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Biostratigraphy and facies of Paleogene deep-water deposits at Gams (Gosau Group, Austria)

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(With 10 text-figures and 2 plates)

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Abstract

Stratigraphical and sedimentological investigations have been carried out on several sections of the Gosau basin near Gams. The 380m thick Gamsbach section comprises the Paleocene and the lowermost Eocene (up to calcareous nannoplankton zone NP12, equivalent to planktonic foraminifera zone P6). Foraminifera assemblages and sedimentary facies suggest that the Paleogene sediments were deposited in a middle to lower bathyal slope environment, partly below the carbonate compensation depth. The Paleogene record in the Gamsbach section is not continuous but punctuated by stratigraphic gaps which comprise zone NP3 and parts of zones NP6 to NP8. As deposits of these zones occur in the near-by Krautgraben and Sommerauer sections, it is assumed that erosional processes in the Paleocene are responsible for the stratigraphic incompleteness of the Gamsbach section. Pronounced reworking of lower Paleocene deposits in the upper Paleocene supports this interpretation. A prominent sedimentary event in the upper Paleocene deposits at Gams is the intercalation of an almost carbonate-free siliciclastic turbidite unit into the carbonate-dominated succession. The comparison with other sections of that stratigraphic level suggests that global shallowing of the carbonate compensation depth across the Paleocene/Eocene-boundary and a coeval climatic change were the most important factors for this lithological shift. The siliciclastic unit is overlain by marlstone containing volcanic ashes from the North Atlantic Igneous Province. The wide dispersal distance of the tephras implies Plinian-scale eruptions. This intense explosive volcanic activity may have terminated the specific climatic conditions in the basal Eocene.

Zusammenfassung

Mehrere Profile im Gosaubecken von Gams wurden stratigraphisch und sedimentologisch untersucht. Die 380m mächtige paläogene Abfolge des Gamsbaches bei Gams (Steiermark) umfasst das Paleozän und das Untere Eozän (bis zur Nannoplanktonzone NP12 bzw. Foraminiferenzone P6). Die Zusammensetzung der Foraminiferenfaunen und die sedimentäre Fazies deuten auf eine Ablagerung der paläogenen Sedimentgesteine auf einem mittel- bis tiefbathyalen Hang hin, teilweise erfolgte die Sedimentation unterhalb der Kalzitkompensationstiefe. In der paläogenen Abfolge des Gamsbach-Profils konnten Ablagerungen der Nannoplanktonzonen NP3, NP6, NP7 und NP8 nicht nachgewiesen werden. Diese Zonen treten aber in den nahe gelegenen Profilen des Krautgrabens und des Schweinbachs auf, sodass die stratigraphischen Lücken im Gamsbach-Profil auf submarine Erosionsvorgänge zurückgeführt werden können. Diese Interpretation wird durch den Nachweis starker Umlagerungen von unterpaleozänem Material im Oberpaleozän gestützt. Das bemerkenswerteste Merkmal der Paläogenabfolge ist die Einschaltung einer kalkfreien siliziklastischen

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Einheit inmitten der oberpaleozänen karbonatreichen Abfolge. Der Vergleich mit anderen Profilen dieses Zeitabschnittes legt die Vermutung nahe, dass dieser Umschwung in der Sedimentation vor allem auf ein globales Ansteigen der Kalzitkompensationstiefe und veränderte klimatische Verhältnisse zurückgeht. Die siliziklastische Einheit wird von Mergel mit einzelnen vulkanischen Aschenlagen überlagert. Diese Aschen aus dem basalen Eozän (Sub-zone NP10a) treten in mehreren ostalpinen Profilen auf und stehen vermutlich mit der Öffnung des Nordatlantik im Zusammenhang. Der Fazieswechsel im Gamsbachprofil deutet darauf hin, dass diese plinianischen Vulkanausbrüche vermutlich eine neuerliche Klimaänderung bewirkten.

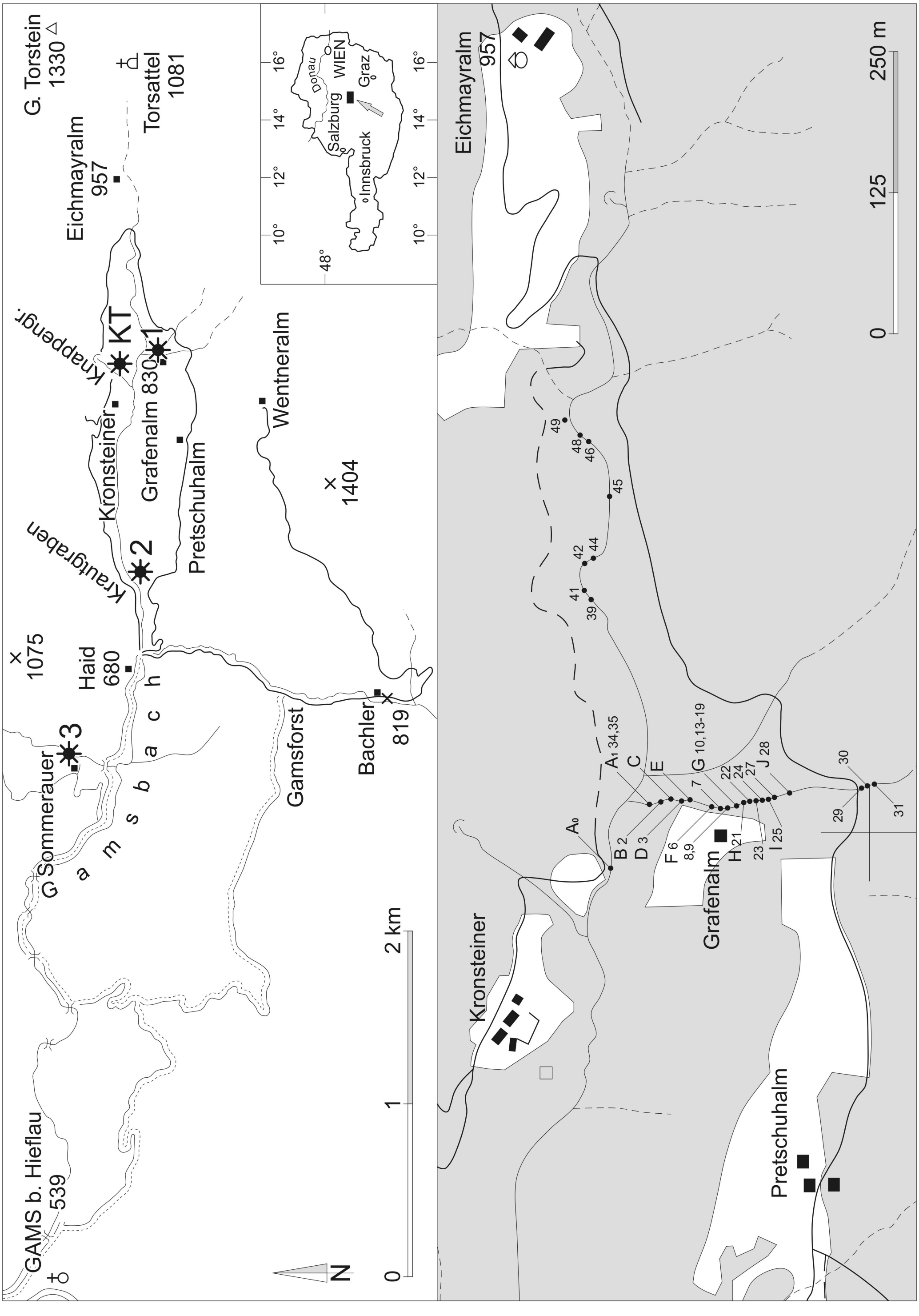
1. Introduction

The Gosau Group of the Northern Calcareous Alps comprises mainly siliciclastic deposits of Late Cretaceous to Paleogene age (for reviews see WAGREICH & FAUPL 1994; WAGREICH 2001). The development of the Gosau basin was interpreted as a result of extension after mid-Cretaceous thrusting, followed by rapid subsidence into deep-water environments due to subduction tectonic erosion (WAGREICH 1993; 1995; WAGREICH & DECKER 2001). In contrast to the well-studied Cretaceous part of the succession, little is known about the paleoenvironmental significance of the Paleogene deposits, although the Paleogene was an episode of major environmental changes in the Eastern Alps. Global climatic perturbations and intense regional tectonic activity have been recognized as the main driving forces for facies development in the contemporaneous Rhenodanubian Flysch basin (EGGER et al. 2002), which bordered the Gosau basin to the north (e.g. BUTT 1981; FAUPL & WAGREICH 2000).

Cretaceous/Paleogene-boundary intervals within the Gosau Group were studied at Gosau (PREISINGER et al. 1986) and in the Knappengraben, near Gams (STRADNER et al. 1987; LAHODYNSKY 1988a, b). In the Gams area, a tectonically largely undisturbed section of the Paleocene up to the Lower Eocene overlies the boundary site (KOLLMANN 1964; EGGER & WAGREICH 2001). This Gamsbach section (Fig. 1) is part of the eastern outcrop area of the "Gams basin" (Gamsforst - Krautgraben - Krimpenbach area; KOLLMANN 1964; KOLLMANN & SUMMESBERGER 1982). The section is not continuously exposed but consists of a number of temporary outcrops which display beds generally dipping to the south-southeast. The deep-water deposits of the section comprise mainly turbidites and other deep-water mass flow deposits of the Zwieselalm Formation and hemipelagic-pelagic deposits of the Nierental Formation (KRENMAYR 1996, 1999). The contact of the Nierental Formation to the Zwieselalm Formation shows a significant diachroneity in the Gams area, becoming younger to the east (WAGREICH & KRENMAYR 1993).

The first detailed descriptions of Paleogene sediments and a preliminary zonation were given by WICHER (1956), who recognized Paleocene up to Early Eocene foraminifera. Later, KOLLMANN (1963, 1964) gave a detailed zonation for the Paleogene using planktonic foraminifera and some larger foraminifera. Our data and the integration of calcareous nannoplankton and planktonic foraminifera, allow a detailed zonation for the Paleogene of the Gams area to be made. Based on this zonation and chronstratigraphic

Fig. 1: Sample locations within the Gams - Krautgraben area. KT denotes Cretaceous-Paleogene boundary site described by LAHODYNSKY (1988a, b), STRADNER et al. (1987) and STRADNER & RÖGL (1988). Investigated sections include section 1 – section Gamsbach east of Kronsteiner and creek east of Grafenalm, detailed map with outcrops A – J; 2 – Krautgraben section east of Haid; 3 - section near Sommerauer, Schweinbach north of contour point 686.


G. Torstein
1330
Torsattel
1081
Eichmayralm
957
Knappengr.
KT
1
Kronsteiner
Grafenalm 830
Pretschuhalm
Krautgraben
2
Wentneralm
1404
1075
Haid
680
3
Sommerauer
G a m s b a c h
Gamsforst
Bachler
819
GAMS b. Hieflau
539
N
0
1
2 km
Donau
WIEN
Salzburg
Innsbruck
Graz
48°
10°
12°
14°
16°
Eichmayralm
957
Kronsteiner
Grafenalm
Pretschuhalm
0
125
250 m

correlations (e.g. AUBRY 1996, BERGGREN & NORRIS 1997; OLSSON et al. 1999) some inferences on sedimentation rates can be made, and the general evolution of the Paleogene in the Eastern Alps can be discussed in comparison with other Paleogene sections (e.g. EGGER et al. 2000, 2002, 2004; WAGREICH 2001).

2. Sections investigated

Samples for sedimentological investigations were collected from the eastern Krautgraben area in the Gamsbach valley, from a section in a small tributary of the Gamsbach, 300m E of Grafenalm (Fig. 1; sample localities 206 to 212 of KOLLMANN 1964). Nannofossil assemblages from samples of the youngest, southernmost outcrops of this creek were previously described by EGGER & WAGREICH (2001). The outcrops in the creek provide a relatively undisturbed composite section through the Paleocene to Lower Eocene, and are continuous to the Cretaceous/Paleogene boundary site in the nearby Knappengraben (LAHODYNSKY 1988a; STRADNER & RÖGL 1988). Several hundred meters further east, two additional sections in the Krautgraben were sampled (localities 1751 to 1760 of KOLLMANN 1964); these cover the missing part between the Cretaceous/Paleogene boundary site and the base of the section in the small tributary near Grafenalm.

Mainly for biostratigraphic and paleoecological investigations, additional samples and sections were studied. The lowermost part of the Paleocene is present in the Cretaceous-Paleogene boundary section at Knappengraben (STRADNER et al. 1987; STRADNER & RÖGL 1988; LAHODYNSKY 1988 a, b). In more detail, this section (GG-75) was investigated here. In another section, further to the west, at Gamsbach near the outcrop no.4 of WICHER (1956) the sequence is continuous from the Lower Paleocene to the Upper Paleocene. An additional section in the Schweinbach creek near the Sommerauer farm house spans the same time range (KOLLMANN 1964: creek N of contour 686 m, localities 67, 687, and new profile 564). Single samples from the Upper Paleocene - lowermost Eocene correspond to KOLLMANN's (1964) sample localities.

3. Methods

For the calcareous nannofossil investigations, smear-slides were prepared from a suspension of unprocessed material and distilled water. The 69 smear slides were studied in a light microscope under crossed and parallel polarisation filters at a magnification of 1000x. The biostratigraphic zonations used to subdivide the Paleogene succession are based on the calcareous nannoplankton events used by MARTINI (1971) for the NP zonation and on the further subdivision of zone NP10 into four subzones as proposed by AUBRY (1996). Carbonate contents were determined from splits of 31 samples by a gas volumetric method (Scheibler-method).

Foraminifera were studied in washed residues from the marlstones and the shales. The samples were broken into pieces and dried overnight at 80° C. Then 200g of sediment were soaked in kerosene for about one hour. Subsequently, the excess kerosene was decanted and hot water was poured over the soaked sample. After one hour the sample was washed through a 63 µm-mesh sieve and, if not completely disintegrated, boiled with sodium hydroxide and sieved again.

The Ti, Zr, Nb and Y analyses were performed on a sequential X-ray spectrometer, Philips 2400, with a Rh-anode and a Philips Super Q, version 1.1 software as evaluation program. For preparation, the ground sample was added to a polyvinyl alcohol solution (binding agent) and the well-mixed blend was pressed to pellets and dried at 70°C.

4. Lithofacies

The Paleogene sediments of the studied sections have been divided into 4 deep-water facies assemblages, partly based on the threefold subdivision of KOLLMANN (1964). The facies boundaries are probably not synchronous throughout the outcrop area (WAGREICH & KRENMAYR 1993).

4.1. Facies 1

This facies comprises the Lower Paleocene, from the Cretaceous/Paleogene boundary up to the top of NP4 (upper part of "Nierentaler Schichten s.l." of KOLLMANN 1964). It is characterized by a predominance of red and grey pelagic to hemipelagic marlstones and marly limestones. The lowermost part of the Paleocene (foraminiferal zones P0 - P1; NP1) is continuous from the Maastrichtian only in the Knappengraben section. Dark shales and silts represent the lowermost part, changing to light grey marls and marlstones. At 3.6m above the C/P boundary, a thick slump layer is interbedded within the succession.

Thin sandstone-calcarenite turbidite beds are present in variable amounts, but sandstone to pelite (S:P) ratios stay below 1:5. The middle part of this interval is characterized by red sediment colours from NP2 onwards. Significant amounts of slump to debris flow deposits have been found in the middle and upper part of this facies (Fig. 2). Light to medium grey marlstones dominate in the upper part. Carbonate contents range from 57 to 61% (3 samples) in the lower part and from 27 to 37% (3 samples) in the upper part of this facies. Turbidite beds are typically calcarenitic with <10% siliciclastic material.

4.2. Facies 2

Facies 2 (NP5 to NP9; lower part of the "Breccien-Sandsteinkomplex" of KOLLMANN 1964) is characterized by sandy turbidites with sandstone to pelite ratios between 1:1 and 5:1. The turbidites, especially thin layers, display only weak cementation due to a very low carbonate content. Turbiditic shales are dark grey, mainly only a few centimeters thick, and largely carbonate free (carbonate contents 2 - 6%, 4 samples). Turbidites can be classified as classical turbidites, often starting with Bouma Tb intervals. Hemipelagic layers are scarce and hardly distinguishable; some red layers with low but significant carbonate contents (sample GAM 03/35: 2%) are identified as hemipelagic layers.

4.3. Facies 3

The largely carbonate-free turbiditic succession of facies 2 grades into a succession dominated by carbonate turbidites (NP10 to NP11; upper part of the "Breccien-Sandsteinkomplex" of KOLLMANN 1964). Facies 3 is characterized by turbidite sandstone beds which display strong cementation, in contrast to the underlying interval, due to the high carbonate content. Fine-grained, up to 2m thick breccia beds with abundant larger

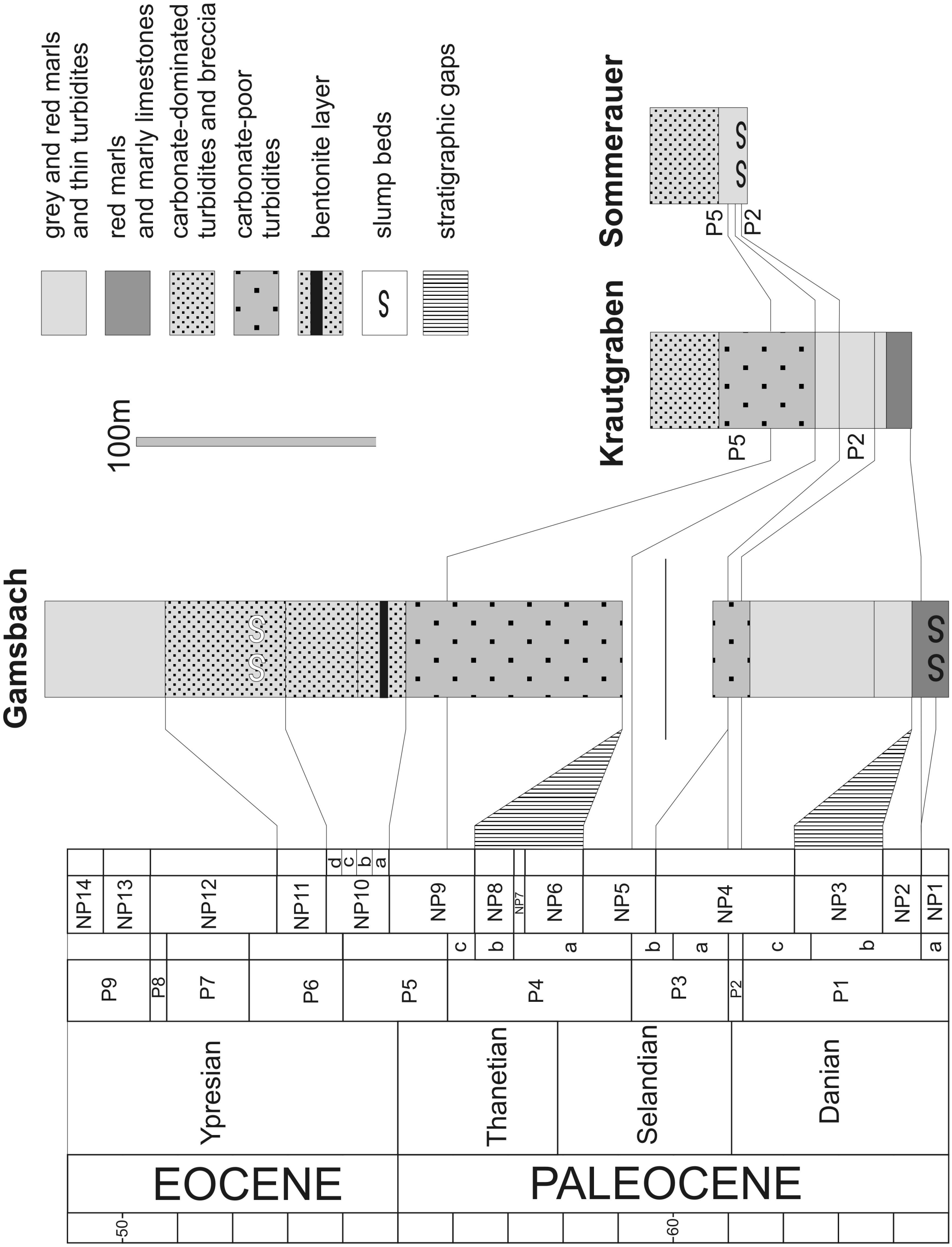
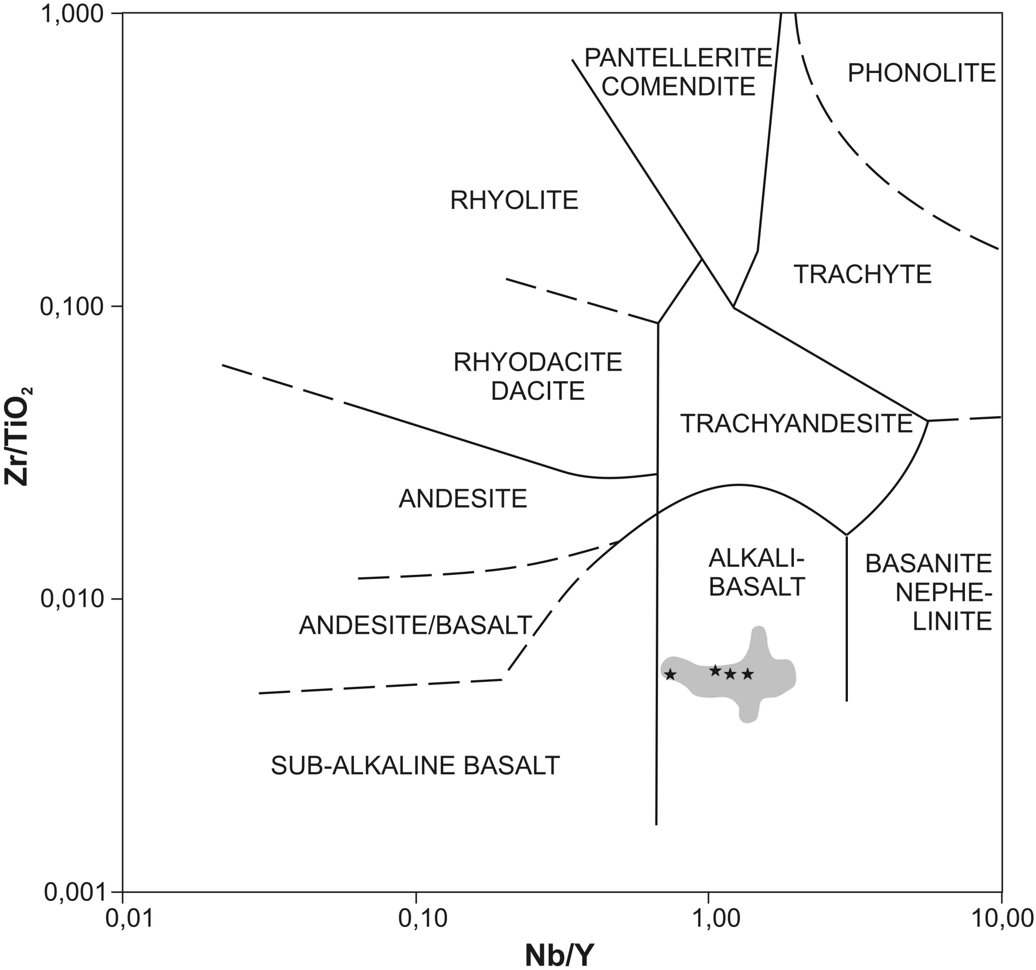


Fig. 2: Schematic sections of the Paleogene part of the Gosau Group of Gams. Section Gamsbach is based on the area east of Grafenalm and Kronsteiner (outcrops KT to J of Fig. 1). Chronostratigraphy based on Berggren et al. (1995), Berggren & Norris (1997) and Olsson et al. (1999).



Sample	Nb	Zr	Y	TiO_2
GAM 03/8	28	274	22	44500
GAM 03/9	27	275	19	44600
GAM 03/11	23	210	30	36900
GAM 03/12	27	263	23	42400

All data in ppm

Fig. 3: Immobile element-concentrations of bentonites (*) from the Gamsbach section (Shaded area indicates the composition of the bentonites from the Gosau Group of the Untersberg section).

foraminifera and black phyllite clasts are common (see PAPP in KOLLMANN 1964). Turbiditic pelites have significantly higher carbonate contents of between 3 and 39% (mean of 16 samples: 23.5%). At least one several meters thick slump bed is present in outcrop J (Fig. 1).

	03/48	03/49	03/46	03/43	03/39	03/39a	03/44e	03/45	03/35	03/06	03/07	03/18	03/21	03/22	03/23	03/24	03/25	03/27	03/29	03/30
Nannoplankton Zone	2		4					9		10a			10b		10c	10d	11		12	
Tribrachiatus orthostylus B																			x	x
Tribrachiatus orthostylus A																	x	x		
Tribrachiatus contortus																x				
Tribrachiatus digitalis													x	x						
Tribrachiatus bramlettei										x	x	x	x	x	x					
Rhomboaster cuspis												x								
Discoaster lodoensis																			x	x
Discoaster gemmifer																				x
Discoaster binodosus											x	x	x	x		x	x	x	x	
Discoaster barbadiensis											x		x		x	x	x		x	x
Discoaster multiradiatus								x	x	x	x	x	x	x	x	x	x	x		
Discoaster lenticularis										x	x	x	x		x	x	x			
Discoaster mediosus											x	x	x							
Discoaster mohleri										x		x								
Discoaster falcatus										x	x	x								
Fasciculithus mitreus								x												
Fasciculithus tympaniformis					x	x	x	x			x	x	x							
Fasciculithus ulii			x		x		x													
Fasciculithus bitectus					x	x														
Fasciculithus pileatus					x	x	x													
Heliolithus kleinpellii								x				x		x			x	x		
Ellipsolithus macellus			x	x	x	x					x	x	x	x	x	x	x	x	x	
Ellipsolithus distichus					x	x	x			x	x	x	x	x						x
Sphenolithus radians																	x		x	x
Sphenolithus anarrhopus				x	x					x	x	x		x	x	x	x			
Zygrhablithus bijugatus											x	x	x	x	x	x	x	x	x	x
Campylosphaera eodela											x	x	x	x	x	x	x			
Chiasmolitus consuetus											x	x	x	x	x	x	x	x	x	
Chiasmolithus bidens								x	x	x	x	x	x	x	x	x	x	x	x	x
Chiasmolithus danicus			x	x	x		x													
Cruciplacolithus subrotundus				x	x	x														
Cruciplacolithus primus	x	x	x	x																
Cruciplacolithus edwardsii					x									x						
Cruciplacolithus tenuis	x	x	x	x	x	x	x						x				x			
Coccolithus pelagicus	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Ericsonia subpertusa	x	x	x																	
Ericsonia robusta	x		x	x	x	x	x						x							
Markalius apertus													x	x	x				x	
Markalius inversus			x			x							x				x			

Fig. 4: Calcareous nannoplankton distribution of the Gamsbach section.

	03/48	03/49	03/46	03/43	03/39	03/39a	03/44e	03/45	03/35	03/06	03/07	03/18	03/21	03/22	03/23	03/24	03/25	03/27	03/29	03/30
Nannoplankton Zone	2		4					9		10a			10b		10c	10d	11		12	
Neochiastozygus saepes			x		x		x													
Neochiastozygus junctus											x	x	x	x			x	x		
Neochiastozygus distentus												x								
Neochiastozygus perfectus				x	x		x										x			
Neochiastozygus primitivus	x	x																		
Placozygus sigmoides	x	x	x		x	x	x													
Neocrepidolithus sp.	x	x	x		x	x	x													
Scapholithus apertus													x							
Toweius gammation																			x	x
Toweius eminens								x		x	x	x	x		x		x			x
Prinsius bisulcus	x		x			x														
Biscutum constans			x		x	x	x					x	x	x			x			
Pontosphaera sp.											x	x	x	x			x			
Rhabdospaera spp.												x	x	x	x	x	x	x	x	x
Thoracosphaera spp.	x	x	x	x		x	x	x			x		x		x		x			x

Fig. 4: continued.

Within the lower part of facies 3 (sub-zone NP10a) four light yellowish to light grey layers consisting essentially of montmorillonite (oral communication by Mandana Homayoun, 2002) were found. These 3 to 9 cm thick bentonite layers are interpreted as volcanic ashes. The presence of laminations within these layers probably indicates some reworking or resedimentation and mixing with non-volcanic material. Due to the complete conversion of the volcanic material to smectitic clay, the original chemical composition of the bentonites must have strongly changed. Consequently, only the immobile elements have been used to assess the composition of the original magma. In the discrimination diagram (WINCHESTER & FLOYD 1977) the samples plot in the field of alkalibasalts (Fig. 3).

4.4. Facies 4

The uppermost part of the section comprises a thin-bedded succession of sandy turbidites and marls of Early Eocene age (NP12, "Tonmergelserie des Paleozän" of KOLLMANN 1964) previously described by EGGER & WAGREICH (2001). This interval is characterized by a few mm to a maximum of 5 cm thick fine-grained sandstone turbidites. Brown to grey turbiditic and hemipelagic marls have carbonate contents up to 21%.

5. Biostratigraphy and paleobathymetry

5.1. Calcareous nannoplankton

For the nannofloral analyses, we investigated 53 samples of the Gamsbach section and 16 additional samples of the Sommerauer section. Calcareous nannofossils (Fig. 4 and

Plate 2) are abundant (> 50 specimens per field of view) in most of the examined samples with the exception of the samples from facies 2 which is almost devoid of carbonate. From this latter unit, only 2 samples (35 and 45) contain rare nannofossils in a poor state of preservation whereas in the rest of the section preservation is moderate. In the moderately preserved samples, the majority of the specimens are slightly etched but all taxa can be easily identified and diversity is about 16 species per sample on average. In the poorly preserved samples, the majority of specimens are intensely etched, identification of taxa is difficult and the diversity is only about 6 species per sample. Reworking of Cretaceous species (not listed in Fig. 4) is significantly less than 1% in the studied samples. Reworking of Paleocene material in the lower Eocene is indicated by rare specimens of *Heliolithus kleinpellii* and *Scapholithus apertus*.

The section investigated spans from the Cretaceous/Paleogene-boundary (STRADNER et al. 1987; LAHODYNSKY 1988 a, b) to the *Discoaster lodoensis* zone (NP12, EGGER & WAGREICH 2001). Prinsiaceae furnish a constant "background" of the studied samples. However, due to the small size of most of these specimens no species determination has been conducted.

Of the 9 standard calcareous nannoplankton zones of the Paleocene (MARTINI 1971) only 4 have been found in the Gamsbach section. The Cretaceous/Paleocene-boundary was studied in detail by Stradner (oral communication, 2004) who determined the thickness of Zone NP1 (*Markalius inversus* zone) as 8.10 m. This zone is dominantly represented by red marlstone with intercalated slump deposits. These sediments continue further up-section into Zone NP2 (*Cruciplacolithus tenuis*-zone). Without any indication of tectonic deformation, Zone NP2 is overlain directly by grey marlstone of Zone NP4 (*Ellipsolithus macellus*-Zone), suggesting a stratigraphic gap which comprises at least the entire Zone NP3. Stratigraphic incompleteness is also indicated further up-section due to the close proximity of the sediments of Zone NP5 and NP9. Zones NP6, NP7 and NP8 have not been found in this outcrop area, although they occur further to the west, in the Sommerauer section. Their absence in the Gamsbach section might be the result of synsedimentary erosional processes or of tectonic elimination.

Zone NP 9 (*Discoaster multiradiatus* Zone) was determined in 2 samples (03/35 and 03/45) of reddish marly claystone, which probably represent the non-turbiditic hemipelagic sediment. Due to carbonate dissolution, the nannoflora is poorly preserved and consists predominantly of dissolution resistant species. This suggests that deposition occurred close to the calcite compensation depth (CCD). The Paleocene/Eocene-boundary is located within Zone NP9. For its recognition, a pronounced negative carbon isotope excursion is used, coinciding with an acme of the dinoflagellate genus *Apectodinium* (CROUCH et al. 2001) and with the appearance of the calcareous nannoplankton genus *Rhomboaster*. This genus is very resistant to dissolution (EGGER et al. 2004); its absence in samples 03/35 and 03/45 suggests that the Paleocene/Eocene-boundary is located further up-section, but as the deposits of outcrops B, C, D and E are devoid of any carbonate, calcareous nannoplankton cannot be used for the determination of the P/E-boundary in this section. Dinoflagellate assemblages from outcrop C, which are very rich in the genus *Apectodinium* (oral communication by Ilse Draxler, 2004) indicate a position close to the P/E-boundary.

Epoch	Ma	Planktonic Foraminifera Biozones Berggren & Norris 1997 Olsson et al. 1999		Berggren & Miller 1988	Calcareous Nanno-plankton
Eocene	54.7	M. velascoensis LAD	P6	P7 P6c P6b	NP12 NP11
Late Paleocene	55.0				NP10
	55.9	G. pseudomenardii LAD	P5	P5-P6a	NP9
	56.5	A. soldadoensis FO	P4c		NP8
	57.1	A. subsphaerica LAD	P4b		NP7
	59.2	G. pseudomenardii FO	P4a		NP6 NP5
	60.0	I. albeari FO	P3b		
Early Paleocene	61.0	M. angulata FO	P3a		NP4
	61.2	Pm. uncinata FO	P2		
	63.0	G. compressa FO	P1c		NP3
	64.5	Ps. triloculinoides FO	P1b		NP2
	64.9	Pg. eugubina LAD	P1a		NP1
	64.97	Pg. eugubina FO	Pα		
	65.0		P0		
Late Cretaceous - A. mayaroensis Zone					

Fig. 5: Paleocene stratigraphy and correlation of planktonic foraminifera and calcareous nannoplankton biozones (acc. to BERGGREN et al. 1995, BERGGREN & NORRIS 1997, OLSSON et al. 1999).

Section GG-75 sample no. / position above Cretaceous / Paleogene boundary	Rö 18/88 top Cretaceous	Rö 101/86/1A 0.0-0.5 cm	Rö 101/86/1B 0.5-0.7 cm	Rö 19-88 4 cm	Rö 103/86 10-15 cm	Rö 20/88 15-22 cm	Rö 21/88 25-30 cm	Rö 22/88 50-55 cm	Rö 23/88 65-70 cm	Preisinger 77.0-78.5 cm	Rö 24/88 80-85 cm	Rö 25/88 86-95 cm	Rö 26/88 95-100 cm	Rö 27/88 100-110 cm	Rö 28/88 127-133 cm	Rö 30/88 151-160 cm	Rö 31/88 181-186 cm	Rö 32/88 200-205 cm	Rö 33/88 250-255 cm	Rö 35/88 350-550 cm	Rö 36/88 550-555 cm	Rö 38/88 675-680 cm	Rö 40/88 800-805 cm
Parvularugoglobigerina eugubina	Maastrichtian A. mayaroensis Zone	Reworking of Upper Cretaceous	Reworking of Upper Cretaceous	cf	x	x	x	x	Agglutinated assemblage	x	x	x	x	x	Agglutinated assemblage		x	x	x	Marl pebble layer and slump	x	x	x
Globoconusa daubjergensis				cf		cf				x	cf		x	x		x	x	x	x		x	x	x
Parvularugoglobigerina sabina				Bathyal benthic assemblage	x	x	x			x		x	x	x		x	x	x	x		x	x	x
Eoglobigerina edita					x			x		x	x	x	x	x			x	x	x		x	x	
Parasubbotina cf. pseudobulloides					x			x		x		x				x	x	x	x			x	x
Subbotina triloculinoides					cf								x	x		x		x				x	x
Guembelitria cretacea					x	x	x	x		x	x		x	x		x	x	x	x		x	x	
Woodringina claytonensis					x			x		x	x	x	x	x		x	x	x	x		x	x	x
Woodringina hornerstownensis					x			x		x		x	x	x		x	x	x	x		x	x	x
Chiloguembelina midwayensis					x		x			x		x	x	x		x		x	x			x	x
Chiloguembelina morsei						x				x	x		x	x		x	x	x	x			x	x
Parasubbotina pseudobulloides										x		x		x								x	
Eoglobigerina eobulloides											x	x	x	x		x		x	x		cf	x	
Subbotina trivialis													x	x		x	x		x			x	x
Praemurica pseudoinconstans														x		x						x	
Praemurica taurica														x								x	
Biostratigraphic Zonation		P0			Pα								P1a										

Fig. 6: Gams, Knappengraben, Cretaceous-Paleocene boundary section GG-75. Distribution of planktonic foraminifera and biostratigraphic zonation.

A major problem in nannoplankton stratigraphy across the Paleocene/Eocene transition is the controversy that has evolved concerning the content and systematic position of the genera *Rhomboaster* and *Tribrachiatus* (see SALIS et al. 1999 for a review). The first occurrence of *Tribrachiatus bramlettei* is used in the classification of MARTINI (1971) to define the base of zone NP10 whereas *Rhomboaster cuspis* should have its first occurrence within Zone NP9. However, it is still unclear if *Tribrachiatus bramlettei* is a synonym of *Rhomboaster cuspis* or not. As a result of these different viewpoints, the determination of the base of Zone NP10 depends on the nannoplankton workers involved. In this paper, the two species have been distinguished and the NP9/NP10-boundary remains as originally defined. Using these criteria, the base of Zone NP10 (*Tribrachiatus contortus* Zone) can be assumed to be close to the base of outcrop F. According to the fourfold subdivision of Zone NP10 proposed by AUBRY (1996), the boundary between sub-Zones NP10a and NP10b is in the uppermost part of outcrop G, whereas the boundaries between sub-Zones NP10b, NP10c, and NP10d are within outcrop I. Also within this outcrop is the base of Zone NP11 (*Discoaster binodosus* Zone).

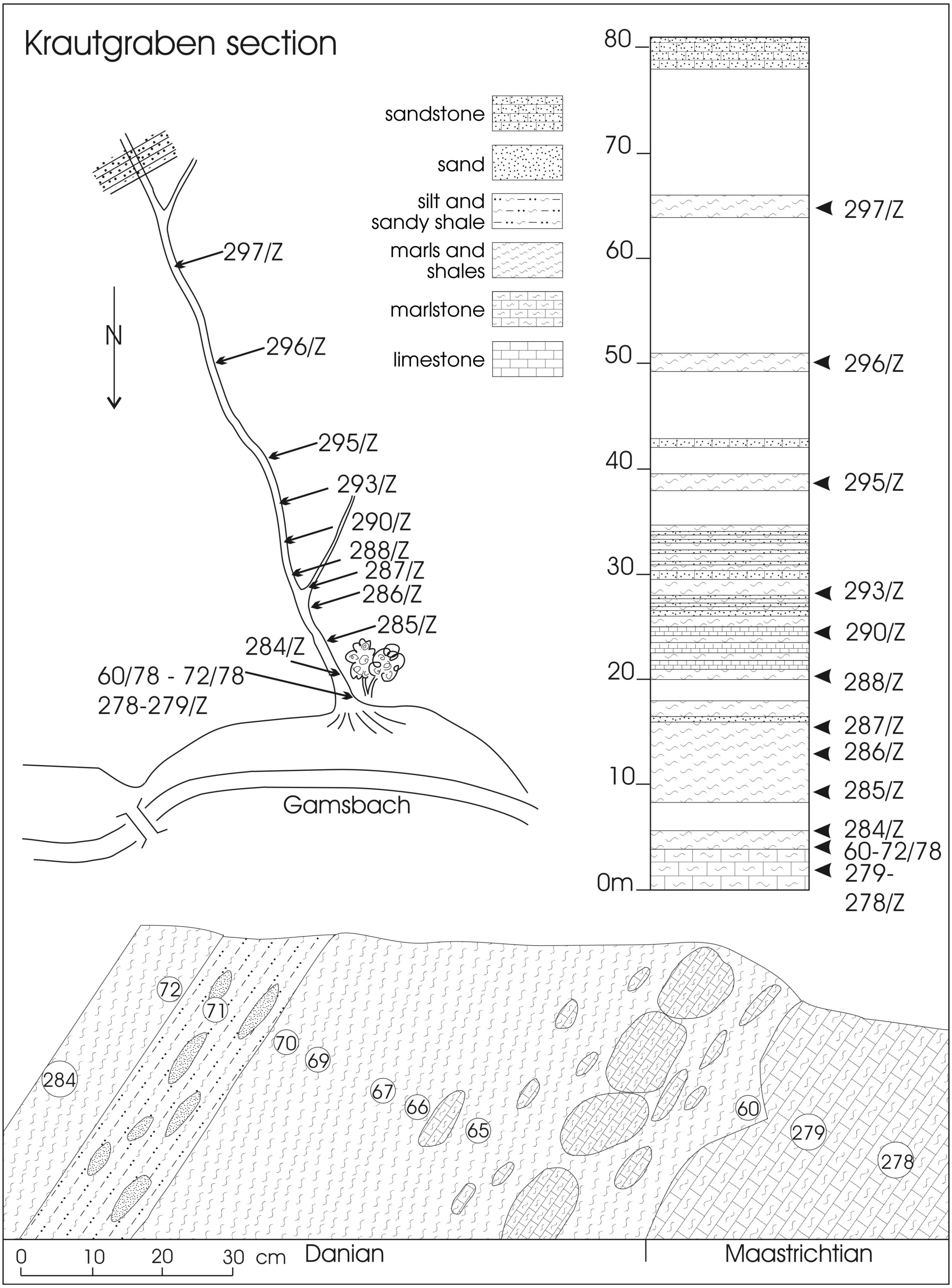


Fig. 7: Krautgraben section; small south directed creek beginning below a double trunk of a beech tree.

5.2. Foraminifera

5.2.1. Stratigraphy

Knappengraben

A revised biostratigraphy of the Cretaceous/Paleogene boundary section (Knappengraben, Fig. 1 and 6) at the base of the Gamsbach section is based on the new planktonic foraminifera zonation of OLSSON et al. (1999). The top of the Maastrichtian contains a rich planktonic assemblage with large specimens of *Abathomphalus mayaroensis* and *Contusotruncana contusa*. The boundary clay (P0) is barren of autochthonous planktonic foraminifera; only reworked Maastrichtian material is present. Just 4 cm above the boundary, the first autochthonous small planktonic specimens appear. Zone Pα, from 10 cm upwards, spans about one meter of sediments and is characterized by the first appearance (FAD) of *Parvularugoglobigerina eugubina* and an assemblage of small species. The following part of section, up to the end at 8 m, belongs to Zone P1a. There a strong increase in number and size of specimens has been observed, characterized by *Subbotina triloculinoides, Parasubbotina* cf. *pseudobulloides, Eoglobigerina edita*, and *Praemurica pseudoinconstans*.

Krautgraben

In this section (Figs. 1, 7 and 8) the top of the Maastrichtian has been eroded. The youngest Cretaceous marlstone contains a rich planktonic fauna with *C. contusa, Globotruncanita stuarti*, and *Gansserina gansseri; A. mayaroensis* is missing. This indicates a correlation of these beds with the *G. gansseri* Zone (e.g. CARON 1985) or the Maastrichtian I of KOLLMANN (1964). The basal Paleocene reddish-brown calcareous shales contain abundant pebbles of reworked Maastrichtian deposits. The assemblage with *P. eugubina, S. triloculinoides, Globanomalina archaeocompressa*, and *E. edita* places the lowermost part of reddish brown shales in Zone P1b. The lowermost Paleocene (P0-Pα) is not preserved. The upper part of the shales belongs to P2, with an assemblage of *Eoglobigerina spiralis* (FAD), *Praemurica pseudoinconstans, P. inconstans, Parasubbotina pseudobulloides*, and *Globanomalina compressa*. Alternating grey and grey brown, partly sandy marls, thin layers of fine grained sandstone and limestone represent Zone P3. *Praemurica uncinata* and *Morozovella angulata* have their first appearance in this zone; *P. inconstans* and *G. compressa* range up into P3. The upper part of section is not well exposed, but dark grey and brownish silty marls with rare sandstone intercalations belong to P4. This zone is defined by the FAD of *Globanomalina pseudomenardii*, which occurs together with *Parasubbotina variospira, Igorina albeari, Morozovella aequa, M. acuta*, and *M. apanthesma*. Further up-section Zone P5 is indicated by *Morozovella gracilis*.

Sommerauer

The base of this section (creek Schweinbach N contour point 686 m of KOLLMANN 1964; for location see Fig. 1) is formed of reddish to brownish marls of Zone P2 (Figs. 9 and 10), dated by the occurrence of *Pm. pseudoinconstans, G. compressa*, and the absence of *Parvularugoglobigerina* spp. and *E. edita*. Reworking of Upper Cretaceous material is rare. The following part, belonging to P3-4, is dominated by grey to red brown silty and sandy marls with a few limestone boulders (lithological units F-H of Fig. 9). To-

Sample	60/78	65/78	66/78	67/78	69/78	70/78	71/78	72/78	284/Z	285/Z	286/Z	287/Z	288/Z	290/Z	293/Z	295/Z	296/Z	297/Z
Eoglobigerina eobulloides	x		x	x														
Eoglobigerina edita	x	x	x	x		x	x	x										
Parvularugoglobigerina eugubina	x	x	x	x	x	x	x											
Subbotina triloculinoides	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		
Subbotina trivialis	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x			
Parasubbotina pseudobulloides	cf	cf	x	x	x	x	x	x	x	x	x		cf	cf	cf		cf	
Globanomalina archaeocompressa	x	x																
Globanomalina planocompressa		x		x	x	x			x									
Praemurica pseudoinconstans			x	x	x	x	x	x	x	x	x	x	x	x	x			
Globoconusa daubjergensis			x	x	x	x	x		x	x	x	x	x	x				
Chiloguembelina midwayensis			x			x	x		x	x	x	x	x	x	x	x		
Parasubbotina varianta				x	x	x	x	x		x	x	x		x	x	x	x	x
Globanomalina compressa				x	x		x	x	x	x	x	x	x	x	x			
Eoglobigerina spiralis					x	x			x	x	x	x		x	x			
Chiloguembelina morsei					x	x		x		x		x	x					
Praemurica inconstans					x		x	x		x	x	x	x	x	x			
Chiloguembelina subtriangularis					x						x		x		x	x		
Globanomalina imitata							x						x		x			
Subbotina triangularis										x	x	x	x	x	x	x	x	x
Subbotina velascoensis												x				x	x	
Globanomalina ehrenbergi												x	x	x				
Praemurica uncinata													x					
Morozovella conicotruncata													x				x	
Morozovella angulata														x		x	x	x
Subbotina cancellata															cf	x	x	x
Globanomalina chapmani																x	x	x
Globanomalina pseudomenardii																x	x	
Parasubbotina variospira																x	x	
Morozovella aequa																x	x	x
Morozovella apanthesma																x	x	x
Igorina albeari																x	x	
Igorina tadjikistanensis																x		
Subbotina inaequispira																	x	
Morozovella velascoensis																	x	
Morozovella acuta																	x	x
Morozovella gracilis																		x
Biostratigraphic Zonation	P1b-c				P2								P3			P4		P5

Fig. 8: Krautgraben section. Distribution of planktonic foraminifera and biostratigraphic zonation.

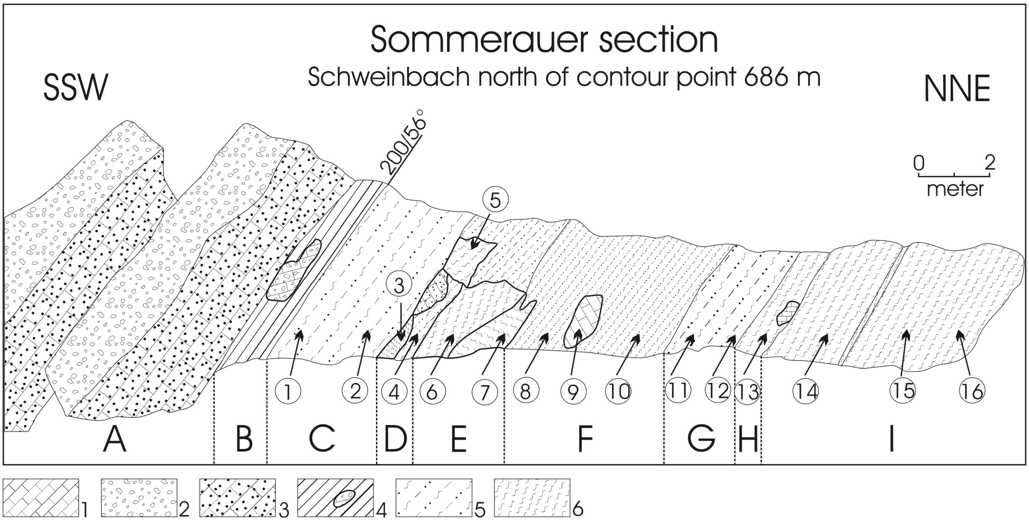


Fig. 9: Sommerauer section (section no. 564 N of contour point 686 m sampled and documented by H.A. Kollmann). Lithologic units: A. grey green sandstone; B. grey laminated sandstone with lignitic remains and a boulder oriented along the bedding; C. grey green sandy, micaceous shales (samples 1-2); D. grey green to yellowish sandy marl with coarse sand (sample 4) and at the upper surface with boulders of light grey marl (sample 3) and sandstone; E. mixture of bright red (sample 5) and red to grey-brown (samples 6-7) marls with interbedded sand limestone pebbles; F. brownish red, grey spotted sandy, micaceous marl (samples 8,10) with a limestone boulder (sample 9); G. light grey sandy marl (samples 11-12); H. grey marl with brownish red spots, and a limestone boulder; I. bright red somewhat sandy, micaceous marl with a greenish bleached horizon and spots along trace fossils (samples 14-16). Lithologic signatures: 1. limestone, 2. coarse sandstone and breccia, 3. bedded sandstone, 4. laminated sandstone with boulder, 5. sandy shale and marl, 6. marls.

wards the top, reworking of Upper Cretaceous and shallow water sediments increases. *M. angulata* (P3-P4a), *M. apanthesma* (P3b-P4), and *Globanomalina ehrenbergi* (upper P2-P3) are biostratigraphically important. An olistolithic mixture of different sediments occurs in lithologic units D-E of Fig. 9. Red brown and grey brown marls of Zone P5 are slumped together with bright red and light grey marls of Zone P3 and a sandstone boulder in greenish grey sandy marls of upper Zone P5. The position within Zone P5 is documented by the occurrence of *Morozovella gracilis* (upper P5-P6) and *M. subbotinae* (FAD at base of P5). Calcareous forms in the topmost grey green, sandy and micaceous shales are probably reworked or transported. The very few subbotinids recorded do not allow a stratigraphic determination. The top of the section is formed of fine and coarse grained sandstone beds of lithological facies 2.

The upper part of Zone P5 is also exposed along the road SW of the Sommerauer farm house (Kollmann 1964, locality 398, comp. Fig. 1). Sandy intercalations consist of a large amount of biogenic detrital material and larger foraminifera (Upper Cretaceous: *Siderolithes, Orbitoides*; Paleocene: *Smoutina, Storrsella, Operculina*). The occurrence of *Morozovella acuta, M. gracilis, M. velascoensis*, and *Globanomalina chapmani* place this part of the section within upper Zone P5. Reworking of P3-4 sediments occurred.

The continuation of the Sommerauer section is exposed along the creek S of contour point 686m, where sediments of facies 4 are present. Unfortunately, samples are commonly barren of foraminifera. Samples of KOLLMANN (1964, loc. 106-108; Paleocene II-Ia) yielded *Morozovella occlusa, M. aequa*, and commonly *Acarinina* (*A. soldadoensis, A. coalingensis*), dating this part as Zone P5. Up-section at localities 111-112, *M. gracilis* and *M. subbotinae* appear additionally and allow a stratigraphic determination of upper Zone P5 to P6 (Lower Eocene).

5.2.2. Paleobathymetry

The uppermost part of Maastrichtian shows pelagic sedimentation dominated by planktonic foraminifera. In the benthic assemblage, *Lenticulina, Nodosaria, Ellipsoidella, Gyroidinoides, Oridorsalis lotus, Gavelinella beccariiformis,* and *Dorothia* are common, whereas the deep water agglutinated forms are dominated by *Hyperammina* and *Recurvoides*. Most of these genera have a bathyal to abyssal distribution. The occurrence of agglutinated genera with calcareous cement, such as *Dorothia, Marsonella*, and *Pseudogaudryinella* deliminate the depth to above the CCD, probably a middle bathyal environment of between 600 and 1000 m (comp. VAN MORKHOVEN et al. 1986; BERGGREN & MILLER 1989; THOMAS 1998).

Lowermost Paleocene, P0- Pα, dark grey facies 1: In the lowermost part of the Paleocene a scarce autochthonous fauna is dominated by tubiform agglutinated deep water genera. Calcareous benthic foraminifera are present in some layers with common *Nuttalides* (middle bathyal to abyssal). Further up-section agglutinated assemblages yield increasing numbers of *Glomospira, Ammodiscus, Caudammina, Kalamopsis* and *Rzehakina*. The change of assemblage compared with the Maastrichtian cannot be interpreted by different deposition depth, since *Dorothia, Marsonella, Pseudogaudryinella,* and *Spiroplectinella dentata* are still common and suggest middle bathyal conditions.

Lower Paleocene, P1a, light grey facies 1: The most important paleoecological change is observed in the increase of number and size of planktonic foraminifera. Tubiform DWAF (deep water agglutinated foraminifera) assemblages are common with large specimens of *Aschemocella, Nothia, Rhabdammina, Rhizammina, Psammosiphonella, Hyperammina, Subreophax*, together with *Ammodiscus, Glomospira, Kalamopsis, Caudammina, Rzehakina, Spiroplectammina spectabilis, Karrerulina, Trochamminoides, Paratrochamminoides*, and frequent *Recurvoides*. Calcareous benthics are common in most layers with *Lenticulina, Astacolus, Nodosaria, Laevidentalina, Chrysalogonium, Stilostomella, Glandulina, Neoflabellina jarvisi, Aragonia velascoensis, Pullenia, Gyroidinoides, Oridorsalis, Nuttalinella florealis, Nuttalides truempyi, Anomalinoides, Cibicidoides*. A deepening of the basin can be interpreted by the increase of DWAF, probably to lower bathyal depths (1000 - 2000m).

Lower Paleocene, P1b - P2, red facies 1: In this part a strong increase of reworked Maastrichtian foraminifera and displacement of shallow water fauna is observed. The interpretation of the paleodepth is impeded by the fact that a high number of benthic deep water species crossed the Cretaceous/Paleocene boundary (BERGGREN & MILLER 1989; THOMAS, 1998). Of interest is the onset of re-deposition of larger foraminifera from a carbonate platform (Upper Cretaceous: *Orbitoides, Siderolithes*, Paleocene: *Operculina, Smoutina, Storrsella*). The DWAF component is reduced in some beds. *Re-*

curvoides is continuously frequent, and occurs together with *Nothia, Hyperammina, Psammosphaera,* and *Ammobaculites jarvisi*. Agglutinated forms with calcareous cement are frequent (*Clavulinoides rivicataractae, Dorothia, Gaudryina, Marssonella, Pseudoclavulina amorpha, Pseudogaudryinella convergens, Vulvulina midwayensis*), but the assemblages are dominated by calcareous species with many "lagenids" and pleurostomellids. *Aragonia velascoensis, Bulimina velascoensis, Cibicidoides dayi, Gavelinella beccariiformis, Nuttallides truempy* are indicators for deposition in a lower bathyal depth environment. Therefore, the higher percentage of calcareous benthic taxa in the foraminifera assemblage might have been caused by other palecological factors than palaeodepth.

Middle Paleocene, P3 - P4, reddish brown to grey facies 1: Depending on the section, in this part rich foraminiferal assemblages with large specimens may be developed, e.g., with *Paratrochamminoides mitratus* and large "lagenids". The assemblages are similar to those of the red facies. Reworking of biogenous detrital material and larger foraminifera is common. No change in paleodepth can be inferred from the assemblages.

Upper Paleocene, P5, grey to brown facies 1: Reworking and sorting increases in the upper part of facies 1, with extensive slumping in the Sommerauer section. Assemblages are reduced, but show relatively more DWAF elements. This may indicate an increase in water depth, but still above the CCD.

Upper Paleocene, P5, carbonate free turbidites of facies 2: In dark shales of distal turbidites only agglutinated foraminifera have been observed. The preservation level of the very rare calcareous specimens indicates that they are reworked. The assemblages consist of typical DWAF with *Ammodiscus, Annectina, Caudammina, Glomospira, Kalamopsis, Rzehakina, Cribrostomoides, Recurvoides, Trochamminoides, Paratrochamminoides,* and some tubular genera as *Hyperammina, Psammosiphonella* and *Rhizammina*. Forms with calcareous cement, *Dorothia* and *Marssonella* still occur. Paleodepth is estimated as upper abyssal (2000-3000m), slightly below the CCD.

Upper Paleocene, P5, calcareous turbidites, facies 3: In sandy and marly intercalations of this facies rich biogenous detritus with larger foraminifera occur (Papp, in Kollmann 1964). Reworked from the Upper Cretaceous are *Orbitoides, Lepidorbitoides, Siderolithes*, from the Paleocene carbonate platform *Smoutina, Storrsella, Operculina,* and small nummulites are transported. Only some of the planktonic species can be regarded as autochthonous; most of the smaller benthic species are transported. Therefore paleodepth estimation is not possible.

Upper Paleocene - Lower Eocene, P5 - P6, dark shales and turbidites, facies 4: Within the sequence, large parts of the shales are barren of fossils and in other layers the foraminifera are rare, small and strongly sorted. Agglutinated forms are *Ammodiscus cretaceus, Glomospira, Recurvoides, Nothia, Hyperammina* and *Rhizammina.* Calcareous benthics are also small: *Cibicidoides, Anomalinoides, Nuttallides, Siphonodosaria, Nodosarella, Bolivina, Bulimina, Pyrulina, Pleurostomella*, and *Pullenia*. Of interest is the deep-water species *Abyssamina poagi* with an occurrence at lower bathyal to abyssal depths. With the appearance of calcareous foraminifera a shallowing above the CCD, to the lower bathyal is assumed.

Sample	564/16	564/15	564/14	564/13	564/12	564/11	564/10	564/9	564/8	564/7	564/6	564/5	564/4	564/3	564/2	564/1
Subbotina trivialis	x	x	x													
Subbotina triloculinoides	x	x	x	x	x	x	x	x	x		x	x	x	x		x
Parasubbotina varianta	x	x	x	x	x	x	x	x	x	x		x	x	x		x
Parasubbotina pseudobulloides	x	cf	x	x	x	x	x		x	x		x	x	x		
Praemurica pseudoinconstans	x	x	x					x				x	x	x		
Globanomalina compressa	x		x				x	x				x				
Subbotina triangularis			x		x		x	x	x	x	x	x	x	x		x
Morozovella angulata				x	x	x	x	x	x	x			x			
Morozovella apanthesma				x	x	x		x	x	x						
Globanomalina chapmani				x												
Globanomalina ehrenbergi				x			x	x	x							
Parasubbotina variospira				x		x										
Morozovella acuta						x										
Morozovella aequa						cf				cf			x			
Praemurica inconstans							x	x		x		x	x	x		
Morozovella conicotruncata									x							
Praemurica uncinata							x						x			
Morozovella subbotinae										x	x					
Acarinina mckannai											x					
Morozovella gracilis													x			
Acarinina subspaerica													x			
Globanomalina imitata													x			
Biostratigraphic Zonation	P2			P3	P3-4	P4	P3-4			P5		P3a	P5	P3a	?	

Fig. 10: Sommerauer section. Distribution of planktonic foraminifera and biostratigraphic zonation.

6. Discussion

The most obvious sedimentary event in the Paleogene deposits at Gams is the intercalation of a nearly carbonate-free siliciclastic turbidite unit (lithofacies 2) into a carbonate-dominated succession. Due to the poor outcrop situation, the onset of this lithological shift is difficult to date. In the Gamsbach section, the first prominent siliciclastic sandstone bed was found within zone NP5; however, this bed co-occurs still with marlstone. Further up-section, two thin red layers (samples: 03/34 and 03/35) of marly shale (carbonate percentages: 5.2% and 2%) were found, containing nannoplankton of zone NP9. The overlying 100m of the succession (outcrops: C, D, E) are largely devoid of any carbonate, whereas in outcrop F greenish marls of the base of zone NP10 are exposed. This suggests that the main part of the siliciclastic unit in the Gamsbach section is restricted to the upper part of zone NP9 and contains the Paleocene/Eocene-boundary. This is consistent with our data from the Sommerauer section, where the lithological change from carbonate bearing to carbonate-poor deposits takes place within foraminifera zone P5 which correlates partly with zone NP9 and partly with zone NP10.

A global episode of enhanced carbonate dissolution is one of the major perturbations at the Paleocene/Eocene-boundary (see Thomas, 1998, for a review). Data from the lower bathyal Gosau deposits of the Untersberg section near Salzburg (Egger et al. 2004) suggest that the level of the carbonate compensation depth (CCD) shoaled to a depth of less than 2000m across the Paleocene/Eocene-boundary. Consequently, the coeval lower bathyal sediments at Gams should also have been deposited below the CCD. As the turbidites of facies 2 do not contain any significant carbonate, it can be assumed that even the source area of the turbidity currents was largely below the CCD. The absence of carbonate within facies 2 can be interpreted as a result of the shift of the level of the CCD into shallower water-depths.

In the northwestern Tethys (Egger et al. 2003 and 2004) and the Atlantic (Schmitz et al. 2003) the sedimentary record at the Paleocene/Eocene-boundary is characterized by an increase in siliciclastic sedimentation rates. This has been interpreted as the result of the establishment of a monsoonal setting, where vegetation was sparse, while periodic high rainfall caused enhanced continental run-off. Probably, the deposition of the siliciclastic facies 2 was another result of these climatic conditions. The estimation of sedimentation rates is very difficult in the Paleogene deposits of Gams since no reliable data can be expected in the Selandian and lower Thanetian due to the extended stratigraphic gaps in that part of the section. In the Danian, Zone NP1 is represented by 8.10m of compacted sediment (oral communication by H. Stradner 2004) which is equivalent to a sedimentation rate of 1.6cmky^{-1}, based on a duration of this zone of 0.5Ma (Berggren et al. 1995). In the upper Thanetian, Zone NP9 (duration: 1Ma) is represented by at least 100m of deposits, which suggests a minimum sedimentation rate of 10cmky^{-1}. For the 50m thick deposits of Zone NP10 (duration: 1.4Ma) a sedimentation rate of 3.6cmky^{-1} has been calculated and for the 50m thick deposits of NP11 (duration: 0.8 Ma) a value of 6.25cmky^{-1} has been calculated.

In the Alpine region, the bentonites of sub-zone NP10a have been correlated with the main ash-phase of the North Sea region (Egger et al. 2000). The wide dispersal distance of the ashes indicates a phase of major explosive volcanism which was associated with the continental break-up between Europe and Greenland. These Plinian-scale eruptions may have terminated the extreme climatic conditions in the basal Eocene (Egger et al. 2004). This idea is supported by the fact that at Gams the top of the siliciclastic facies 2 coincides with the appearance of the bentonites.

7. Conclusion

The sedimentary record of the Paleogene slope deposits at Gams is characterized by erosional and redepositional processes. A comparison of several sections indicates strong primary differences in thicknesses of nannofossil zones, which may be a consequence of slumping out of the section, channelized turbidite sedimentation, differing erosional relief of turbidite channels or overall reduced sedimentation rates. The most obvious sedimentary event is a phase of increased siliciclastic input in the upper Paleocene. A comparison of the Gams data with those of other Alpine Paleogene sections (Anthering and Untersberg) suggests that global shallowing of the CCD across the Paleocene/Eocene-boundary and a coeval climatic change were the most important factors in initiating the deposition of a siliciclastic unit within the carbonate dominated succession. The bentonite bearing marlstone overlying the siliciclastic unit suggests that a subsequent climatic change, a result of explosive volcanism, represents a higher-order control on facies than possible local factors. Nevertheless, the discrimination between regional and global factors influencing the pattern of sedimentation is difficult and further detailed sedimentological and biostratigraphic investigations are necessary for a better understanding of the facies development in the Paleogene deposits at Gams.

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Plate 1

Fig. 1: Facies 1: red pelagic marly limestones (NP 3), Krautgraben; outcrop 49 (see Fig. 1)

Fig. 2: Facies 1: red to grey marls with carbonate turbidites (NP 4), Krautgraben; outcrop 49 (see Fig. 1)

Fig. 3: Facies 2: carbonate-poor, sandy turbidites (NP4); Krautgraben; outcrop A.

Fig. 4: Facies 2: carbonate-poor turbidites (NP4), Krautgraben ; outcrop east of A1

Fig. 5: Facies 3: Bentonites (NP10a); outcrop G.

Fig. 6: 1.7 m thick breccia-bed within facies 3; outcrop I.

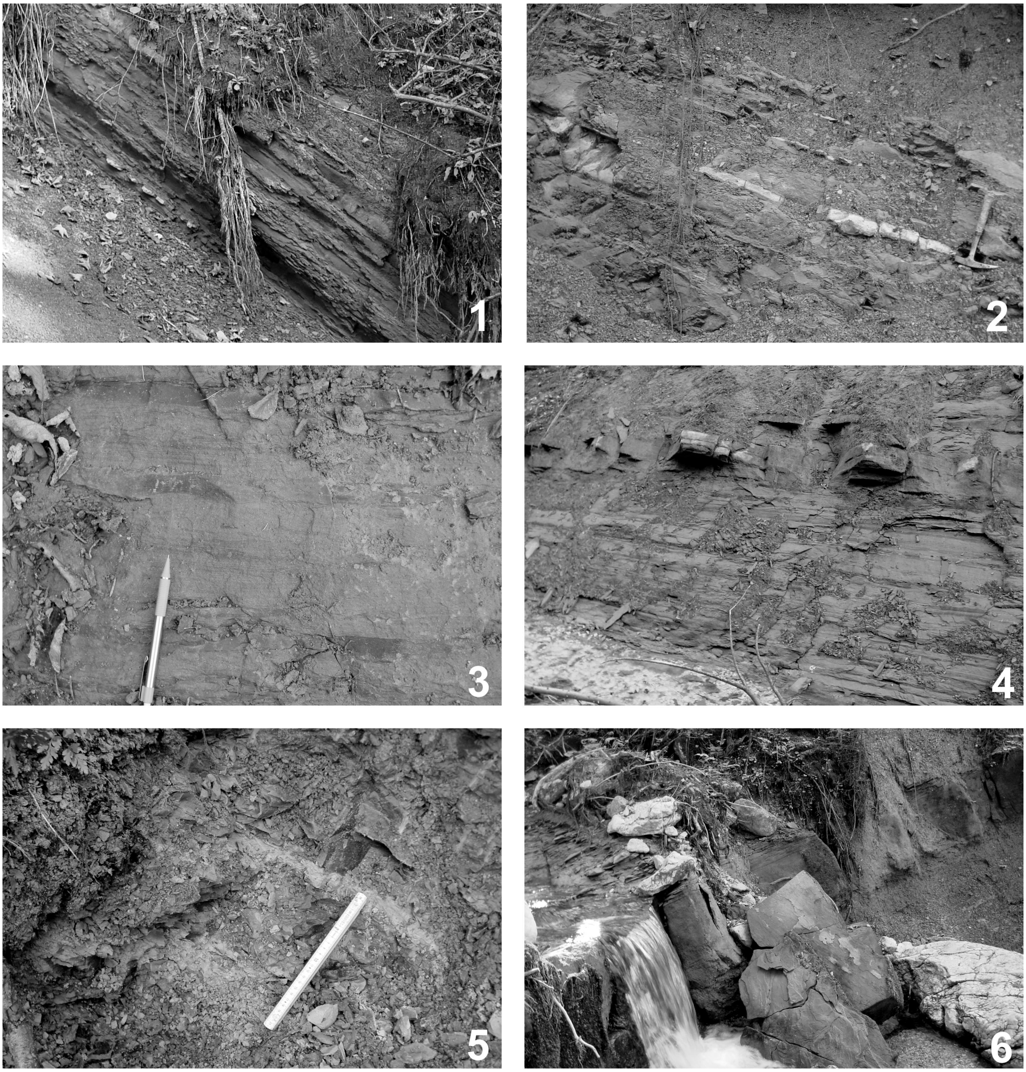
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Plate 2

LM photographs of important calcareous nannofossil species of the Paleocene of Gams. All photographs have crossed Nichols and the same scale as Fig. 1.

Fig. 1: *Neochiastozygus junctus* (Sample GAM03/44e)

Fig. 2: *Chiasmolithus consuetus* (Sample GAM03/24)

Fig. 3: *Chiasmolithus bidens* (Sample GAM03/21)

Fig. 4: *Cruciplacolithus edwardsii* (Sample GAM03/39)

Fig. 5: *Cruciplacolithus tenuis* (Sample GAM03/39a)

Fig. 6: *Cruciplacolithus subrotundus* (Sample GAM03/39a)

Fig. 7: *Zygrhablithus bijugatus* (Sample GAM03/07)

Fig. 8: *Ellipsolithus macellus* (Sample GAM03/18)

Fig. 9: *Placozygus sigmoides* (Sample GAM03/39a)

Fig. 10: *Fasciculithus involutus* (Sample GAM03/07)

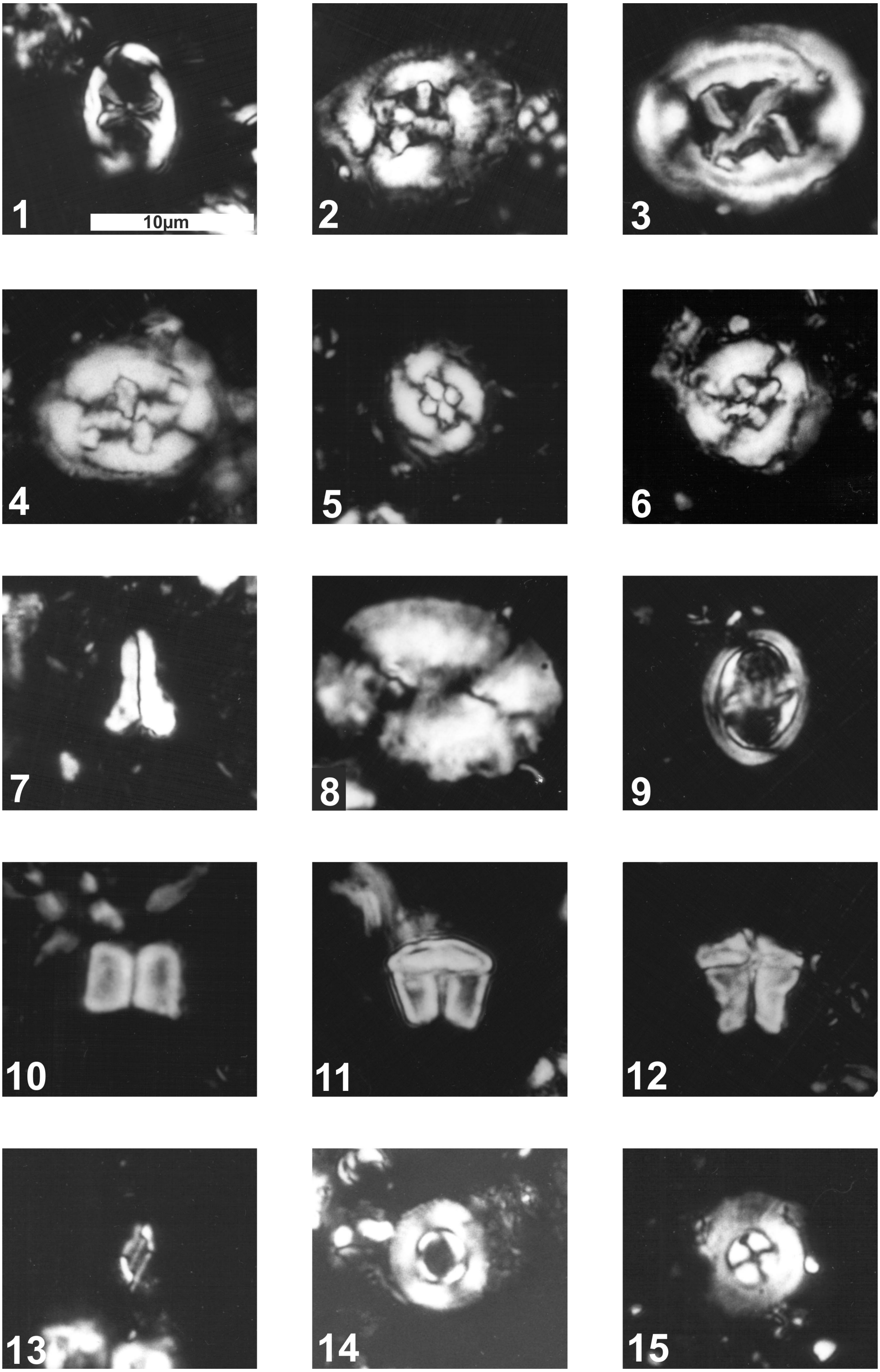
Fig. 11: *Fasciculithus pileatus* (Sample GAM03/39a)

Fig. 12: *Fasciculithus bitectus* (Sample GAM03/39a)

Fig. 13: *Scapholithus apertus* (Sample GAM03/21)

Fig. 14: *Markalius apertus* (Sample GAM03/23)

Fig. 15: *Markalius inversus* (Sample GAM03/21)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