata*, taxa characteristic for assemblage 1 occurs in very low numbers with *A. ottnangiensis* as the most common. Dinoflagellate cysts show affinities to assemblages 3–4 with high abundances of *Apteodinium* spp. and significantly decreased abundances of *Achomosphaera*/*Spiniferites* spp. and *L. machaerophorum* while increased abundances of *Cribroperidinium* spp. and *E. insigne* indicate relations to assemblage 1. Reticulofenestrids decrease markedly in their abundance while helicosphaerids show a slight increase.

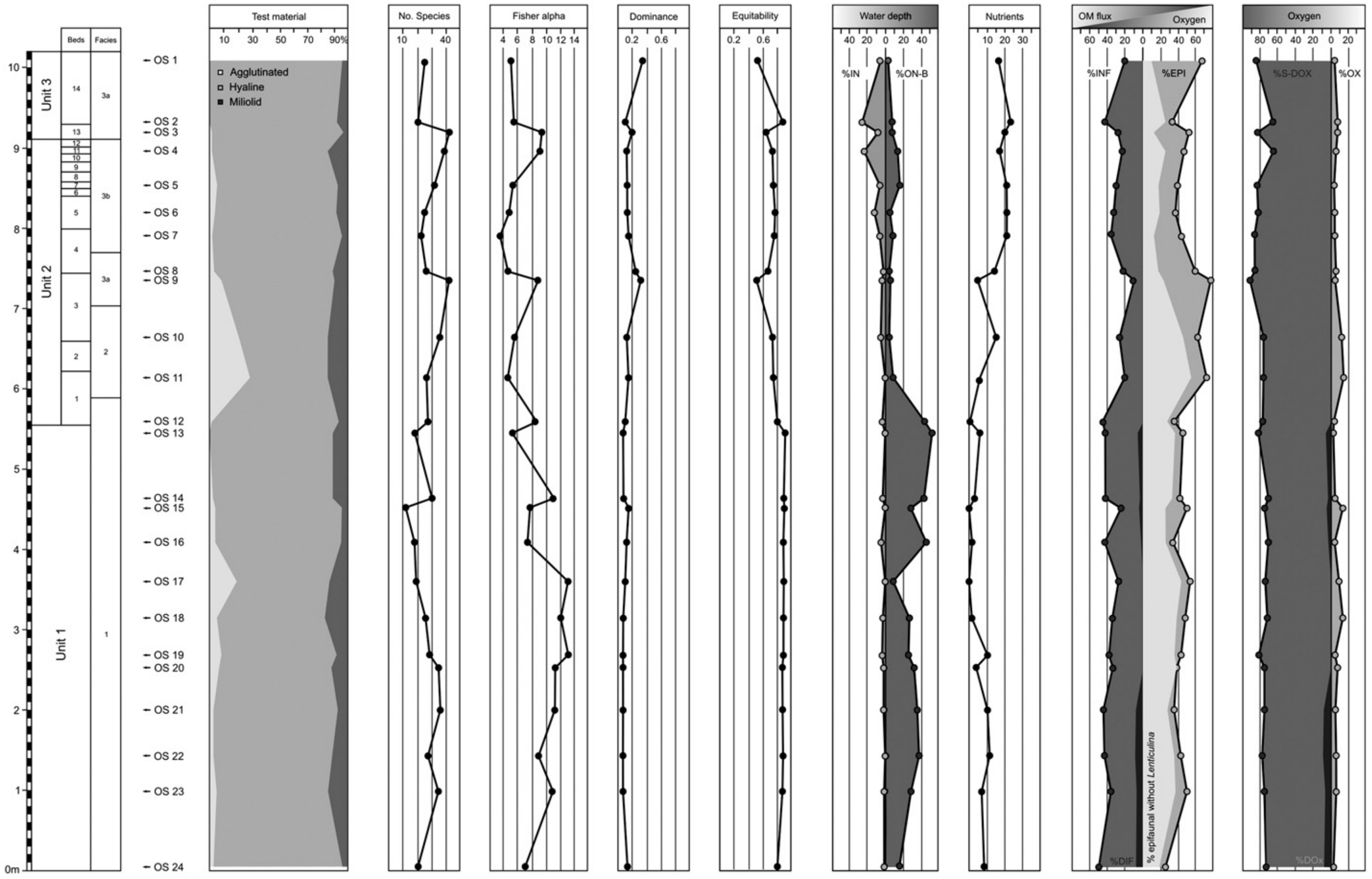

Fig. 6. Trends in benthic foraminiferal assemblages (see also Table 2). Nomenclature for oxic, suboxic and dysoxic indicators follows Kaiho (1994). Trends in epifaunal, infaunal and deep-infaunal taxa reflect the antagonistic relationship of organic matter flux and bottom-water oxygenation (Jorissen et al., 1995; Van der Zwann et al., 1999; see discussion for details). IN = inner neritic species, ON–B = outer neritic–bathyal species, INF = infaunal species, EPI = epifaunal species, DIF = deep-infaunal species, OX = oxyphilic species, S-DOX = sub- and dysoxic indicators, DOX = dysoxic indicators, OM = organic matter.

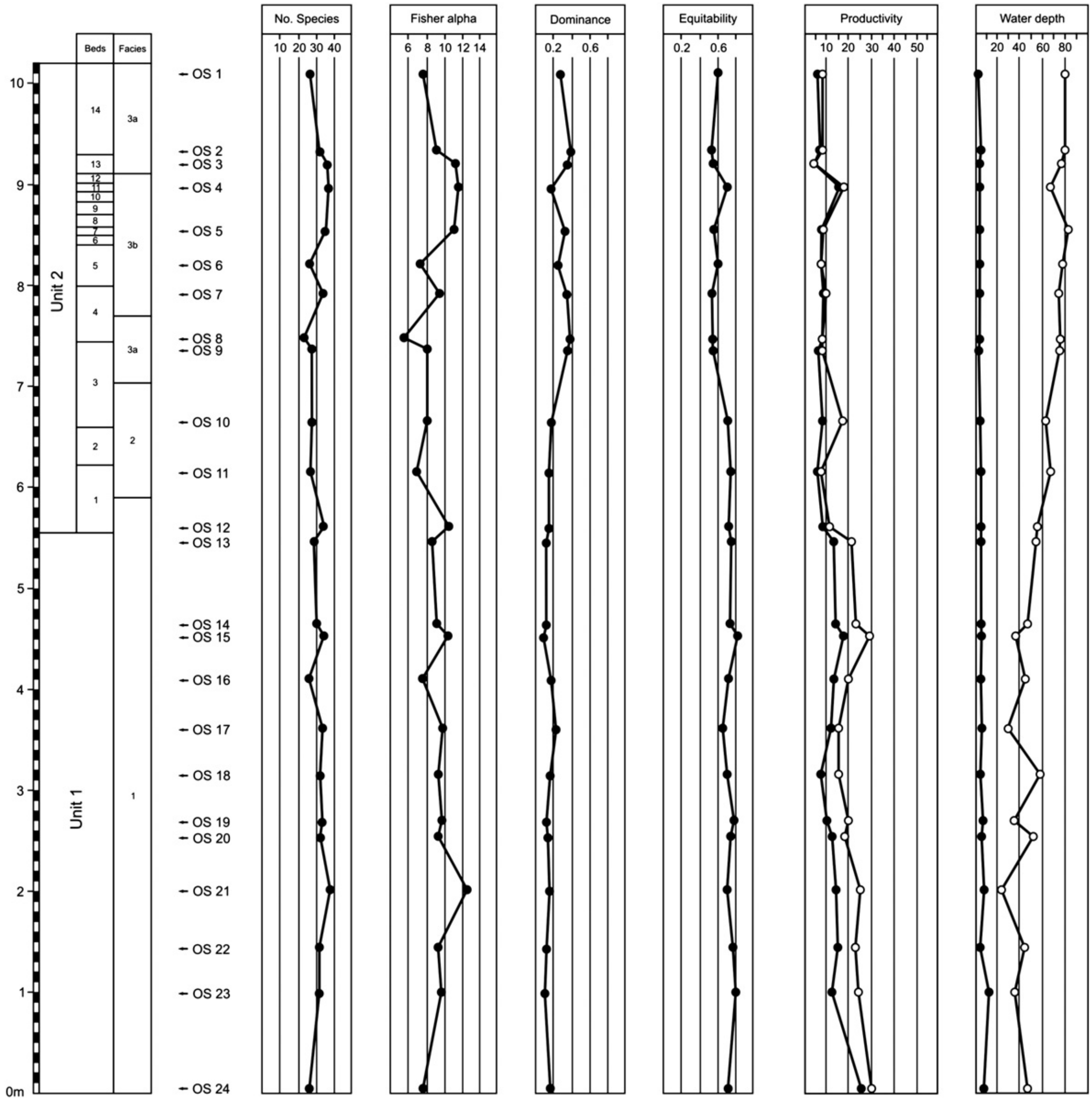

Fig. 7. Trends in dinoflagellate cyst assemblages. Coastal taxa include *Apteodinium* spp., *Cleistosphaeridium* spp., *Cribroperidinium* spp., *Exochosphaeridium insigne*, *Glaphyrocysta* spp., *Homotryblium tenuispinosum*, *Operculodinium* spp., *Polysphaeridium zoharyi* and *Tuberculodinium vancompae* (Marret and Zonneveld, 2003; Pross and Brinkhuis, 2005; de Vernal and Marret, 2007). *Impagidinium* spp., *Nematosphaeropsis* spp. and *Reticulatosphaera actinocoronata* are considered oceanic taxa (Pross and Brinkhuis, 2005; de Vernal and Marret, 2007).

Assemblage 3 (OS 7–4) comprises samples from the upper portion of bed 4 up to bed 12 of Unit 2. *L. inornata* and *Caucasina* spp. dominate the foraminiferal assemblages and *Alabamina tangentialis*, *Astrononion perfossum* and *Spiroloculina* spp. occur frequently. Unusually high abundance of *P. zoharyi* together with *Apteodinium* spp. and low occurrences of *Achomosphaera*/*Spiniferites* spp. characterize dinoflagellate cysts. The ratio between reticulofenestrids and helicosphaerids is approximately even.

Assemblage 4 (OS 9–8, 3–1) summarizes the upper part of bed 3 and the lower portion of bed 4 of Unit 2 and Unit 3. Foraminifers are dominated by *L. inornata* and *Caucasina* spp. with minor abundance of *Nonion commune*. Amongst dinoflagellate cysts, *Apteodinium* spp. shows highest abundance of all samples while *Achomosphaera*/*Spiniferites* spp. reveals very low abundance. Reticulofenestrids and helicosphaerids are evenly distributed.

5. Discussion

Paleogeographic reconstructions indicate that the sediments of the stratotype were deposited towards the center of the NAFB, c. 50–60 km off the northern coastline along the Bohemian Massif (Fig. 1b; Kuhlemann and Kempf, 2002). Consequently, the paleoenvironment was described as a tranquil sublittoral shelf in previous studies (Rögl et al., 1973; Wagner, 1998; Kuhlemann and Kempf, 2002; Rupp et al., 2008). Based on the new results that indicate a more diverse depositional environment for the stratotype, several types of facies will be discussed in the following. The improved facies model will then be compared to previous studies from Upper Austria and eastern Bavaria in order to put it in the context of the overall development along the shelf of the terminal Burdigalian Seaway.

5.1. Facies development

5.1.1. Facies 1: outer neritic to bathyal "Schlier of Ottnang"

Lithology: Unit 1, Unit 2/bed 1
Samples: OS 24–12
Fossil assemblage: 1

Facies 1 represents the characteristic "Schlier of Ottnang"-facies which has been frequently described from the studied outcrop as well as from the Ottnang Fm. in general (Reuss, 1864; Petters, 1936;

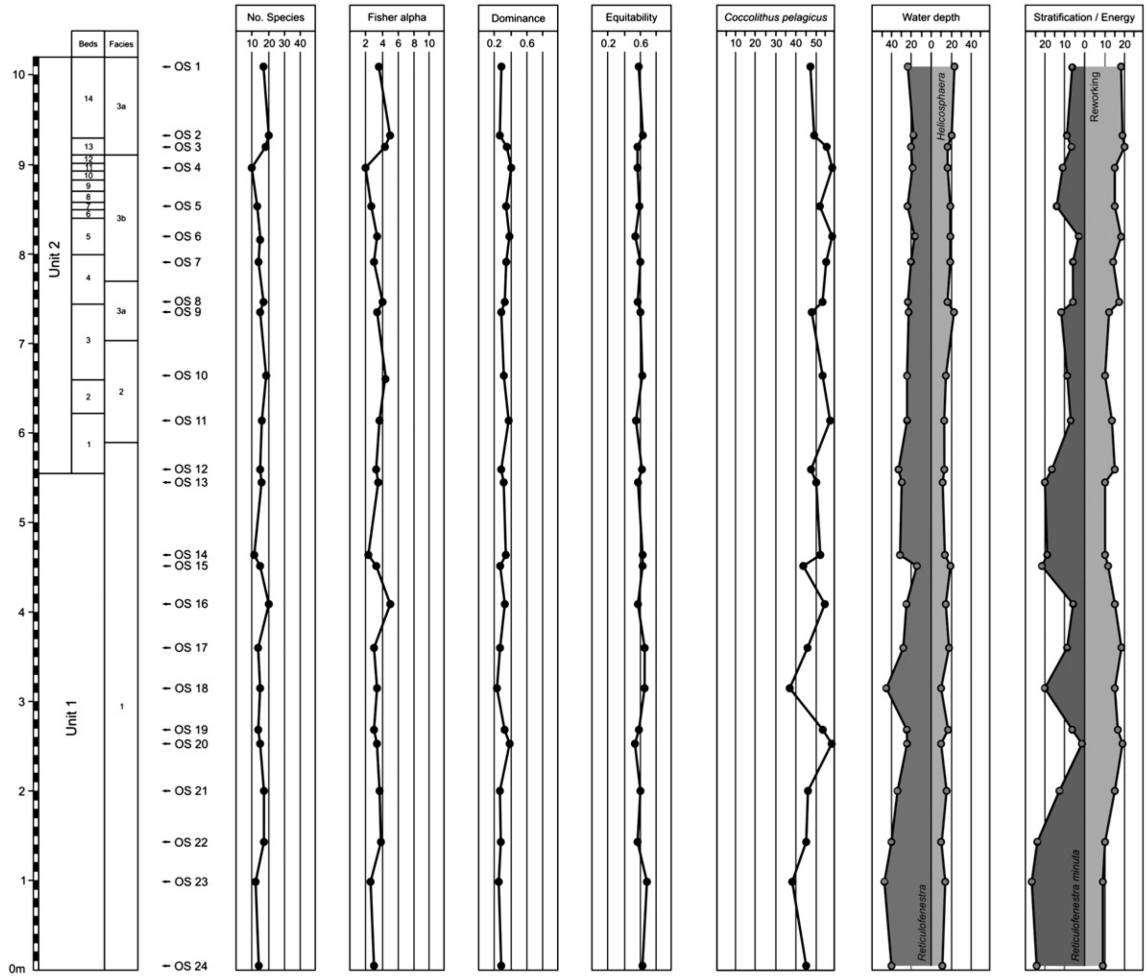

Fig. 8. Trends in calcareous nannoplankton assemblages. Abundances of *Reticulofenestra* and *Helicosphaera* are used as indicators for water depth, abundances of *Reticulofenestra minuta* and reworked coccoliths as indicators of water column stratification and water energy (Ćorić and Hohenegger, 2008). See Discussion for details.

Bürgl, 1949; Aberer, 1958; Rögl et al., 1973; Hochuli, 1978; Rupp and van Husen, 2007; Rupp et al., 2008). The foraminiferal assemblages with *Laevidentalina* spp., *O. umbonatus*, *Gyroidinoides* spp. and *V. complanata* are characteristic for an outer neritic to bathyal setting of 100–250 m (e.g., Poag, 1981; Wenger, 1987; Leckie and Olson, 2003; Murray, 2006). The accessory benthic foraminifers *Amphicoryna ottnangensis*, *Cibicidoides* spp., *N. commune*, *S. pectinata* and *S. ottnangensis* support this interpretation (Wenger, 1987; Leckie and Olson, 2003; Murray, 2006; Frieling et al., 2009; Pippèrr and Reichenbacher, 2010). Diversity values between 5.2 and 13 range well within those reported for benthic foraminifers from normal marine shelf and deep-water assemblages (Murray, 2006). The occurrences of the dinoflagellate cysts *Nematosphaeropsis* spp., *Reticulatosphaera actinocoronata* and *Impagidinium* spp. as well as increased dinoflagellate diversity additionally indicate an outer neritic–bathyal environment (Dale, 1996; Vink et al., 2000; Pross and Brinkhuis, 2005; de Vernal and Marret, 2007).

A eutrophic environment with high surface water productivity is suggested by all studied biota. Amongst dinoflagellate cysts, increased abundance of heterotrophic protoperidinoid taxa and the autotrophic *L. machaerophorum* documents fairly productive surface waters (Marret and Zonneveld, 2003). Eutrophic surface waters stimulating high primary productivity are also indicated by high abundances of *C. pelagicus* and *R. minuta*. The latter has been reported to thrive along eutrophic continental margins with increased continental runoff and river input (Haq, 1980; Aubry, 1992; Flores et al., 2005; Wade and Bown, 2006). Further indications for increased primary productivity are documented in literature by Rögl et al. (1973) and Bachmann (1973) who report high amounts of diatoms, radiolarians and silicoflagellates. Bachmann (1973), points out that many of the silicoflagellates are similar to those of a contemporaneous upwelling site in the Lower Austrian NAFB (Roetzel et al., 2006; Grunert et al., 2010b). For the Upper Austrian study area, riverine input via the Wachtberg delta has been suggested as the primary source of nutrients during the Ottnangian (Faupl and Roetzel, 1987; Brügel et al., 2003).

Increased organic matter flux to the sea-floor is clearly documented in benthic foraminifers which are largely composed of infaunal species adapted to sub- and dysoxic environments. Food availability and oxygenation of bottom waters are antagonistic key-parameters that determine the distribution of benthic foraminifers (“TROX” and “TROX-2” models; Jorissen et al., 1995; Van der Zwann et al., 1999). The high food availability of eutrophic environments usually results in low oxygenated bottom waters due to microbial degradation of organic matter and foraminiferal assemblages are dominated by infaunal species. At Ottnang–Schanze, the abundances of infaunal foraminifers as well as indicators for lowered oxic conditions suggest a eutrophic, suboxic environment for Facies 1. The poorly oxygenated environment is also reflected in the composition of the mollusk fauna with high amounts of chemosymbiont bearing lucinids and infaunal echinoids like *Brissopsis ottnangensis* (Rögl et al., 1973; Kroh, 2007; Rupp and van Husen, 2007). Extant relatives of the latter are known to withstand suboxic conditions (Thompson et al., 1985; Smallwood et al., 1999; Levin, 2003).

Sedimentary structures have been obscured by bioturbation and direct evidence for current activity is missing. In most samples the elevated abundance of *R. minuta* suggests a minor influence of

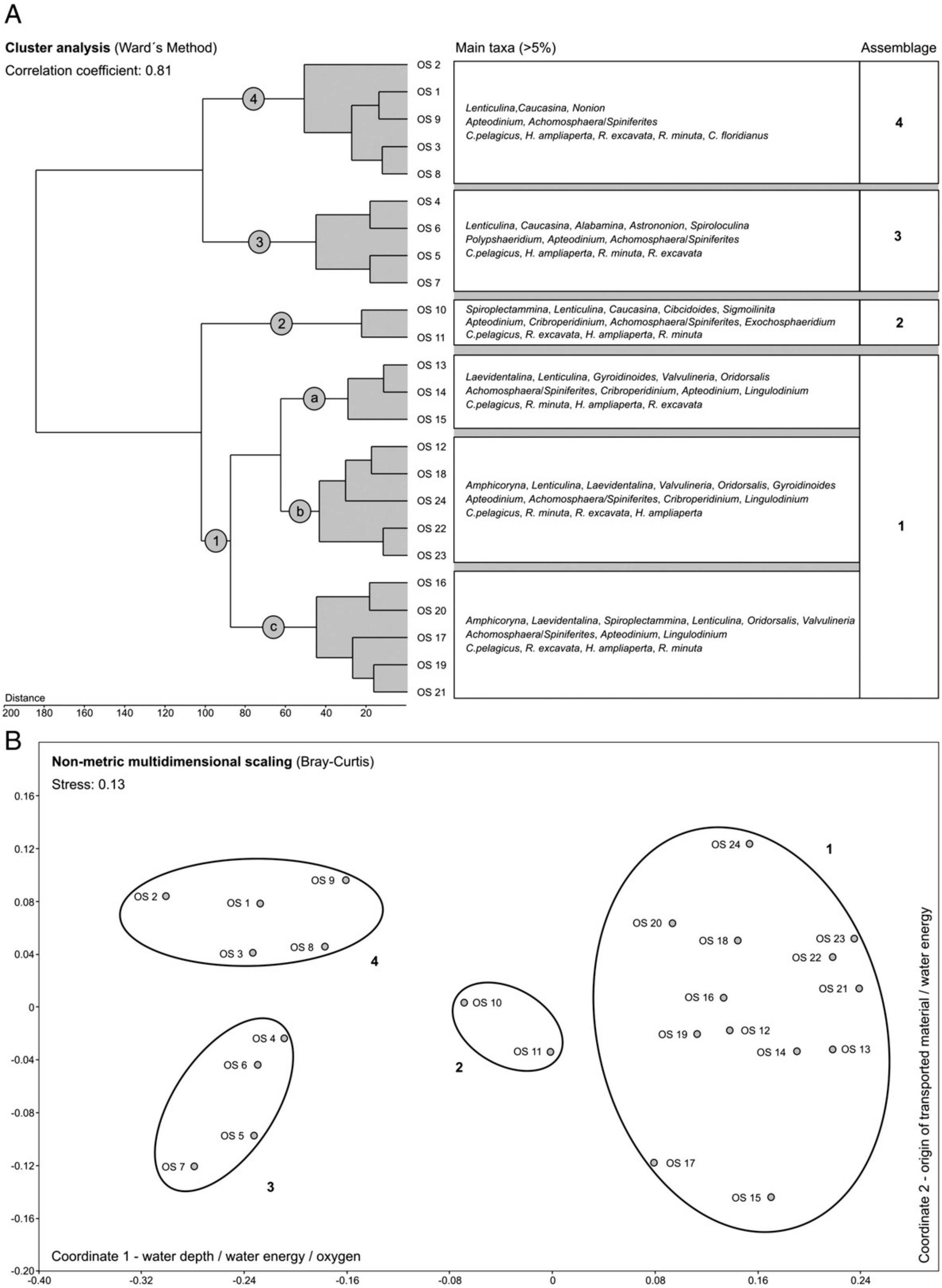

Fig. 9. Statistical analyses based on foraminiferal, dinoflagellate cyst and calcareous nannoplankton assemblages. (A) Cluster analysis with indication of the main taxa characterizing each of the revealed clusters and the inferred assemblages 1–4. (B) Non-metric multidimensional scaling with position of assemblages 1–4. Gradients of environmental parameters determining the distribution of the samples along each of the coordinates are indicated. See Discussion for details.

currents as blooms of small reticulofenestrids have been described as indicators for a well stratified water column (Ćorić and Hohenegger, 2008). A temporary increase in current strength might be indicated for the middle part of Unit 1 (OS 20–16) where *R. minuta* is less abundant and reworked nannoplankton taxa as well as coastal dinoflagellate cysts become more prominent. This assumption is supported by a higher sand content in samples OS 20–16 similar to OS 11–8 and OS 5 from Unit 2 (Fig. 5). Noteworthy, the parallel disappearance of dysoxic foraminiferal taxa and a decrease in *L. machaerophorum* indicate lowered surface water productivity and better oxygenated, low oxic bottom-waters and document subtle changes within the outer neritic–upper bathyal environment of Facies 1.

5.1.2. Facies 2: tide- and storm-influenced outer–middle neritic

Lithology: Unit 2, beds 1–3
Samples: OS 11, 10
Fossil assemblage: 2

Facies 2 marks the beginning of a shallowing trend from an outer neritic to upper bathyal towards a middle neritic environment. Increasing sand content, heavy flaser and wavy bedding, cross bedding, bivalve coquinas, commonly occurring plant debris and erosional surfaces document an agitated shelf environment under the strong influence of storm events and currents (Johnson and Baldwin, 1996; Reading and Collinson, 1996; Dashtgard et al., in press). The characteristic outer neritic–bathyal foraminiferal communities of Facies 1 are replaced by middle–outer neritic *Spiroplectammina–Lenticulina–Caucasina* assemblages (Wenger, 1987; Leckie and Olson, 2003; Murray, 2006). A shallowing is also suggested by increased abundances of the coastal dinoflagellate cysts of *Apteodinium* spp. and *Cribroperidinium* spp. (Pross and Brinkhuis, 2005).

Based on the foraminiferal assemblages with *S. pectinata*, *L. inornata* and *Caucasina* spp. flux of organic matter remained high (Kaiho, 1994; Bernhard and Sen Gupta, 2002; Murray, 2006). Besides the above mentioned foraminiferal taxa the samples are characterized by high abundances of the miliolids *S. tenuis* and *S. ottnangensis*. The fossil and extant records suggest that the abundance of these species is controlled rather by food supply and oxygen conditions than water depth. Accordingly, increased abundances of *S. pectinata* and *S. ottnangensis* in the NAFB have been reported from the outer neritic to bathyal Neuhofen Beds (Wenger, 1987; Pippèrr and Reichenbacher, 2010; Pippèrr, 2011) as well as from marginal inner neritic paleoenvironments (Frieling et al., 2009). *S. ottnangensis* is an endemic species of the Burdigalian Central Paratethys (Wenger, 1987; Cicha et al., 1998) and often compared to the extant *Sigmoilopsis schlumbergeri* from the Adriatic Sea. Jorissen (1987) showed a positive correlation of *S. schlumbergeri* with organic matter input. Together with the increased abundance of oxyphilic *S. tenuis* improved bottom-water oxygenation due to increased storm and current energy is indicated.

5.1.3. Facies 3: current-influenced middle neritic

Lithology: Unit 2, Unit 3
Samples: OS 9–1
Fossil assemblages: 3, 4

The abundance of inner neritic benthic foraminifers in Facies 3 clearly increases (e.g., *Ammonia* spp., *A. perfossum*, *Elphidium* spp., *Quinqueloculina* sp., *Spiroloculina* spp.) while outer neritic–bathyal taxa, most notably *Gyroidinoides* spp., *O. umbonatus* and *V. complanata*, vanish. This trend coincides with an increased sand content and most likely reflects a shallowing towards a middle neritic environment and increased current-driven sediment transport from the inner shelf. The bathymetric and hydrodynamic changes are further documented in the high abundances of the coastal dinoflagellate cysts *Apteodinium* spp. and *P. zoharyi*, decreasing abundances of *R. minuta* and increased reworking of calcareous nannoplankton (Marret and Zonneveld, 2003; Pross and Brinkhuis, 2005; Ćorić and Hohenegger, 2008). Furthermore, an evaluation of diatom assemblages from samples OS 9–7, 4 and 1 revealed assemblages mainly composed of the shallow marine taxa *Paralia sulcata*, *Actinocyclus* spp., *Coscinodiscus* spp. and *Sceptroneis* sp. (pers. comment I. Galović; Fenner, 1991; Zong, 1997; McQuoid and Nordberg, 2003a,b; Gebühr et al., 2009).

Eutrophic conditions together with elevated surface water productivity prevailed as strong currents delivered high amounts of nutrients from the Wachtberg delta to the study area (Faupl and Roetzel, 1987). Increased nutrient input is reflected by the dominance of *C. pelagicus* and the increasing abundance of *H. ampliaperta*. Dinoflagellate cyst assemblages show an average drop of 12% in productivity proxies. This is mainly caused by the vanishing of *L. machaerophorum* whereas the abundance of heterotrophic protoperidinoids remains constant. *L. machaerophorum* is the cyst of the autotrophic dinoflagellate *Lingulodinium polyedrum* which might be outcompeted by siliceous phytoplankton thriving on the increased input of nutrients from the hinterland. Planktic diatoms and silicoflagellates are reported frequently from this part of the section (Bachmann, 1973; Rögl et al., 1973) and large centric valves of diatoms were commonly observed in samples from Units 2 and 3. Together with input of nutrients stimulating phytoplankton growth, food supply for the benthic communities remained high. Detritivore *Caucasina* spp. and *Fursenkoina acuta*, as well as *S. tenuis* and *S. ottnangensis*, taxa that are adapted to high organic matter flux, frequently show increased abundances (Jorissen, 1987; Spezzaferri et al., 2002; Murray, 2006).

Within Facies 3, two different depositional subenvironments (Facies 3a, b) can be distinguished from microfossil assemblages and grain-size analysis. These reflect different levels of water energy and transport and varying sources of transported material within the middle neritic environment.

5.1.4. Facies 3a

Lithology: Unit 2, beds 3–4, 13–14
Samples: OS 9–8, 3–1
Fossil assemblage: 4

A middle neritic environment is suggested for Facies 3a by the high occurrences of *L. inornata* and *Caucasina* spp. together with commonly occurring *N. commune* and *A. tangentialis* (Murray, 1984; Liu et al., 1997; Leckie and Olson, 2003; Murray, 2006; Frieling et al., 2009). Highest abundances of *Apteodinium* spp. in all assemblages and the presence of species of *Cleistosphaeridium*, *Cribroperidinium* and *Operculodinium* document increased transport from the inner shelf as a consequence of increased current strength (Brinkhuis, 1994; Marret and Zonneveld, 2003).

While all samples of Facies 3a show great similarities in microfossil abundance, grain-size analysis reveals increased amounts in silt and clay for samples OS 1–3 clearly separating them from OS 8–9 (Fig. 5). This change is accompanied by a different set of sedimentary structures in Unit 3 including commonly occurring lamination and small-sized mollusk coquinas in sand lenses besides still heavy flaser bedding. We suggest that the latter features indicate at least temporarily decreased water energy and transport.

5.1.5. Facies 3b

Lithology: Unit 2, beds 4–12
Samples: OS 7–4
Fossil assemblage: 3

The most prominent feature that distinguishes Facies 3b from the other revealed facies types is the high abundance of *P. zoharyi* in the dinoflagellate assemblages and the increased abundance of *Spiroloculina* spp. in the foraminiferal assemblages. Today, *P. zoharyi* is known from mesotrophic inner neritic near-shore associations and littoral embayments, often associated with the presence of mangrove swamps (Williams and Bujak, 1977; Marret and Zonneveld, 2003). Its ability to tolerate strong salinity fluctuations has been documented from estuarine environments with increased freshwater influx (e.g., Rossignol, 1962; Edwards, 1998; Marret and Zonneveld, 2003; de Vernal and Marret, 2007) as well as high saline lagoonal environments (Wall and Warren, 1969; Wall et al., 1977; Morzadec-Kerfourn, 1979, 1983; Bradford and Wall, 1984; McMinn, 1990; Edwards and Andrle, 1992). From the Central Paratethys, increased abundances of *P. zoharyi* have been reported from a middle Ottnangian restricted near-shore environment (Jiménez-Moreno et al., 2006).

Species of *Spiroloculina* are commonly described from brackish as well as hypersaline marine environments with a maximum water-depth of 40 m (e.g., Graham and Militante, 1959; Kumar and Manivannan, 2001; Wang and Chappell, 2001; Langer and Lipps, 2003; Gandhi and Rajamanickam, 2004; Murray, 2006; Izuka and Resig, 2008). In many cases these shallow-water environments are influenced by strong current activity (e.g. Gandhi and Rajamanickam,

Table 6
Relative abundances (%) of the most important (>5% in at least one sample) foraminiferal, dinoflagellate cyst and calcareous nannoplankton taxa.

	OS 1	OS 2	OS 3	OS 4	OS 5	OS 6	OS 7	OS 8	OS 9	OS 10	OS 11	OS 12	OS 13	OS 14	OS 15	OS 16	OS 17	OS 18	OS 19	OS 20	OS 21	OS 22	OS 23	OS 24
Alabamina tangentialis	2	**6**	**7**	**10**	**14**	4	**9**	5	4	1	1	0	0	1	0	0	2	1	0	1	0	1	1	0
Ammonia spp.	1	**9**	3	5	2	2	1	0	0	1	0	0	0	0	0	4	0	1	2	0	1	0	0	1
Amphicoryna ottnangiensis	1	2	1	1	1	2	4	0	1	**6**	**8**	**19**	3	4	0	5	**19**	**14**	**15**	**11**	**13**	**6**	**9**	**25**
Astrononion perfossum	3	0	2	5	5	**14**	**7**	**6**	3	2	0	0	0	0	0	1	0	2	1	3	0	0	0	0
Caucasina cylindrica	**15**	**21**	**20**	**17**	**21**	**21**	**20**	**14**	5	**14**	5	0	0	0	0	0	0	1	**6**	3	1	0	0	0
Cibicidoides spp.	3	4	5	2	2	3	3	2	3	**6**	**6**	1	2	4	**8**	4	2	2	1	3	2	3	3	2
Fursenkoina acuta	2	3	3	2	4	**8**	**9**	**6**	2	2	2	0	0	0	0	1	2	1	0	1	0	0	0	0
Gyroidinoides spp.	0	0	0	1	0	0	0	0	0	1	2	**12**	**15**	**10**	0	3	2	5	5	**9**	5	4	**7**	0
Hanzawaia boueana	1	**6**	1	2	1	1	2	0	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Laevidentalina spp.	1	1	1	1	2	0	0	0	1	0	2	**17**	**17**	**12**	**21**	**21**	2	**13**	**8**	**8**	**6**	**7**	0	1
Lenticulina inornata	**56**	**6**	**39**	**19**	**21**	**19**	**29**	**43**	**55**	**17**	**16**	**9**	**7**	**9**	**25**	**7**	**12**	**11**	**8**	2	**6**	**9**	**14**	**7**
Marginulina spp.	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	2	4	**6**	5
Nonion commune	3	**16**	5	5	**6**	5	3	4	2	5	0	4	2	1	**13**	5	**7**	1	2	**6**	**7**	3	3	**8**
Oridorsalis umbonatus	0	0	0	1	0	0	0	0	0	0	3	5	**10**	**6**	4	**7**	2	**6**	**10**	4	**9**	**10**	**7**	**9**
Praeglobobulimina spp.	0	0	0	0	0	0	0	0	0	0	0	0	**6**	3	0	2	0	0	0	0	**7**	**9**	**6**	**8**
Valvulineria complanata	0	0	0	1	0	0	0	0	0	0	0	5	**10**	**10**	0	**14**	0	2	2	**8**	**11**	**14**	**11**	**6**
Sigmoilinita tenuis	0	0	0	1	1	0	0	3	1	**6**	**6**	0	0	0	0	0	5	**8**	2	3	1	2	3	1
Sigmoilopsis ottnangiensis	2	0	0	0	0	2	2	**6**	**6**	4	**6**	2	**9**	3	4	0	5	**7**	5	**7**	3	**7**	**6**	3
Spiroloculina spp.	2	**8**	2	**13**	3	5	3	1	1	4	0	3	0	2	0	0	0	0	0	0	0	0	0	0
Spiroplectammina pectinata	0	0	1	1	5	3	1	3	**9**	**20**	**28**	1	0	2	4	4	**19**	5	**9**	**7**	2	3	5	3
Apteodinium spp.	**62**	**66**	**60**	**39**	**27**	**39**	**14**	**62**	**57**	**38**	**28**	**26**	**20**	**17**	**12**	**28**	**16**	**34**	**16**	**29**	**11**	**19**	**16**	**37**
Achomosphaera/ Spiniferites spp.	**8**	4	**7**	**7**	3	**8**	**7**	**8**	**8**	**12**	**12**	**23**	**15**	**21**	**19**	**28**	**43**	**17**	**27**	**17**	**36**	**23**	**23**	**14**
Cleistosphaeridium spp.	3	0	1	1	**8**	**10**	2	**6**	3	2	4	4	**6**	4	5	2	**6**	4	**6**	2	4	**8**	4	2
Cribroperidinium spp.	2	1	2	2	2	0	1	4	5	5	**29**	**13**	**19**	**19**	**14**	5	1	**12**	5	4	3	4	4	4
Exochosphaeridium insigne	1	3	5	2	2	3	1	4	3	**14**	5	**6**	4	1	3	4	4	4	4	**10**	2	**6**	**7**	2
Glaphyrocysta spp.	**7**	**7**	2	**7**	1	0	1	0	1	0	0	1	0	1	0	0	2	0	0	0	0	0	0	0
Lejeunecysta spp.	0	1	1	4	2	2	2	2	2	4	1	1	3	3	**7**	3	4	1	2	3	5	3	3	**6**
Lingulodinium machaerophorum	2	0	0	2	0	0	0	1	1	5	2	2	**9**	**10**	**11**	**9**	4	**8**	**10**	**7**	**12**	**7**	**12**	4
Polysphaeridium zoharyi	3	1	4	**13**	**42**	**26**	**55**	0	0	2	0	2	2	1	0	1	0	0	2	2	1	3	1	0
Round brown cysts	3	3	1	**9**	2	3	4	5	5	3	3	5	4	5	3	1	3	4	3	2	3	3	2	**7**
Selenopemphix spp.	2	2	1	2	0	1	2	0	0	2	1	2	3	2	4	2	2	0	3	**6**	3	**6**	**6**	**12**
Spiniferites spp.	0	2	0	0	0	0	1	4	4	4	3	3	2	1	**6**	2	5	1	**6**	0	1	0	1	0
Coccolithus pelagicus	**48**	**49**	**56**	**59**	**52**	**59**	**55**	**53**	**48**	**53**	**58**	**48**	**50**	**51**	**43**	**54**	**46**	**37**	**53**	**59**	**46**	**44**	**38**	**45**
Cyclicargolithus floridianus	5	**10**	**6**	5	**6**	3	5	5	**8**	5	4	**7**	**7**	4	4	4	**6**	5	5	**6**	4	3	3	3
Helicosphaera ampliaperta	**19**	**16**	**11**	**16**	**17**	**17**	**15**	**15**	**18**	**10**	**10**	**11**	**9**	**12**	**18**	**11**	**16**	**8**	**15**	**9**	**12**	**6**	**9**	**9**
Helicosphaera spp.	2	4	**6**	1	2	2	4	2	3	2	2	1	2	1	1	3	2	2	2	1	4	4	4	3
Reticulofenestra excavata	**12**	**6**	**11**	**6**	**6**	**10**	**11**	**13**	**7**	**11**	**12**	**12**	**9**	**10**	**8**	**14**	**14**	**21**	**14**	**17**	**17**	**15**	**14**	**14**
Reticulofenestra minuta	**7**	**9**	**7**	**11**	**14**	**4**	**6**	**6**	**12**	**9**	**7**	**16**	**20**	**19**	**21**	**6**	**8**	**20**	**6**	1	**13**	**24**	**27**	**24**
Reticulofenestra spp.	4	4	2	2	3	4	3	4	4	5	5	4	1	2	4	5	**6**	3	5	**6**	3	1	3	2

Abundances >5% are highlighted in bold numbers.

2004; Gargouri-Ben Ayed et al., 2007). In contrast, the commonly occurring hyaline foraminiferal species *A. tangentialis*, *A. perfossum*, *Caucasina* spp., *F. acuta*, *N. commune* and *L. inornata* are known from fully marine middle neritic environments (e.g., Murray, 1984; Liu et al., 1997; Leckie and Olson, 2003; Murray, 2006). Furthermore, recent and past environments with strongly fluctuating salinity are usually dominated by species of *Ammonia*, *Elphidium* and increased amounts of miliolids and agglutinated taxa (Poag, 1981; Rögl, 1998b; Culver and Buzas, 2002; Leckie and Olson, 2003; Murray, 2006). In our samples these taxa make up only a minor amount of the assemblages and tests of *Quinqueloculina* are often abraded and heavily damaged indicating transport and mixed assemblages. We suggest that Facies 3b documents highest current energy of the section with a potential estuarine source for the transported material.

5.2. Facies development of the terminal Burdigalian Seaway

The revealed facies development suggests a prograding sublittoral environment during the late early Ottnangian in the study area. However, at the stratotype the Ottnang Fm. is only represented with its middle to upper part with the top eroded. Including available data of a wider area allows the discussion of the revealed bathymetric trend in the context of the overall development of the Burdigalian Seaway during the early Ottnangian.

In the area of Upper Austria, most studies focus on the tide-influenced shelf deposits from which sand waves and tidal channels have been reported along the northern coastline of the Burdigalian Seaway from the lower Ottnangian Atzbach Fm. (Aberer, 1958; Faupl and Roetzel, 1987, 1990; Krenmayr, 1991; Uchmann and Krenmayr, 1995; Krenmayr et al., 1996; Rupp and van Husen, 2007; Rupp et al., 2008). A meso- and macrotidal setting with current velocities of 0.5 m/s and complex patterns of tidal currents have been suggested in several studies (Faupl and Roetzel, 1987, 1990; Bieg, 2005). Accordingly, benthic foraminiferal assemblages from a study area located c. 30 km NE from Ottnang–Schanze near the city of Wels (Fig. 2a) document a high energy environment with strong current transport from the inner shelf for the Atzbach Fm. (Petters, 1936; Aberer, 1958; Rupp and Haunold-Jenke, 2003; Rupp et al., 2008). The well-sorted assemblages mainly contain species of *Cibicidoides*, known to occur attached to coarse grained material in high energetic environments (Schönfeld, 1997; Murray, 2006), and inner to middle neritic taxa such as *Ammonia*, *Elphidium*, *Lobatula* and *Nonion* (Wenger, 1987; Rupp and Haunold-Jenke, 2003). The Ottnang Fm. as represented by the stratotype is overlying and partly interfingering with these deposits and is regarded as the outer neritic equivalent to the sands of the Atzbach Fm. (Rögl et al., 1973; Roetzel and Rupp, 1991; Krenmayr et al., 1996; Rupp and van Husen, 2007; Rupp et al., 2008). The present study shows however that several facies

Table 7
Results from SIMPER analysis for assemblages 1–4 (cut-off at 80%).

Average dissimilarity	Main taxa	Contribution	Cumulative %	A assemblage 1	A assemblage 2	A assemblage 3	A assemblage 4
41.05	*Apteodinium* spp.	4.66	11.35	21.6	33.0	29.8	61.4
	Lenticulina inornata	3.80	20.62	9.7	16.5	22.0	39.8
	Polysphaeridium zoharyi	2.80	27.44	1.2	1.0	34.0	1.6
	Achomosphaera/Spiniferites spp.	2.47	33.44	23.5	12.0	6.3	7.0
	Caucasina cylindrica	2.45	39.42	0.8	9.5	19.8	15.0
	Reticulofenestra minuta	1.52	43.13	15.8	8.0	8.8	8.2
	Amphicoryna ottnangiensis	1.47	46.71	11.0	7.0	2.0	1.0
	Spiroplectammina pectinata	1.45	50.24	4.9	24.0	2.5	2.6
	Laevidentalina spp.	1.44	53.73	10.2	1.0	0.8	0.8
	Cribroperidinium spp.	1.42	57.19	8.2	17.0	1.3	2.8
	Coccolithus pelagicus	1.36	60.50	50.8	56.3	55.5	47.2
	Lingulodinium machaerophorum	1.09	63.16	0.8	0.5	3.5	8.1
	Valvulineria complanata	1.05	65.72	0.0	0.3	0.0	7.2
	Oridorsalis umbonatus	0.98	68.12	0.0	0.3	1.5	6.9
	Alabamina tangentialis	0.97	70.48	4.8	9.3	1.0	0.5
	Helicosphaera ampliaperta	0.87	72.61	15.8	16.3	10.0	11.2
	Gyroidinoides spp.	0.86	74.71	0.0	0.3	1.5	5.9
	Reticulofenestra excavata	0.84	76.75	9.8	8.3	11.5	13.8
	Astrononion perfossum	0.76	78.60	2.8	7.8	1.0	0.5

types can be distinguished along the sublittoral shelf. Different facies types within the Ottnang Fm. have been indicated but not discussed by Rupp and Haunold-Jenke (2003) from the Wels area. There, the faunal composition with high abundances of *Cibicidoides*, *Lobatula*, *Elphidium* and other inner to middle neritic taxa reveals strong similarities with the Atzbach Fm. Given the location of the Wels study area closer to the northern coast and the considerably low abundances of middle to outer neritic foraminifers, a more proximal setting shallower than Facies 3 is indicated for both, the Atzbach and Ottnang Fms.

A bathymetric trend similar to that from the stratotype has been reconstructed from foraminiferal assemblages for the Neuhofen Beds that represent synchronous pelitic deposits in eastern Bavaria (Wenger, 1987; Doppler et al., 2005; Pippèrr and Reichenbacher, 2010; Pippèrr, 2011). While the lower part of the Neuhofen Beds suggests a middle to outer neritic environment with high organic matter flux and suboxic bottom waters, the upper part suggests a shallowing of the environment with higher diversity and better oxygenated bottom waters (Pippèrr and Reichenbacher, 2010; Pippèrr, 2011). The latter authors link these trends to the system tracts of a sequence stratigraphic framework indicating a transgressive phase during the earliest Ottnangian and a maximum flooding surface with a subsequent highstand system tract during the late early Ottnangian (Zweigel, 1998; Pippèrr, 2011).

The comparison of the data from Upper Austria and eastern Bavaria consistently shows a shallowing trend during the late early Ottnangian reflected in different facies types of the prograding northern shelf of the terminal Burdigalian Seaway. In Upper Austria, the lower part of the stratotype represents the most distal sediments deposited during a basin-wide transgression. Its upper part together with more northwards positioned localities represent an inner to middle neritic environment under the influence of storm events and strong currents, the latter most likely related to intensified tidal conditions. The present results confirm the interpretation of Pippèrr (2011) that the maximum marine transgression occurred during early Ottnangian and the available age estimate for the stratotype constrains the maximum flooding surface to c. 18 Ma (Grunert et al., 2010b).

6. Conclusions

In the present study, new quantitative micropaleontological, sedimentological and geophysical data are evaluated from the section Ottnang–Schanze, the stratotype for the regional Ottnangian stage (Central Paratethys; Lower Miocene, middle Burdigalian). Assemblages of benthic foraminifers, dinoflagellate cysts, calcareous nannoplankton, grain-size distribution and background gamma radiation reveal trends in bathymetry, primary productivity, bottom-water oxygenation and water energy that indicate a more diverse paleoenvironment than previously suggested. Several facies of a eutrophic environment are distinguished that document a transition from a suboxic outer neritic to upper bathyal towards a better-oxygenated middle neritic environment under the influence of storm events and tidal currents.

Previous studies in eastern Bavaria have shown a regressive trend during late early Ottnangian. A comparison of microfossil data from the stratotype and other localities in Upper Austria indicates that the outer neritic to upper bathyal facies from the lower part of the stratotype represents the most distal sediments. The upper part together with localities situated closer to the northern coast records inner to middle neritic environments under strong influence of tidal currents. The revealed facies distribution results from the progradation of the tide-influenced northern shelf of the North Alpine Foreland Basin, heralding the closure of the Burdigalian Seaway and the final regression of the sea towards the East. The available age dating for the stratotype constrains the onset of the regressive phase to 18 Ma.

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References

Aberer, F., 1958. Die Molassezone im westlichen Oberösterreich und in Salzburg. Mitteilungen der Geologischen Gesellschaft in Wien 50, 23–93.

Abreu, V.S., Haddad, G.A., 1998. Glacioeustatic fluctuations: the mechanism linking stable isotope events and sequence stratigraphy from the Early Oligocene to Middle Miocene. In: Graciansky, C.-P., Hardenbol, J., Jacquin, T., Vail, P.R. (Eds.), Mesozoic and Cenozoic Sequence Stratigraphy of European Basins. : Sedimentary Geology Special Publication, 60. Society for Sedimentary Geology, Tulsa, pp. 245–260.

Allen, P.A., Homewood, P., 1984. Evolution and mechanics of a Miocene tidal sandwave. Sedimentology 31, 63–81.

Allen, P.A., Mange-Rajetzky, M., Matter, A., Homewood, P., 1985. Dynamic palaeogeography of open Burdigalian sea-way, Swiss Molasse Basin. Eclogae Geologicae Helveticae 79, 351–381.

Aubry, M., 1992. Late Paleogene calcareous nannoplankton evolution: a tale of climatic deterioration. In: Prothero, D.R., Berggren, W.A. (Eds.), Eocene-Oligocene Climatic and Biotic Evolution. Princeton University Press, Princeton, pp. 272–309.

Bachmann, A., 1973. Die Silicoflagellaten aus dem Stratotypus des Ottnangien. In: Papp, A., Rögl, F., Seneš, J. (Eds.), Miozän M2 – Ottnangien. Die Innviertler, Salgotarjaner, Bantapusztaer Schichtengruppe und die Rzehakia Formation. : Chronostratigraphie und Neostratotypen, Miozän der Zentralen Paratethys, vol. 3. Verlag der Slowakischen Akademie der Wissenschaften, Bratislava, pp. 275–295.

Báldi, K., 2006. Paleoceanography and climate of the Badenian (Middle Miocene, 16.4–13.0 Ma) in the Central Paratethys based on foraminifera and stable isotope (δ^{18}O and δ^{13}C) evidence. International Journal of Earth Science 95, 119–142.

Baldí, T., Seneš, J., 1975. OM – Egerien. Die Egerer, Pouzdraner, Puchkirchener Schichtengruppe und die Bretkaer Formation. Chronostratigraphie und Neostratotypen, Miozän der Zentralen Paratethys, vol. 5. Verlag der Slowakischen Akademie der Wissenschaften, Bratislava.

Barmawidjaja, D.J., Jorissen, F.J., Puskaric, S., Van der Zwaan, G.J., 1992. Microhabitat selection by benthic foraminifera in the northern Adriatic Sea. Journal of Foraminiferal Research 22, 297–317.

Berger, J.-P., 1996. Cartes paléogéographiques-palinspastiques du bassin molassique suisse (Oligocène inférieur – Miocène moyen). Neues Jahrbuch für Geologie und Paläontologie 202, 1–44.

Bernhard, J.M., Sen Gupta, B.K., 2002. Foraminifera of oxygen-depleted environments. In: Sen Gupta, B.K. (Ed.), Modern Foraminifera. Kluwer Academic Publishers, Dordrecht-Boston-London, pp. 201–216.

Bieg, U., 2005. Palaeooceanographic modelling in global and regional scale: an example from the Burdigalian Seaway. Ph.D. Thesis, Eberhard-Karls-Universität Tübingen, Germany.

Bradford, M.R., Wall, D.A., 1984. The distribution of recent organic-walled dinoflagellate cysts in the Persian Gulf, Gulf of Oman, and northwestern Arabian Sea. Palaeontographica B 192, 1–84.

Brinkhuis, H., 1994. Late Eocene to Early Oligocene dinoflagellate cysts from the Priabonian type-area (Northeast Italy): biostratigraphy and paleoenvironmental interpretation. Palaeogeography, Palaeoclimatology, Palaeoecology 107, 121–163.

Brügel, A., Dunkl, I., Frisch, W., Kuhlemann, J., Balogh, K., 2003. Geochemistry and geochronology of gneiss pebbles from foreland molasse conglomerates: geodynamic and paleogeographic implications for the Oligo–Miocene evolution of the Eastern Alps. Journal of Geology 111, 543–563.

Bürgl, H., 1949. Zur Stratigraphie und Tektonik des oberösterreichischen Schliers. Verhandlungen der Geologischen Bundesanstalt 1946, 123–151.

Cicha, I., Seneš, J., Tejkal, J., 1967. M3 (Karpatien). Die Karpatische Serie und ihr Stratotypus. Chronostratigraphie und Neostratotypen, Miozän der Zentralen Paratethys, vol. 1. Verlag der Slowakischen Akademie der Wissenschaften, Bratislava.

Cicha, I., Rögl, F., Rupp, C., Ctyroká, J., 1998. Oligocene–Miocene foraminifers of the Central Paratethys. Abhandlungen der Senckenbergischen Naturforschenden Gesellschaft 549, 1–325.

Clarke, K.R., 1993. Non-parametric multivariate analysis of changes in community structure. Australian Journal of Ecology 18, 117–143.

Ćorić, S., Hohenegger, J., 2008. Quantitative analyses of calcareous nannoplankton assemblages from the Baden-Sooss section (Middle Miocene of Vienna Basin, Austria). Geologica Carpathica 59, 447–460.

Corliss, B.H., 1991. Morphology and microhabitat preferences of benthic foraminifera from the northwest Atlantic Ocean. Marine Micropaleontology 17, 195–236.

Culver, S.J., Buzas, M.A., 2002. Biogeography of neritic benthic foraminifera. In: Sen Gupta, B.K. (Ed.), Modern Foraminifera. Kluwer Academic Publishers, Dordrecht-Boston-London, pp. 92–102.

Dale, B., 1996. Dinoflagellate cyst ecology: modeling and geological applications. In: Jansonius, J., McGregor, D.C. (Eds.), Palynology: Principles and Applications. American Association of Stratigraphic Palynologists Foundation Books, vol. 3. American Association of Stratigraphic Palynologists, Dallas, pp. 1249–1275.

Dashtgard, S.E., MacEachern, J.A., Frey, S.E., Gingras, M.K., in press. Tidal effects on the shoreface: towards a conceptual framework. Sedimentary Geology. doi:10.1016/j.sedgeo.2010.09.006.

De Leeuw, A., Bukowski, K., Krijgsman, W., Kuiper, K.F., 2010. Age of the Badenian salinity crisis. Impact of Miocene climate variability on the circum-mediterranean region. Geology 38, 715–718.

De Vernal, A., Marret, F., 2007. Organic-walled dinoflagellate cysts: tracers of sea-surface conditions. In: Hillaire-Marcel, C., Vernal, A. (Eds.), Proxies in Late Cenozoic Paleoceanography. : Developments in Marine Geology, vol. 1. Elsevier, Amsterdam, pp. 371–408.

Den Dulk, M., Reichardt, G.J., Van Heyst, S., Zachariasse, W.J., Van der Zwaan, G.J., 2000. Benthic foraminifera as proxies of organicmatter flux and bottomwater oxygenation? A case history from the northern Arabian Sea. Palaeogeography, Palaeoclimatology, Palaeoecology 161, 337–359.

Doppler, G., Heissig, K., Reichenbacher, B., 2005. Die Gliederung des Tertiärs im süddeutschen Molassebecken. Newsletters on Stratigraphy 41, 359–375.

Edwards, L.E., 1998. Modern and near modern dinocysts from Florida Bay. Abstracts from the Sixth International Conference on Modern and Fossil Dinoflagellates, p. 37.

Edwards, L.E., Andrle, V.A.S., 1992. Distribution of selected dinoflagellate cysts in modern marine sediments. In: Head, M.J., Wrenn, J.H. (Eds.), Neogene and Quaternary Dinoflagellate Cysts and Acritarchs. American Association of Stratigraphic Palynologists, Dallas, pp. 259–288.

Faupl, P., Roetzel, R., 1987. Gezeitenbeeinflußte Ablagerungen der Innviertler Gruppe (Ottnangien) in der oberösterreichischen Molassezone. Jahrbuch der Geologischen Bundesanstalt 130, 415–447.

Faupl, P., Roetzel, R., 1990. Die Phosphoritsande und Fossilreichen Grobsande: Gezeitenbeeinflußte Ablagerungen der Innviertler Gruppe (Ottnangien) in der oberösterreichischen Molasse. Jahrbuch der Geologischen Bundesanstalt 133, 157–180.

Fenner, J., 1991. Taxonomy, stratigraphy, and paleooceanographic implications of Paleocene diatoms. Proceedings ODP Scientific Results 114, 123–154.

Fensome, R.A., Taylor, F.J.R., Norris, G., Sarjeant, W.A.S., Wharton, D.I., Williams, G.L., 1993. A classification of living and fossil dinoflagellates. Micropaleontology Special Publication 7, 1–351.

Fensome, R.A., MacRae, R.A., Williams, G.L., 2008. DINOFLAJ2, version 1. American Association of Stratigraphic Palynologists Data Series, vol. 1. American Association of Stratigraphic Palynologists, Dallas.

Flores, J.A., Sierro, F.R., Filippelli, M.R., Bárcena, M.A., Pérez-Folgado, M., Vásquez, A., Utrilla, R., 2005. Surface water dynamics and phytoplankton communities during deposition od cyclic late Messinian sapropel sequences in the Western Mediterranean. Marine Micropaleontology 56, 50–79.

Frieling, D., Pippèrr, M., Schneider, S., Reichenbacher, B., 2009. Sedimentology and stratigraphy at the rocky coast of the upper Burdigalian Molasse Sea: a case study from Gurlarn near Passau (SE Germany). Facies 55, 47–62.

Friedman, G.M., 1962. On sorting, sorting coefficient and log normality of the grain size distribution of sandstone. The Journal of Geology 70, 737–756.

Füchtbauer, H., 1959. Zur Nomenklatur der Sedimentgesteine. Erdöl und Kohle 12, 605–613.

Gandhi, M.S., Rajamanickam, G.V., 2004. Distribution of certain ecological parameters and foraminiferal distribution in the depositional environment of Palk Strait, east coast of India. Indian Journal of Marine Sciences 33, 287–295.

Gargouri-Ben Ayed, Z., Souissi, R., Souissi, M., Abdeljaouad, S., Zouari, K., 2007. Sedimentary dynamics and ecological state of Nakta tidal flat (littoral), South of Sfax, Gulf of Gabès, Tunisia. Chinese Journal of Geochemistry 26, 244–251.

Gebühr, C., Wiltshire, K.H., Aberle, N., Beusekom, J.E.E., van and Gerdts, G., 2009. Influence of nutrients, temperature, light and salinity on the occurence of *Paralia sulcata* at Helgoland Roads, North Sea. Aquatic Biology 7, 185–197.

Graham, J.J., Militante, P.J., 1959. Recent Foraminifera from the Puerto Galera, Northern Mindoro, Philippines. Stanford University Publications, Stanford.

Green, O.R., 2001. A Manual of Practical Laboratory and Field Techniques in Palaeobiology. Kluwer Academic Publishers, Dordrecht-Boston-London.

Grunert, P., Soliman, A., Harzhauser, M., Müllegger, S., Piller, W.E., Roetzel, R., Rögl, F., 2010a. Upwelling conditions in the Early Miocene Central Paratethys Sea. Geologica Carpathica 61, 129–145.

Grunert, P., Soliman, A., Ćorić, S., Scholger, R., Harzhauser, M., Piller, W.E., 2010b. Stratigraphic re-evaluation of the stratotype for the regional Ottnangian stage (Central Paratethys, middle Burdigalian). Newsletters on Stratigraphy 44, 1–16.

Hammer, Ø., Harper, D.A.T., 2006. Paleontological Data Analysis. Blackwell Publishing, Oxford.

Hammer, Ø., Harper, D.A.T., Ryan, P.D., 2001. PAST: paleontological statistics software package for education and data analysis. Palaeontologia Electronica 4, 1–9.

Haq, B.U., 1980. Miocene biogeographic history of calcareous nannoplankton and paleoceanography of the Atlantic Ocean. Marine Micropaleontology 7, 119–194.

Harzhauser, M., Piller, W.E., 2007. Benchmark data of a changing sea. Palaeogeography, palaeobiogeography and events in the Central Paratethys during the Miocene. Palaeogeography, Palaeoclimatology, Palaeoecology 253, 8–31.

Hedberg, H.D., 1976. International Stratigraphic Guide. John Wiley and Sons, New York.

Heimann, F.U.M., Schmid, D.U., Pippèrr, M., Reichenbacher, B., 2009. Re-interpreting the Baltringer Horizont as a subtidal channel facies: implications for a new understanding of the Upper Marine Molasse “Cycles” (Early Miocene). Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen 254, 135–149.

Hochuli, P.A., 1978. Palynologische Untersuchungen im Oligozän und Untermiozän der Zentralen und Westlichen Paratethys. Beiträge zur Paläontologie von Österreich 4, 1–132.

Hohenegger, J., 2005. Estimation of environmental paleogradient values based on presence/absence data: a case study using benthic foraminifera for paleodepth estimation. Palaeogeography, Palaeoclimatology, Palaeoecology 217, 115–130.

Homewood, P., Allen, P.A., 1981. Wave-, tide-, and current-controlled sandbodies of Miocene Molasse, Western Switzerland. AAPG Bulletin 65, 2534–2545.

Izuka, S.K., Resig, J.M., 2008. Evidence for Late Pliocene–Early Pleistocene marine environments in the deep subsurface of the Lihue Basin, Kauai, Hawaii. Palaios 23, 442–451.

Janz, H., Vennemann, T.W., 2005. Isotopic composition (O, C, Sr, and Nd) and trace element ratios (Sr/Ca, Mg/Ca) of Miocene marine and brackish ostracods from North Alpine Foreland deposits (Germany and Austria) as indicators for palaeoclimate. Palaeogeography, Palaeoclimatology, Palaeoecology 225, 216–247.

Jiménez-Moreno, G., Head, M.J., Harzhauser, M., 2006. Early and Middle Miocene dionflagellate cyst stratigraphy of the Central Paratethys, Central Europe. Journal of Micropalaeontology 25, 113–139.

Johnson, H.D., Baldwin, C.T., 1996. Shallow clastic seas, In: Reading, H.G. (Ed.), Sedimentary Environments: Processes, Facies and Stratigraphy, 3rd edition. Blackwell Science, Oxford, pp. 232–280.

Jones, R.W., 1994. The Challenger Foraminifera. Oxford University Press, Oxford.

Jorissen, F.J., 1987. The distribution of benthic foraminifera in the Adriatic Sea. Marine Micropaleontology 12, 21–48.

Jorissen, F.J., Stigter, H.C.D., Widmark, J.G.V., 1995. A conceptual model explaining benthic foraminiferal microhabitats. Marine Micropaleontoloy 26, 3–15.

Kaiho, K., 1994. Benthic foraminiferal dissolved-oxygen index and dissolved-oxygen levels in the modern ocean. Geology 22, 719–722.

Kaltbeitzer, J., 1988. Geologische, sedimentpetrologische und hydrogeologische Untersuchungen im Hausruckgebiet östlich von Eberschwang. Master thesis, Ludwig-Maximilians-Universität, Munich, Germany.

Keller, B., 1989. Fazies und Stratigraphie der Oberen Meeresmolasse (unteres Miozän) zwischen Napf und Bodensee. Ph.D. Thesis, University of Bern, Switzerland.

Kouwenhoven, T.J., van der Zwaan, G.J., 2006. A reconstruction of late Miocene Mediterranean circulation patterns using benthic foraminifera. Palaeogeography, Palaeoclimatology, Palaeoecology 238, 373–385.

Krenmayr, H.-G., 1991. Sedimentologische Untersuchungen der Vöcklaschichten (Innviertler Gruppe, Ottnangien) in der oberösterreichischen Molassezone im Gebiet der Vöckla und der Ager. Jahrbuch der Geologischen Bundesanstalt 134, 83–100.

Krenmayr, H.G., Schnabel, W., 2006. Geologische Karte von Oberösterreich 1:200.000, 1 sheet, 2 additional maps. Geological Survey of Austria, Vienna.

Krenmayr, H.-G., Roetzel, R., Rupp, C., 1996. Stop 2: Puchkirchen-Berg. In: Krenmayr, H.-G., Roetzel, R. (Eds.), Exkursionsführer, 11. Sedimentologentreffen, Exkursion B2, Oligozäne und miozäne Becken- und Gezeitensedimente in der Molassezone Oberösterreichs: Berichte der Geologischen Bundesanstalt, 33, pp. 1–43.

Kroh, A., 2007. Climate changes in the early to Middle Miocene of the Central Paratethys and the origin of its echinoderm fauna. Palaeogeography, Palaeoclimatology, Palaeoecology 253, 169–207.

Kroh, A., Harzhauser, M., 1999. An echinoderm fauna from the Lower Miocene of Austria: paleoecology and implications for Central Paratethys paleobiogeography. Annalen des Naturhistorischen Museums Wien 101A, 145–191.

Kroh, A., Menkveld-Gfeller, U., 2006. Echinoids from the Belpberg Beds (Obere Meeresmolasse, Middle Burdigalian) in the area of Bern (Switzerland). Eclogae Geologicae Helvetiae 99, 193–203.

Kuhlemann, J., Kempf, O., 2002. Post-Eocene evolution of the North Alpine Foreland Basin and its response to Alpine tectonics. Sedimentary Geology 152, 45–78.

Kumar, V., Manivannan, V., 2001. Benthic foraminiferal responses to bottom water characteristics in the Palk Bay, off Rameswaram, southeast coast of India. Indian Journal of Marine Sciences 30, 173–179.

Langer, M.R., Lipps, J.H., 2003. Foraminiferal distribution and diversity, Madang Reef and Lagoon, Papua New Guinea. Coral Reefs 22, 143–154.

Leckie, R.M., Olson, H.C., 2003. Foraminifera as proxies for sea-level change on siliciclastic margins. In: Olson, H.C., Leckie, R.M. (Eds.), Micropaleontologic Proxies for Sea-Level Change and Stratigraphic Discontinuities. : Society for Sedimentary Geology Special Publication, vol. 75. Society for Sedimentary Geology, Tulsa, pp. 5–19.

Lemcke, K., 1988. Geologie von Bayern I. Das bayerische Alpnevorland vor der Eiszeit. Schweizerbart, Stuttgart.

Lesueur, J.-P., Rubino, J.-L., Giraudmaillet, M., 1990. Organisation et structures internes des dépôts tidaux du Miocène rhodanien. Bulletin de la Societe Geologique de France 6, 49–65.

Levin, L.A., 2003. Oxygen minimum zone benthos: adaptation and community response to hypoxia. Oceanography and Marine Biology 41, 1–45.

Lirer, F., Harzhauser, M., Pelosi, N., Piller, W.E., Schmid, H.P., Sprovieri, M., 2009. Astronomically forced teleconnection between Paratethyan and Mediterranean sediments during the Middle and Late Miocene. Palaeogeography, Palaeoclimatology, Palaeoecology 275, 1–13.

Liu, C., Browning, J.V., Miller, K.G., Olsson, R.K., 1997. Paleocene benthic foraminiferal biofacies and sequence stratigraphy, Island Beach borehole, New Jersey. In: Miller, K.G., Snyder, S.W. (Eds.), Proceedings of the Ocean Drilling Program: Scientific Results, 150, pp. 267–275.

Lourens, L., Hilgen, F., Shackleton, N.J., Laskar, J., Wilson, D., 2004. The Neogene Period. In: Gradstein, F.M., Ogg, J.G., Smith, A.G. (Eds.), A Geologic Time Scale 2004. Cambridge University Press, Cambridge, pp. 409–440.

Mandic, O., Steininger, F.F., 2003. Computer-based mollusc stratigraphy — a case study from the Eggenburgian (Lower Miocene) type region (NE Austria). Palaeogeography, Palaeoclimatology, Palaeoecology 197, 263–291.

Marret, F., Zonneveld, K.A.F., 2003. Atlas of modern organic-walled dinoflagellate cyst distribution. Review of Palaeobotany and Palynology 125, 1–200.

Martel, A.T., Allen, P.A., Slingerland, R., 1994. Use of tidal-circulation modeling of paleogeographical studies: an example from the Tertiary of the Alpine perimeter. Geology 22, 925–928.

Martins, V., Dubert, J., Jouanneau, J.M., Weber, O., da Silva, E.F., Patinha, C., Dias, J.M.A., Rocha, F., 2007. A multiproxy approach of the Holocene evolution of shelf-slope circulation on the NW Iberian Continental Shelf. Marine Geology 239, 1–18.

McMinn, A., 1990. Recent dinoflagellate cyst distribution in eastern Australia. Review of Paleobotany and Palynology 65, 305–310.

McQuoid, M.R., Nordberg, K., 2003a. Environmental influence on the diatom and silicoflagellate assemblages in Koljö Fjord (Sweden) over the last two centuries. Estuaries 26, 927–937.

McQuoid, M.R., Nordberg, K., 2003b. The diatom *Paralia sulcata* as an environmental indicator species in coastal sediments. Estuarine, Coastal and Shelf Science 56, 339–354.

Morzadec-Kerfourn, M.-T., 1979. Indicateurs écologiques du domaine littoral: végétation et plancton organique. Oceanis 5, 207–213.

Morzadec-Kerfourn, M.-T., 1983. Interêt de dinoflagellés pour l'établissement de reconstruction paléogéographique: exemple du Golfe de Gabes (Tunésie). Cahiers de Micropaléontologie 4, 15–22.

Müller, G., 1961. Das Sand-Silt-Ton Verhältnis in rezenten marinen Sedimenten. Neues Jahrbuch für Mineralogie, Monatshefte 148–163.

Murray, J.W., 1984. Paleogene and Neogene benthic foraminifers from Rockall Plateau: Initial Reports of the Deep Sea Drilling Project, 81, pp. 503–534.

Murray, J.W., 2006. Ecology and Applications of Benthic Foraminifera. Cambridge University Press, Cambridge.

Papp, A., Cicha, I., 1973. Die Entwicklung der Innviertler Schichtengruppe – M2$_{a\text{-}c(d)}$ – und ihrer Äquivalente in Österreich und anschließenden Gebieten. In: Papp, A., Rögl, F., Seneš, J. (Eds.), Miozän M2 – Ottnangien. Die Innviertler, Salgotarjaner, Bantapusztaer Schichtengruppe und die Rzehakia Formation. : Chronostratigraphie und Neostratotypen, Miozän der Zentralen Paratethys, vol. 3. Verlag der Slowakischen Akademie der Wissenschaften, Bratislava, pp. 54–78.

Papp, A., Rögl, F., Seneš, J., 1973. Miozän M2 – Ottnangien. Die Innviertler, Salgotarjaner, Bantapusztaer Schichtengruppe und die Rzehakia Formation. Chronostratigraphie und Neostratotypen, Miozän der Zentralen Paratethys, vol. 3. Verlag der Slowakischen Akademie der Wissenschaften, Bratislava.

Papp, A., Marinescu, F., Seneš, J., 1974. M5 – Sarmatien (sensu E. Suess, 1866). Die Sarmatische Schichtengruppe und ihr Stratotypus. Chronostratigraphie und Neostratotypen, Miozän der Zentralen Paratethys, vol. 4. Verlag der Slowakischen Akademie der Wissenschaften, Bratislava.

Papp, A., Cicha, I., Seneš, J., Steininger, F., 1978. M4 – Badenien (Moravien, Wielicien, Kosovien). Chronostratigraphie und Neostratotypen, Miozän der Zentralen Paratethys, vol. 6. Verlag der Slowakischen Akademie der Wissenschaften, Bratislava.

Papp, A., Jámbor, Á., Steininger, F.F., 1985. M6 – Pannonien (Slavonien und Serbien). Chronostratigraphie und Neostratotypen, Miozän der Zentralen Paratethys, vol. 7. Verlag der Slowakischen Akademie der Wissenschaften, Bratislava.

Passega, R., 1957. Texture as characteristic of clastic deposition. Bulletin of the American Association of Petroleum Geologists 41, 1952–1984.

Passega, R., 1964. Grain size representation by CM patterns as a geological tool. Journal of Sedimentary Petrology 34, 830–847.

Passega, R., 1977. Significance of CM diagrams of sediments deposited by suspension. Sedimentology 24, 723–733.

Passega, R., Byramjee, R., 1969. Grain-size image of clastic deposits. Sedimentology 13, 233–252.

Petters, V., 1936. Geologische und mikropaläontologische Untersuchungen der Eurogasco im Schlier Oberösterreichs. Petroleum Zeitschrift 32, 3.

Pezelj, Đ., Sremac, J., Sokač, A., 2007. Palaeoecology of the Late Badenian foraminifera and ostracoda from the SW Central Paratethys (Medvednica Mt., Croatia). Geologia Croatica 60, 139–150.

Piller, W.E., Harzhauser, M., Mandic, O., 2007. Miocene Central Paratethys stratigraphy — current status and future directions. Stratigraphy 4, 151–168.

Pippèrr, M., 2011. Characterisation of Ottnangian (middle Burdigalian) palaeoenvironments in the North Alpine Foreland Basin using benthic foraminifera: a review of the Upper Marine Molasse of southern Germany. Marine Micropaleontology 79, 80–99.

Pippèrr, M., Reichenbacher, B., 2010. Foraminifera from the borehole Altdorf (SE Germany): proxies for Ottnangian (early Miocene) palaeoenvironments of the Central Paratethys. Palaeogeography, Palaeoclimatology, Palaeoecology 289, 62–80.

Poag, C.W., 1981. Ecologic Atlas of Benthic Foraminifera of the Gulf of Mexico. Marine Science International, Woods Hole. (174 pp).

Pross, J., Brinkhuis, H., 2005. Organic-walled dinoflagellate cysts as paleoenvironmental indicators in the Paleogene; a synopsis of concepts. Paläontologische Zeitschrift 79, 53–59.

Reading, H.G., Collinson, J.D., 1996. Clastic coasts, In: Reading, H.G. (Ed.), Sedimentary Environments: Processes, Facies and Stratigraphy, 3rd edition. Blackwell Science, Oxford, pp. 154–231.

Reiter, E., 1989. Das Naturdenkmal “Ottnangien” zwischen Wolfsegg und Ottnang am Hausruck. Oberösterreichische Heimatblätter 43, 262–270.

Reolid, M., Rodríguez-Tovar, F.J., Nagy, J., Olóriz, F., 2008. Benthic foraminiferal morphogroups of mid to outer shelf environments of the Late Jurassic (Prebetic Zone, southern Spain): characterization of biofacies and environmental significance. Palaeogeography, Palaeoclimatology, Palaeoecology 261, 280–299.

Reuss, A.E., 1864. Die Foraminiferen des Schliers von Ottnang. Verhandlungen der Geologischen Reichsanstalt 1864, 20–21.

Roetzel, R., Rupp, C., 1991. Ottnang, Sandgrube Fischer. In: Roetzel, R., Nagel, D. (Eds.), Exkursionen im Tertiär Österreichs. Österreichische Paläontologische Gesellschaft, Vienna, pp. 36–38.

Roetzel, R., Ćorić, S., Galović, I., Rögl, F., 2006. Early Miocene (Ottnangian) coastal upwelling conditions along the southeastern scarp of the Bohemian Massif (Parisdorf, Lower Austria, Central Paratethys). Beiträge zur Paläontologie 30, 387–413.

Rögl, F., 1998a. Palaeogeographic considerations for Mediterranean and Paratethys seaways (Oligocene to Miocene). Annalen des Naturhistorischen Museums in Wien 99A, 279–310.

Rögl, F., 1998b. Foraminiferenfauna aus dem Karpat (Unter-Miozän) des Korneuburger Beckens. Beiträge zur Paläontologie Österreichs 23, 123–174.

Rögl, F., Spezzaferri, S., 2003. Foraminiferal paleoecology and biostratigraphy of the Mühlbach section (Gaindorf Formation, Lower Badenian), Lower Austria. Annalen des Naturhistorischen Museums in Wien 104A, 23–75.

Rögl, F., Schultz, O., Hölzl, O., 1973. Holostratotypus und Faziostratotypen der Innviertler Schichtengruppe. In: Papp, A., Rögl, F., Seneš, J. (Eds.), Miozän M2 – Ottnangien. Die Innviertler, Salgotarjaner, Bantapusztaer Schichtengruppe und die Rzehakia Formation. Chronostratigraphie und Neostratotypen, Miozän der Zentralen Paratethys, vol. 3. Verlag der Slowakischen Akademie der Wissenschaften, Bratislava, pp. 140–196.

Rossignol, M., 1962. Analyse pollinique de sédiments marins Quaternaires en Israël. II. Sédiments pléistocènes. Pollen Spores 4, 121–148.

Rupp, C., 1986. Paläoökologie der Foraminiferen in der Sandschalerzone (Badenien, Miozän) des Wiener Beckens. Beiträge zur Paläontologie Österreichs 12, 1–180.

Rupp, C., Haunold-Jenke, Y., 2003. Untermiozäne Foraminiferenfaunen aus dem oberösterreichischen Zentralraum. Jahrbuch der Geologischen Bundesanstalt 143, 227–302.

Rupp, C., van Husen, D., 2007. Zur Geologie des Kartenblattes Ried im Innkreis. In: Egger, H., Rupp, C. (Eds.), Beiträge zur Geologie Oberösterreichs, Arbeitstagung der Geologischen Bundesanstalt 2007. Geological Survey of Austria, Vienna, pp. 73–112.

Rupp, C., Roetzel, R., Stojaspal, F., 1991. Ottnang–Schanze. In: Roetzel, R., Nagel, D. (Eds.), Exkursionen im Tertiär Österreichs. Österreichische Paläontologische Gesellschaft, Vienna, pp. 38–41.

Rupp, C., Hofmann, T., Jochum, B., Pfleiderer, S., Schedl, A., Schindlbauer, G., Schubert, G., Slapansky, P., Tilch, N., Husen, D., van Wagner, L., Wimmer-Frey, I., 2008. Geologische Karte der Republik Österreich 1:50.000, Blatt 47 Ried im Innkreis. Erläuterungen zu Blatt 47 Ried im Innkreis. Geological Survey of Austria, Vienna.

Salvermoser, S., 1999. Zur Sedimentologie gezeitenbeeinflußter Sande in der Oberen Meeresmolasse und Süßbrackwassermolasse (Ottnangium) von Niederbayern und Oberösterreich. Münchner Geologische Hefte A 26, 1–179.

Schaad, W., Keller, B., Matter, A., 1992. Die Obere Meeresmolasse (OMM) am Pfänder: Beispiel eines Gilbert-Deltakomplexes. Eclogae Geologicae Helveticae 85, 145–168.

Schläger, A., 1988. Geologische Aufnahme des Hausruckgebietes nördlich von Ottnang/Oberösterreich. Master thesis, Ludwig-Maximilians-Universität, Munich, Germany.

Schlunegger, F., Leu, W., Matter, A., 1997. Sedimentary sequences, seismic facies, subsidence analysis, and evolution of the Burdigalian Upper Marine Molasse Group, Central Switzerland. AAPG Bulletin 81, 1185–1207.

Schönfeld, J., 1997. The impact of Mediterranean Outflow Water (MOW) on Benhic foraminiferal assemblages and surface sediments at the southern Portuguese continental margin. Marine Micropaleontology 29, 211–236.

Smallwood, B.J., Wolff, G.A., Bett, B.J., Smith, C.R., Gage, J.D., Patience, A., Hoover, D., 1999. Megafauna can control the quality of organic matter in marine sediments. Naturwissenschaften 86, 320–324.

Spezzaferri, S., Tamburini, F., 2007. Paleodepth variations on the Eratosthenes Seamount (Eastern Mediterranean): sea-level changes or subsidence? eEarth Discussions 2, 115–132.

Spezzaferri, S., Ćorić, S., Hohenegger, J., Rögl, F., 2002. Basin-scale paleobiogeography and paleoecology: an example from Karpatian (Latest Burdigalian) benthic and planktonic foraminifera and calcareous nannofossils from the Central Paratethys. Geobios 35, 241–256.

Steininger, F., Seneš, J., 1971. M1 – Eggenburgien. Die Eggenburger Schichtengruppe und ihr Stratotypus. Chronostratigraphie und Neostratotypen, Miozän der Zentralen Paratethys, vol. 2. Verlag der Slowakischen Akademie der Wissenschaften, Bratislava.

Stevanović, P., Nevesskaja, L.A., Marinescu, F., Sokac, A., Jámbor, A., 1990. Pl1 – Pontien (sensu F. Le Play, N.P. Barbot, N. I. Andrusov). Chronostratigraphie und Neostratotypen, Neogen der Westlichen ("Zentralen") Paratethys, vol. 8. Verlag der Slowakischen Akademie der Wissenschaften, Bratislava.

Sztanó, O., 1994. The tide-influenced Petervasara Sandstone, early Miocene, northern Hungary: sedimentology, paleogeography and basin development. Geologica ultraiectina 120, 1–155.

Sztanó, O., 1995. Palaeogeographic significance of tidal deposits: an example from an early Miocene Paratethys embayment, Northern Hungary. Palaeogeography Palaeoclimatology Palaeoecology 113, 173–187.

Sztanó, O., de Boer, P.L., 1995. Amplification of tidal motions in the Early Miocene North Hungarian Bay. Sedimentology 42, 665–682.

Tessier, B., Gigot, P., 1989. A vertical record of different tidal cyclicities: an example from the Miocene Marine Molasse of Digne (Haute Provence, France). Sedimentology 36, 767–776.

Thompson, J.B., Mullins, H.T., Newton, C.R., Vercoutere, T., 1985. Alternative biofacies model for dysaerobic communities. Lethaia 18, 167–179.

Uchmann, A., Krenmayr, H.-G., 1995. Trace fossils from Lower Miocene (Ottnangian) molasse deposits of Upper Austria. Paläontologische Zeitschrift 69, 503–524.

Uchmann, A., Krenmayr, H.-G., 2004. Trace fossils, ichnofabrics and sedimentary facies in the shallow marine Lower Miocene Molasse of Upper Austria. Jahrbuch der Geologischen Bundesanstalt 144, 233–251.

Van der Zwann, G.J., Duijnstee, I.A.P., den Dulk, M., Ernst, S.R., Jannik, N.T., Kouwenhoven, T.J., 1999. Benthic foraminifers: proxies or problems? A review of paleocological concepts. Earth-Science Reviews 46, 213–236.

Van Hinsbergen, D.J.J., Kouwenhoven, T.J., van der Zwaan, G.J., 2005. Paleobathymetry in the backstripping procedure: correction for oxygenation effects on depth estimates. Palaeogeography, Palaeoclimatology, Palaeoecology 221, 245–265.

Vasiliev, I., de Leeuw, A., Filipescu, S., Krijgsman, W., Kuiper, K., Stoica, M., Briceag, A., 2010. The age of the Sarmatian–Pannonian transition in the Transylvanian Basin (Central Paratethys). Palaeogeography Palaeoclimatology Palaeoecology 297, 54–69.

Vavra, N., 1979. Die Bryozoenfauna des österreichischen Tertiärs. Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen 157, 366–392.

Vink, A., Zonneveld, K.A.F., Willems, H., 2000. Organic-walled dinoflagellate cysts in western equatorial Atlantic surface sediments: distributions and their relation to environment. Review of Palaeobotany and Palynology 112, 247–286.

Wade, B.S., Bown, P.R., 2006. Calcareous nannofossils in extreme environments: the Messinian Salinity Crisis, Polemi Basin, Cyprus. Palaeogeography 233, 271–286.

Wagner, L., 1998. Tectono-stratigraphy and hydrocarbons in the Molasse Foredeep of Salzburg, Upper and Lower Austria. In: Mascle, A., Puigdefábregas, C., Luterbach, H.P., Fernández, M. (Eds.), Cenozoic Foreland Basins of Western Europe. : Geological Society Special Publications, vol. 134. Geological Society, London, pp. 339–369.

Wall, D., Warren, J.S., 1969. Dinoflagellates in Red Sea piston cores. In: Degens, E.T., Ross, D.A. (Eds.), Hot Brines and Recent Heavy Metal Deposits in the Red Sea. Springer, Berlin, pp. 317–327.

Wall, D., Dale, B., Lohmann, G.P., Smith, W.K., 1977. The environmental and climatic distribution of dinoflagellate cysts in Modern marine sediments from regions in the North and South Atlantic Oceans and adjacent seas. Marine Micropaleontology 2, 121–200.

Wang, P., Chappell, J., 2001. Foraminifera as Holocene environmental indicators in the South Alligator River, Northern Australia. Quaternary International 83–85, 47–62.

Wenger, W.F., 1987. Die Foraminiferen des Miozäns der bayerischen Molasse und ihre stratigraphische sowie paläogeographische Auswertung. Zitteliana 16, 173–340.

Williams, G.L., Bujak, J.P., 1977. Distribution patterns of some North Atlantic Cenozoic dinoflagellate cysts. Marine Micropalaeontology 2, 223–233.

Zong, Y., 1997. Mid and late Holocene sea level changes in Roudsea marsh, northwest England: a diatom biostratigraphical investigation. The Holocene 7, 311–323.

Zorn, I., 1995. Preliminary report on the ostracodes from the Ottnangian (Early Miocene) of Upper Austria. Proceedings of the 12th International Symposium on Ostracoda, Prague, Czech Republic, pp. 237–243.

Zweigel, J., 1998. Eustatic Versus Tectonic Control on Foreland Basin Fill. Contributions to Sedimentary Geology 20. Schweizerbart, Stuttgart.