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Biostratigraphy of the lower red shale interval in the Rhenodanubian Flysch Zone of Austria

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Abstract

In the Rhenodanubian Flysch Zone of Austria, between the Aptian–Albian "Gault Flysch" and the Cenomanian–Turonian Reiselsberg Formation, an interval with predominant red shales ("Untere Bunte Schiefer") occurs. In the Oberaschau section near Attersee (Upper Austria) a ca. 18-m-thick interval of alternating red and grey shales and marlstones with minor sandstones is present. Thin sandstone intercalations are interpreted as distal turbidites. Dinoflagellate cyst assemblages indicate the *Litosphaeridium siphoniphorum* Zone. The concurrent presence of *Litosphaeridium siphoniphorum* and *Ovoidinium verrucosum* in all samples allows a correlation to the lower part of this zone, thus defining a Late Albian–Early Cenomanian age. Based on foraminifera, the red beds can be assigned to the topmost *Rotalipora appenninica* Zone and the *Rotalipora globotruncanoides* Zone due to the presence of small morphotypes of the index taxa. Nannofossils indicate standard zones CC9/UC0 throughout the red interval, defined by the first occurrence of *Eiffellithus turriseiffelii*, and UC1 above the red shales. Based on these multistratigraphic data, a latest Albian–Early Cenomanian age can be inferred.
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Keywords: Rhenodanubian Flysch Zone; Albian; Cenomanian; Dinoflagellates; Foraminifera; Nannofossils

1. Introduction

The Rhenodanubian Flysch Zone (RFZ) of the Eastern Alps of Austria and Bavaria comprises several tectonic units of mainly deep-water turbidite and hemipelagic successions, deposited below the calcite compensation depth (CCD) as part of the Alpine flysch belt (Fig. 1). Three distinct intervals of variegated red shales or marlstones occur in the Cretaceous RFZ of Austria (e.g., Egger, 1992; see Fig. 2), in the Albian–Cenomanian ("Untere Bunte Schiefer": Prey, 1950), the Coniacian/Santonian (Seisenburg Formation), and the Late Campanian (Perneck Formation). These shales comprise mainly carbonate-free red clays with rare intercalations of sandstones. As these red sediments indicate oxic intervals in this part of the Tethys, their stratigraphy and relationship to Cretaceous anoxia is currently under discussion (e.g., Hu et al., 2005). The facies of the red shales in the RFZ displays significant similarities to other Cretaceous Oceanic Red Beds (CORBs; Hu et al., 2005). Distinctive, red hemipelagic-pelagic intervals within otherwise turbidite-dominated successions of the RFZ have been interpreted primarily as the result of low sedimentation rates in a deep, siliciclastic flysch basin below the local CCD (Egger, 1993).

This paper presents the results of our investigations of one of a few sections containing the lowermost red interval of the RFZ in Upper Austria. Multistratigraphic methods, including the use of dinoflagellates, foraminifera and calcareous nannofossils, have been applied to specify more precisely the chronostratigraphic age and significance of this interval. This gives a new basis for a better correlation with known occurrences of mid-Cretaceous CORBs in other parts of the Tethys (e.g., Hu et al., 2003).

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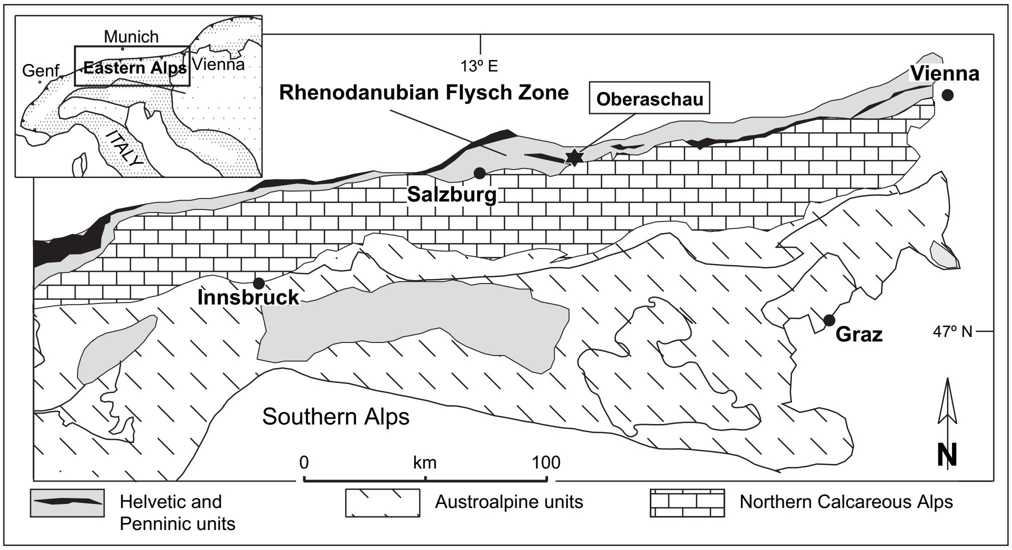


Fig. 1. Schematic tectonic map of the Eastern Alps. Oberaschau section is situated in the Rhenodanubian Flysch Zone of Upper Austria (after Faupl and Wagreich, 2000).

2. Geological setting

The palaeogeographic position of the RFZ has been discussed extensively in the last few years, based on new data concerning facies and provenance (e.g., Mattern, 1999; Wortmann et al., 2001; Egger et al., 2002). In general, an original position south of the southern European continental margin (the Helvetic Realm) and within the Penninic Ocean (equivalent to the Alpine Tethys) is agreed on (e.g., Faupl and Wagreich, 2000; Stampfli et al., 2002).

The RFZ consists of several stacked thrust-units. The investigated outcrop is situated in Upper Austria in the Salzkammergut area, between the lakes of Wolfgangsee and Attersee. Near Oberaschau, a tectonically undisturbed section from the Lower to the Upper Cretaceous is present. The outcrops were investigated in a small tributary creek of the Steingraben, south-west of the village of Oberaschau (Fig. 3). These outcrops belong to the southernmost, tectonically highest thrust-unit of the RFZ in that area. Red shales and marlstones (“Untere Bunte Schiefer”; no formal lithostratigraphic definition is available at present) occur between the Aptian–Albian “Gault Flysch” (Rehbreingraben Formation of Wortmann et al., 2004) and the Cenomanian–Turonian sandstone-rich Reiselsberg Formation.

Thick marlstone turbidites and thin, green and minor black and brown hemipelagic intercalations, similar to the Ofterschwang Beds of the Bavarian flysch (Mattern, 1999), are overlain by a ca. 18-m-thick interval of alternating red and grey shales and marlstones with rare, thin sandstone/siltstone beds. Sandstone intercalations up to 8 cm thick display mainly Tc, Td and Te Bouma divisions, indicating the presence of distal turbidites in the succession. Carbonate contents vary between 0 and 37% in the shales and marlstones. Red colours occur both in carbonate-free clays and claystones (carbonate content between 0 and 3%) and in distinct, up to 35-cm-thick marlstone beds (carbonate content between 7.5 and 33.7%). Consequently, the claystones are interpreted as hemipelagic sediments deposited below the CCD, whereas the marlstones comprise fine-grained muddy turbidites from a pelagic source area.

3. Material

Twelve samples from the succession at Oberaschau were prepared for palynological investigation. Six of these (OAU03/1-6; see Fig. 4) were also examined for their nannofossil and foraminiferal content. The nannofossil samples were taken exclusively from turbiditic marls and marlstones, because the hemipelagic clays are devoid of carbonate. Consequently, reworking of nannofossils by turbidites cannot be excluded.

4. Palynomorphs

4.1. Methods

Palynological preparation included HCl and HF treatment, heavy liquid separation and oxidation with HNO_3. Strew mounts were made in glycerine jelly and are now housed in the collections of the Sofia University “St. Kliment Ohridski”.

4.2. Results

Six of the samples investigated proved to contain rich, diverse, well-preserved palynological assemblages. Their positions in the section are shown in Fig. 4. Marine elements predominate in all of them, being represented mainly by dinoflagellate cysts, some acritarchs and foraminiferal linings; for the taxonomy of the dinoflagellate cysts, see Williams et al. (1998). Terrestrial elements are subordinate in quantity and are represented by the spore species *Bikolisporites toratus*, *Cicatricosisporites hughesii* and *Vadaszisporites urkuticus*.

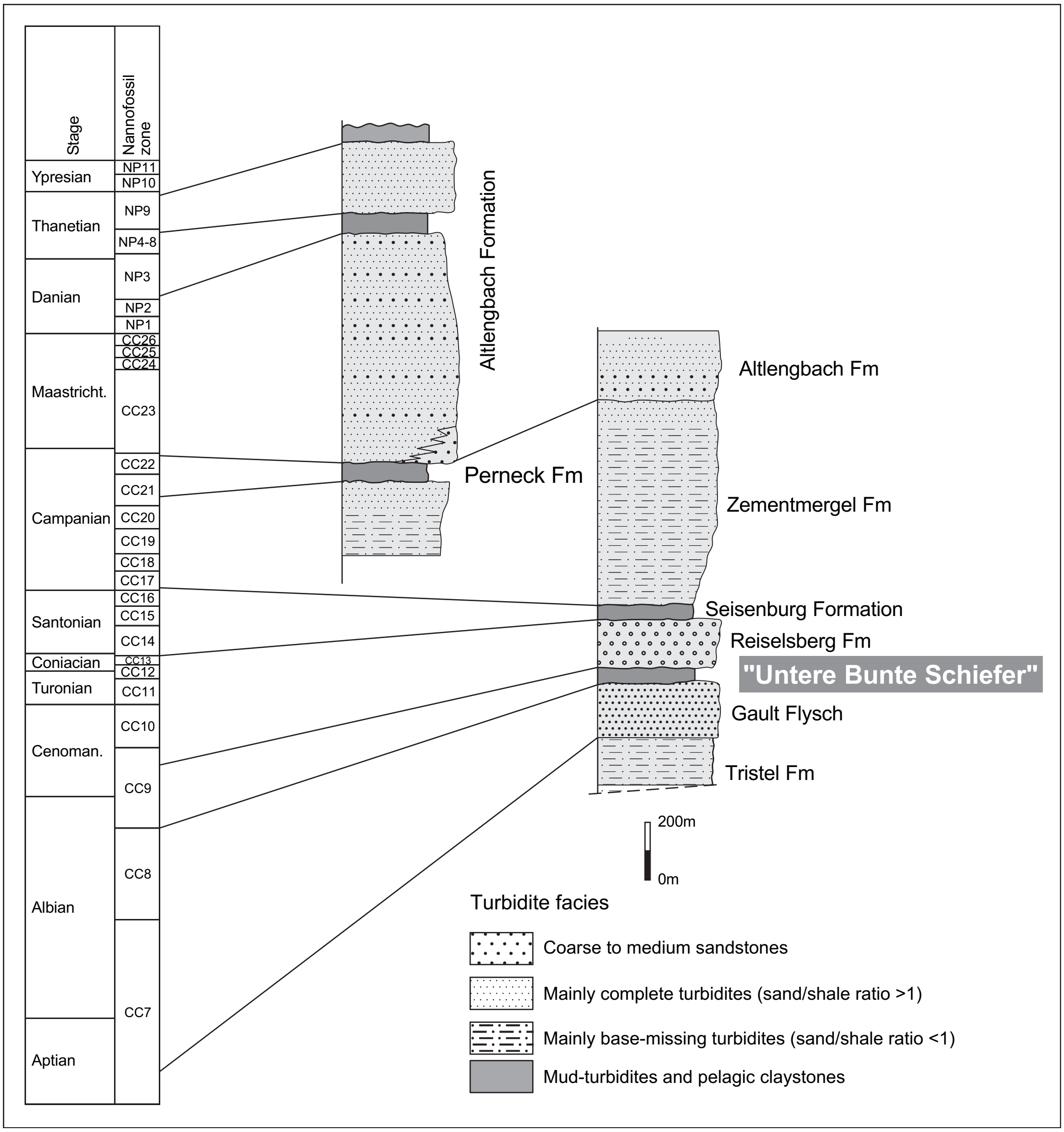


Fig. 2. Overview of the stratigraphy and facies of the Rhenodanubian Flysch Zone in Salzburg and Upper Austria, and the stratigraphic position of the "Untere Bunte Schiefer" (modified from Egger, 1992). CC zones after Perch-Nielsen (1985); NP zones after Martini (1971); turbidite facies associations according to Egger (1992).

The marine palynoflora suggests an open marine depositional environment with normal marine salinity within the photic zone. The diversity of the dinoflagellate cyst assemblage is shown in Fig. 5.

4.3. Age and correlation

The dinoflagellate assemblage indicates the *Litosphaeridium siphoniphorum* Zone throughout the section, based on the consistent presence of the index species and the characteristic zonal association. The *L. siphoniphorum* Zone was first introduced by Herngreen (1978) for the Upper Albian–Lower Cenomanian in the Netherlands. Later, its range was emended to uppermost Albian (*Stoliczkaia dispar* Ammonite Zone) to Early Cenomanian by Foucher (1983) for the Paris Basin and northern Europe. Foucher (1979) outlined the

Fig. 3. Detailed sample location map of the Steingraben and the environs of Oberaschau to the east of Highway A1, Upper Austria.

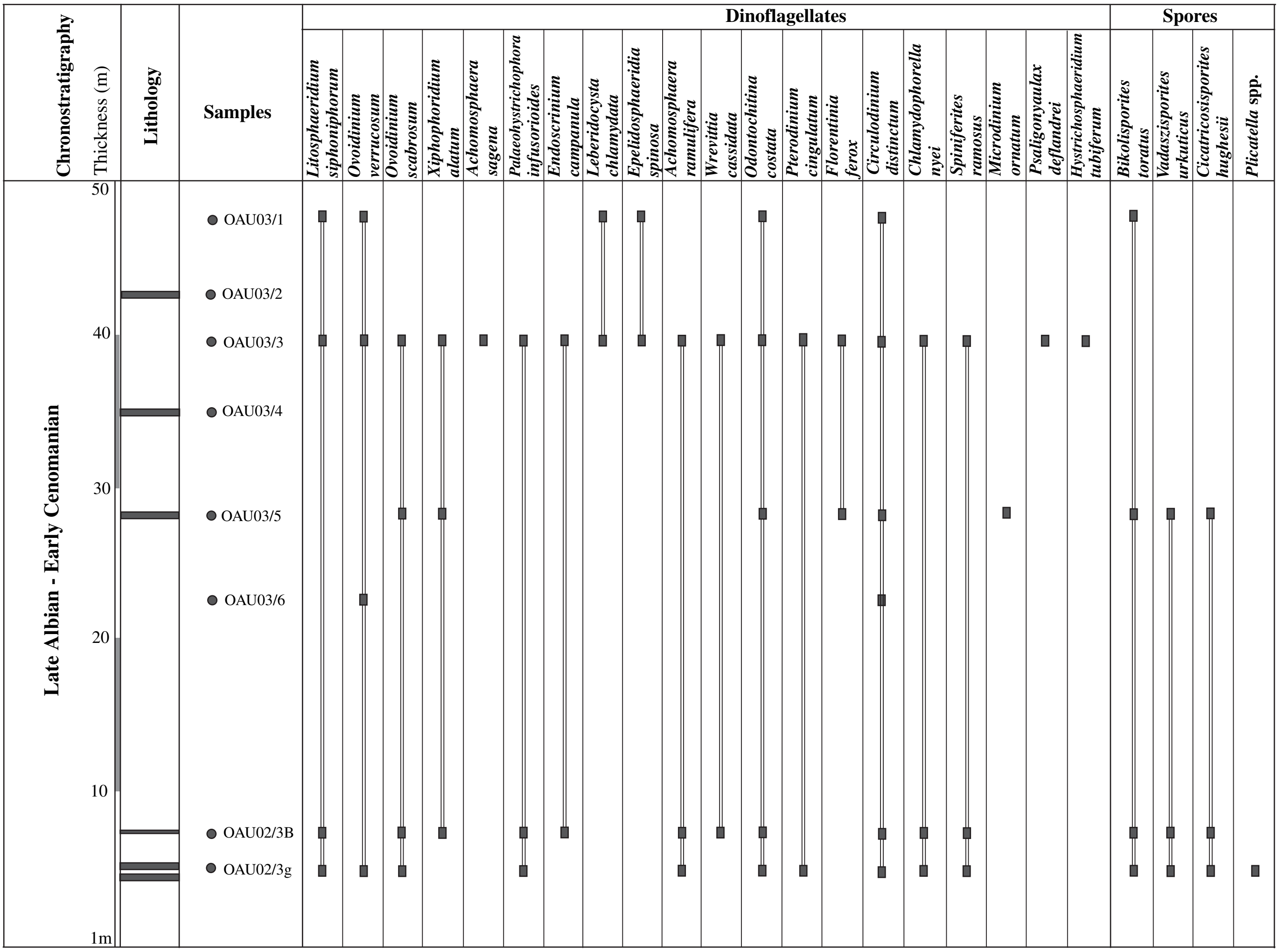


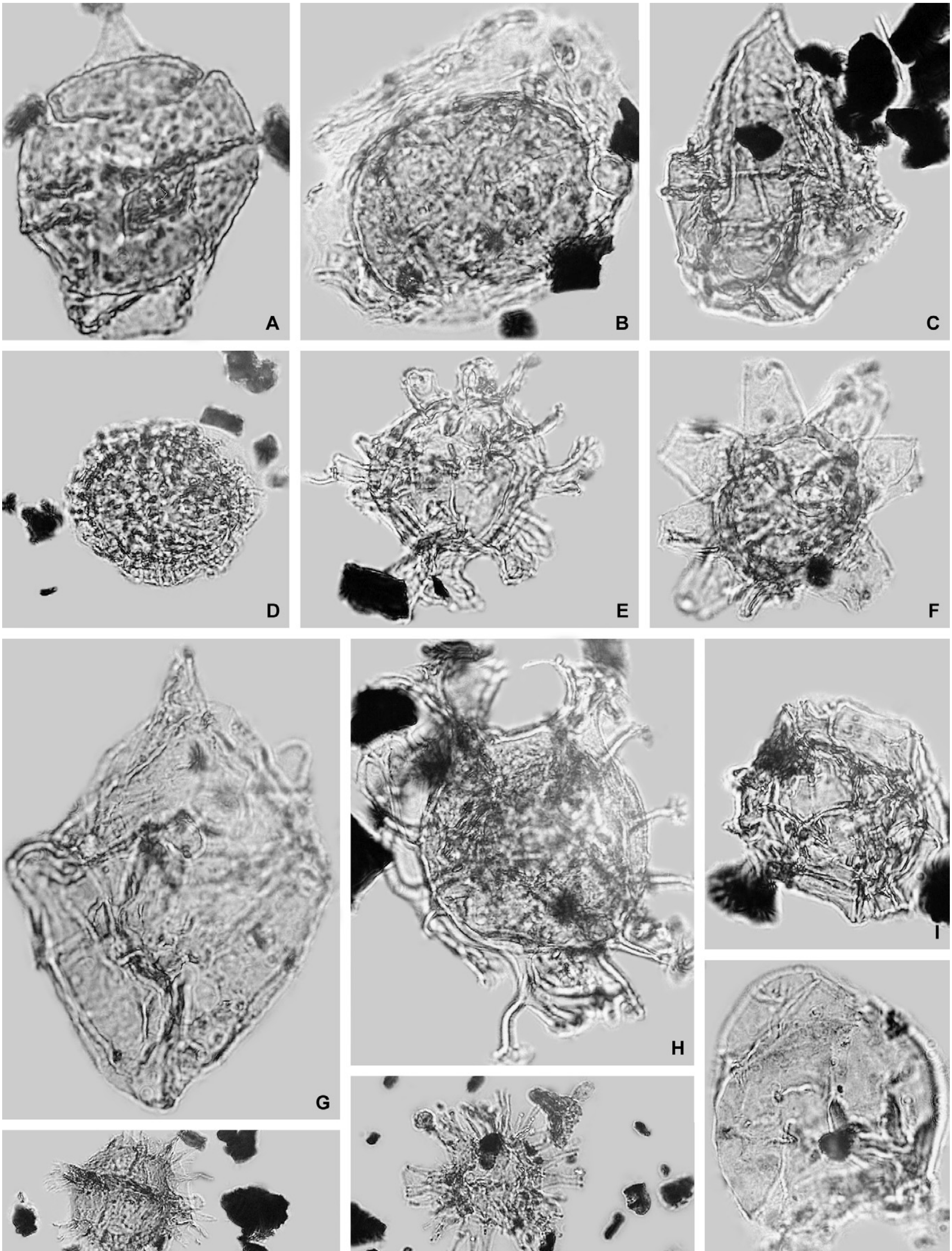
Fig. 4. Palynomorph stratigraphy and simplified lithological log of the Oberaschau section. Black = prominent red shale and marlstone intervals.

stratigraphic distribution of 100 dinoflagellate taxa in the Upper Cretaceous in the Paris Basin and northern Europe. He considered *L. siphoniphorum* to be a good marker for the latest Albian–Cenomanian time interval, whereas the stratigraphic distribution of the species *Ovoidinium verrucosum* was reported to be from the uppermost Albian (*S. dispar* Ammonite Zone) to the lower part of the Lower Cenomanian (*Mantelliceras mantelli* Ammonite Zone).

A calibration of selected dinocyst events in the Tethyan and Boreal realms with ammonite zones was presented by Leereveld (1995). He pointed out that the first occurrence (FO) of *L. siphoniphorum* is well documented from the middle part of the Upper Albian *Mortoniceras inflatum* Ammonite Zone in the Tethyan Realm and southeast France (Davey and Verdier, 1973; Leereveld, 1995) and from the top of the *M. inflatum* Ammonite Zone in the Boreal Realm and northwest Germany (Prössl, 1990; Leereveld, 1995). Stover et al. (1996) summarised the stratigraphic ranges of selected Cretaceous dinoflagellate taxa, based on data from England and type sections in France and the Netherlands. They concluded that, within the Albian, the most easily recognised biohorizon appears to be the first appearance datum (FAD) of *L. siphoniphorum*, within the *M. inflatum* Ammonite Zone according to Costa and Davey (1992), and within the overlying *S. dispar* Ammonite Zone according to Haq et al. (1987). As for the most important dinocyst event within the Cenomanian, they highlighted the last appearance datum (LAD) of *Ovoidinium verrucosum* at the Lower/Middle Cenomanian boundary.

The concurrent presence of *L. siphoniphorum* and *O. verrucosum* in samples from the Oberaschau section allows a correlation to the lower part of the *L. siphoniphorum* Zone and, together with the characteristic zonal association, indicates

Fig. 5. Dinoflagellate cysts of the Oberaschau section. All photomicrographs were taken using conventional light microscopy. A–I, L, ca. × 1000; J, K, ca. × 400. A, *Ovoidinium verrucosum*, sample OAU03/3. B, *Leberidocysta chlamydata*, OAU03/3. C, *Wrevittia cassidata*, OAU02/3B. D, *Chlamydophorella nyei*, OAU03/3. E, *Achomosphaera ramulifera*, OAU02/3B. F, *Litosphaeridium siphoniphorum*, OAU03/3. G, *Endoscrinium campanula*, OAU03/3. H, *Achomosphaera sagena*, OAU03/3. I, *Pterodinium cingulatum*, OAU02/3g. J, *Xiphophoridium alatum*, OAU03/3. K, *Florentinia ferox*, OAU03/3. L, *Ovoidinium scabrosum*, OAU02/3B. All images are stored in the collections of the Sofia University 'St. Kliment Ohridski'.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SAMPLE	*Guembelitria cenomana*	*Heterohelix moremani*	*Globigerinelloides bentonensis*	*Globigerinelloides caseyi*	*Globigerinelloides ultramicrus*	*Globigerinelloides* sp.	*Hedbergella delrioensis*	*Hedbergella* cf. *infracretacea*	*Hedbergella planispira*	*Hedbergella simplex*	*Hedbergella* cf. *trochoidea*	*Hedbergella* sp.	*Hedbergella* indet.	*Praeglobotruncana delrioensis*	*Praeglobotruncana stephani*	*Rotalipora appenninica*	*Rotalipora globotruncanoides*	*Rotalipora* sp.	*Schackoina bicornis*	*Schackoina cenomana*	*Lagena* sp.	*Saracenaria* sp.	*Praebulimina* sp.	*Gavelinella* sp.
OAU03/1		r				r	r	r	c	r		r								f				
OAU03/2		f	f	f		f	a		a	c	f	f		r	r	r	r	r	f	f	r	r		r
OAU03/3							r	r	r			r							r	f				
OAU03/4	r	r	f	f		f	a		a	c		f		r				r	c	f	r	r		
OAU03/5	r				r		f		c									r		r			r	
OAU03/6		r				r	f		f				f										r	

Fig. 6. Stratigraphic distribution of foraminifera from the Oberaschau section (for stratigraphic position of samples, see Fig. 4). R, <5 specimens; f, 6–20; c, 21–50; a, >50.

a Late Albian–Early Cenomanian age for the CORB. This age assignment is in accordance with the data given by Kirsch (2003) for red shales of the Bavarian flysch. According to Kirsch (2003), and based on the occurrence of *Palaeohystrichophora infusorioides*, the Oberaschau section can be correlated with the *P. infusorioides* Zone of Early Cenomanian age, using the zonal scheme of Prössl (1990).

According to the dinoflagellate events listed by Williams et al. (2004) for the northern mid-latitudes, the assemblage of *L. siphoniphorum*, *O. verrucosum*, *Xiphophoridium alatum*, *P. infusorioides*, *Pterodinium cingulatum*, *Odontochitina costata* and *Epelidosphaeridia spinosa* defines an age of 99.65–95.84 Ma, using the time-scale of Gradstein et al. (1995). This corresponds again to a late Late Albian–Early Cenomanian age (Gradstein et al., 1995). According to Williams et al. (2004), the presence of *Xiphophoridium alatum* points to an Early Cenomanian age (FO at 98.02 Ma), although there are some doubts as to the reliability of this species; for example, a considerably older FAD in Italy has been reported by Fiet and Masure (2001).

5. Foraminifera

5.1. Methods

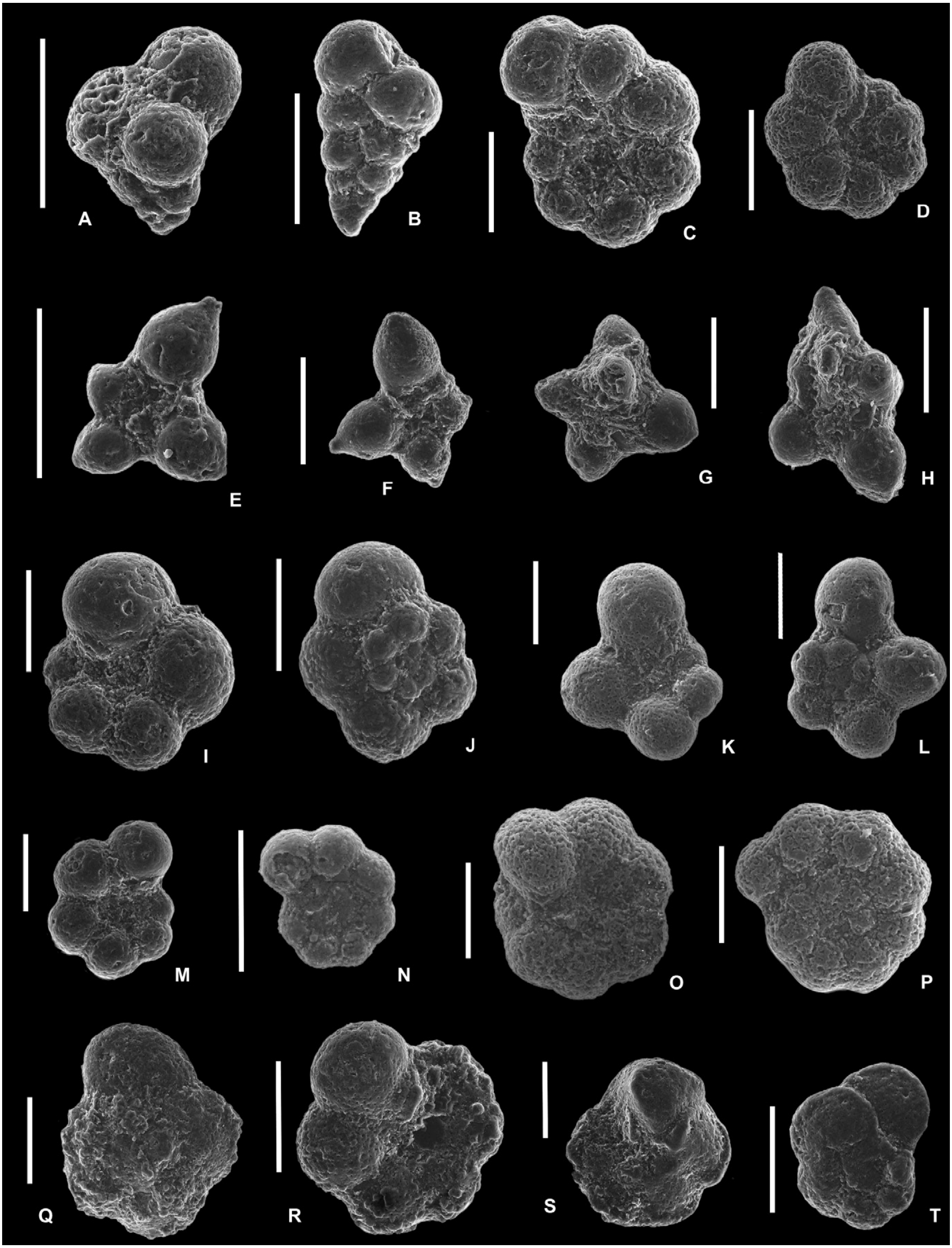
Each sample of 400 g dry-weight was disintegrated by repeated boiling and freezing in sodium carbonate solution, and washed over a 63-μm sieve. Foraminifera were found mainly in the <150-μm fraction, being most abundant in the washed residues of this fraction. All specimens were picked from samples OAU03/1, 03/3, 03/5, 03/6, as they contained <100 specimens per sample, and up to 300 specimens from OAU03/4 and 03/2 (red marlstones). The washed residue of sample OAU03/2 consists almost entirely of foraminifera, in this respect resembling a kind of deep-water "foraminiferal ooze".

5.2. Assemblages

Planktonic foraminifera are the only, or the dominating, element of the foraminiferal assemblages examined. The composition of all of the assemblages is generally similar; however, the number of specimens recovered differs considerably. The state of preservation is relatively good, but examination of specimens under a scanning electron microscope revealed considerable recrystallisation and traces of corrosion. As a result of both this and the very small dimensions of most of the specimens, determinations to species and even to genus level were commonly uncertain.

The assemblages are dominated by hedbergellids, with *Hedbergella delrioensis* and *H. planispira* being the most common species (Fig. 6). *Globigerinelloides caseyi* and *G. bentonensis* are also relatively frequent along with *Hedbergella simplex*, which was understood to include the species described as *H. amabilis* and *H. simplicissima*, in accordance with Robaszynski and Caron (1979) and Gasiński (1983).

Fig. 7. Selection of significant planktonic foraminifera from the Oberaschau section. A, *Guembelitria cenomana*, sample OAU03/5. B, *Heterohelix moremani*, OAU03/4. C, *Globigerinelloides caseyi*, OAU03/2. D, *Globigerinelloides bentonensis*, OAU03/2. E, *Schackoina cenomana*, OAU03/2. F, *Schackoina cenomana*, OAU03/3. G, H, *Schackoina bicornis*, OAU03/4. I, J, *Hedbergella delrioensis*, OAU03/4. K, L, *Hedbergella simplex*, OAU03/2. M, *Hedbergella planispira*, OAU03/2. N, *Hedbergella planispira*, OAU03/1. O, P, *Hedbergella* cf. *trocoidea*, OAU03/2. Q, *Praeglobotruncana delrioensis*, OAU03/2. R, *Praeglobotruncana stephani*, OAU03/2. S, *Rotalipora globotruncanoides* (=*R. brotzeni*), OAU03/2. T, juvenile form of *Rotalipora* sp., OAU03/4. Scale bar represents 100 μm.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Heterohelix moremani, *Schackoina cenomana* and *S. bicornis*, though less common, are characteristic and easily recognised taxa (Fig. 7). Some specimens of *Praeglobotruncana delrioensis* and *P. stephani* are present, as well as a form determined as *Hedbergella* cf. *infracretacea*, along with *H.* cf. *trocoidea* and very rare specimens of *Guembelitria cenomana*. *Rotalipora* is represented mainly by rare juvenile forms (Fig. 7), among which *R. appenninica* and *R.* cf. *globotruncanoides* were identified. Sporadically occurring benthic taxa, such as *Gavelinella* sp. and nodosariids, were also seen in the assemblages.

5.3. Age assignment

Hedbergella delrioensis and *H. planispira*, present in each sample, are long-ranging species and, therefore, not particularly age diagnostic (Caron, 1985; Premoli Silva and Sliter, 2002). *Hedbergella simplex*, *Globigerinelloides bentonensis* and *Praeglobotruncana delrioensis* have been reported from the Middle Albian–Cenomanian, *Heterohelix moremani* ranges from the Middle Albian to the Santonian, and *Praeglobotruncana stephani* occurs in the Upper Albian–Turonian (Premoli Silva and Sliter, 2002). *Rotalipora appenninica,* the index taxon of the last Albian planktonic foraminiferal zone, ranges up to Middle Cenomanian. *Rotalipora globotruncanoides* is the nominate taxon of the first Early Cenomanian zone (an equivalent of the former *Rotalipora brotzeni* Zone, e.g., Bralower et al., 1995; Robaszynski and Caron, 1995). According to Premoli Silva and Verga (2004), *Schackoina cenomana* first appears in the *R. appenninica* Zone of the latest Albian, while *Schackoina bicornis* appears in the *R. globotruncanoides* Zone of the Early Cenomanian. *Globigerinelloides caseyi* ranges from the Cenomanian to the Santonian, according to Premoli Silva and Sliter (2002), but has been also reported from Upper Albian deposits (Gasiński, 1983). This morphotype was regarded by Caron (1985) as a variety of *G. bentonensis*. The range of *Hedbergella trocoidea* is Late Aptian–Early Albian according to Premoli Silva and Sliter (2002), but it has also been considered to range approximately into the Upper Albian (Miles and Orr, 1980). Thus, if the specimens in the samples identified as *H.* cf. *trocoidea* (Fig. 7O, P) are correctly determined, and if the possibility of reworking is excluded, then the assemblages indicate the upper part of the *R. appenninica* and the lower part of the *R. globotruncanoides* zones.

Despite the fact that OAU03/6, 03/5 and 03/3 are impoverished in foraminifera, all six samples seem to represent the same biostratigraphic zone. However, it is worth mentioning that *Schackoina cenomana* has been found in all of the samples apart from the lowest, and *S. bicornis* has been recorded from the third sample from the bottom (Fig. 6). Thus, if the range of the latter taxon is taken into account, and the fact that *S. cenomana* has also been regarded by some (e.g., Prokoph, 1997) as indicative of the Cenomanian, the possibility that the lowermost part of the section is significantly older than the succeeding deposits cannot be discounted.

The presence of foraminifera only in the smallest fractions may indicate sorting and redeposition by bottom, or dilute turbidity, currents. The fact that almost exclusively planktonic

SAMPLE	PRESERVATION	ABUNDANCE	*Amphizygus ?* sp.	*Axopodorhabdus albianus*	*Biscutum constans*	*Biscutum ellipticum*	*Braarudosphaera* sp.	*Broinsonia* cf. *B. enormis*	*Chiastozygus litterarius*	*Corollithion kennedyi*	*Corollithion signum*	*Cretarhabdus striatus*	*Cribrosphaerella ehrenbergii*	*Cylindralithus* sp.	*Eiffellithus* cf. *E. gorkae*	*Eiffellithus turriseiffelii*	*Eprolithus floralis*	*Gartnerago* sp.	*Hagius circumradiatus*	*Helenea chiasta*	*Helicolithus compactus*	*Helicolithus trabeculatus*	*Isocrystallithus compactus*	*Lithraphidites carniolensis*	*Manivitella pemmatoidea*	*Owenia hillii*	*Prediscosphaera columnata*	*Prediscosphaera cretacea*	*Prediscosphaera spinosa*	*Radiolithus planus*	*Rhagodiscus angustus*	*Rhagodiscus asper*	*Rhagodiscus reniformis*	*Rhagodiscus splendens*	*Seribiscutum primitivum*	*Sollasites* cf. *S. horticus*	*Staurolithites* sp.	*Stradneria crenulata*	*Tranolithus orionatus*	*Watznaueria barnesiae*	*Zeughabdotus diplogrammus*	*Zeughabdotus embergeri*	NANNOFOSSIL ZONE
0AU03/1	M	20		x	x	x			x	x	x		x	x		x	x	x	cf	x	x	x	x	x	x	x		x	cf	cf	x			x				x	x	x		x	UC1
0AU03/2	P	10			x	x	x	x				x	x		x	x	x	x			cf				x			x			x	x		x				x	x	x	x	x	UC0
0AU03/3	P	10							x							x								x	x					x				x				x	x	x	x		
0AU03/4	P	10		x	x	x	x	x			x	x		x	x	x	x	x	x		x	x		x	x			cf			x		x					x	x	x	x	x	
0AU03/5	P	5			x	x			x							x								x	x		x	cf										x	x	x	x	x	
0AU03/6	M	5	x		x			x	x			cf		x		x	x							x	x		x	cf		x	x	x		x	x	x	x	x		x	x		

Fig. 8. Stratigraphic distribution of nannofossils from the Oberaschau section: for stratigraphic position of samples, see Fig. 4; for taxonomy, see Gale et al. (1996) and Burnett et al. (1998). Overall nannofossil abundance: 5, 1–5 specimens per field of view (FOV); 10, 5–10 specimens per FOV; 20, 11–20 specimens per FOV. Preservation: M, moderate (specimens exhibit some overgrowth but most are identifiable to species level); P, poor (specimens exhibit strong overgrowth and fragmentation).

assemblages have been found in the sediments, which are considered to have been deposited below the CCD, also supports this suggestion, pointing to fairly rapid accumulation by dilute, pelagic turbidity-currents that hindered dissolution of the calcareous tests.

6. Calcareous nannoplankton

6.1. Methods

Smear-slides of nine samples from the Oberaschau section were prepared using a small piece of sediment and a drop of distilled water. The sediment was smeared on a glass slide using a knife and the dried slide and a glass coverslip were affixed with Canada balsam. The slides were examined under the light microscope for their nannofossil content; see Burnett et al. (1998) for the taxonomy of the species encountered.

6.2. Results

The calcareous nannofossil assemblages recovered are rather limited owing to their moderate to poor preservation, i.e., strong etching and diagenetic overgrowth of nannofossils, especially in the red marlstones. They indicate Standard Zone CC9 (Perch-Nielsen, 1985) for the red shales and marlstones, as previously reported by Egger (1992). Although the preservation of the nannofossils is rather poor, *Eiffellithus turriseiffelii* (Figs. 8, 9) is present in all samples from the section. Zone CC9 indicates a Late Albian–Early Cenomanian age (Perch-Nielsen, 1985).

The FO of *Eiffellithus turriseiffelii* is regarded as a Late Albian event by most authors (e.g., Perch-Nielsen, 1985; Bralower et al., 1995), within or on top of the *Mortoniceras inflatum* Ammonite Zone (e.g., Jeremiah, 1996). The topmost sample, from grey turbiditic marls 8 m above the uppermost red marlstone, contains the marker-species for the overlying nannofossil zone, *Corollithion kennedyi*. According to the zonation of Burnett et al. (1998), the red interval can be assigned to Zone UC0 (equivalent to Subzones CC9a-b), defined as the interval from the FO of *E. turriseiffelii* to the FO of *C. kennedyi*, which appears in the lower part of the *Mantelliceras mantelli* Ammonite Zone (Burnett et al., 1998). *Calculites anfractus*, the FO of which has been reported from just below the Albian/Cenomanian boundary (Burnett in Gale et al., 1996), has not been found in our samples. The topmost sample already belongs to UC1 according to the zonation of Burnett et al. (1998). The absence of nannoconids proves the pelagic character of the assemblage.

7. Discussion and conclusions

Based on our multistratigraphic investigation, the red shales and marlstones can be assigned to the lower part of the *Litosphaeridium siphoniphorum* Dinoflagellate Zone, determined from the presence of *L. siphoniphorum* and *Ovoidinium verrucosum*, the uppermost part of the *Rotalipora appenninica* and lowermost part of the *R. globotruncanoides* (=*R. brotzeni*) Planktonic Foraminiferal zones, based on the presence of juvenile, small *R. globotruncanoides,* and the Standard Nannoplankton zones CC9/UC0, determined from the presence of *Eiffellithus turriseiffelii* below the FO of *Corollithion kennedyi*. The absence of *Rotalipora ticinensis* indicates the *R. appenninica* Planktonic Foraminiferal Subzone (latest Albian) of Gale et al. (1996) and the *Rotalipora globotruncanoides* Planktonic Foraminiferal Zone (Early Cenomanian).

The base of the Cenomanian has been fixed at the FO of *Rotalipora globotruncanoides* Sigal in the Global Boundary Stratotype Section and Point section at Mont Risou, southeast France (Gale et al., 1996; Kennedy et al., 2004; Gradstein et al., 2004), immediately below the FO of the ammonite *Mantelliceras mantelli*. Based on correlations with ammonite zones (e.g., Leereveld, 1995; Burnett et al., 1998), and detailed biostratigraphic zonations and chronostratigraphic correlations around the Albian/Cenomanian boundary interval (e.g., Bralower et al., 1995; Gale et al., 1996; Kennedy et al., 2004; Williams et al., 2004), our data indicate a correlation with the uppermost part of the *Stoliczkaia dispar* Ammonite Zone (Upper Albian–Albian/Cenomanian boundary interval) and to the lower part of the *M. mantelli* Ammonite Zone (lower part of the Lower Cenomanian) (Fig. 10).

Reports on a significant interval of red shale or red marlstone deposition during this time-interval in other Cretaceous sections are rather rare. Similar red shales have been reported by Bąk (1998, 2000) from the Early Cenomanian *R. globotruncanoides* Planktonic Foraminiferal Zone (Macelowa Marl Member) of the Pieniny Klippen Belt (Polish Inner

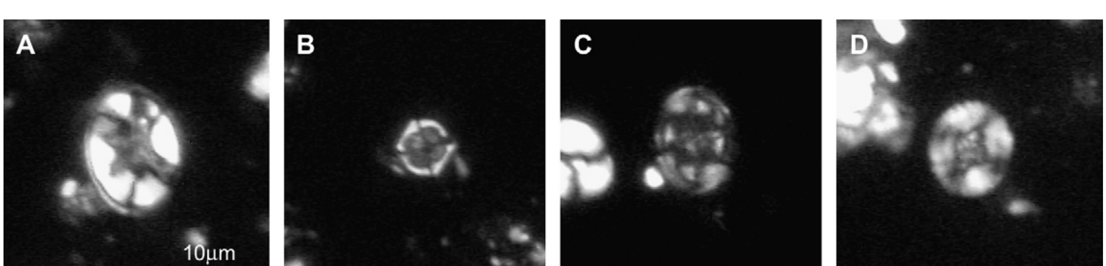

Fig. 9. Nannofossil marker-species present in the Oberaschau section, all from sample OAU03/1. A, *Eiffellithus turriseiffelii*. B, *Corollithion kennedyi*. C, *Axopodorhabdus albianus*. D, *Helenea chiastia*.

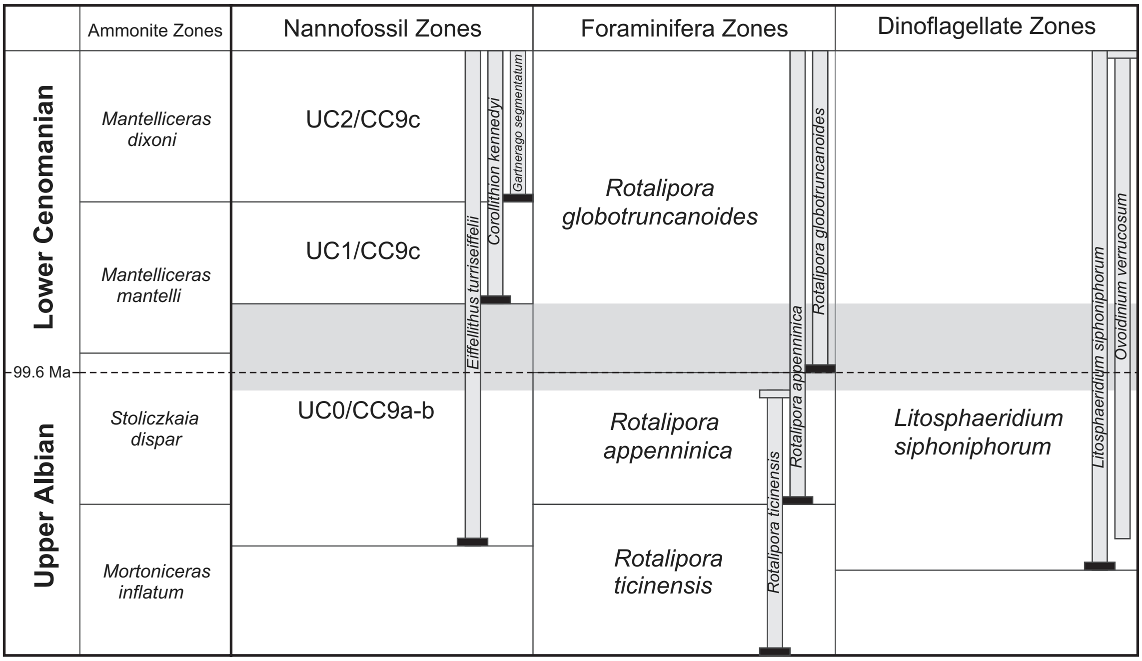

Fig. 10. Stratigraphic position of the red shales and marlstones of the Oberaschau section studied. Chronostratigraphic correlation chart based on Gradstein et al. (1995, 2004), including standard ammonite zonal scheme as correlated by Burnett et al. (1998). The chronostratigraphic range of the red shales and marlstones of the Oberaschau section (grey rectangle) is based on the correlation of foraminifera, nannofossils and dinoflagellates. Planktonic foraminiferal zones and marker-species ranges according to Bralower et al. (1995) and Kennedy et al. (2004); nannofossil zones and marker-species ranges based on Perch-Nielsen (1985: CC zones) and Burnett et al. (1998: UC zones); dinoflagellate marker-species ranges according to Leereveld (1995) and Williams et al. (2004).

Carpathians). Mid-Cretaceous red marlstones to limestones also occur in central Italy, in the Umbria-Marche Basin, although the horizons reported by Hu et al. (2003: lower part of the *R. appenninica* Planktonic Foraminiferal Zone and topmost part of the *R. brotzeni* Planktonic Foraminiferal Zone) are not contemporaneous with the red shale interval recognised in the Rhenodanubian Flysch Zone.

According to our data from the Oberaschau section, we conclude that the red shale interval of the Austrian part of the RFZ can be dated as latest Albian–earliest Cenomanian, based on planktonic foraminifera, dinoflagellates and nannofossils. The apparent tectonic control of flysch sedimentation in the RFZ (e.g., Mattern, 1999; Egger et al., 2002), and the rather regional extent of this horizon, which seems to be very rare or absent outside the Alpine–Carpathian mountain belt, suggest that these red shales and marlstones are controlled primarily by turbidite facies and clastic input into the flysch basins and do not mark a Tethyan or global oxic event during the Early Cenomanian.

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Appendix

Species of foraminifera determined

Globigerinelloides bentonensis (Morrow)
Globigerinelloides caseyi (Bolli et al.)
Guembelitria cenomana Keller
Hedbergella delrioensis (Carsey)
Hedbergella cf. *infracretacea* (Glaessner)
Hedbergella planispira (Tappan)
Hedbergella simplex (Morrow)
Hedbergella cf. *trocoidea* (Gandolfi)
Heterohelix moremani (Cushman)
Praeglobotruncana delrioensis (Plummer)
Praeglobotruncana stephani (Gandolfi)
Rotalipora appenninica (Renz)
Rotalipora globotruncanoides Sigal
Schackoina bicornis Reichel
Schackoina cenomana (Schacko)