Rapid Environmental/Climate Changes and Catastrophic Events in Late Cretaceous and Early Paleogene

RECCCE Workshop

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Abstracts and Excursion Guide

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Content

Preface

The Late Cretaceous to Paleogene is the time interval of the last long term evolution of global climate from the Super-Greenhouse during the Mid-Cretaceous to Icehouse during the Oligocene. This long-term profound change of the earth's climate was punctuated by a number of short-term climatic events and environmental crises, namely the Late Cenomanian Oceanic Anoxic Event 2 (OAE 2), the Cretaceous/Paleogene boundary event (K/T or K/Pg), and the Late Paleocene to early Eocene Thermal Maximum events (PETM, ELMO), all of which led to significant environmental changes and extinctions, especially the K/Pg event. A wealth of minor climatic, environmental and palaeoceanographic events was also described from that time span.

Theories for those catastrophic events and severe crises for life are strongly debated and include undoubtedly extraterrestrial causes such as asteroid impacts, and massive volcanism of Large Igneous Provinces (LIPs) during Cretaceous and Palaeogene. Other influences on climate and the ocean current convestion may have arised from dissociation of marine gas hydrates, changing in chemical weathering rates, opening and closing of major seaways, e.g. the Atlantic gateway or the closing of Tethyan basins, and mountain building due to Alpine and Laramide orogenies.

The RECCCE (Rapid environmental/climate changes and catastrophic events in late Cretaceous and Paleogene) workshop discusses recent advances in the understanding of these short-term events, including excursions at investigated sites in Austria. The workshop started on the basis of a Joint Seminar sponsored by the Austrian Science Fund FWF and the Russian Foundation for Basic Research RFBR. The workshop forms also part of the UNESCO-IGCP 555 Project - Rapid Environmental /Climate Change in the Cretaceous Greenhouse World: Ocean-Land Interactions.

Our thanks are due to the community of Gams and the Geozentrum Gams for providing the infrastructure, and the sponsoring organizations, the Austrian Science Fund FWF, the Russian Foundation for Basic Research RFBR, the Austrian Academy of Science, the Geological Survey of Austria, the Nature Park Eisenwurzen and the Styrian Nature Park Academy.

Michael WAGREICH

Abstracts RECCCE Workshop

Rapid Environmental/Climate Changes and Catastrophic Events in Late Cretaceous and Early Paleogene

Stratigraphy, nature and origin of the near KT breccia, relation with the Chicxulub impact

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Breccias with altered impact glass and located at or near the K-T boundary in Texas (USA), northern and southern Mexico, Belize, Guatemala, Haiti and Brazil are investigated to determine their age, stratigraphy and origin. Ages are variable. The oldest breccia deposit is within the uppermost Maastrichtian in the southern USA (Brazos, Texas), NE Mexico (e.g., Loma Cerca, El Penon) and in the Chicxulub impact crater cores on Yucatan (e.g., cores Yaxcopoil-1, Y6, C1). In all these sections, the geochemistry of glass within the breccias is identical and consistent with Chicxulub impact ejecta. The K-T boundary, Ir anomaly and mass extinction is located well above these impact breccia layers. This strongly supports a pre-K-T age for the Chicxulub impact, as also determined based on sedimentology, stratigraphy and paleontology. In NE Mexico and Texas the oldest Chicxulub impact spherule ejecta layer is interbedded in normal marine sedimentation in the upper Maastrichtian (base of CF1 Zone), about 300'000 year prior to the K-T boundary. All stratigraphically younger spherule ejecta layers represent repeated episodes of reworking and transport of the original layer during a sea-level regression and re- deposition in incised valleys in shallow environments (e.g., Brazos, Texas, La Popa Basin NE Mexico) and submarine canyons in deeper environments via mass flows and turbidites (e.g. Mimbral, Penon, Loma Cerca and many other section throughout NE Mexico). In southern Mexico, Belize and eastern Guatemala, the widespread thick microspherule and larger spheroid deposits are interbedded with breccia, microbreccias and conglomerates in the early Danian as a result of erosion in shallow carbonate platform sediments. The presence of early Danian planktic foraminifera in the matrix of the breccia, as well as within spherule clasts, indicate that redeposition occurred during the early Danian Parvularugoglobigerina eugubina (P1a) zone. In Haiti (Beloc sections), spherule deposits and microbreccias are also reworked together with late Maastrichtian microfossils and redeposited during the early Danian zone P1a. In NE Brazil (Poty Quarry) and Argentina (Neuquen Basin), the breccia layers identified as K-T age are also younger and deposited in the early Danian P1a and P1c zones, respectively. No extraterrestrial markers, such as glass, glass spherules or shocked quartz are present. These breccia and sandstone deposits thus represent normal sedimentary processes with deposition primarily linked to sea-level changes. However, an Ir anomaly is detected in the Early Danian P1a(1) subzone (100-200ky after the KT boundary) in southern Mexico (Coxquihui, Bochil), Guatemala (Actela), Haiti (Beloc) and Brasil (Poty). This suggests that the K-T transition was a time comet showers with current evidence of two large impacts, the pre-K-T Chicxulub impact and K-T impact, and smaller impacts in the early Danian and late Maastrichtian (Boltysh crater). The distribution of the K-T impact breccia is consistent with a multi-impact scenario.

The Late Eocene Impact Ejecta Layer: Chesapeake Bay impact structure (Virginia, USA), and comparison with the K-T Event

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During the late Eocene (LE), over a period of about 2 million years, a dramatic increase of the influx of extraterrestrial matter onto Earth has been documented from He isotopic studies, possibly as a result of a comet (Farley et al., 1998) or an asteroid (Tagle and Claeys, 2004) shower. In addition, at least five known impact structures formed during this time, two of which belong to the largest impact structures known on Earth and are associated with possibly global ejecta (Koeberl, 2009). The two largest LE impacts are the 85-km-diameter Chesapeake Bay impact structure (CBIS) and the 100-km-diameter Popigai impact structure (http://www.unb.ca/passc/ImpactDatabase/index.html). Two closely spaced LE ejecta layers have been documented at different places around the world (e.g., Koeberl, 2009). The older ejecta layer contains spherules with clinopyroxene and/or Ni-rich spinel and is associated with the Popigai impact (Whitehead et al., 2000). The younger layer of tektites, microtektites, and shocked minerals correlates with the North American strewn field, which has been linked to the CBIS (Deutsch and Koeberl, 2006). The LE impactoclastic layers are associated also with increased Ir contents and 3He values (Koeberl, 2009). Another global ejecta, the K-T ejecta from Chicxulub, form an Ir-rich layer with shocked minerals and spherules of impact melt (Kring, 2007), which lacks a 3He anomaly.

The target rocks of the CBIS were crystalline rocks of the Appalachian orogen covered by poorly consolidated siliciclastic sediments 1 - 1.5 km thick (Poag et al., 2004). In 2005 - 2006 the central part of the CBIS was drilled at Eyreville as part of an ICDP-USGS drilling project (Gohn et al., 2006). The drilling and consequent studies, in which our group participated (see e.g., Bartosova et al., 2009a,b), helped to further constrain the structure, geology, and formation of the CBIS. The Popigai target rocks are similar: gneisses covered by 1.25 km of sandstones and carbonates (Masaitis et al., 1980). The Chicxulub impact structure, in contrast, was formed in a crystalline basement overlain by some siliciclastic sediments and 2 - 3 km of easily volatilized carbonates and anhydrite (Claeys et al., 2003).

It has been suggested that the period of global cooling (from middle Eocene to Oligocene) was interrupted by a warming pulse in the LE, which could have been caused by the multiple impact event. This relatively warmer period was followed by a sharp temperature drop near the Eocene/Oligocene boundary (Bodiselitsch et al., 2004). No evidence for mass extinction or ocean-wide pelagic crisis analogous to the K-T boundary was found in connection with the LE impacts. The presence of a dead zone, which is evident in the CBIS drill cores immediately after the impact deposits, indicates a hostile environment for both benthic and planktonic organisms for about 1 - 3 kyr after the impact event (Poag et al., 2004).

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Cretaceous/Paleogene boundary in north-eastern Romania

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Two sections from north-eastern Moldavia from the four investigated until now, are especially representative for the K/Pg boundary: Putna Valley in Putna area and Seaca Valley in Frasin area. Bercheza and Rusca valleys sections from Sucevita area were not so concludent, due to the tectonics of the region. The lithology consists of an interlayering of clays, marls and sandstones, which represent a typical flysch facies.

Calcareous nannofossils and foraminifera assemblages from the turbidites of the Putna Valley section (Hangu and Izvor formations) were investigated in order to identify the Cretaceous/Paleogene boundary. This seems to be the only continuous section in this area, outcropping over about 160 meters. The abundant late Cretaceous and Paleogene calcareous nannofossil assemblages along the first part of the section are followed by a barren interval in nannofossils, then, again the Paleogene forms and sometimes reworked late Cretaceous taxa. The Cretaceous biozones with *Micula prinsii, M. murus* and *Nephrolithus frequens* are present. The first part of the Paleogene contains frequent calcispheres – especially *Opercudinella operculata* and *Markalius inversus*, *Ericsonia* ssp., *Cruciplacolithus primus*. As concerning the agglutinated foraminifera, the first occurrence of *Rzehakina fissistomata* and the last occurrence of *Caudammina gigantea* have been used as markers for the Cretaceous - Paleogene boundary in lower bathyal settings, where planktonic foraminifera are scarce or absent (Chira et al., in press).

The entire section from Seaca Valley comprises about 680 meters (Chira et al., 2008). The tectonic of the region determines that Upper Cretaceous and Paleogene deposits alternate. The Hangu Formation contain rich Upper Cretaceous assemblages, generally better preserved as those from Putna Valley section, were coccoliths frequently present overgrowths. The Upper Cretaceous assemblage from the lower part of the section indicates the presence of the CC25-26 Biozones (after Sissingh, 1977). It follows an interval barren in nannofossis or with few taxa. The calcareous nannnofossil assemblages contain rarely reworked Cretaceous taxa and few Lower Paleogene taxa: *Cyclagelosphaera alta, Biantolithus sparsus, Opercudinella operculata*. Frequent Lower Paleocene forms are present especially in the upper part of the section from Seaca Valley: *Cruciplacolithus primus, C. tenuis, Prinsius martinii, Markalius apertus, Ercsonia subpertusa, Cyvclageospahaera alta, Coccolithus pelagicus, Zeugrhabdotus sigmoides, Neocrepidolithus fossus*, wich belong to NP1 (after Martini, 1971). Reworked Cretaceous taxa are also present.

The samples from the uppermost part of the section contain again relatively rare calcareous nannofossils. Lower Paleogene taxa are present, together with more Cretaceous taxa.

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Evolution of climatic zonality during Cretaceous greenhouse epoch

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Palaeoclimatic maps of all twelve Cretaceous stages were reconstructed and the major climatic belts reconstructed using numerous lithologic, paleontologic and geochemic paleoclimatic indicators. The reconstructions allow the study of the evolution of climatic zonality during Cretaceous. Climatic zonation of the Cretaceous Earth was radically different from the present. In the first half of the Cretaceous (Berriasian-Aptian) the Earth's low and, partly, middle latitudes were occupied by a vast arid belt that stretched in the western hemisphere from 45o N to 45o S. In the Albian this belt was split by a narrow equatorial humid belt in two arid belts. This event was coeval and probably a result of the breakup of Western Gondwana and the opening of the South Atlantic Ocean. The equatorial humid belt developed and broadened up to the Maastrichtian along with the broadening of the Ocean. The middle latitudes in the Cretaceous featured a warm and rather humid or variably humid climate. The high latitudes were occupied by belts with temperate humid climate. No undisputable glacial deposits have been found in the high latitudes of the both hemispheres. Only very sporadic beds with traces of seasonal ice rafting are known in the high latitudes of Valanginian-Albian stages. This points to very rare and short episodes of sea freezing in spite of long winter seasons in the high latitudes only during Valanginian-Albian stages. The temperate climate of high Cretaceous latitudes differed of course from modern in that it had alternating long polar nights and days and, consequently, sharp seasonal fluctuations in insolation and temperature. Palaeoclimatic maps made for the stages averaged climates on a time of some millions years. Short climatic fluctuations can be recognized by detailed lithologic or isotopic investigations of sections, as reconstructed for the Cretaceous of Italy and deep oceans.

The Chicxulub impact and the Cretaceous-Paleogene (K-Pg) boundary: Current status and pending issues

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About 30 years ago, it was proposed that a large asteroid impact (now identified as the Chicxulub impact event) hit the Earth at the end of the Cretaceous (~65 m.yrs. ago), thereby causing the dramatic mass extinction at the K-Pg (formerly "K-T") boundary (e.g., Alvarez et al., 1980). Meanwhile, many details of the impact event and the associated mass extinctions have been revealed, though the causative link is still unanswered. We will discuss examples for (A) the general evidence for the Chicxulub impact event and its link to the ejecta deposits at the K-Pg boundary, and (B) lines of research useful to further clarify impact-induced effects in the aftermath of the Chicxulub event.

(A) Evidence for the Chicxulub impact and the mm- to m-thick deposits at the K-Pg boundary being its world-wide ejecta is provided mainly by the presence of (a) shocked minerals and ejected lithic clasts with shock features, (b) glass spherules of in part exotic composition, (c) microkrystites, (d) Ni-rich spinels with a high ratio of ferric/ferrous iron, and (e) specific geochemical signatures (e.g., Smit, 1999). These geochemical signatures include (i) tracers for the projectile (e.g., Cr isotope ratios, high concentrations of platinum group elements and their inter-element ratios), (ii) stable isotope excursions that indicate a sudden productivity and temperature drop following the impact event, and (iii) an abrupt increase of element concentrations, change in elemental ratios, and a spike in the $^{87}Sr/^{86}Sr$ isotope ratio, all seen as indicator for a high flux of material from the continents and the surrounding shelf in the pelagic realm. Slumping and mass wasting at the Gulf of Mexico and the Atlantic continental slope may be evidence for the seismic effects of the Chicxulub impact in proximal regions (see Schulte and Deutsch, this volume). In addition, these mass flows may be responsible for the occasional occurrence of multiple Chicxulub ejecta deposits in northeastern Mexico (Schulte et al., 2003). However, all boundary layers that are generally agreed to be stratigraphically complete contain only one horizon rich in impact debris and that layer is intimately associated with faunal and floral evidence for the mass extinction at the K-Pg boundary. Moreover, the excellent correlation of the Chicxulub impact with ejecta found in the K-Pg boundary layer worldwide provide no support for multiple large impact events at the End of the Cretaceous.

(B) Any approach to better understand the impact event and related environmental perturbations must be centered on the fact that impact of a chondritic projectile with a diameter of 10 km is a high-energetic event, releasing energy on the order of $1.5e+21 \times 10^2$ Joules. Second important fact is the extreme short time-scale causing "sudden" changes, followed by more long-lasting effects. Environmental effects of the Chicxulub impact event range from multiple tsunamis to a short heat pulse, acid rain, and – more importantly – a short period of global cooling due to injection of vapor, dust, and formation of sulfate aerosols in the stratosphere (e.g., Pierazzo et al., 2003; Kring, 2007). Translating these various hazards to the biosphere into the ultimate cause for the extinction of certain species is a difficult task due to the short timescale of the processes and the usually condensed sedimentation recorded in the K-Pg boundary clay. Moreover, published results on the amount of dissociated carbonates and evaporites differ by several orders of magnitude (Ivanov and Deutsch 2002). Therefore, experimental observations (e.g., Agrinier et el., 2001) as well as ejecta investigations (e.g., Schulte et al., 2009) both provide further clues on the dissociation of carbonate and sulfate-bearing target rocks. Additional investigation of the K-Pg boundary clay and earliest Danian on a sub-mm scale, e.g., by LA-ICP-MS, may then give further records of the immediate environmental effects of the Chicxulub impact event (see Deutsch et al., this volume). Finally we want to point out that only few geological processes are understood that well as impact cratering. This is due to the fact that the basis of knowledge covers very different fields, ranging from “real-time” observations (e.g., impact of comet SL-9 on planet Jupiter in 1994; nuclear tests; cratering and shock experiments) over data collection in 3D (field work and drilling on Earth; remote sensing on other bodies in the solar system), analyses in the lab to modeling. Modeling is a very effective tool to check if proposed processes are compatible with the laws of physics, and modeling results may help to understand observations, whereas observations help to refine models!

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Concurrent PGE anomaly, negative carbon isotope shift, and Chicxulub ejecta at the K-T boundary in ODP Leg 207: No evidence for multiple- impact scenario

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An up to 2-cm-thick Chicxulub ejecta deposit was recovered in 6 holes drilled during ODP Leg 207 (Demerara Rise, about 380 km north of Suriname and ~4500 km off the Chicxulub crater); no other ejecta or volcanic ash layers have been reported from any of these drill sites. The ejecta deposit occurs precisely at (and only at) the biostratigraphic boundary; it also correlates with a sharp negative $\delta^{13}C$ excursion of –2.5‰, a sharp drop of the carbonate productivity from >80 wt% to <20 wt%, and a drastic decline in the abundance of calcareous microfossils. This spherule deposit is the first dual-layer K/T boundary found in marine settings. The most exciting discovery is the presence of calcite and dolomite clasts next to shocked tectosilicates in its topmost millimetre. These carbonate clasts show very distinct, in part exotic features that are obviously related to shock metamorphism. Due to the total lack of bioturbation in this deposit, it is an ideal sample to dissect the "iridium anomaly", and other geochemical peculiarities. We have performed a detailed survey on the distribution of 40 trace elements in five, up to 7200-µm-long profiles across the K-T boundary using La-ICP-MS with a very high spatial resolution. The most important results are (i) the PGE show particularly high concentrations (e.g., up to 0.095 ppm Pt, and 0.02 ppm Ir) only in the uppermost 1000 µm of the ejecta layer concomitant withthe presence of shocked quartz and carbonate clasts; (ii) the low Ni/Cr ratios but also the rather flat distribution patterns of the rare earth elements (REE) point to mafic in addition to the known silicic materials as part of the Chicxulub ejecta; and (iii) the very low Zr/Hf and Nb/Ta ratios, occurring over the whole analysed part of K-T boundary layer (i.e., ~ 6000 µm) but neither below nor higher up in the section, indicate that – contemporaneous with ejecta deposition – supracrustal material was washed off the Guyana Craton into the Atlantic.

Schulte, P., Deutsch, A., Salge, T., Berndt, J., Kontny, A., MacLeod, K.G., Neuser, R.D., Krumm, S. A. (2009): A dual-layer Chicxulub ejecta sequence with shocked carbonates from the Cretaceous–Paleogene (K–Pg) boundary, Demerara Rise, western Atlantic. Geochim. Cosmochim. Acta 73, 1180–1204.

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The Paleocene-Eocene Boundary in Austria

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In the Eastern Alps (Austria) several marine successions, which were deposited ranging from shallow shelf to bathyal slope and abyssal basin, provide detailed records across the Paleocene/Eocene-boundary (P/E-boundary). The Frauengrube section (20 km to the north of Salzburg) originates from the **neritic northern shelf of the Penninic Basin** and exposes shallow water deposits. An erosional unconformity between an Upper Thanetian (calcareous nannoplankton Zone NP9) rhodolitic limestone and a calcareous sandstone (NP11-12) indicates a substantial break in sedimentation in the earliest Eocene, probably an effect of a major eustatic sea-level fall.

Only about 6 km to the south of the Frauengrube-section, the 250m thick Anthering-section (Rhenodanubian Flysch nappe) exposes turbidite deposits originating from the **abyssal Penninic Basin**. This section comprises Zones NP9 to NP11 and records several of the P/E-boundary events, including the $\delta^{13}C$ isotope excursion (CIE) and the acme of the dinoflagellate genus *Apectodinium (*including *A. augustum)*. During this short time a strong increase in the rate of hemipelagic sedimentation suggests enhanced continental run-off, probably an effect of both, a low sea-level and an increase in monsoonal activity. The increased influx of nutrients into the ocean caused acmes in the abundance of diatoms, radiolaria and dinoflagellates. Agglutinated foraminifera occur only sporadically during the CIE and consist primarily of the genus *Glomospira*. However, in contrast to the calcareous benthic foraminifera assemblages there was no major extinction of agglutinated taxa across the P/E-boundary. Consequently, the major turnover of benthic foraminifera at the onset of the Eocene shall be called Calcareous Benthic Foraminifera Extinction Event (CBFEE).

About 18km to the south of the Anthering-section, the 40m thick Untersberg section (Northern Calcareous Alps) spans the upper part of calcareous nannoplankton zone NP9 and the lower part of zone NP10 (sub-zone NP10a). The section was deposited at the **bathyal southern slope of the Penninic Basin** in a paleodepth of about 2000m. Within the dominantly marlstone sequence, a 5.5m thick intercalation of red and green shale and marly shale represents the CIE-interval. The CIE was associated with a shallowing of the calcite compensation depth by at least 1km. A 49% increase in detrital quartz and feldspar within the CIE-interval again suggests enhanced continental run-off. The increased terrestrially derived input is associated with abundant radiolarian casts indicating high primary productivity. The benthic foraminifera faunas of the samples rich in siliceous plankton are strongly dominated by *Glomospira spp*., *Nuttalides truempyii*, *Abyssamina poagi*, *Anomalinoides praeacutus*, *A. nobilis* and *Oridorsalis spp*. The calcareous nannoplankton assemblage of the CIE-interval is characterized by the first occurrences of the genus *Rhomboaster* and of *Discoaster araneus* and *Discoaster mahmoudii* whereas *Scapholithus apertus* became extinct at the P/E-boundary.

At the **neritic southern shelf**, a stratigraphic gap within the Gosau Group in the Krappfeld area (Carinthia) encompassess the Maastrichtian and Paleocene. After a sea-level rise in the lower part of zone NP12, nummulitic marlstone and limestone were deposited. This transgression is synchronous to the transgression at the northern shelf. Since the northern and southern shelves of the Penninic Basin belonged to different tectonic domains, with different potentials of crustal subsidence, the temporal similarity of sea-level changes on both shelves in the latest Paleocene and earliest Eocene suggests that these sea level fluctuations were mainly eustatic in origin. As a proxy for the onset of the sea-level fall, which caused the erosional unconformities on both shelves, the strong increase in the terrestrially-derived input into the Penninic Basin can be used, which occurred shortly before the P/E-boundary.

Decline and recovery of foraminifera at the northern Tethyan margin during the Cenomanian-Turonian OAE-2: the Rehkogelgraben record (Ultrahelvetic Zone, Upper Austria)

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The Oceanic Anoxic Event 2 at the Cenomanian-Turonian boundary is one of the major paleoceanographic events during the Cretaceous. We present the results of foraminiferal assemblage-censuses across OAE 2 from a key section situated at the northern Tethyan margin (Wagreich et al., 2008). Although benthic forms are also present, our focus is on the planktic species representing the changes in the upper water column.

Planktic foraminifera are particularly frequent in the Late Cenomanian (56000 individuals/gram dry sediment, ind/gr). Their number decreases to 0.8 ind/gr during the OAE, and even 0.5 ind/gr immediately after the black shale deposition in the basal Turonian. Their number increased to about 12000 ind/gr in the Early Turonian.

About 70-80% of the Cenomanian assemblages are Hedbergellids (*Muricohedbergella*). Their percentages decrease during the OAE and vary between 10 and 50% in the Early Turonian. The fraction of Heterohelicids decreases already during the Late Cenomanian from 15 to 2%, is low during OAE and varies strongly in the Early Turonian (2-15%). *Whiteinella* occurs with 6 to 19% in Late Cenomanian samples, varies between 0 and 30% during the OAE and continues with about 30% in the Turonian. “Boreal” species (e.g., *W. baltica*) have their highest fractions (19%) during the late OAE and the basal Turonian. Percentages of *Praeglobotruncana* are low during Late Cenomanian (1-5%) and the OAE (0-4%) and increase noticeable in the Turonian (6->50%). Rotaliporids occur with 0.7 to 2.5% in Late Cenomanian samples.

Frequency of benthic foraminifera varies between 0.6 ind/gr during the OAE and more than 5800 ind/gr in the late Cenomanian. The majority (number) of benthics is part of the 0.063 to 0.125 mm fraction (about 95%). The lowest frequency is in the >0.250 mm fraction (0 to 7 ind/gr). The drop in frequency at the end of the Cenomanian is sharp. Benthic foraminiferal recovery after OAE 2 appears to be slow and is less than 500 ind/gr during the *W. archaeocretacea*-Zone. Pre-OAE levels are reached during the *H. helvetica*-Zone.

The records show distinct changes in planktic and also benthic assemblages, which are interpreted as direct consequences of changes in the oceanic environment. Well developed *K*-selected Late Cenomanian assemblages with abundant Rotaliporids (although dominated by Hedbergellids) are replaced by *r*-selected assemblages with low total numbers and relatively high fractions of the species *Schackoina cenomana* and *W. baltica*. Recovery of the paleo-ecosystem is represented by increasing numbers of larger and partly keeled species of the genera *Praeglobotruncana*, *Whiteinella, Dicarinella,* and *Helvetoglobotruncana*.

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Morphology and composition of the cosmic dust and micrometeorites in the Transitional Clay Layer at the Cretaceous–Paleogene Boundary in the Gams Section (Eastern Alps)

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Results of investigation of the cosmic substance in the transitional clay layer at the Cretaceous–Paleogene boundary in the Gams section, Eastern Alps, are presented. A great diversity of iron microspherules and particles of different morphologies, pure nickel spherules, awaruite (Ni3Fe) particles, and diamond crystals are discovered. Iron microspherules are also met in the overlying Paleocene deposits. The discovered metallic microspherules and particles are described, their chemical compositions are presented, and their origin is discussed.

Many characteristics of the discovered Fe and Fe-Ni spherules are analogous to those of the spherules found in deep-sea clays of the Pacific Ocean by the *Challenger* expedition, in the Tunguska catastrophe area, at the fall sites of the Sikhote-Alin' meteorite (Krinov, 1971) and Nio meteorite in Japan, in Miocene marls of the Northern Apennines, in present-day deep-sea deposits. In all cases, except for the Tunguska catastrophe area and the fall site of the Sikhote-Alin' meteorite, the formation of both spherules and particles of various morphologies consisting of pure iron (sometimes with a Cr admixture) and Ni–Fe alloy is unrelated to impact events. We derive their formation from cosmic interplanetary dust falling onto the Earth's surface. This process has continued uninterruptedly since the moment of the Earth's formation and is, in a sense, a background phenomenon. Compositions of many particles studied in the Gams section are similar to the bulk chemical composition of the meteoritic substance found at the fall site of the Sikhote-Alin' meteorite (Krinov, 1971). The presence of Mo in some particles is not unexpected. Native molybdenum and molybdenite were also found in the composition of lunar dust collected by the Luna-16, Luna-20, and Luna-24 automatic probes (Mokhov et al., 2007).

Pure nickel spherules with a well-crystallized surface found for the first time are known neither in magmatic rocks nor in meteorites, where nickel invariably contains a significant amount of admixtures. Such a surface structure of nickel spherules could have formed in the case of an asteroid (meteorite) fall, which would result in release of energy sufficient not only for melting the material of the falling body but also for its evaporation.

Awaruite (Ni_3Fe) particles found together with spherules of metallic nickel are a product of the meteorite ablation and belong to the category of meteoric dust, while molten iron particles (micrometeorites) should be regarded as meteoritic dust (according to Krinov's terminology, Krinov, 1971).

Diamond crystals met together with nickel spherules might have formed during ablation of meteorite from the same vapor cloud in the process of its subsequent cooling. However, a final conclusion on the origin of diamond can be drawn after its detailed isotope investigations, which require a sufficiently large amount of substance.

Thus, the study of the transitional clay layer at the Cretaceous–Paleogene boundary revealed the presence of cosmic substance in all parts of the layer (units **J**1 to **J**6); however, indicators of an impact event are fixed only beginning from the **J**4 units.

Microstructure and compositions of many particles, investigated by authors from the Chicxulub Crater (section El Pinon), are similar to the bulk chemical composition of the meteoritic substance found in the Gams section.

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The K/T Boundary of Gams (Eastern Alps, Austria) and the nature of terminal Cretaceous Mass Extinction

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1. The Gams stratigraphic sequence is characterized by a clearly pronounced transitional layer at the K/T boundary and many peculiarities of this layer were first studied. The lower part of the sequence notably differs from the upper part by high concentrations of As, Zn, Cu, Pb, Cr, Ir, Co, V, Ni. In the upper portion of the transitional layer, the content of these elements decreases significantly.
2. Four Ir anomalies were found: the large well expressed anomaly at the K/T boundary, two other anomalies above and one anomaly below the boundary. The Ir enrichment in clays at the K/T boundary layer is not necessarily of impact origin, but may have originated from plume volcanism [Zoller et al., 1983; Officer et al., 1987]. As Keller (2008) has shown recently, iridium anomalies are not unique and therefore not infallible K/T markers.
3. The lower part of the transitional layer has a smectite content of >65%, which decreases gradually upwards, whereas the percentage of illite increases to 20%.
4. Variations in the concentrations of rare earth elements in the Gams sequence are insignificant. The flat configuration of the NASC-normalized REE patterns is typical of the rocks of Mesozoic and Cenozoic continental margins.
5. The study of minerals in the transitional layer at the K/T boundary in Gams provides an explanation of the distribution of trace elements. Our data indicate that there are two distinct populations of minerals in the transitional layer and therefore two different stages in the deposition history. The first one includes the sedimentation in anaerobic conditions due to the spreading volcanic aerosol. The volcanic activity is related to the mantle plume (existence of native platinum, rhenium, sulfides, barite and titanomagnetite).The environments of sedimentation have changed drastically during the deposition of the upper portion of the layer. The paragenesis of hexagonal polymorph of diamond (lonsdaleite) with pure nickel spherules which were discovered here proves an asteroid (meteorite) fall.
6. The ratio $^{3}He/^{4}He$ in the Gams section changes from the bottom to the top of the transitional layer. The difference between the lowermost and uppermost units is significant and (by more than ten times) exceeds the measurement uncertainty (5%) considerably. 7. The variations in ^{18}O and ^{13}C in the vertical section show a pronounced shift toward negative values at the K/T boundary. It is important to emphasize that the minimum ^{18}O and ^{13}C values are characteristic of the transitional layer occurring below the unit corresponding to the impact event. The most remarkable fact is that no microfauna was found in these units. These anomalies in ^{18}O and ^{13}C ratios in the Gams sequence are close to the analogous variations documented elsewhere.
8. The distribution of foraminifera in the K/T boundary in the Gams section shows that the extinction of genera began well before the accumulation of the layer J. The deterioration may have resulted from an input of arsenic and other toxic elements from volcanic aerosol, which resulted in poisoning from these toxic metals in the anoxic environments. The barren interval (dead zone) was detected in the middle part of the transitional layer below the appearance of impact material.
9. Our research eliminates the need in opposing volcanism to an impact event. Both took place, but the changes in the biota were related to volcanism, as it was the case with the Ir anomaly itself. The cosmic body fell only some 500–800 years later!

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The Cenomanian/Turonian Boundary Event: A review of the micropalaeontological evidence

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The Cenomanian/Turonian Boundary Event (CTBE, Bonarelli Event or OAE II) is one of the most distinctive of the mid-Cretaceous "anoxic events" and has been recorded on (almost) every continent. The first detailed documentation of the palaeontological changes across the CTBE was the seminal paper by Dick Jefferies (1962). His palaeoecological inferences were coloured by the contemporary work of Burnaby (1962), who's interpretation of the ecology of benthic foraminifera (and the depth of the chalk sea) was unfortunately highly inaccurate. Although Hart & Tarling (1974) attempted to show that the CTBE was a widespread "event", Schlanger & Jenkyns (1976) were probably the first to recognise the possible link with oceanic anoxia.

In the 1980s, Jarvis and co-workers in the U.K. (Jarvis *et al*., 1988) and Kauffman and co-workers in the U.S.A. (Pratt *et al*., 1985; Kauffman & Eicher, 1988) identified the global nature of the "event" and the extinctions associated with it. The CTBE is now grouped with the "Oceanic anoxic events" of the mid-Cretaceous and recognised world-wide (e.g., Europe, USA, Brazil, West Africa, Morocco, Tunisia, Middle East, Russia, India, Australia and in many ocean basins and on oceanic plateaux). The anatomy of the $\delta^{13}C$ and $\delta^{18}O$ excursions has been studied in detail and the curves are near-identical world-wide. The palaeontological turnover is global and the various extinction events regarded as synchronous. The majority of these are at the level of genus or species (not family) and this separates the CTBE from the "Big Five" extinction events. Milankovitch cycles indicate a possible duration for the "event" of 300,000 to 500,000 years: a relatively short period of time in which to cause (and recover from) such an oceanic perturbation.

Despite the volume of work thrown at the CTBE in the last 20 years (post – Jarvis *et al*., 1988), are we any nearer to understanding what happened? Was it a sudden sea level rise (or fall)? Was it a sudden "cold" event in the general mid-Cretaceous greenhouse climate? Was it an expansion of the oxygen minimum zone in the oceans or was it simply that the normal oxygen minimum zone was drawn onto the expanded mid-Cretaceous shelves during a sea level highstand? What do the occurrence of oceanic black mudstones or red beds tell us about the oceans below the oxygen minimum zone?

The debate continues……!

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Benthic foraminifera across the K/T boundary: Brazos River (Texas, USA) compared to Stevns Klint (Denmark)

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While the majority of micropalaeontologists have concentrated on the planktic foraminifera of the Brazos River succession (in order to define the position of the K/T boundary), there are relatively few studies of the benthic foraminifera published. There are a number of sites available for study, including the Brazos River itself and the tributaries of Cottonmouth Creek and Darting Minnow Creek. There have also been a number of drill cores recovered from the area including the Mullinax – 1 core which we have studied. Almost all of the benthic foraminifera recovered from the Mullinax – 1 core were described by Joseph Cushman (1946) in his monograph.

The Corsicana Formation (Kemp Formation of the State Geological Map) of latest Maastrichtian age is overlain by the Littig Member of the Kincaid Formation which includes, at its base, the so-called “Event Bed”. The base of this unit is the “impact-defined K/T boundary” of many authors (e.g., Yancey, 1996). The “Event Bed” contains a number of discreet (but thin) sedimentary units including spherule-rich layers, shell lags and a number of hummocky sandstone beds (Gale, 2006). In a recent paper, Keller et al. (2009) have identified an “impact” layer *below* the “Event Bed” and a K/T boundary higher in the succession that most other authors.

In the Mullinax – 1 core, there is a diverse fauna of benthic foraminifera, although the species count is much less than that described by Cushman (1946). This is almost certainly the result of the small sample size available in the small diameter core. There is a distinctive assemblage of mid–outer shelf taxa, including agglutinated foramininfera (*Tritaxia*, *Verneuilina*, *Plectina*, etc.) and aragonitic taxa (*Epistomina*). The numbers of agglutinated taxa in the Mullinax – 1 core are much reduced at the level of the “Event Bed” and this, coupled with the changes in the planktic fauna, indicates a (fairly) marked drop in sea level. Both Yancey (1996) and Gale (2006) argue that this brings the sea floor into the range of storm wave base and that this is what is indicated by the “Event Bed”.

There are a number of water-depth changes in the famous Stevns Klint succession in Denmark, although the majority of the benthic taxa are different. All belong to the normal Chalk Sea assemblage of North West Europe. The planktic assemblage in Denmark is limited and there are no aragonitic taxa (preservation problems). Benthic foraminifera are rare, though generally more abundant in the chalks immediately below the K/T boundary.

Work on material from Denmark and the Brazos River successions is on-going and, as this involves a detailed assessment of the various morphogroups represented, will not be completed until later this year. The presence of an unusual “foraminiferal sand” within the lowermost Paleocene of the Cottonmouth Creek succession has yet to be fully described and its presence is not fully understood (environmental control or re-deposition?).

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Floristic changes near the K/T boundary in North-eastern Russia, Far East and Northern Alaska: role of plant migrations and climate fluctuations

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Study of fossil floral successions from the K/T boundary interval in Far East (Zeya-Bureya Trough), North-eastern Russia (Koryak Highland) and Northern Alaska (Sagavanirktok River Basin) is crucial for better understanding of events, which took place at this boundary. Investigation of these floras proves our ideas on the role of palaeoclimatic and palaeogeographic factors in the boundary events. Revision of fossil floras from the Zeya-Bureya Trough and North China allows substantiating a succession of the regional floral assemblages. This succession comprises taphofloras of Santonian, Campanian, early Danian, Danian and Danian-Selandian age. The early Danian Boguchan Flora keeps continuity in composition and dominating taxa with the Campanian Late Kundur Flora; therefore, the catastrophic floral change at the K/T boundary is not recorded in this region. The Koryak Flora of the Amaam Lagoon (North-eastern Russia) comprises 32 fossil plant species of horsetails, ferns, ginkgoales, conifers and angiosperms. It is dated as late Maastrichtian based on correlation of plant-bearing beds with regional marine biostratigraphy. The Early and Late Sagwon floras of Northern Alaska are Danian - Selandian and Paleocene in age judging from palynology and plant megafossils. The Danian-Selandian Early Sagwon Flora comprising about 30 plant species is most similar to the late Maastrichtian Koryak Flora of the Amaam Lagoon in taxonomic composition and dominating plants. This similarity indicates that floral development in the North Pacific Region also does not support a hypothesis on the global extend of the ecological crisis at the K/T boundary. Therefore, fossil floras of the Russian Far East and high latitudes of Asia and North America show no evidence of catastrophic event at the K/T boundary. Their development was most probably controlled by climate changes, plant evolution and migration. The Paleocene Late Sagwon Flora from Northern Alaska is similar to Danian or Danian-Selandian flora from the middle part of the Upper Tsagayan Subformation of the Amur Region and from the lower Wuyun Formation of the Heilongjiang Province in China. In a florogenic aspect, trans-Beringian plant migrations from North-eastern Asia and southern palaeolatitudes of the Far East, which became possible due to climate warming in Arctic, have played an important role in forming of the Paleocene floras of Northern Alaska.

Micropaleontological changes at the Cenomanian- Turonian boundary in the Bohemian Cretaceous Basin, Czech Republic

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Initial transgressive Cretaceous deposits of the Bohemian Cretaceous Basin are represented by siliciclastic sediments of the Cenomanian age (Peruc-Korycany Formation with tree members: Peruc, Korycany and Pecínov) and hemipelagic marlstones and limestones of the Turonian age (Bílá Hora Formation). Transgressive successions include fluvial, marsh, estuarine, inner shelf and open marine facies assemblages (Čech et al., 2005). Generally, character of calcareous nannofossils, foraminifers and palynological assemblages reflects depositional conditions near the Ce-Tu boundary.

Biostratigraphically important angiosperm pollen *Complexiopollis vulgaris* appears in late middle Cenomanian (A. jukes-brownei Zone) (Uličný et al. 1997). Halophyte pollen of *Classopollis/Corollina* is important component of the coastal marshes. *Palaeohystrichophora infusorioides, Spiniferites ramosus* becomes the most common types and characterize near shore deposition. The first sparce occurrence of agglutinated foraminifers was recognized in the upper part of the Cenomanian sandstones of Korycany Member. In the inner shelf facies of calcareous clayey glauconitic siltstones of the Pecínov Member mostly agglutinated species and calcareous benthos with sporadic representants of planktonic genera *Hedbergella* and *Whiteinella* were found. Stratigraphically important species *Gavelinella cenomanica* indicates Cenomanian stage of sediments which belong to planktonic interval and partial range zone Whiteinella archaeocretacea (upper part of Upper Cenomanian to the lowermost part of Lower Turonian) sensu Robaszynski & Caron (1995). Lithological changes and low oxygen content of the Pecínov Member are reflected in well-pronounced variation within palynological record. Poor dinocyst assemblage, abundant foraminiferal chitinous linings, scolecodonts (jaw apparatus of worms) and amorphous organic matter characterize the uppermost part. Dinocyst species *Epelidosphaeridia spinosa* was found together with *Praeactinocamax plenus* (Upper Cenomanian, *M. geslinianum* Zone). Upper Cenomanian foraminiferal assemblage with rare occurrence of planktonic species, a low diversity of dinocyst species, relatively frequent acritarchs and prasinophytes and poor nannofossils assemblages with higher numbers of *Watznaueria barnesae*, *Broinsonia signata,* and strongly etched specimens, indicate shallow marine conditions at the beginning of transgression (upper part of the Peruc-Korycany Fm.).

Influx of abundant nannoflora, very rich, highly diversified dinocyst assemblage supports Turonian transgression and change to neritic conditions. More diverse foraminiferal assemblages with abundance of planktonic keeled type of tests and juvenil specimens with calcareous tests give evidence for conditions of the open sea in the Lower Turonian. These foraminiferal assemblages belong to Helvetoglobotruncana helvetica Zone (Robaszynski & Caron 1995) due to the occurrence of *H. helvetica*. Also the presence of calcareous benthos as *Cassidella tegulata, Frondicularia inversa* and agglutinated *Gaudryina angustata, G. folium* is characteristic for the foraminiferal assembalge of this planktonic zone. The lowermost Turonian is well evidenced by FO *Eprolithus octopetalus* followed by LO *Helenea chiastia* and FO *Eprolithus moratus*. First appearance of nannofossil species *Eprolithus moratus* coincides with first occurrence of foraminiferal planktonic species *Helvetoglobotruncana helvetica* in hemipelagic sediments of the Bílá Hora Formation. Dinocyst assemblage with increasing gonyaulacean types such as *Surculosphaeridium? longifurcatum, Oligosphaeridium complex, Achomosphaera ramulifera, Pervosphaeridium pseudhystrichodinium, Hystrichodinium pulchrum* and especially open marine form *Pterodinium cingulatum* are most abundant. *Complexiopollis* and *Atlantopollis* are most common angiosperm pollen in Lower Turonian sediments.

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Is Deccan Volcanism the real cause for the KT Mass Extinction?

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Could Deccan volcanic eruptions in India be the real cause for the KT mass extinction? Several recent discoveries strongly suggest this possibility: (1) The main phase (80%) of Deccan Trap eruptions likely occurred over as little as 10,000 to 100,000 years (Chenet et al., 2007, 2008). (2) The KT mass extinction coincides with the end of this main phase of volcanism (Keller et al., 2008, 2009a,b). (3) The longest lava flows in Earth's history, spanning 1000 km across India and out to the Gulf of Bengal, mark this phase of Deccan volcanism and the mass extinction. (4) SO_2 emissions associated with just one of these major volcanic pulses, or megaflows, are on the order of SO_2 emissions estimated from the Chicxulub impact; the total SO_2 emissions during the main phase of Deccan volcanism are estimated at 30 to 100 times that of the Chicxulub impact (Chenet et al., 2007, 2008). Thus, the short duration of volcanic eruptions and repeated massive SO_2 injections may have caused a deadly runaway effect that lead to the K-T mass extinction.

Critical new data on the KT mass extinction comes from investigations of Deccan Trap outcrops in central India, quarry outcrops in SE India (Rajahmundry) and subsurface cores from the Krishna-Godavari Basin, SE India, by the Oil and Natural Gas Corporation of India (ONGC). In eight subsurface cores examined, a total of 9 volcanic megaflows have been identified as occurring in very rapid succession. The biotic effects of these megaflows can be evaluated based on planktic foraminifera, which suffered the most severe mass extinction of all organisms. After the first megaflow more than 50% of the species disappeared and with each new megaflow more species died out culminating in near total mass extinction coincident with the last megaflow at the KT boundary. After the mass extinction, no megaflows reached the Krishna-Godavari Basin for about 250-280 ky during which a low diversity early Danian assemblage of small new species evolved. The last major Deccan volcanic pulses began at the C29R/C29N boundary and appear to have been the cause for the long delay in the full biotic recovery. Deccan volcanism can thus explain both the KT mass extinction and the long delayed biotic recovery that has been an enigma for so long.

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The role of the Chicxulub Impact in the KT Mass Extinction

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The Chicxulub impact is the commonly accepted cause for the end-Cretaceous (KT) mass extinction whereas other catastrophes, such as volcanism and climate change, are considered at best secondary effects. However, this popular scenario can no longer be supported by the emerging database on the pre-KT age and biotic effects of the Chicxulub impact in Mexico and Texas. At these localities reworked impact spherule layers form the base of a sandstone complex, which has been erroneously interpreted as impact-generated mega-tsunami deposit. The KT boundary clay and Ir anomaly are well above the sandstone complex and never associated with impact spherules (Keller et al., 2007; Keller, 2008). The sandstone complex infills submarine channels that formed during the latest Maastrichtian sea level fall and cooling (100-150 ky) that followed the greenhouse warming between 400-150 ky before the KTB. The primary impact spherule deposit was discovered in undisturbed marls up to 8 m below the sandstone complex in NE Mexico sections (El Penon, Mesa Juan Perez, Loma Cerca) and in claystone below the sandstone complex in Texas. Chicxulub impact spherule deposition occurred near the base of zone CF1, predating the KTB by ~300 ky. The Chicxulub impact and K-T mass extinction are thus two separate and unrelated events.
Evaluations of the biotic effects across the primary Chicxulub impact layer in Mexico and Texas reveal that not a single species went extinct as a result of this impact. No significant changes occurred in species populations, climate, or sedimentary environments. This suggests that even a much larger impact at the KT boundary would likely have been insufficient to cause the KT mass extinction (Keller et al., 2009a, b). This result is surprising only because we assumed that the Chicxulub impact caused the mass extinction. No other large impacts are associated with mass extinctions. No species extinctions or significant environmental changes were caused by the late Eocene Popigai and Chesapeake impacts (craters of ~100 km in diameter). This suggests that environmental effects of impacts were short-lived. If not the Chicxulub impact, what caused the KT mass extinction? Deccan volcanism is the other major catastrophe near the end of the Cretaceous. Recent studies suggest that the main phase (80%) of Deccan eruptions may have been very rapid and ended near the KT boundary, suggesting volcanism as viable cause for the KT mass extinction.

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Paleocene-Eocene freshwater aquatic and wetland ecosystems of the Zeya-Bureya Basin, Russian Far East and their responses to climate change

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The Paleocene middle and upper members of the Tsagayan Formation with uppermost Kivda beds and the Eocene Raichikha Formation in the SE part of the Zeya-Bureya Basin (Amur Region, Russian Far East) have yielded rich fossil records of plants (megafossils and palynomorphs), insects, and invertebrates (Krassilov, 1976; Kamaeva, 1990; Flora and dinosaurs…, 2001; Akhmetiev et al. 2002). The Lower Tertiary coal-bearing sediments were deposited on a broad alluvial plain. Freshwater wetlands were widely distributed across the region. Several types of paleoenvironments with associated floristic and faunal assemblages have been recognized: flood plains, shallow lakes and ponds, peatswamps, and streembanks with levees. Because freshwater aquatic and wetland ecosystems are very vulnerable to climate change, their study can provide additional data useful for our understanding of terrestrial biota responses to global climatic event at the Paleocene/Eocene boundary.

The Paleocene Middle Tsagayan wetlands were dominated by plant communities including mainly *Taxodium – Nyssa – Mesocyparis* swamp forests. Herbaceous plants (horsetail *Equisetum,* ferns *Osmunda* and *Woodwardia,* monocot *Zingiberopsis*) could have inhabited freshwater marshes. The Tsagayan aquatic plants are relatively diverse and represent primarily extinct genera *Nelumbites, Nuphar, Quereuxia, Haemanthophyllum, Paranymphaea*. The only free-floating plant is *Quereuxia.* Shallow lake sediments represented by gray indistinctly laminated clays contain rare freshwater gastropod remains (cf. *Viviparus*) and numerous aquatic and terrestrial fossil insects. The Tsagayan insect assemblages are dominated by dragonflies (Odonata, mainly suborder Zygoptera), cockroaches (Blattodea), cicadas and bugs (Homoptera, Heteroptera), beetles (Coleoptera, families Gyrinidae, Buprestidae and Cupedidae), and caddisflies (Trichoptera), while mayflies (Ephemeroptera), scorpionflies (Mecoptera), and Phasmatodea insects are less abundant (Popov, 1971; Ponomarenko, 1977, Sukatsheva, 1982; Alexeev, 1995; Vasilenko, Bugdaeva, 2006). The evidences of plant-insect interactions (leaf damages, galls, mines) have also been recorded.

The Kivda wetlands were inhabited by *Taxodium, Metasequoia, Ditaxocladus, Pseudolarix,* and *Myrica.* The most common plants of non-forested wetlands in the region were horsetails (*Equisetum*), ferns (e.g. *Arctopteris*) and especially monocots including aroid plant *Caladiosoma*. The only two aquatic plants are known: unidentified free-floating plant of the Hydrocharitaceae family and fern *Azolla*. Abundant *Daphnia* in sediments indicates eutrophic water. Generally, lowland deciduous coniferous-broadleaved forests with Taxodiaceae, *Trochodendroides*, platanoids, Betulaceae, and cornalean plants are reconstructed for the Tsagayan time. The climate was humid warm-temperate to temperate.

The Eocene Raichikha flora is highly distinct from those of Paleocene. None of the woody angiosperm Raichikha taxa are known from Tsagayan flora. Raichikha plant assemblage is dominated by Lauraceae, Leguminosae, Rhamnaceae, Sapindaceae (Akhmetiev, 1973, 2008; Fedotov, 1983). Physiognomic analysis of fossil leaves indicates a MAT of 14.8 - 15°C. The thermophilic character of the Eocene flora of the Zeya-Bureya Basin may be explained by relatively rapid plant migrations during global warming at the Paleocene/Eocene boundary. Possible migration routs are discussed. The Raichikha aquatic ecosystems have changed considerably. Aquatic and helophytic plant communities has yielded both dicots (*Nelumbo, Nuphar*) and monocots (*Limnobiophyllum*, Araceae), as well as heterosporous ferns (*Salvinia, Azolla, Regnellidium*). Insect assemblages are dominated by mayflies (Ephemeroptera). The wetlands were inhabited mainly by shrubs (*Hibiscus, Myrica, Vaccinium*) and ferns. Some aquatic plants demonstrate high level of adaptability to the environment variations.

Planktonic foraminifera from the Cretaceous-Paleogene boundary deposits of Gams (Eastern Alps, Austria)

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In Gams, the Cretaceous/Paleogene boundary clay has been found in three sections (Gams-1, Gams-2, Gams-3). The Gams sequence which is of world significance was studied comprehensively in a large sample across the boundary (the "monolith") and in single samples taken at the outcrops.

In the monolith, the Cretaceous-Paleogene boundary layer (layer J) is a dark-colored, almost black clay of 1-2 cm in thickness. Its lower part is mainly composed of illite and the higher one of smectite. As a whole, layer J is characterized by high concentrations of As, Cr, Ni, Fe_2O_3, a very low content of Ca, and abundant cosmic particles, i.e., "meteoritic dust" and "meteoritic iron".

Some of the planktonic foraminifera from the layer J and the overlying layers L and M differ by their appearance and preservation from those of underlying deposits as follows:

1. All tests of Globotruncanidae are slightly deformed and milk-white in color. The same is true for the Paleogene *Globoconusa daubjergensis* (smaller morphotype) from the upper portion of layer J and keeled forms tentatively referred to *Morozovella*.
2. Some tests of *Racemiguembelina fructicosa* from the upper part of layer J are evidently eroded while tests of small planktonic foraminifers of *Hedbergella* and Heterohelicidae and *Globigerina* from the underlying deposits are of common appearance and preservation.
3. Noteworthy is that changes in appearance and/or preservation occur exclusively in planktonic foraminifers but not in benthic forms of the same samples. What is the reason of such selectivity?
4. In the studied interval of the Late Maastrichtian *Abathomphalus mayaroensis* Zone (layers A-I), the diversity of planktonic foraminifer taxa ranges from 6-7 to 14-15 specimens per association. It is most abundant in the layers D (10 cm below layer J) and I (immediately below layer J).
5. A minimum of taxa was recorded in layer G (4 cm below J).
6. In the layers A-I, planktonic foraminifera associations are dominated by the families Heterohelicidae and Globotruncanidae whereas the Rugoglobigerinidae and Hedbergellidae are represented only by a few species. Species of the Globotruncanidae are more diverse but relatively rare. Finally, the Heterohelicidae are represented by 2-5 species, two of which (*Racemiguembelina fructicosa* and *Pseudotextularia elegans*) are most abundant.

Two peculiar features of the associations of planktonic foraminifers shall be emphasized:

7. In the layers A-I (inclusively), half of the total number of tests belongs to *Racemiguembelina fructicosa* and *Pseudotextularia elegans* of the family Heterohelicidae.
8. In the same layers, an increase in abundance of *Racemiguembelina fructicosa* is accompanied by a decrease of *Pseudotextularia elegans* (and vice versa).

Such trends may be interpreted by species competition. The species may also have occupied different ecological niches and the fluctuations of abundance reflect cycles of environmental changes, e.g. of water temparature.

At present, we cannot resolve whether the afore-mentioned distribution of *Racemiguembelina fructicosa* and *Pseudotextularia elegans* characterizes the pre-crisis populations or if it was common in the mid- latitude seas during a longer time interval.

It is also not clear whether the sharp predominance of these two species on one hand, and their competition on the other hand is related to the general extinction of planktonic foraminifers or not.

Nevertheless, it should be noted that a sharp decrease in the number and relative abundance of species was recorded in layer G, 4 cm below J. Immediately prior to the extinction of planktonic foraminifers, the Heterohelicidae species *Racemiguembelina* *fructicosa* and *Pseudotextularia elegans* were most abundant. Very likely, they were in competition to each other.

9. In layer I, immediately below J, the population shows an increasing abundance of sinistral tests of *Contusotruncana contusa* var. *sinistralis* and *Globotruncana rosetta*. The latter passed into the lower part of layer J. Was the increase in abundance of sinistral tests caused by a general climatic deterioration before the deposition of layer J or by changes in water mass circulation in a separate basin?

10. The earliest "typical" Paleogene planktonic foraminifers of the genus *Globoconusa* were recorded in the higher part of layer J (Sublayers J-5 + J-6).

The resolution of Cenomanian events in the Crimea and eastern Central Asia

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Cenomanian deposits of 3 paleobiogeographial provinces at the northeastern margin of the Peritethys spread over eastern Central Asia (from the Pamirs and Fergana in the east to the lower course of Amu Darya River in the west), the Russian Platform and Crimea, their biostratigraphy and their foraminiferal associations are discussed.
A Cenomanian zonation based on both planktonic and benthic foraminifers with emphasis on new data from these regions is proposed.
1. A layer containing metallic particles and microspheres of cosmic origin was found in Lower Cenomanian sandstones of the Crimea. It may be the evidence of a hitherto unknown Early Cenomanian impact event.
2. The isotopic event (MCE-1) $\delta^{18}O$ of the early Middle Cenomanian has been identified in the Crimea.
3. Several isotopic events (AOE-2) were found to have happened during the deposition of the Crimean “black shales” (analogous to the Bonarelli event) in the Late Cenomanian.
4. An episode of phosphorite accumulation in the *Praeactinocamax plenus* Zone is considered to be the most significant event on the Russian Platform.
5. An episode of marine transgression over the continent, which resulted in the submergence of areas of enormous size (Fergana depression, Alai Strait, Southwestern Darvaz, Northern Pamirs), occurred in the early Middle Cenomanian and probably reflected the Ce-3 eustatic event.
6. A wide-spread carbonate platform inhabited by typical benthic foraminifers of the Mediterranean Province (*Merlingina, Biconcava, Charentia, Orbitolina, Cuneolina*) was established in the early Middle Cenomanian in eastern Central Asia. During the Cenomanian, it was probably located at the eastern margin of the Mediterranean paleobiogeographic province.
7. The cool-water belemnite fauna of *Praeactinocamax plenus* and accompanying foraminiferal associations penetrated into southeastern Central Asia from the European paleobiogeographic province.

Iridium Coincidence Spectrometry in the University of Vienna Gamma Spectrometry Laboratory: Determination of Iridium in Very Low Abundances in geological Samples

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The search for an extraterrestrial component in, e.g., impact-melt rocks, impact breccias, or in sedimentary layers at stratigraphic boundaries, is mainly done by geochemical analyses of the contents of siderophile elements Ni, Co, and Cr, as well as the platinum group elements (PGEs). Iridium is the most studied PGE in the search for, and confirmation of, extraterrestrial events. Its low concentration in the sub-ppb (parts per billion) range, however, demands an analytical method with a very low detection limit. Such a sensitive analytical technique is, besides radiochemical neutron activation analysis (RNAA) and inductively coupled plasma source mass spectrometry (ICP-MS) - both of which need chemical separation from the bulk sample - iridium coincidence spectrometry (ICS).

About 10 years ago, a multiparameter γ-γ coincidence spectrometer for iridium was constructed at the Department for Lithospheric Research for the non-destructive study of small amounts of geological materials with iridium concentrations in the ppt-range (parts per trillion) (Koeberl and Huber, 2000; Huber, 2003). The ICS method aims to reduce the background radiation and to remove spectral interferences. The decay of ^{192}Ir due to thermal neutron activation yields to the emission of gamma rays at 1201.05, 920.92, 784.58, 612.47, 468.07, 416.47, 316.51, 308.46, and 295.96 keV. The system consists of two low energy planar HPGe-detectors, which measure two γ-rays of the cascading decay of ^{192}Ir within a coincidence window.

Powdered sample material is weighed (≤150 mg) and sealed in Suprasil® quartz glass vials. Additionally, a series of iridium standards for calibration purposes, with a variety of Ir contents, ranging from low to high, are used as well. These standards are made by diluting the powder of the Allende meteorite standard, a carbonaceous chondrite with 740 ppb Ir (Jarosewich, 1987), with ultrapure SiO_2 powder. A series of samples and the respective standards are placed into an irradiation vial (usually aluminum) and irradiated for 24 - 48 h at a flux of about $7 \cdot 10^{13}$ n • cm^{-2} • s^{-1}. About ten weeks after the end of the irradiation, equivalent to about one half-life of ^{192}Ir (73.8 days) the individual samples and standards are measured for 12 - 48 hours each. After calibration with a ^{152}Eu source with γ-emission at 344 and 444 keV, the counted signals are plotted in a 1024 x 1024 channel matrix, from which the iridium peak regions of interest (316.5 x 468.1 keV) are taken for calculations and corrections (live time -, decay time -, and flux corrections, background subtraction). Data reduction of the acquired spectrum is done with a custom-made evaluation program, which provides the net peak volume and the background value as output. These data, as well as the sample weight, date, time and duration of measurement, are entered into an Excel template to calculate the iridium content of the samples. The ICS method takes several months from the sample preparation to the final results, but is nevertheless a very sensitive and non-destructive method for determining the iridium concentrations in very small geological samples.

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The Palaeocene-Eocene boundary in turbiditic successions: an example from the Słopniczanka section of the Magura Nappe, Polish Outer Carpathians

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The Magura Nappe, the largest and innermost unit of the Polish Outer Carpathians, is mainly composed of the Upper Cretaceous to Eocene deep-sea turbiditic sediments. This nappe is subdivided into four facies zones (Krynica, Bystrica, Rača and Siary zones), which display strong facies changes, particularly in the Palaeogene. The Magura Basin was filled with sediment successions, representing three turbiditic stages of the Late Cretaceous-Palaeocene, Palaeocene-Middle Eocene and Late Eocene-Oligocene ages. Each one starts with hemipelagic variegated shales deposited below CCD, passing upwards into thin- and medium-bedded turbidites with intercalations of turbiditic limestones and marls, followed by thick-bedded, sandy turbidites capped by thin-bedded turbidites (Oszczypko, 2006).
The outcrops of the Senonian-Palaeocene Ropianka Fm, Eocene Łabowa Shale Fm and Beloveža Fm deposits of the Rača Zone, forming three thrust sheets and a syncline, can be traced along the Słopniczanka river on a distance of more than 1 km (Uchman, 2008), providing rare opportunity to study Palaeocene-Eocene boundary interval in the Magura Nappe. The Ropianka Fm represents the final stage of the first turbiditic succession, and the Łabowa Shale Fm forms the lower part of the second turbiditic succession. Biostratigraphy of these deposits is based mainly on deep-water agglutinated foraminiferal assemblages (DWAF) of the flysch biofacies (Malata, 2002). According to our preliminary results, the upper part of the Ropianka Fm consists of a relatively rich and diverse Palaeocene agglutinated assemblage with *Annectina grzybowskii* (Jurkiewicz) and *Rzehakina fissistomata* (Grzybowski), while the overlying variegated shales contain less diversified DWAF Early Eocene assemblages corresponding to the Glomospira acme zone (see: Bąk, 2001), and higher up an assemblage with *Karrerulina*, displaying slight increase in diversity and abundance. Also trace fossil assemblages display distinct decrease in diversity from the upper part of the Ropianka Fm to the variegated shales. These changes can be related to the rapid, worldwide increase of oligotrophy. A decrease in accumulation of organic matter corresponds to the facies change from the Palaeocene grey shales in the Ropianka Fm to the Eocene red shales.

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From OAE 2 anoxia to oxic CORBs – rapid environmental changes in the Late Cretaceous

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CORBs - Cretaceous Oceanic Red Beds - are red to pink to brown, fine-grained sedimentary rocks of Cretaceous age deposited in pelagic marine environments, including red carbonates, shales, and radiolarian cherts. CORBs are an important facies of deep-water pelagic deposits and pelagic/hemipelagic sedimentary systems. The two major global events of of CORB deposition in the Cretaceous are the event at nannofossil zone CC7 just shortly after the OAE1a and the second in CC11 after the OAE2. Three general facies types were recognized with the end members clay, carbonate, and chert. The depositional environments are fairly deep oceanic basins, generally far from a shoreline. Significant controlling factors of CORB formation were slow sediment accumulation rates at great paleo-water depths.

The transition from OAE 2 black shales to CORBs was studied in three ultrahelvetic sections in the Eastern Alps that were deposited at the distal European continental margin of the (Alpine) Tethys (Neuhuber et al., 2007).

The first section at Rehkogelgraben comprises a 5 m thick succession of Upper Cenomanian marl-limestone cycles overlain by a black shale interval composed of three black, organic-rich (ca. 5% TOC, kerogen type II) layers and carbonate-free claystones, followed by Lower Turonian white to light grey marly limestones with thin marl layers. Carbon isotope values of bulk rock carbonates display the well documented positive shift around the OAE2 black shale interval therefore the Rehkogelgraben section can be correlated to other sections. Except for the OAE2 event the content of organic carbon is low in the entire section.

Early Turonian sediments of similar facies are exposed in the second section at Buchberg that contains white to light grey marly upper- to middle bathyal carbonates. In this section red-colored carbonatic CORBs develop within a time span of about 1.5 my in the Middle Turonian. The total organic carbon content is very low throughout the section, similar to the Rehkogelgraben section. However, benthic foraminifera associations indicate repeated phases of enhanced organic matter flux and less aerated bottom waters during the transitional interval from white to red carbonatic marl deposition. Sedimentation of red layers was controlled by periods of well oxygenated bottom waters, reduced sedimentation rates, and degradation of organic matter in the underlying sediments. Principal component analysis of carbonate chemical data showed that the development of red coloured pelagic sediments is accompanied by a shift towards highly oligotrophic conditions in the surface ocean as well as a decrease in hydrothermal activity. The general formation of red beds is most likely associated with a shift towards more oxic conditions.

Above the Cenomanian-Turonian interval, red limestone-marl cycles of Coniacian-Santonian age are present. Mineralogical data suggest a constant source area over the investigated interval. The relatively higher content of organic carbon in the Upper Santonian may indicate a regressive event in accordance with the global sea-level curve. Plagioclase and organic carbon correlate positively and might indicate enhanced input of nutrient- like trace metals during episodes of higher volcanic activity. Terrigeneous elements (Al, Li, Rb, Be) decrease upwards. Iron speciation data for marl and limestone layers attest to oxic early diagenesis during marl deposition compared to limestone episodes.

Low sediment accumulation rates (2.5 mm/ka) are reconstructed. On the whole, geochemistry (Ba) and stable carbon isotope data indicate a highly oligotrophic environment with efficient recycling of organic matter and nutrients in the upper water column. The investigated Santonian CORBs were deposited above the Upper Cretaceous CCD and show that nutrient availability varied and resulted in periods of higher primary production.

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Palynological respond at the Cretaceous/Paleogene boundary in the Northern Calcareous Alps, Gams area, Austria

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For the first time, an integrated palynological investigation was carried out across the Cretaceous/Paleogene (K/Pg) boundary in two sections (Knappengraben and Gamsbach sections) in the Gosau Basin of Gams in the Eastern Alps, Austria.
More than 180 dinoflagellate species and subspecies were identified from 88 rock samples concentrated around the K/Pg boundary. In most samples the dinocysts are well preserved but associated with reworked material. The dinoflagellate cyst assemblages from most samples are dominated by *Achomosphaera ramulifera* (Deflandre, 1937) Evitt, 1963, *Heterosphaeridium cordiforme* Yun, 1981, *Hystrichosphaeridium salpingophorum* Deflandre, 1935, *Hystrichosphaeridium tubiferum* (Ehrenberg, 1838) Deflandre, 1937, *Riculacysta amplexus* Kirsch, 1991, Trithyrodinium evittii Drugg 1967, *Areoligera* spp, *Spiniferites* spp, *Batiacasphaera* spp and *Cordosphaeridium* spp.
Bioevents, such as the *Spongodinium delitiense* (Ehrenberg 1838) Deflandre 1936 acme which is known from other K/Pg boundary sections around the world, were recognized within both sections 90-110 cm above the K/Pg boundary.
Quantitative analysis of the most abundant genera such as *Achomosphaera*, *Areoligera*, *Batiacasphaera*, *Cribroberdinium*, *Glapherocysta*, *Heterosphaeridium*, *Hystrichosphaeridium*, *Peterodinium*, *Spiniferites* and *Spongodinium*, the Peridinioid/Gonyaulacoid (P/G) ratio and the palynofacies (by counting the total sedimentary organic materials (TSOM) as phytoclasts (brown and black materials), amorphous organic material (AOM), and palynomorphs (dinoflagellates, foraminiferal linings, spores and pollen grains)) were applied to interpret the paleoenvironmental conditions.
Preliminary results suggest that most residues are characterized by abundant sedimentary organic materials (SOM) which are dominated by phytoclasts. The paleonvironment was outer neritic marine with a high terrestrial influx and was characterised by low productivity except above the K/T boundary (90-110 cm) which was highly productive.

The continental Cretaceous-Paleogene transition from the southern Pyrenees: magnetostratigraphy and vertebrate succession correlations

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The successions spanning the Cretaceous-Paleogene (K/Pg) boundary in the southcentral Pyrenees record a general regressive trend evidenced by the succession of marine (Arén Formation), transitional (Grey unit of the Tremp Formation) and terrestrial facies (Lower Red unit, Vallcebre Limestone and Upper Red unit of the Tremp Formation). Therefore, this area allows to explore the Late Cretaceous extinction patterns in the terrestrial environments. The aim here is to correlate the Isona section from the Tremp basin (south-central Pyrenees) with the previously studied Vallcebre section (Oms et al, 2004) located further to the east. In addition, correlations can also be proposed to other extra regional sections (Provence, northern Pyrenees etc.).

The charophyte sucession and magnetostratigraphy indicates that the K/Pg boundary is located at the base of the Vallcebre Limestones, as also indicated by stable isotope data from Fontllonga section in the Ager valley (López-Martinez et al, 1998). Sedimentology indicates a progressive regression from marine through lagoonal to entirely continental environment along the entire Maastrichtian. The Vallcebre section is dominated by mudstones deposited under low energy conditions, while the Isona section incorporates more sandstone and conglomerate levels. In both cases, a basin-wide regression maximum is recorded close to the K/Pg boundary as it happens in the Provence sections. This regression maximum is marked by the input of coarse-grained (alluvial) sediments that record a dramatic change in the landscape (mud plains evolved to sandy floodplains deposited by high-energy currents). This coarse grained rapid input suggests that an abrupt paleoenvironmental change took place in the continental basins of southwestern Europe just predating the K/Pg event.

Although the presence-absence of dinosaur remains may not be considered a robust evidence, it becomes useful when constraining the location of the K/Pg boundary (particularly ichnites, which are an evidence that rules out reworking). Hundreds of levels with dinosaur fossils are found in the studied sections (footprints, bones and particularly eggshells). An accurate vertical location of these sites along the studied stratigraphy reveals that no dinosaur fossil is found above the coarse-grained levels (as it happens in the French sections). The stratigraphycally highest dinosaur remains are the ornithopod footprints and bones found in these coarse levels close the K/Pg boundary. Thus, a constraint in the location of the K/Pg boundary can be addressed by the last occurrence of dinosaurs.

In order to correlate the Isona section with the Vallcebre and Fontllonga sections, we have undertaken a magnetostratigraphic study and a vertebrate fauna prospection. Several dinosaur sites (i.e., Costa Roia and Barranc de Guixers localities) have been found in the upper part of the Lower Red unit. Although the paleomagnetic signal from sediments in the Tremp basin is not yet fully understood some magnetostratigraphic constraints along the Isona section can be made and a tentative correlation to Vallcebre can be made. The general polarity pattern from the Tremp basin matches the correlation with the Vallcebre and Fontllonga magnetostratigraphy and stratigraphy.

The general integration of the southpyrenean record is leading to the understanding of terrestrial environmental changes in SW Europe around the K/Pg boundary event.

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Palynological investigation of the Cenomanian–Turonian boundary section in the Ultrahelvetic Zone, Eastern Alps, Austria

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The biostratigraphy of the Cenomanian–Turonian boundary interval in the Rehkogelgraben section, Ultrahelvetic unit, Austria, is defined mainly based on calcareous nannofossils with additional information from planktonic foraminifera (Wagreich et al., 2008). Correlations to Oceanic Anoxic Event 2 are possible via the occurrence of black shales (Wagreich et al., 2008).

This contribution concentrates on the palynological assemblages and the palynofacies associated with the Cenomanian–Turonian interval. Four samples from this section have yielded some low diversity but distinctive palynological associations which have both stratigraphic and palaeoenvironmental significance. The sporomorph association is dominated by representatives of the Normapolles group. Most profuse species are *Atlantopollis microreticulatus* and *Atlantopollis reticulatus* together with *Complexiopollis praeatumescens* and *Complexiopollis christae*. The concurrent presence of these pollen species is regarded as characteristic in previously reported latest Cenomanian and especially Early Turonian assemblages from Southern France, Portugal and Bulgaria (Medus et al., 1980; Robaszynski et al., 1982; Pavlishina & Minev, 1996). Their calibration to the nannofossil and planktonic foraminiferal successions in the Rehkogelgraben section is of biostratigraphical importance. A low diversity dinocyst association is identified in the Cenomanian – Turonian boundary interval samples. It is dominated by the *Cyclonephelium compactum – Cyclonephelium membraniphorum* complex and *Circulodinium* species. The dinocyst association is encountered in palynofacies rich in organic matter of granular amorphous composition considered to be characteristic for deposition in restricted, anoxic conditions. The palaeoenvironmental significance of the low diversity *Cyclonephelium/Eurydinium* association in preparations dominated by granular amorphous organic matter was outlined by Marshall and Batten (1988) for the Cenomanian–Turonian black shale sequences of Northern Europe and gives ground for correlations with the studied section.

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Petromagnetic analysis of the K/Pg boundary layer of Gams (Eastern Alps) and other K/Pg sections

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We present results of detailed petromagnetic and microprobe studies of the sections Gams-1, Gams-2 and other K/Pg sections - Teplovka (Volga region), Koshak (Mangyshlak) and Tetritskaro (Georgia). We used petromagnetic studies included measurements of specific magnetic susceptibility, hysteresis characteristics and magnetic anisotropy of samples. The hysteresis characteristics of the samples were analyzed by a coercivity spectrometer. The ratios of hysteresis parameters Hcr/Hc and Mrs/Ms provide constraints on the domain state, i.e., the sizes of magnetic grains. Measurements on the coercivity spectrometer are used to obtain curves of isothermal magnetization of superparamagnetic particles. Thermomagnetic analysis (TMA) of samples was conducted with the help of express Curie balance by measuring the temperature dependence of inductive magnetization at a heating rate of 100 degree C/min. The concentrations of magnetite, titanomagnetite, metallic iron, hemoilmenite, and goethite in samples was estimated by determining from the TMA curves, the contribution to magnetization of a given magnetic mineral and dividing this value by the specific saturation magnetization of this mineral. A microprobe analysis of the magnetic fraction extracted from several samples was also performed.

Intense accumulation of iron hydroxides is observed at the K/Pg boundary, and most likely this a global phenomenon unrelated to local physiographic conditions of accumulation of terrigenous material in sediments. Apparently, most of iron hydroxides accumulated in the K/Pg boundary layer and other deposits have different origins: they are products of hydrothermal activity in the first case and terrigenous activity in the second. Accumulation of iron hydroxides extended in time attains a maximum in the lower part of the boundary layer and sharply drops upon the transition to over- and underlying deposits of the Danian and Maastrichtian. The base of the boundary layer **J** (Gams-1) is enriched in titanomagnetite grains of volcanic origin. Titanomagnetite was accumulated through eolian precipitation of products of a volcanic eruption. The related process of eruptive activity was short and local. The jump in titanomagnetite accumulation at the base of the boundary layer (Gams-1) is unrelated to impact events; indicators of the latter (the presence of metallic nickel and its alloy with iron) are confined to the upper part of the layer **J**, whereas the interval of a higher concentration of iron hydroxides covers the entire thickness of the boundary layer. Moreover, an abrupt rise in the iron hydroxide concentration is noted in all of the aforementioned sections, whereas metallic nickel is found only in the Gams section. None of the sections studied yields evidence for enrichment in cosmic metallic iron particles at the K/Pg boundary; on the contrary, in the boundary layer they are met mostly in its upper (Gams-1) or lower (Gams-2) part. Therefore, the K/Pg boundary is not marked by direct indicators of an impact event. Thus, only the enrichment in iron hydroxides of predominantly hydrothermal origin can be regarded as a global phenomenon, consistently associated with the K/Pg boundary and unrelated to impact events. The observed pattern of different positive correlations between accumulated iron hydroxides, magnetite, titanomagnetite, and metallic iron point to different implications of redeposition for the accumulation of these minerals, ranging from the initial accumulation stage, when the correlation is absent due to their different primary sources, to formations in which redeposited material plays a significant role. Very likely that single grains of nickel and Ni-Fe alloy in some layers of Danian sediments (Gams-1) are result of redeposition from boundary layer.

Preliminary geochemical features of non-marine biogenic carbonates from the Maastrichtian of the southern Pyrenees

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The south-central Pyrenees are well known for their Maastrichtian-Danian non-marine record. Thick non-marine successions change laterally to marine sequences to the west. The studied sections belong to the Tremp Fm., within which four lithologic units of variable thickness can be recognized. They are, from base to top: (1) a marine to continental transitional Grey unit mainly consisting of marls with abundant invertebrates, lignites, limestones, and sandstone layers; (2) a fluvial Lower Red unit that includes red mudstones, sandstones, and paleosols; (3) the lacustrine Vallcebre Limestones and laterally equivalent strata that contain charophytes and *Microcodium*; and (4) a fluvial Upper Red unit that is composed of red mudstones, sandstones, and conglomerates. The two basal units are Maastrichtian in age. The K/Pg boundary is found at the base of the unit 3 on the basis of correlation with marine strata, charophyte distribution and paleomagnetic studies.

For our preliminary carbon and oxygen stable isotopic study we have considered the south-eastern Pyrenean area (Vallcebre Syncline, 500 metres of section thickness), and the south-central Pyrenean area (Tremp Basin: Coll de Nargó section and Isona localities, 450 metres and 90 metres of section thickness, respectively). We have sampled all the available biogenic and pedogenic carbonates which may have a potential primary signature: invertebrate shells from the Grey unit (brackish and freshwater molluscs, and terrestrial gastropods) and dinosaur eggshells, pedogenic nodules and *Microcodium* from the Lower Red unit.

In $\delta^{13}C$/ $\delta^{18}O$ plots the values of pedogenic nodules display a large single grouping ($\delta^{13}C$ from -5 per mil to -10 per mil; $\delta^{18}O$ from -3 per mil to -5 per mil) whereas the dinosaur eggshells are found in two main groups: one, well defined, with $\delta^{13}C$ from -11 per mil to -14 per mil and $\delta^{18}O$ from -3 per mil to 1 per mil and the other, which is partially coincident with the pedogenic nodule grouping. Between the two eggshell groups intermediate values are found. The features of one of these two domains which record a partial effect of diagenesis or a differentiated primary signal are discussed. For the invertebrate shells, a relationship between the autoecological inferences and the isotopic features of the carbonate has been deduced.

Carbon release, transient global warming, and productivity feedback during the Paleocene-Eocene Thermal Maximum (PETM) and related hyperthermal events

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The Paleocene-Eocene Thermal Maximum (PETM), ~55.5 Myr ago, was a geologically brief (~170 kyr) episode of globally elevated temperatures that occurred superimposed on the long-term late Paleocene and early Eocene warming trend. The PETM was marked by a 5-8°C global warming, ocean acidification, rapid sea-level fluctuations, an enhanced hydrological cycle, and a major biotic response on land and in the oceans (Bowen et al. 2006; Sluijs et al. 2008; 2009; Zachos et al. 2005). In addition, the PETM is associated with a prominent negative 2-3 ‰ $\delta^{13}C$ carbon isotope excursion ("CIE"; Kennett and Stott 1991; Koch et al. 1992). The CIE can only be explained by a massive (>1500 Gt) injection of isotopically light CO_2 and/or CH_4 into the ocean-atmosphere carbon pool (Dickens et al. 1995). The PETM has been studied extensively since its discovery in 1991 because it may serve as a deep-time analogue for current global warming. In addition, several events that appear similar to the PETM in nature, but of smaller magnitude, were identified to have occurred during the Paleocene and the early Eocene (e.g., Nicolo et al., 2007; Speijer, 2005). Although the research carried out in the last 15 years has provided new constraints that improved our understanding of PETM carbon cycle and climate change, the source and the mechanisms that caused the carbon input still remains enigmatic.

The currently favored hypothesis to explain the carbon release are (i) large-scale dissociation of oceanic methane hydrate on continental margins (e.g., Dickens et al. 1995) and (ii) sill emplacement in organic-rich sediments, followed by metamorphism and venting that took place in the Northwest Atlantic (Planke et al., 2009). However, by calculating the mass balance of carbon input through the magnitude of the CIE, Pagani et al. (2006) suggested that CO_2 released from methane hydrates or by oxidation of terrestrial and/or marine organic carbon would both require extremely large carbon inputs to explain the warming. Thus carbon from these sources could only have caused the PETM if the climate sensitivity to CO_2 was much higher than currently assumed. In consequence, the PETM either resulted from an enormous input of CO_2 for which currently no satisfying explanation exists, or climate sensitivity to CO_2 was extremely high and possibly enhanced by yet unidentified climate feedbacks.

Beside ongoing investigations related to the source of the carbon, recent work has focused on the importance of high productivity during the peak phase of the PETM, suggesting that shelf areas may have acted as large carbon sinks due to increased weathering and sea level rise (John et al., 2008; Schulte et al., 2009 subm.). Other questions of interest include the role of the additional Paleocene and Eocene hyperthermal events (Speijer & Wagner 2002, Nicolo et al., 2007) as well as the relevance of eustatic sea-level changes during these hyperthermals (Sluijs et al., 2008).

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The Chicxulub impact, shocked carbonates, and correlation to the Cretaceous-Paleogene (K-Pg) boundary: New data from ejecta deposits in the Gulf of Mexico area

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Current issues related to the Chicxulub impact event are centered on the release of climatically-sensitive gases and dust during this impact and on the relation of this event to the clay layer and mass extinction at the Cretaceous-Paleogene (K-Pg) boundary. New data from Mexico, Texas and Alabama as well as from various ODP sites (e.g., Leg 171, 174, and 207) show not only the variable composition of silicic Chicxulub ejecta spherules – documenting contribution from basic to acidic target rocks – but also the ubiquitous presence of carbonate clasts (e.g., Schulte and Kontny, 2005; Yancey and Guillemette, 2008; Schulte et al., 2009). Four types of carbonate clasts with specific impact-related textures have been observed: (i) calcite globules with feathery crystallites, indicative of a former molten state and rapid cooling; (ii) carbonates and dolomites rimmed and intersected by ribbons of phyllosilicates that are interpreted as altered melt lithologies and may indicate intimate mixing of silicic and carbonate melt; (iii) accretionary carbonates consisting of loosely-bound, µm-sized calcite crystals within a silicic (smectite) matrix. The internal aggregate microfabric of these calcite clasts indicates that they formed by accretion of small calcite particles within the vapor plume of the Chicxulub impact (Yancey and Guillemette, 2008; Schulte et al., 2009). The small calcite particles may have originated in carbonate back-reactions – this is subject of our ongoing investigations; (iv) carbonate clasts with a specific porous texture that strongly resembles textures produced in carbonate degassing experiments (Agrinier et al., 2001) and therefore, may be interpreted as material from the Yucatán carbonate platform that has experienced various degrees of shock metamorphism, followed in part by thermal overprint in the ejecta plume. These observations suggest that on one hand, carbonate back-reactions may have limited the release of CO_2 during the impact event. The common presence carbonate-silicic melt interaction associated with dissociation and degassing, on the other hand, may have provided an additional source of climatically sensitive gases.

The presence of a compositionally complex, up to 1 m thick Chicxulub ejecta layer at the K-Pg boundary in diverse depositional systems covering an area ranging from Mexico to Alabama to Texas to the Western Atlantic margin (e.g., ODP Leg 171, 174, and 207) strongly suggests that the Chicxulub impact exactly concurs with the K-Pg boundary. Large scale contemporaneous reworking of ejecta into one distinct layer up to several hundred kyrs. after the impact event seems sedimentologically impossible as such event deposits are rapidly dispersed and diluted after deposition. Moreover, detailed tectonic, sedimentological, and petrographic investigations of K-Pg outcrops in NE Mexico and Texas reveal that either slumping and sliding and/or syn-sedimentary faulting are responsible for the generation of local, lense-like ejecta deposits within latest Maastrichtian marls (Schulte & Kontny, 2005). The cm-thick clay layer found below the ejecta spherule layer in Brazos, Texas, was clearly identified as volcanic ash layer and showed no evidence for distinct ejecta phases (spherules, carbonates, shocked quartz, etc.) otherwise present in the Chicxulub ejecta deposits. In conclusion, combining petrographical characteristics of the ejecta deposits with sedimentological outcrop investigations in the Gulf of Mexico K-Pg sections provides no evidence for a “Chicxulub preceding the K-Pg boundary scenario” (e.g., Keller et al., 2007). Moreover, the excellent correlation of ejecta from these K-Pg sites with ejecta found in distal K-Pg sections, for instance in the western North and South Atlantic, further confirms Chicxulub as the K-Pg boundary impact.

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Environmental change during the PETM drives formation of gigantic biogenic magnetite

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About 55 Ma at the Paleocene /Eocene boundary, the planet experienced a 5-9°C jump in global temperatures within less than 10,000 years known as the Paleocene-Eocene Thermal Maximum (PETM). Debate is still ongoing on what triggered the event that lasted ~180,000 years. However, several lines of evidence suggest that large releases of greenhouse gases, in particular methane from gas hydrates, contributed to the rapidity and extent of the warming event. The event reflects a drastic perturbation of the Earth's ocean and atmospheric systems and was associated with a significant diversification of the terrestrial fauna and flora but also of marine life. Numerous deep-sea benthic foraminifera species disappeared and new forms evolved.

The sediments deposited during the PETM serve as archives that contain distinct paleontological, mineralogical, magnetic, chemical and isotopic evidence of these climatic changes. Kopp et al., (2007) and Lippert & Zachos (2007) report an extraordinary magnetofossil 'Lagerstätte' in kaolinite-rich clay sediments deposited during the PETM at subtropical paleolatitude in the Atlantic Coastal Plain of New Jersey. They used ferromagnetic resonance (FMR) spectroscopy, other rock magnetic methods, and transmission electron microscopy (TEM) of magnetic separates to characterize sediments from boreholes at Ancora (ODP Leg 174AX) and Wilson Lake, NJ, respectively. These sediments contain abundant ~40- to 300-nm cuboidal, elongate-prismatic and bullet-shaped magnetofossils, sometimes arranged in short chains, resembling crystals in living magnetotactic bacteria. Aside from abundant bacterial magnetofossils, these same sediments also contain exceptionally large and novel biogenic magnetite crystals unlike any previously reported from living organisms or from sediments (Schumann et al., 2008).

The spearhead-like, spindle-like and elongated hexaoctahedra magnetite crystals exhibit chemical composition, lattice perfection and oxygen isotopic composition consistent with a biogenic origin. The spearheads and spindles can be up to 4000 nm long (8 times larger than magnetite produced by magnetotactic bacteria). The elongated hexaoctahedra may be up to 1400 nm long and are thus "giant" magnetofossils. They are probably too big to be produced intracellular by prokaryotes, although exceptionally large prokaryotes having cellular diameters up to 750 µm have been reported. In a few cases, we observed apparently intact, tip-outward spherical assemblages of spearhead-like particles that possibly represent the preserved original biological arrangement of these crystals in a hitherto unknown magnetite producing organism.

The discovery of these exceptionally large biogenic magnetite crystals that possibly represent the remains of new micro-organisms that appeared and disappeared with the PETM sheds some light upon the ecological response to biogeochemical changes that occurred during the warming event. Magnetotactic bacteria usually live in the oxic-anoxic transition zone of fresh, brackish, and marine environments including the suboxic zone of

sediments. The occurrence of these new forms together with conventional magnetofossils suggests that they shared a similar ecological niche. The development of a thick suboxic zone with high iron bioavailability – a product of dramatic changes in weathering and sedimentation patterns driven by severe global warming – may have resulted in diversification of magnetite-forming organisms, likely including eukaryotes.
In this study we extended the search for these new magnetofossils to other PETM locations of the Atlantic margin and to a possible modern analog environment in the Amazon delta system.

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Upper Maastrichtian cephalopods and the correlation to calcareous nannoplankton and planktic foraminifera zones in the Nierental Formation of Gams (Styria, Austria)

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A short section within the siliciclastic succession of the Gosau Group of the Gams Basin provides for the first time an upper Maastrichtian cephalopod fauna, which consists of: *Angulithes* (*Angulithes*) sp. indet., *Hauericeras* sp. indet. juv., *Pachydiscus* (*Pachydiscus*) *gollevillensis* (D'ORBIGNY 1850), *Glyptoxoceras* cf. *rugatum* (FORBES, 1846) and *Neancyloceras bipunctatum* (SCHLÜTER 1872). The ammonite *Pachydiscus* (*Pachydiscus*) *gollevillensis* (D'ORBIGNY 1850) is a typical Late Maastrichtian taxon.

Nannofossil investigations indicate the presence of *Lithraphidites quadratus* in all the samples and the absence of *Micula murus* and *Nephrolithus frequens*, which allows the recognition of standard nannplankton zones CC25b and UC20a^{TP}. Planktic foraminiferal data indicate the presence of the marker species *Globotruncanita stuarti* and *Rosita contusa*, typical Maastrichtian species. Additional marker species include *Abathomphalus intermedius* and *Racemiguembelina intermedia. B*oth have a first occurrence higher up in the Maastrichtian, within the *Gansserina gansseri* Zone. Thus, the samples can be attributed to the upper part of the *Gansserina gansseri* Zone, the *Contusotruncana contusa* (Sub-) Zone, just below the first occurrence of *Abathomphalus mayaroensis*, which marks the base of the *A. mayaroensis* Zone*.* A "middle" Maastrichtian age can be inferred from this planktic foraminiferal assemblage.

Integrating foraminiferal and nannofossil data for a correlation to the boreal belemnite zonation of NW Europe leads to a position within the *Spyridoceramus tegulatus /Belemnitella junior* Subzone to the lower part of the *Tenuipteria argentea /Belemnitella junior* Subzone.

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Ichnofabrics of the Cenomanian-Turonian Boundary Event in the Betic Cordillera, southern Spain

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Dark and lighter calcareous and non-calcareous sediments of the Oceanic Anoxic Event at the Cenomanian-Turonian boundary interval (OAE-2) from the Betic Cordillera, southern Spain, display different degree of bioturbation. Their ichnofabrics contain trace fossils *Chondrites* isp., *Palaeophycus heberti*, *Planolites* isp., *Thalassinoides* isp., *Trichichnus linearis*, *Zoophycos* isp., and bioturbational structures (Rodríguez-Tovar et al., in press). Analysis of the ichnofabrics and trace fossil features (diversity, abundance) allowed reconstruction of oxygenation changes. Anoxic sediments display primary lamination and dark colour and commonly are poorly calcareous or noncalcareous. Dysoxic and oxic sediments are lighter and totally bioturbated. Before the OAE-2 oxygenation of sediments was generally good, but it was punctuated by short anoxic sub-events. During the OAE-2, several longer anoxic intervals were recurrently interrupted by shorter dysaerobic and oxic periods. After the OAE-2 oxygenation improved and almost all trace fossils known before OAE-2 occurred again. Nevertheless, oxygenation fluctuated and dropped a few times to anoxia. Generally, the short oxygenation changes reveal a periodicity, which maybe corresponds to the Milankovitch cyclicity.
Two sections (Hedionda and El Chorro, Malaga Province, South Spain) of the Cenomanian–Turonian boundary interval, belonging to the Penibetic domain in the southern Iberian continental palaeomargin were correlated and compared to evaluate changes in palaeoceanographic conditions (Rodríguez-Tovar et al., 2009). The sections originally were located about 70 km apart. The oxic/anoxic sub-events display a tendency to expansion from the more distal section (Hedionda) towards the proximal one (El Chorro). The anoxia spread out from the open sea, probably from slope upwellings. Higher diversity and abundance of trace fossils in comparatively distal position during the pre- and post-event intervals can be caused by a higher abundance of food available for tracemakers. Shape of the correlation bands of the OAE-2 event suggests that the event started earlier by about a few tens of thousands years in the most distal areas than in proximal, slightly higher bottom settings. The proximal section is also thicker pointing to distinctly higher sedimentation rate.
Ichnological analysis of the Cenomanian-Turonian boundary interval in the deep-sea turbiditic sediments of the Polish Carpathians (Magura Unit) revealed similar features in the pre-event and event part of the studied section (Barnasiówka). However, the post-event segment displays very well-oxygenated, oligotrophic, non-calcareous variegated shales (Uchman et al., 2008).

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Ichnological analysis of the Cretaceous–Palaeogene boundary interval in the Caravaca and Agost sections, southern Spain

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Ichnological analysis of the K–Pg boundary at Caravaca brings new important data for the interpretation of the boundary event. The uppermost Maastrichtian marls below the boundary contain the dark-coloured trace fossils *Chondrites targionii, Planolites, Thalassinoides, Zoophycos*, and *Alcyonidiopsis*, which are filled with sediment from the dark boundary layer. The trace fossil taxa in the upper Maastrichtian and lower Danian marls are generally the same, yet much more poorly preserved in the latter. The dark-coloured trace fossils penetrate from two bioturbated horizons in the dark boundary layer, separated by two horizons with primary lamination. The ichnofauna rapidly recovered after the K–Pg event following deposition of the lower, parallel-laminated bed, 14 mm thick, that occurs in the dark boundary layer above the K–Pg boundary. In general, there is no evidence of a severe macroinfaunal crisis among tracemakers at the K–Pg boundary. *Zoophycos* is the deepest ichnofossil, penetrating as far as 90 cm below the K–Pg boundary, probably in stiff or partly firm substrate, which was dewatered to some extent during the slow accumulation of the Danian dark boundary layer. *Chondrites targionii* penetrates 35 cm and *Thalassinoides* 20 cm below the boundary. The firmness probably prevented the *Chondrites* tracemaker from deeper burrowing. The Maastrichtian sediments may be contaminated with Danian microfossils due to bioturbation (Rodríguez-Tovar & Uchman, 2006).

The rusty layer at the base of the dark boundary layer, usually related to the K–Pg boundary impact, is traditionally considered as undisturbed. However, at the Caravaca section the rusty boundary layer is cross-cut vertically by *Zoophycos* and *Chondrites*. It is also penetrated laterally by *Chondrites*, revealing an important colonization of the substrate. Colonization of unfavorable substrates by *Zoophycos* and *Chondrites* tracemakers, as that represented by the rusty boundary layer, was possible because of constructing of open, probably of actively ventilated burrows that facilitate colonization of sediments poor in oxygen and food. Significant bioturbational disturbance of the rusty layer can cause vertical and horizontal redistribution of the components related to the K–Pg boundary impact and, in consequence, to induce erroneous interpretations (Rodríguez-Tovar & Uchman, 2008).

In the Agost section, *Chondrites* ?*targionii*, *Zoophycos*, *Planolites*, *Thalassinoides*, *Alcyonidiopsis longobardiae*, and *Diplocraterion* ?*parallelum* have been identified in the uppermost Maastrichtian below the K-Pg boundary (Rodríguez-Tovar & Uchman, 2004a). They show endobenthic tiering, being *Chondrites* and *Zoophycos* the deepest burrows. The trace fossil assemblage represent vertical partitioning of a singled multi-tiered community under steady-stable conditions in well-oxygenated water bottom, reflecting gradual changes deep into the sediment, with decreasing oxygen pore water and benthic food, and increasing substrate consistency, or a sequential colonisation and community replacement, reflecting the work of two successive communities. In the latter scenario, *Planolites*, *Alcyonidiopsis* and *Thalassinoides*, was produced in a shallow, oxygenated soft substrate by vagile or semi-vagile burrowers. This community was replaced by deeply burrowing stationary deposit-feeding or farming organisms that produced *Chondrites*, and by chemichnial ?sipunculoid worm that produced *Zoophycos*. This replacement is related to decreasing oxygen content and benthic food availability (Rodríguez-Tovar & Uchman, 2004b).

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From the Cretaceous/Paleogene boundary to the Paleocene/Eocene-boundary in the Gosau Group of Gams (Austria)

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In the area of Gams, Paleogene deposits of the Gosau Group crop out in the Gamsbach creek and several tributary creeks. The ca. 400 m thick sedimentary succession was deposited in a middle to lower bathyal environment and comprises the Paleocene and the lowermost Eocene (calcareous nannoplankton zones NP1 to NP12). Both the Cretaceous/Paleogene boundary and the Paleocene/Eocene boundary have been investigated in this area (Egger et al., 2009).

The Cretaceous/Paleogene boundary section includes the upper part of the Cretaceous *Nephrolithus frequens* Zone (CC26) and the lower part of the Paleocene *Markalius inversus* Zone (NP1). The boundary is characterized by (1) an enrichment of the contents of the siderophile elements Ir, Co, Ni, and Cr compared to background and continental crustal values, (2) a sudden decrease of carbon and oxygen isotopic ratios, (3) a sudden decrease of carbonate content, and (4) an acme of the calcareous dinoflagellate cyst *Operculodinella operculata*, which is succeeded by an acme of the small coccolith species *Neobiscutum parvulum.*

The Danian is characterized by a predominance of red and grey pelagic to hemipelagic marlstones and marly limestones. Thin sandy turbidite beds are present in variable amounts, but sandstone to shale ratios stay below 1:5. Turbidite beds are typically calcarenitic, with <10% siliciclastic material.

The Selandian to lowermost Ypresian is characterized by siliciclastic turbidites with sandstone to shale ratios between 1:1 and 5:1. The turbidites display only weak cementation due to very low carbonate content. Centimetre thick turbiditic shales are dark grey and largely carbonate free. The Paleocene/Eocene-boundary interval has been recognized by the lower occurrence of the genus *Rhomboaster*. It occurs in a siliciclastic, high-frequency turbidite succession.

The largely carbonate-free turbiditic succession of the Paleocene/Eocene-transition grades into a succession dominated again by carbonate turbidites (NP10 to NP11). Within the lower part of this succession (sub-zone NP10a) four 3 to 9 cm thick montmorillonite layers were discovered, which are interpreted as volcanic ashes. Similar layers have been found in other Austrian sections and were correlated with the positive ash–series of the Fur Formation in northern Denmark.

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A Southern Hemisphere Study of dinoflagellate cysts and miospores assemblages from the Cretaceous-Paleogene boundary – Ecosystems response and restitution time

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This comparative study of Southern Hemisphere latest Maastrichtian to early Paleocene marine and terrestrial ecosystems aims at providing detailed knowledge of how the two different types of ecological systems responded, timing of events and restitution of the biota following the Cretaceous-Paleogene Boundary (KTB) event. For this purpose samples across the KTB in several marine Southern Hemisphere sites are investigated palynologically with focus on correlation of marine organic-walled dinoflagellate cysts (phytoplankton), spores and pollen.

Global, massive turnovers in the terrestrial and marine ecosystems coincident with the KTB event have been reported from both hemispheres (Vajda et al., 2001; 2003; Nichols & Johnson, 2002). However, the global dinoflagellate cyst record shows no major extinction related to the KTB. Instead, evolution of dinoflagellate taxa takes place in earliest Paleocene and several new species turn up in the fossil record e.g. *Carpatella cornuta, Damassadinium californicum* and *Senoniasphaera inornata*.

Interestingly, in the southwest Pacific the first occurrence of *Trithyrodinium evittii* is immediately above the KTB and this species becomes very abundant in two periods during the earliest Paleocene (Helby et al., 1987: Wilson, 1987; 1988; Willumsen 2003; 2004; 2006; Willumsen et al., 2004). In the New Zealand region the two earliest Paleocene “acme intervals” of *T. evittii* are separated by an acme interval of *Paleoperidinium pyrophorum* (Willumsen, 2002; 2003; Willumsen et al., 2004). The sudden occurrence of *P. pyrophorum* are interpreted to reflect a regional cold water pulse taking place after a period with relatively warmer sea-surface temperature e.g. *T. evittii* dominated dinocyst assemblages. The early Paleocene biological production is considered to be relatively high in the ocean surrounding New Zealand continent, because marine sediments from this period contain, apart from palynomorphs, high concentrations of radiolarian test and diatom frustules (Hollis et al., 1995; Hollis et al. 2003). The rapid changes in the dinoflagellate cyst composition during the earliest Paleocene reflect that major ecological shifts took place in the on the shelf during the first c. 1.5 Ma after the KTB event (Willumsen et al., 2004). In the aftermath of the asteroid impact *T. evittii* invaded the southwest Pacific, which support an extended recovery period in the marine realm compared with the terrestrial record. This observation is in accordance with D´Hondt et al. (1998) who propose that the marine ecosystem was radically altered due to the KTB event and that the open-ocean ecosystem did not fully recover for the first c. 3 Ma of the early Paleocene.

Earliest Paleocene acme intervals of *T. evittii* have also been observed in middle to higher latitudes on the Northern Hemisphere (Nøhr-Hansen and Dam, 1999; 1997). The sudden abundance of this “warm-water” species has been interpreted to reflect Early Paleocene global warming (Smit & Brinkhuis, 1996; Galeotti et al., 2004).

Recently, Habib and Saeedi (2007) reported that a spike of *Manumiella seelandica* is present immediately below the KTB in Bass River section, New Jersey, USA. They correlate this spike, based on isotopic evidence, to a mild global cooling period of tens of thousands of years preceding the KTB event. However, in the New Zealand Region is the genus *Manumiella*, including *M. seelandica*, are most abundant in the earliest Paleocene strata during which siliceous sediments were deposited in an outer shelf to slope setting. Based on the evidence available from New Zealand we therefore conclude that high relative occurrence of *Manumiella* is not restricted to marginal marine sediments, or exclusively observed in uppermost Maastrichtian strata. Thus, further investigations are needed and will focus on carrying out several detailed studies of palynomorph assemblages from marine sediments deposited on the shelf.

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Excursion Guide to RECCCE Workshop

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The ecxursion route crosses three main units of the Eastern Alps, i.e., the Northern Calcareous Alps at Gams (Austro-Alpine Unit), the Helvetic Unit near Gmunden at the Rehkogelgraben, and the Rhenodanubian Flysch Zone as part of the Penninic units (Fig. 1).

During the Cretaceous to Paleogene, these units were arranged paleogeographically from north to south: the Helvetic and Ultrahelvetic units formed parts of the European shelf and continental slope to the north, the Penninic Rhenodanubian Flysch Zone was part of the Alpine Tethys south of the European continental margin, and the Northern Calcareous Alps formed parts of an active continental margin and orogenic wedge south/southeast of the Penninic realm.

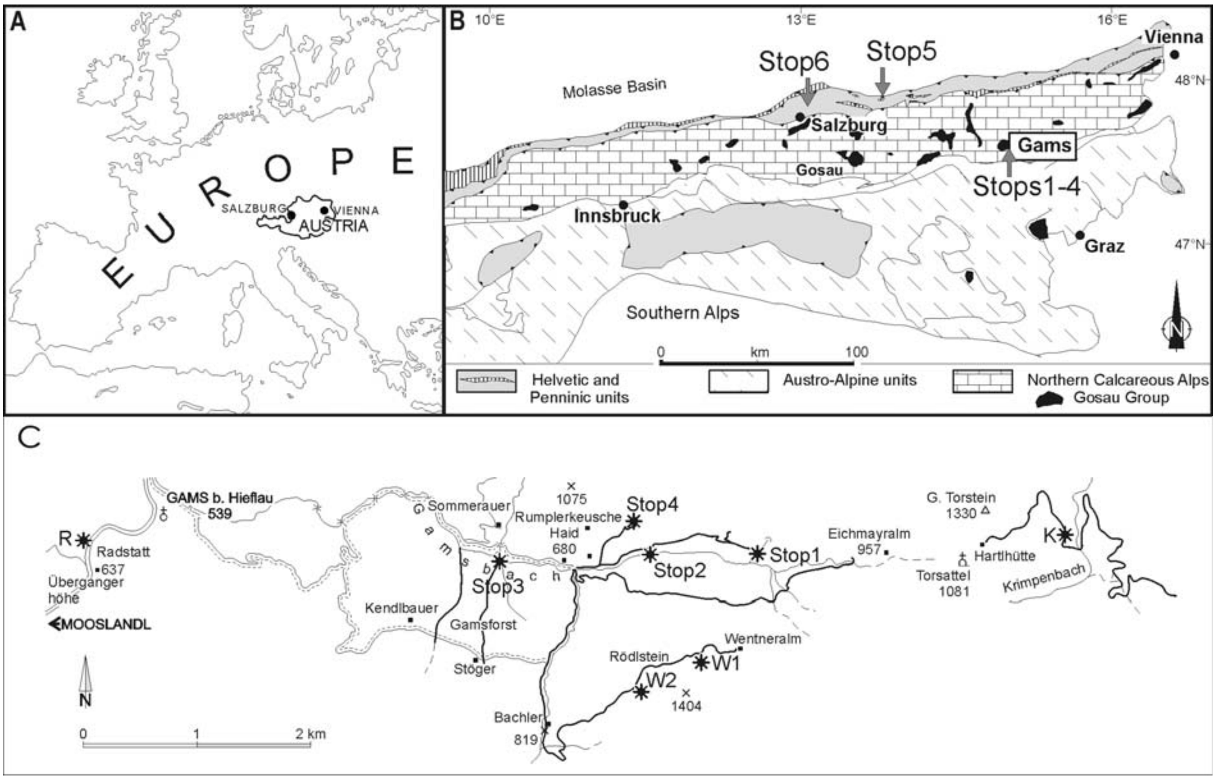


Fig. 1. The Gosau deposits at Gams are located between Salzburg and Vienna in Austria (1A and 1B). 1C: Map of the outcrops visited in the Gams area: Stop 1 Knappengraben K/Pg boundary, Stop 2 – Gamsbach K/Pg boundary, Stop 3 - Paleocene-Eocene boundary interval, Stop 4 – Maastrichtian cephalopod site at Haid. Additional points of stratigraphical interest in the Gams basin: ammonite sites Wentneralm (W1, W2), Krimpenbach (K) and Radstatt (R) (Summesberger & Kennedy, 1996; Summesberger et al., 1999).

The Gosau Group of Gams

The Gosau Group of the Northern Calcareous Alps was deposited in the northwestern Tethys realm during the Late Cretaceous and Paleogene (Wagreich & Faupl, 1994). Paleomagnetic inclination data and general plate tectonic reconstructions for these deposits suggest a paleolatitude of 20° to 30° N (Pueyo et al., 2007).
The Gosau Group comprises mainly siliciclastic and mixed siliciclastic-carbonate strata deposited after Early Cretaceous thrusting (e.g., Wagreich & Faupl, 1994). Deposition of the Gosau Group was the result of transtension, followed by rapid subsidence into deep-water environments due to subduction tectonic erosion at the front of the Austro-Alpine microplate (Wagreich, 1993, 1995). Within the Northern Calcareous Alps the Gosau Group unconformably overlies folded and faulted Triassic to Lower Cretaceous strata. Terrestrial to shallow-marine clastics prevailed during Late Turonian to Campanian, followed by deep-water sedimentation until the Eocene.

The Gosau Group of Gams (Fig. 2) consists of a terrestrial to shallow-marine part of Late Turonian to Early Campanian age (Lower Gosau Subgroup) and deep-marine Campanian to Lower Eocene deposits (Kollmann, 1964; Upper Gosau Subgroup). Outcrops of the Lower Gosau Subgroup are more or less restricted to the western part of the E-W-elongated outcrop belt ("western basin" of Kollmann, 1964; Kollmann & Summesberger, 1982). The following lithostratigraphic units have been distinguished based on Kollmann (1964), Siegl-Farkas & Wagreich (1997) and Egger et al. (2004):

(1) A basal unit of red alluvial conglomerates up to 70 m thick (Kreuzgraben Formation).

(2) A succession of shales and clays with rarely intercalated sandstones, and coaly clays, containing marine fossils, coal and jet (Schönleiten Formation; Kollmann & Sachsenhofer, 1998).

(3) A succession up to 400 m thick of grey shales containing coal seams, sandstone with serpentinite sands, Trochacteon and rudist limestones (Noth Formation; Upper Turonian; Siegl-Farkas & Wagreich, 1997).

(3) Several hundred meters of grey silty shales with rare sandstone tempestites (Grabenbach Formation; Upper Turonian - Santonian), containing ammonites and inoceramids (Kollmann & Summesberger, 1982; Summesberger & Kennedy, 1996).

(4) A transgressive succession of conglomerates, sandstones and grey shales (Krimpenbach Formation, Late Santonian - Late Campanian age, Summesberger et al., 1999; Wagreich, 2004).

(5) Deep-water shales and turbidites of the Nierental Formation, including turbidites and olisthostromes (Upper Campanian – Lower Paleocene) (Wagreich & Krenmayr, 1993, 2005).

(6) Sandstone-rich turbiditic successions (Middle Paleocene – Lower Eocene) (Egger et al., 2001, 2004).

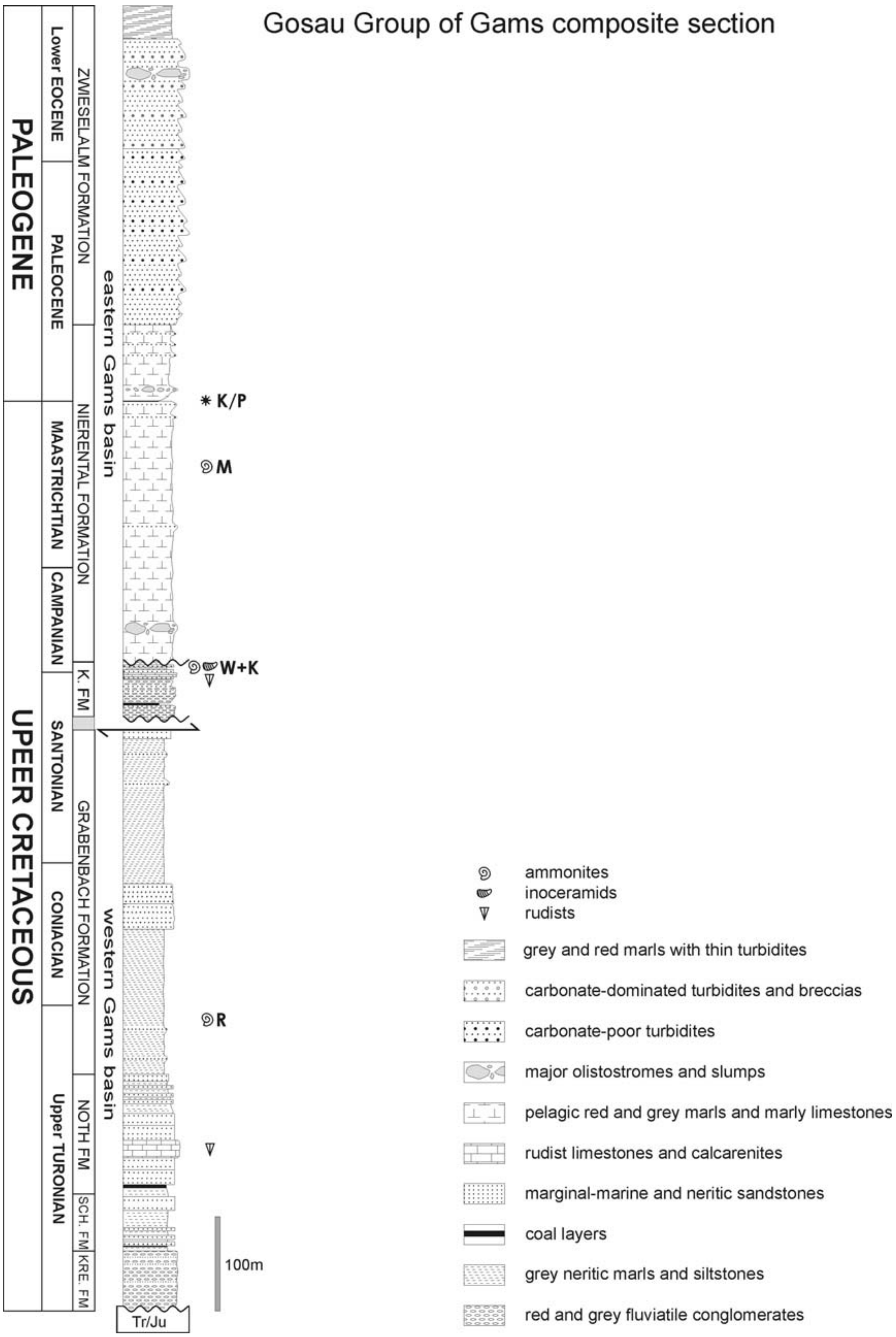


Fig. 2. Composite log of the Gosau Group of the Gams area (modified from Summesberger et al., 2009) (K. FM – Krimpenbach Formation; SCH. FM – Schönleiten Formation; KRE. FM – Kreuzgraben Formation; for abbreviations R, W, M, K/P see Fig. 1) (Summesberger et al., 2009).

RECCCE Excursion Day 1, Saturday, April 25, 2009

STOP 1 Cretaceous/Paleogene boundary at Knappengraben/Gams

Andrei F. GRACHEV & Heinz A. KOLLMANN

Topic: Cretaceous/Paleogene boundary section Gams 1
Lithostratigraphic unit: Nierental Formation (Upper Gosau Subgroup)
Age: Late Maastrichtian (CC26) – early Paleocene (NP1)
Tectonic unit: Untersberg nappe / Göller nappe (Tirolicum), NCA
Location: Outcrops along an abandoned forest road from Haid to Kronsteiner
Coordinates: Latitude 47^0 39.783 N, longitude $14^0$52.982 E, altitude 813.1 m
Specialities: first K/Pg boundary section recognized in that area; recent findings of geochemistry and mineralogy; discussion on impact and volcanism.
References: Lahodynsky (1988a,b), Grachev et al., 2005, 2007, 2008, 2009

The outcrop is located 700 m south of the abandoned farmhouse Kronsteiner (see: Austrian map 1:50.000, sheet 101, Eisenerz) at the crossing between the forest road and the Knappengraben torrent. It is protected by a fenced shelter.

Scientific background

An overview of the Basin of Gams and the stratigraphy of its late Cretaceous/Palaeogene rocks has been given by Kollmann (1964). Detailed studies on the K/T boundary of Gams have first been performed at the Knappengraben outcrop. The lithological section has been described by Lahodynsky (1988a,b). Nanno- and micropalaeontological work has been performed by Wicher (1956), Stradner & Rögl (1988), Wagreich & Krenmayer (1993), Egger et al. (2004), Grachev et al. (2005) and Korchagin & Kollmann in Grachev (2009).

Geological situation

In the outcrop which is currently protected by a fence, a section of the Nierental Formation across the K/Pg boundary is exposed. Beds are dipping at 40° towards SSE (ss 170/40). The base is formed by pale grey, late Maastrichtian shaly limestones with a well-defined ichnofauna (*Chondrites, Zoophycos, Thalassinoides*). The transitional layer consists of dark grey plastic clay containing small mica particles. It is overlain by grey clays and thin, yellowish to brown fine-grained sandstone layers.

The monolith

The major source of information of Grachev et al. (2005) and Grachev (2009) is the "monolith", a block cut out from this outcrop by members of the Department of Geology and Palaeontology of the Vienna Museum of Natural History. It represents a section of 23 cm across the K/Pg boundary.

***Mayaroensis* Zone**.The statigraphically lower part (layers A – I) consists of light grey shaly limestones. Dark spots of approximately 1mm in diameter are sections through *Chondrites*. The burrows are filled with dark boundary clay. Comparable traces are known from K/T boundary sections of Italy, France, Spain, Bulgaria and others and indicate an *Abathomphalus mayaroensis* or *Pseudoguembelina hariaensis* zones of the *Globotruncanidae* and *Heterohelicidae* standard zonation. Planktonic foraminifera, especially *Abathomphalus mayaroensis* and and *Globotruncanita stuarti*, suggests a position at the top of the Zone *Abathomphalus maryaensis*. It corresponds well with other East Alpine sections in the Bavarian Alps (Herm et al., 1981) and "Bed 9" in the Rotwandgraben of the Basin of Gosau, Austria (Peryt et al., 1993). Also in Tunisia (Keller, 1988) it was recorded close to the upper boundary of the Abathomphalus maryaensis Zone of the standard scale.

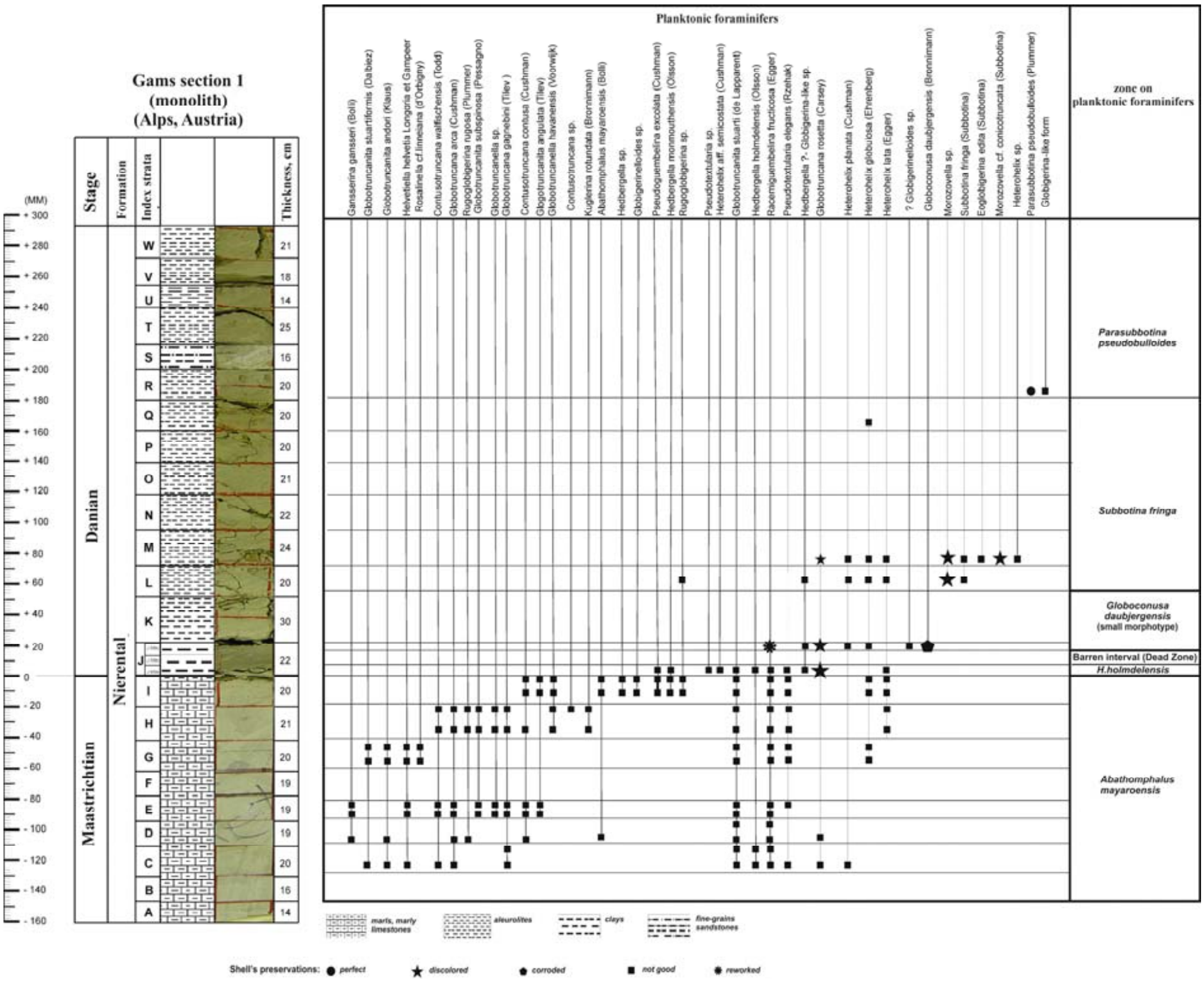


Fig. 3. Distribution of planktonic foraminifera in the monolith (Korchagin & Kollmann in: Grachev, 2009)

The foraminifera assemblage is characteristic for the *Globotruncanita stuarti* Zone, suggesting a position at the top of this zone. While *Gansserina gansseri* LO has been recorded in Gams slightly below the top of the marls underlying the boundary layer J, it extends to the top of the Maastrichtian in the El-Kef section (Tunisia). We therefore infer that the terminal Maastrichtian has been retained in the Gams section.

The K/Pg boundary clay (Layer J) has a thickness of about 2 cm. It is vertically heterogeneous and its texture varies according to its clastic content and the clay matrix distribution. For detailed examination, the layer was subdivided into 6 subunits of 2–3 mm thickness each. The following planktonic foraminifera zones have been recorded:

***Holmdelensis* Zone**. The lower part of the transitional clay of Gams (unit J) contains also an assemblage of small heterohelicids and hedbergellids including *H. holmdelensis* (Grachev, Korchagin, Kollmann et al., 2005). We therefore distinguish the *holmdelensis* Zone also in Gams and correlate it with the boundary clay in Spain. However, the redeposition of *H. holmdelensis* together with other typical Cretaceous planktonic foraminifers cannot be ruled out completely.

Barren interval (dead zone). This interval in the middle part of unit J comprises dark green to black clay. It is approximately 0.2 cm in thickness and lacks foraminifers. It is still premature to speculate about the geographical distribution of this interval because evidence is too scarce.

***Globoconusa daubjergensis* Zone**. Lower boundary defined by FO of index species (= *Globoconusa daubjergensis* Zone in Grachev, Korchagin, Kollmann et al., 2005). The first appearance of *Globoconusa daubjergensis* in Gams is above the barren interval in the unit J.

***Fringa* Zone**. Unit K is a lens of grey, sandy clay with slickensides. It rests on the eroded top of the boundary clay and was produced by a submarine slide. It is overlain by yellow to brownish, fine-grained sandstone and grey clays containing *Subbotina fringa*. Therefore, *Globoconusa daubjergensis* occurs in Gams below the base of the fringa zone and therefore at a lower stratigraphical level.

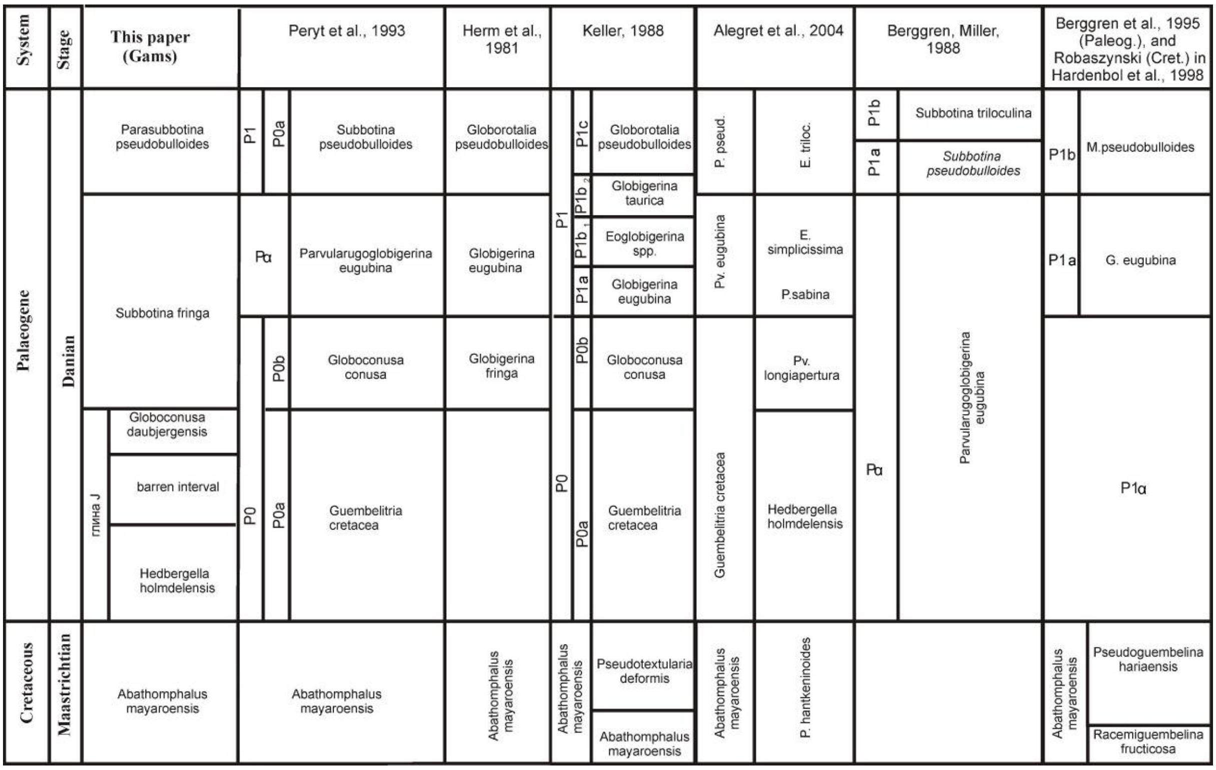


Fig. 4. Correlation chart of Cretaceous/Palaeogene boundary sections (Korchagin & Kollmann in: Grachev, 2009)

Distribution of foraminifera

The distribution chart of foraminifera (Fig. 3) shows that the extinction of genera began well before the accumulation of the boundary clay. The lower part of unit J shows an impoverished fauna of planktonic foraminifera while the benthic foraminifera remained diverse. *Globoconusa daubjergensis* appears first immediately above the barren zone and therefore below the base of the fringe zone (Grachev, Korchagin, Kollmann et al., 2005) and therefore at a lower stratigraphical level.

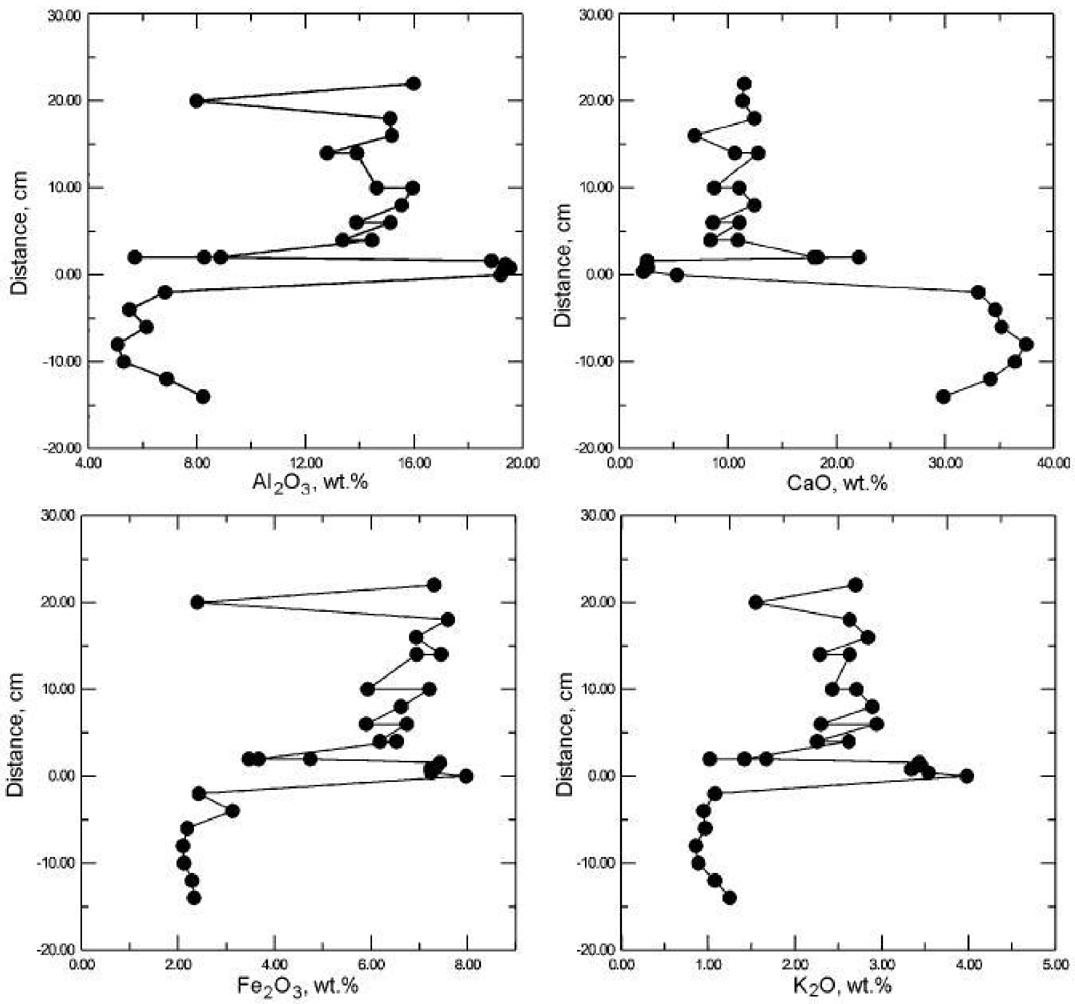


Fig. 5. Distribution of Al_2O_3, Fe_2O_3 and TiO_2 and a very low content of $CaCo_3$ in the monolith (Grachev, 2009)

Composition of the boundary layer

Compared with the underlying and overlying rocks, layer J is characterized by elevated concentrations of Al_2O_3, Fe_2O_3 and TiO_2 and a very low content of $CaCo_3$. In its lower part, the fraction of smectite equals 60% and decreases gradually upwards. The fraction of illite simultaneously increases by 20%. As subunit J1 contains notable amounts of titanomagnetite whose composition is identical to that of basalts, it is reasonable to conclude that smectite developed from volcanic material. The Ir concentration of layer J increases drastically from 5 to 9 ppm up to the barren zone (subunits J1 to J4) and than drops to 3pm in the upper third (subunits J5 to J6). The contents of As, Pb, Ag, Au and Br change synchronously. Above J4, the subunits contain nickel, iron and nickel-iron alloy similar to awaruite (Fe_3Ni) which reach a maximum at J6. The same unit contains beads of practically pure Ni and diamonds ranging in size from submicrons to tens of microns.

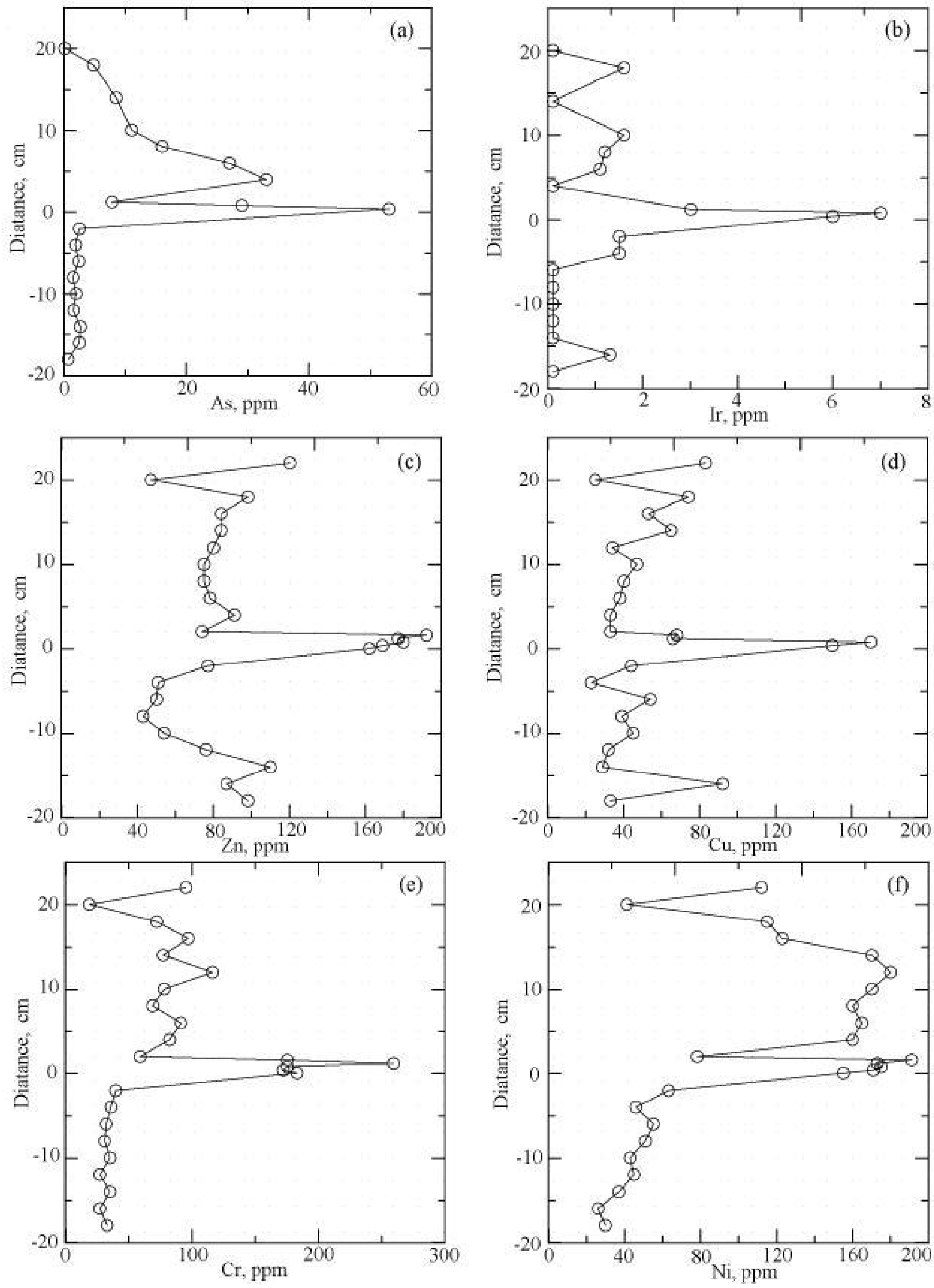


Fig. 6. The distribution of As, Ir, Zn, Cu, Cr and Ni in the monolith (Grachev, 2009)

Conclusions

The distribution of titanomagnetite, As, Pb, Ag, Au and Br in the unit J suggests a volcanic origin of the boundary layer. The subunits J5 – J6 which are characterized by nickel, iron, and an iron-nickel alloy and in J 6 also be diamond crystal were affected by the fall of an asteroid (meteorite).

The **Gams 2** site, a hitherto undescribed outcrop E of the old Haid sawmill (see Austrian Map, 1:50.000, sheet 101, Eisenerz) is a river cut on the right (north) side of the Gamsbach river, just above the alluvial flat (latitude 47°39.47´N, longitude 14°52.05´E). In this outcrop the Nierental Formation with the K/Pg boundary is exposed a a length of approximately 10 m. Besides a larger portion of the calcareous shales below the K/Pg boundary, the section is comparable to the previous one. The rocks dip at 15-30° towards SW. There are subangular fragments of cross-bedded, fine-grained sandstones of 1 cm in size just above the dark brown (rusty) layer of 1-2 mm containing drop-like grains of Ni spinel (Grachev et al., 2006). A neptunian dike extends into the Maastrichtian limestone from the top towards a depth of 1 m. It´s infilling consists of clay with a high mica content. Although it has been formed before the deposition of the transitional layer, the composition of clays in virtually the same.

STOP 2 Cretaceous/Paleogene boundary at Krautgraben/Gams

Hans EGGER & Michael WAGREICH

Topic: Cretaceous/Paleogene boundary section
Lithostratigraphic unit: Nierental Formation (Upper Gosau Subgroup)
Age: Late Maastrichtian (CC26) – early Paleocene (NP1)
Tectonic unit: Untersberg nappe / Göller nappe (Tirolicum), NCA
Location: Outcrops along a bend of Krautgraben (=upper Gamsbach) main creek
Coordinates: E 14°51'50" N 47°39'51"
Specialities: new K/Pg boundary section investigated by Grachev et al. (2008) and Egger et al. (submitted); stratigraphy, sedimentology, geochemistry and mineralogoy data.
References: Grachev et al. (2008); Egger et al. (submitted)

A second K/Pg boundary site in the Gams area is found in the Krautgraben, the valley of the Gamsbach River about 1.25 km west of the Knappengraben site (Fig. 1C). The base of the 6.5 m long section lies 2.5 m below the K/Pg boundary. Egger et al. (submitted) report first results from a combined palaeontological and geochemical analysis of that section.
The section is part of the Nierental Formation of the Gosau Group. The log of the section is given in Fig. 3. The most conspicuous feature is the ca. 2cm thick boundary clay. The base of this clay has been taken as 0 meter level in the columnar log. The sample numbers represent the centimeter distance of the sample above (+) or below (-).
The Gamsbach section consists mainly of fine-grained pelitic rocks. Below the K/Pg boundary light to medium gray marlstones and marly limestones occur (mean carbonate content of 11 samples is 54.9wt.%; mean content of total organic carbon is 0.18wt.%), which are interbedded with thin (< 15cm) sandstone turbidites (fig. 3). Dark gray mottles due bioturbation are present especially in more indurated marly limestone beds. Chondrites- and
well indurated, bioturbated marly limestone with an irregular, wavy upper surface. Above this surface, 0.2 to 0.4cm of yellowish clay marks the base of the Paleocene. The yellowish clay is overlain by gray clay with a maximum carbonate content of about 13wt.% in the upper part of the layer. The overlying 200cm thick middle to dark gray marl to marlstone contains ca. 20 – 50wt.% carbonate (mean content of total organic carbon 0.23wt.%). Twelve thin (0.5 to 5cm) sandy to silty turbidite layers are intercalated in the first 9cm of this marlstone. The color of the marls and marlstones changes up-section from light to medium gray, and they are interbedded with brown to reddish layers. Turbiditic beds become thicker there (up to 14cm). A variegated marl/marlstone bed (40cm thick) occurs at 323cm. It contains clasts of red and brown marly limestone up to 15cm in diameter and some slump folds. Above this mass-flow bed, the grayish-red marl-marlstone succession extends to the top of the section, 400cm above the K/Pg boundary
The section comprises the upper part of the Cretaceous *Nephrolithus frequens* Zone (CC26) and the lower part of the Paleocene *Markalius inversus* Zone (NP1). The boundary is characterized by
(1) an enrichment of the contents of the siderophile elements Ir, Co, Ni, and Cr compared to the background and continental crustal values,
(2) a sudden decrease of carbon and oxygen isotope values,
(3) a sudden decrease of carbonate content, and
(4) an acme of the calcareous dinoflagellate cyst *Operculodinella operculata*, which is succeeded by an acme of the small coccolith species *Neobiscutum parvulum*. The *Neobiscutum* acme is associated with a positive excursion of δ18 O indicating a transient cooling of ocean surface waters due to short-lived changes in the configuration of ocean circulation after the impact.

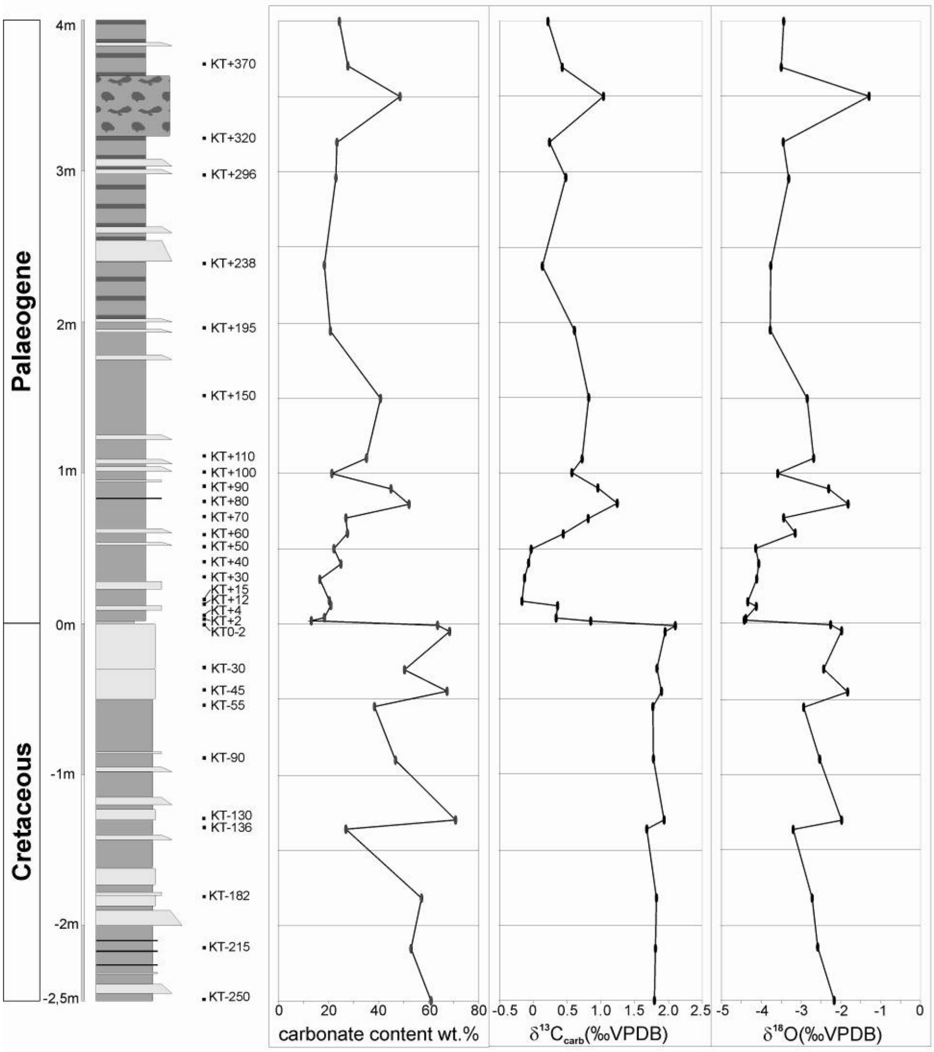


Fig. 7. Stratigraphic log of the Gamsbach section, with carbonate content and variation in the stable isotope abundances (Egger et al., submitted).

STOP 3 Paleocene-Eocene boundary interval in tributary of Gamsbach

Hans EGGER & Michael WAGREICH

Topic: Sedimentology, stratigraphy and isotope geochemistry of Paleocene-Eocene boundary interval
Lithostratigraphic unit: Zwieselalm Formation (Upper Gosau Subgroup)
Age: Thanetian (NP9-NP10) – Ypresian (NP10a,b,)
Tectonic unit: Unterberg nappe / Göller nappe (Tirolicum), NCA
Location: Outcrops along a southern tributary creek of Krautgraben (=upper Gamsbach), S of farm house Sommerauer
Coordinates: 014° 50’ 25’’ E, 47° 39’ 40’’ N
Specialities: high-frequency turbidites through an extended Paleocene-Eocene boundary interval
References: Egger et al. (2004, and submitted)

The Paleogene record in the studied Gams sections is not continuous but punctuated by stratigraphic gaps which comprise zone NP3 and parts of zones NP6 to NP8 (Fig. 8).The Danian deposits are characterized by a predominance of red and grey pelagic to hemipelagic marlstones and marly limestones with thin turbidites. The Selandian to lowermost Ypresian deposits exposed in the tributary creel of the Gamsnach S of Sommerauer are characterized by siliciclastic 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 devoid of carbonate.

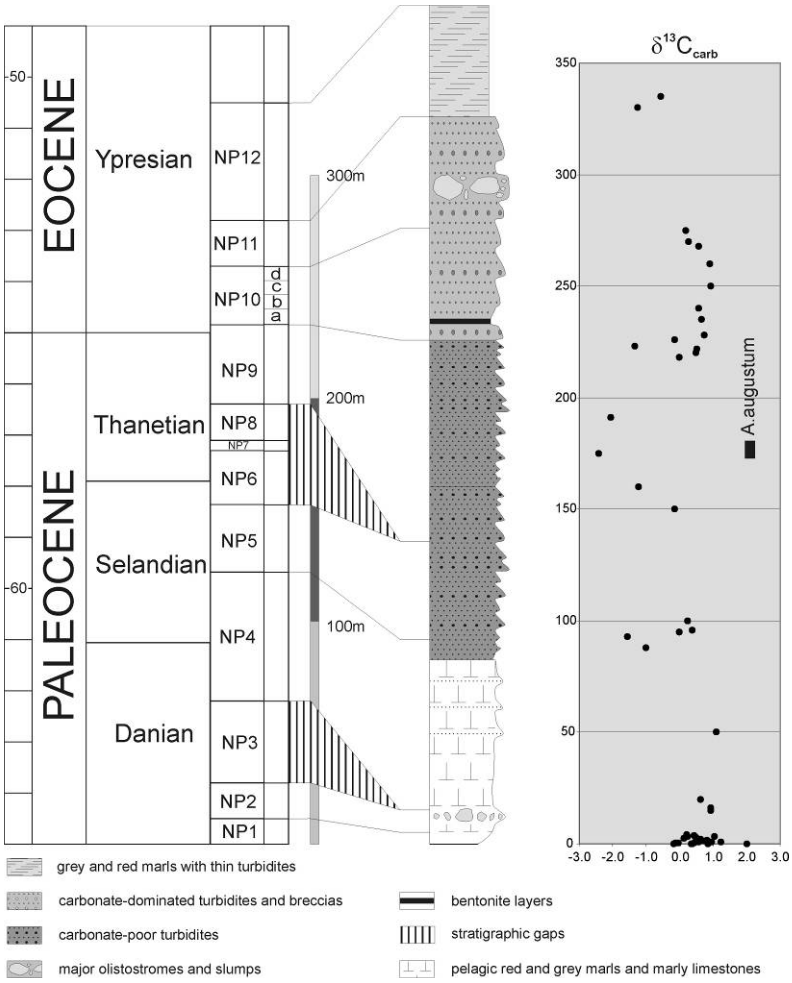


Fig. 8. Paleogene section and Paleocene/Eocene boundary interval at Gamsbach tributary.

The basal Eocene has been recognized in a ca. 100 m thick succession of thin-bedded turbidites and alternating hemipelagic claystone and marly claystone. Occasionally, thin layers and concretions occur consisting essentially of early diagenetic siderite. The succession is characterized by a negative excursion of carbon isotope values, the occurrence of the dinoflagellate species *Apectodinium augustum* and the first occurrence of the calcareous nannoplankton genus *Rhomboaster*.
The largely carbonate-free turbiditic succession of the Paleocene/Eocene-transition grades into a succession dominated by carbonate turbidites (NP10 to NP11). Within the lower part of this succession (sub-zone NP10a) four 3 to 9 cm thick montmorillonite layers were discovered, which are interpreted as volcanic ashes. Similar layers have been found in other Austrian sections and were correlated with ashes of the Fur Formation in northern Denmark. The wide dispersal distance of the tephras implies Plinian scale eruptions and multiple ejections of large volumes of pyroclastic material.

STOP 4 Mid-Maastrichtian ammonite site E of Haid

Herbert SUMMESBERGER, Michael WAGREICH & Gerhard BRYDA

Topic: Sedimentology and integrated stratigraphy in mid-Maastrichtian deposits
Lithostratigraphic unit: Nierental Formation (Upper Gosau Subgroup)
Age: upper part of *Gansserina gansseri* Zone, CC25b/ UC20a^{TP}
Tectonic unit: Untersberg nappe / Göller nappe (Tirolicum), NCA
Location: Outcrops along a forest road and creek northeast of Haid
Coordinates: 14° 51' 35'' E, 47° 40' 00'' N
Specialities: high-frequency turbidites through the Paleocene-Eocene boundary interval
References: Summesberger et al. (2009)

The investigated outcrop within the Nierental Formation exposes about 5 metres of thin and evenly bedded sandy/silty grey shales and marls with a few intercalations of coarse sandstones below 10 cm thickness. The beds are a few centimetres thick, the bedding planes are more or less even. Some bedding planes are coated by a rusty cover. Bioturbation is common, especially in the lower part of the outcrop. *Chondrites* is a typical trace fossil present at topmost parts of graded sandstone/ siltstone turbidite beds. Some bedding planes also show grazing traces by echinoids. Pelitic beds can be subdivided into soft sandy turbiditic shales and more indurated marls, which are interpreted as hemipelagic. The stratigraphic position of the cephalopod-bearing grey marl bed is below a 16 cm thick graded sandstone layer and thus is also interpreted as a hemipelagic, non-turbiditic layer.

Nannoplankton

The most important marker species recognized in the six samples is *Lithraphidites quadratus.* This species is rare to very rare (1 specimen in around 100 fields of view). The presence of *L. quadratus* in all the samples and the absence of *Micula murus* and *Nephrolithus frequens* allow the recognition of standard nannplankton zones CC25b (according to Sissingh, 1977; Perch-Nielsen, 1985) and UC20a^{TP} (Burnett, 1998). The presence of *Corollithion completum* further corroborates this assignement according to Burnett (1998). An early Late Maastrichtian age is interpreted in correlation to belemnite zonations (*tegulatus /junior* Subzone or younger; Burnett, 1998). Very rarely, Campanian to Lower Maastrichtian taxa such as *Broinsonia* and *Quadrum* are found, which are interpreted as reworked from older strata.

Planktonic Foraminifer

All 3 samples contain a similar foraminifera assemblage, mainly characterized by high amounts (>90 %) of planktic foraminifera. The most characteristic and stratigraphically important taxa present are: *Globotruncanita stuarti; Rosita contusa, Abathomphalus intermedius, Racemiguembelina intermedia.*
Globotruncanita stuarti and *Rosita contusa* are typical Maastrichtian species. *Abathomphalus intermedius* and *Racemiguembelina intermedia* both have a first occurrence higher up in the Maastrichtian, within the *Gansserina gansseri* Zone (Robaszynski & Caron, 1995). According to Robaszynski & Caron (1995) *Racemiguembelina fructicosa* occurs below the *Abathomphalus mayaroensis* Zone.
Thus, the samples can be attributed to the upper part of the *Gansserina gansseri* Zone, the *Contusotruncana contusa* (Sub-) Zone, within the upper part of the of the *Gansserina gansseri* Zone, just below the first occurrence of *Abathomphalus mayaroensis*. According to LI et al. (1999, 2000), based on data from El Kef/Tunisia, the assemblage with *Racemiguembelina* (*Pseudotextularia*) *intermedia and Rosita contusa* defines planktic zone CF5 (*Pseudotextularia intermedia* Zone).

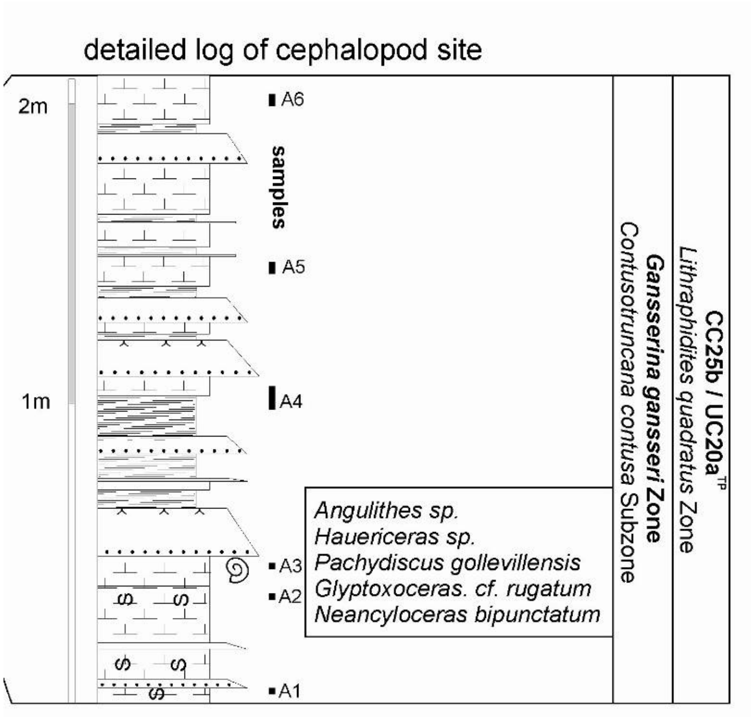


Fig. 9. Section of Stop 4 east of Haid (Summesberger et al., 2009).

Cephalopods and chronostratigraphic correlation

The most indicative ammonite taxon present is *Pachydiscus* (*P.*) *gollevillensis* (D'ORBIGNY, 1850), which ranges at Zumaya (Spain) from the upper part of the *Gansseri* Zone to the middle *Mayaroensis* Zone (Ward & Kennedy, 1993). In terms of ammonite zones this corresponds to the *Anapachydiscus fresvillensis* Zone, which is upper Lower Maastrichtian to lower Upper Maastrichtian. The L.O. level of *P.* (*P.*) *gollevillensis* at Zumaya is within the Upper Maastrichtian zones of *Anapachydiscus fresvillensis* and *Abathophalus mayaroensis* (Ward & Kennedy, 1993: fig. 5), and above the F.O. of *Lithraphidites quadratus* in the Biscay region (Burnett, et al. 1992), within nannofossil zone UC20 (Burnett, 1998). At Sopelana I (Spain) *P. gollevillensis* occurs about 50 m below the K/P boundary near the base of the *Mayaroensis* Zone (Ward & Kennedy, 1993), at Sopelana II (Spain; Ward & Kennedy 1993) it occurs about 50 m below K/P in the *Gansseri* Zone, at Hendaye (France, loc.cit., fig. 8) it ranges within the topmost Maastrichtian Zone of *Anapachydiscus terminus*. Its extinction level is about 10 m below K/P. At Bidart II (France, loc.cit., fig. 11) it occurs in the *Mayaroensis* Zone. Taken together all informations from the Bay of Biscay *P. gollevillensis* is mainly an Upper Maastrichtian species, appearing at the top of the upper Lower Maastrichtian *Gansseri* Zone.

Combining nannofossil (CC25b/UC20a^{TP}) and planktic foraminiferal data (upper part of *Gansserina gansseri* Zone, *Contusotruncana contusa* (Sub-) Zone, CF5 of Li et al., 1999; below the first occurrence of *Abathomphalus mayaroensis*) gives a more precise stratigraphic frame for the cephalopod fauna and allows correlation to other zonations, e.g. the boreal belemnite zonation of northern Europe. The first occurrence of *Lithraphidites quadratus* was recognized within the *Belemnitella junior* Zone of NW Germany, i.e. within the *tegulatus/junior* Subzone, the lowermost subzone of the Upper Maastrichtian. According to the absence of the nannofossil *Micula murus* in our samples, the age cannot be younger than the top of the *Belemnitella junior* Zone. Integrating foraminiferal data, especially the lack of *Abathomphalus mayaroensis*, leads to a correlation of the investigated cephalopod horizon with the interval from the base of the *Spyridoceramus tegulatus /Belemnitella junior* Subzone to the lower part of the *Tenuipteria argentea /Belemnitella junior* Subzone (Burnett, 1998 and TSCreator, www.stratigraphy.org).

RECCCE Excursion Day 2, Tuesday, April 28, 2009

STOP 5 Cenomanian-Turonian at Rehkogelgraben/Hagenmühle (Upper Austria)

Michael WAGREICH, Stephanie NEUHUBER & Hans EGGER

Topic: hemipelagic sediments, black shales and the Cenomanian-Turonian transition, CORBs
Lithostratigraphic unit: "Buntmergelserie" (Upper Gosau Subgroup)
Age: upper part of *Gansserina gansseri* Zone, CC25b/ UC20a^{TP}
Tectonic unit: Ultrahelvetic unit
Location: Outcrops in Rehkogelgraben creek
Coordinates: 013° 55' 30" E, 47° 56' 08" N
Specialities: black shales below water table (use rubber boots) and cyclicity including CORBs
References: Rögl in Kollmann & Summesberger (1982), Wagreich et al. (2008)

The Ultrahelvetic units of Austria are remnants of the European continental slope, lying between the Helvetic shelf in the north and the abyssal Rhenodanubian/Penninic Flysch basins, a part of the Alpine Tethys. The Rehkogelgraben section (Kollmann & Summesberger, 1982) belongs to an Ultrahelvetic slice within the Rhenodanubian Flysch Zone between Hagenmühle and Greisenbach, to the east of Gmunden (Upper Austria, Figure 10). The investigated Cenomanian-Turonian boundary section includes distinctive black shale horizons and a transition from black shales into marly limestones and red marls, which are typical for Ultrahelvetic sections in Upper Austria (Fig. 11). Strata within these tectonic windows have been traditionally attributed to the "Buntmergelserie", an informal lithostratigraphic unit comprising Aptian/Albian to Eocene pelagic and hemipelagic shales, marlstones, and marly limestones with rhythmic limestone and marl alterations. Upper to middle bathyal water depths have been inferred for the Ultrahelvetic units.

The section comprises a 5 m thick succession of Upper Cenomanian marl-limestone cycles overlain by a black shale interval composed of three black shale layers and carbonate-free claystones, followed by Lower Turonian white to light grey marly limestones with thin marl layers (Fig. 12). The main biostratigraphic events in the section are the last occurrence of *Rotalipora* and the first occurrences of the planktic foraminifer *Helvetoglobotruncana helvetica* and the nannofossil *Quadrum gartneri*. The thickest black shale horizon has a TOC content of about 5%, with predominantly marine organic matter of kerogen type II. Vitrinite reflectance and Rock-Eval parameter T_{max} (< 424°C) indicate low maturity. HI values range from 261 to 362 mg HC/g TOC. $\delta^{13}C$ values of bulk rock carbonates display the well documented positive shift around the black shale interval, allowing correlation of the Rehkogelgraben section with other sections such as the Global Boundary Stratotype Section and Point (GSSP) succession at Pueblo, USA. In the lower part of the section, values lie uniformly around 2.5 ‰ and show a slight decrease before the first small peak of 2.6 ‰, which is associated with the LO of the nannofossils *Lithraphidites acutus.* The first occurrence of the nannofossil *Eprolithus octopetalus*, above black shale 2, is associated with a second carbon isotope peak of up to 3.4 ‰, followed by a small peak below 3 ‰ immediately after last the increase in TOC, succeed by a final peak of 3 ‰. Towards the top of the section, values progressively decrease down to 2.7 ‰, but never reach values as low as in the Upper Cenomanian. Sedimentation rates at Rehkogelgraben (average 2.5 mm/ka) are significantly lower than those at Pueblo.

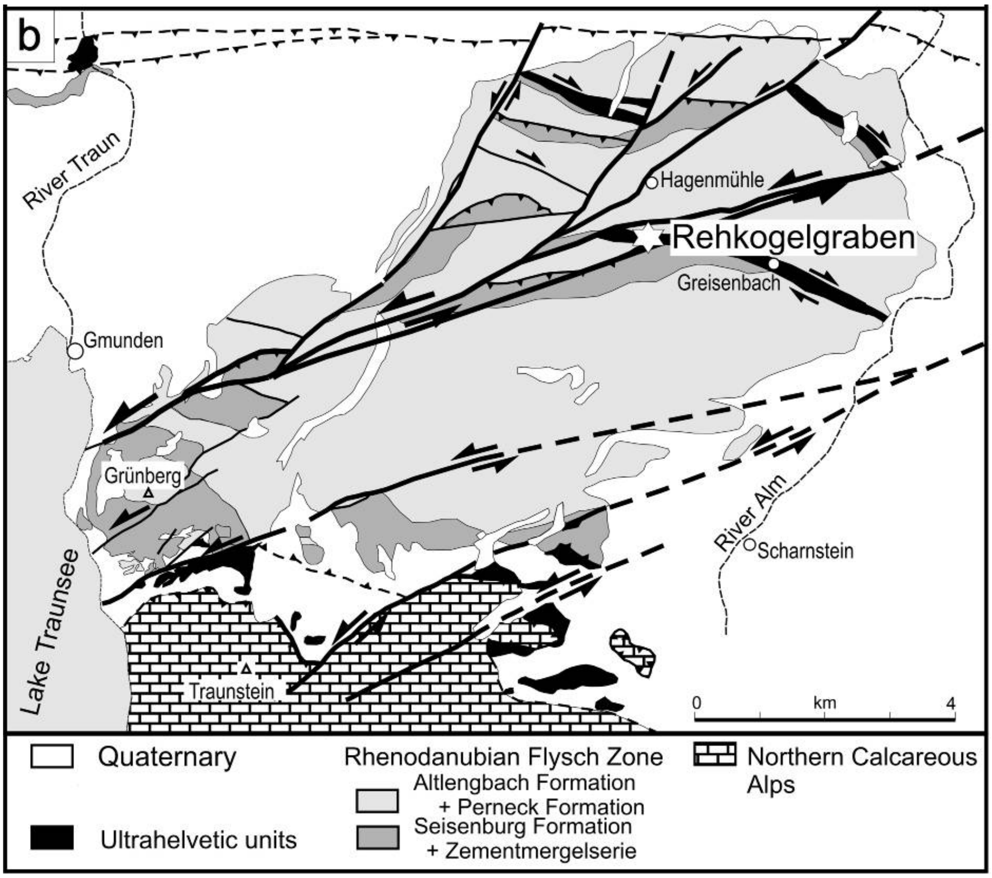


Fig. 10. Geological sketch map of the area east of Gmunden, including outcrop Rehkogelgraben.

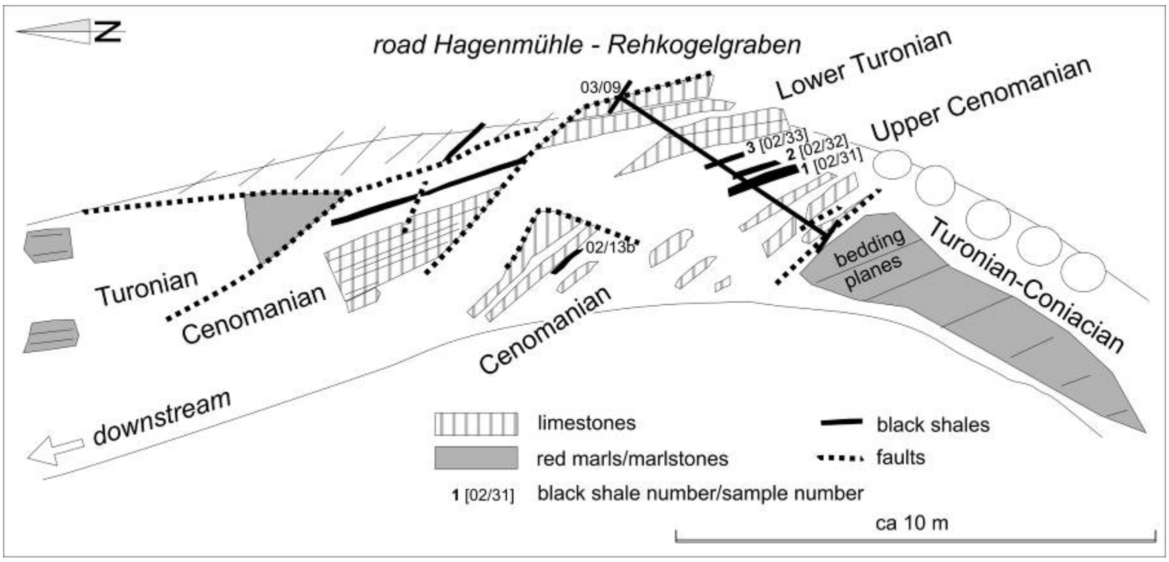


Fig. 11. Map view sketch of the Cenomanian-Turonian outcrop in the creek Rehkogelgraben.

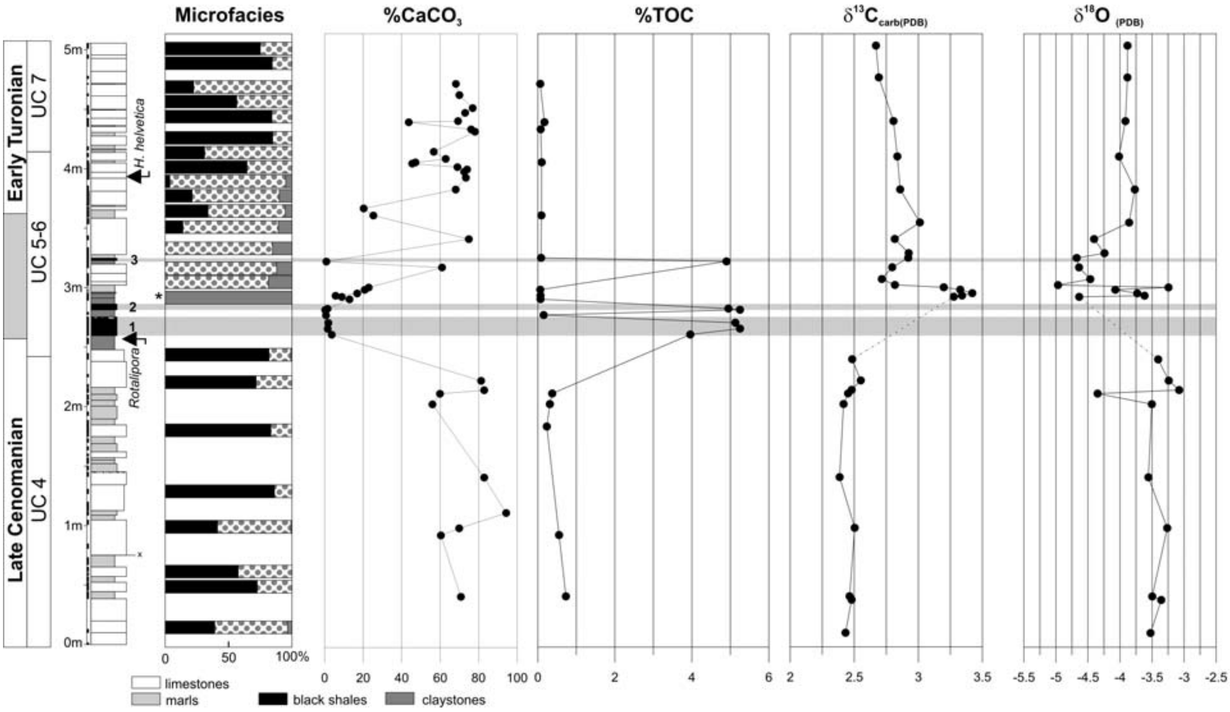


Fig. 12. Sedimentological log of the Rehkogelgraben Cenomanian-Turonian section, including microfacies data based on counts of planktonic foraminifera (black), calcispheres (stippled) and radiolaria (grey) in selected thin sections (except sample marked with * which is a washed residue from a radiolaria-bearing claystone), carbonate and TOC contents, carbon and oxygen isotope values (Wagreich et al., 2008).

STOP 6 Paleocene-Eocene at Anthering near Salzburg

Hans EGGER

Topic: Paleocene/Eocene-boundary section in a succession of deep-water turbidites and hemipelagites
Lithostratigraphic unit: Rhenodanubian Group, Anthering Formation
Age: upper part of calcareous nannoplankton Zone NP9 to upper part of NP10
Tectonic unit: Rhenodanubian Flysch Zone
Location: Outcrops in the Kohlbachgraben near Anthering
Coordinates: E 13° 01’ 17’’, N 47° 53’ 19’’
Specialities: carbon isotope event, *Apectodinium* acme, Lower Eocene bentonites
References: Heilmann-Clausen & Egger, 1997, Egger, Heilmann-Clausen & Schmitz (2000), Crouch et al. (2001), Egger et al. (2003), Huber et al. (2003), Egger & Brückl (2006), Egger, Heilmann-Clausen &Schmitz (2009),

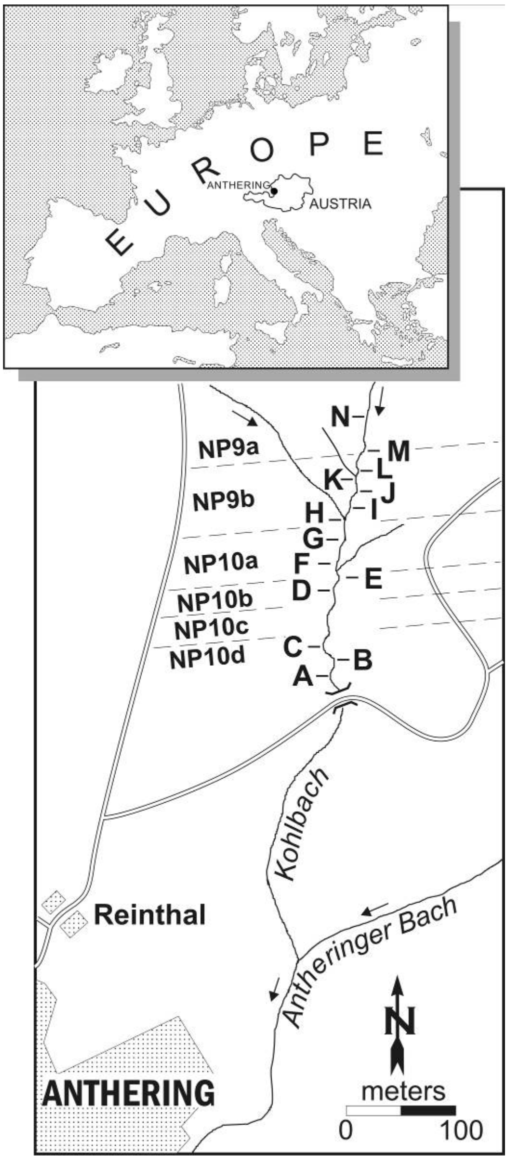


Fig.13. Location of the Anthering section (A-N … outcrops)

The 250 m thick Anthering section (Fig. 13) contains deposits from calcareous nannoplankton zones NP9 and NP10 and displays the global negative carbon isotope excursion (CIE) and the acme of the dinoflagellate genus *Apectodinium* in the upper part of zone NP9. The outcrop across the CIE displays a two-fold lithological subvision (Fig. 14).

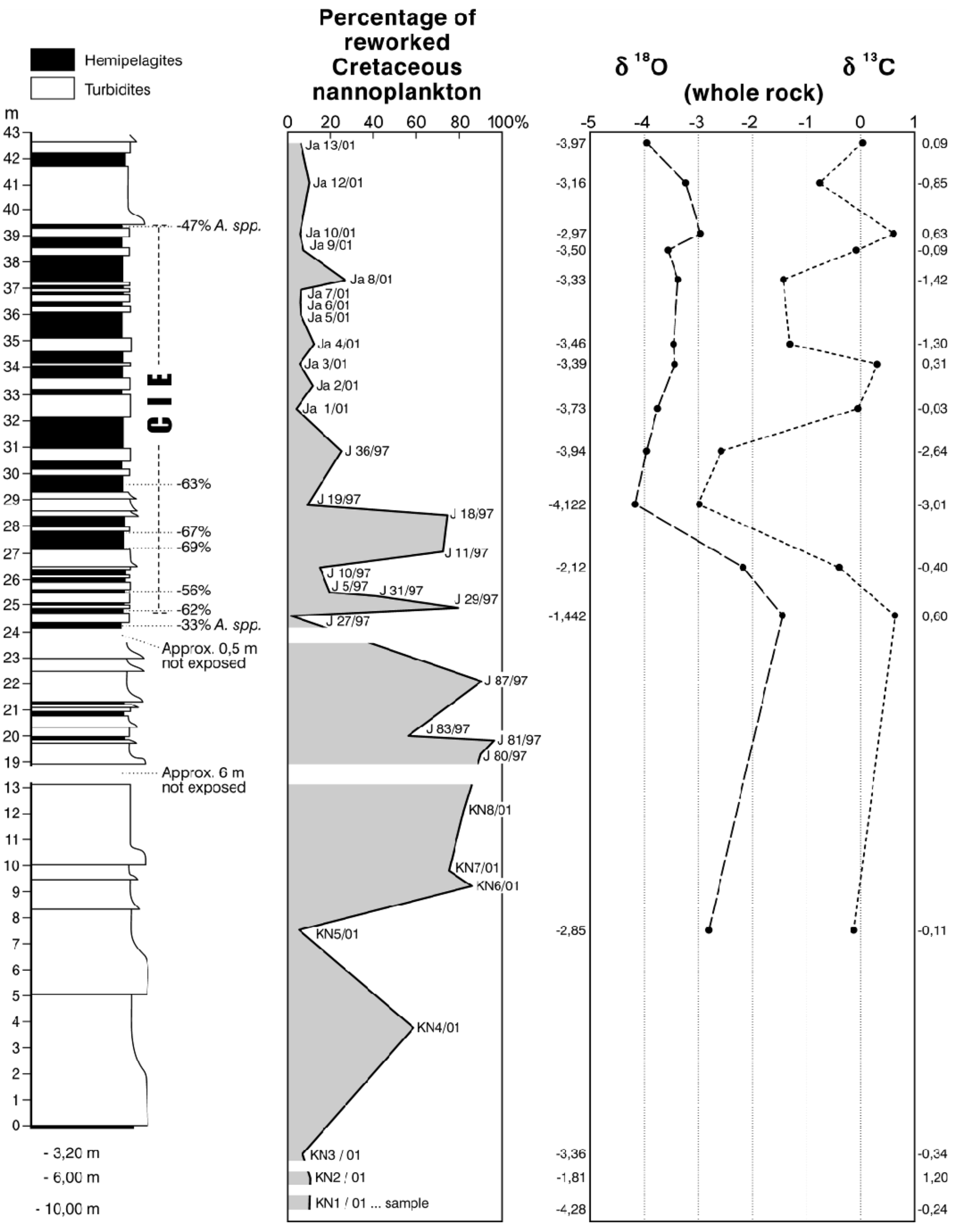


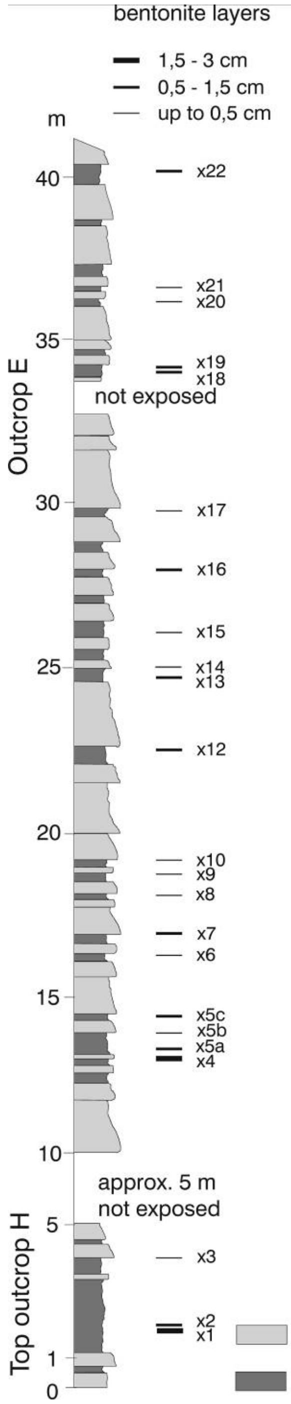
Fig. 14. Lithostratigraphy, percentages of redeposited Cretaceous nannoplankton and stable isotope record of oxygen and carbon across the CIE-interval at Anthering (A. spp…...percentages of the genus *Apectodinium* in the dinoflagellate assemblages).

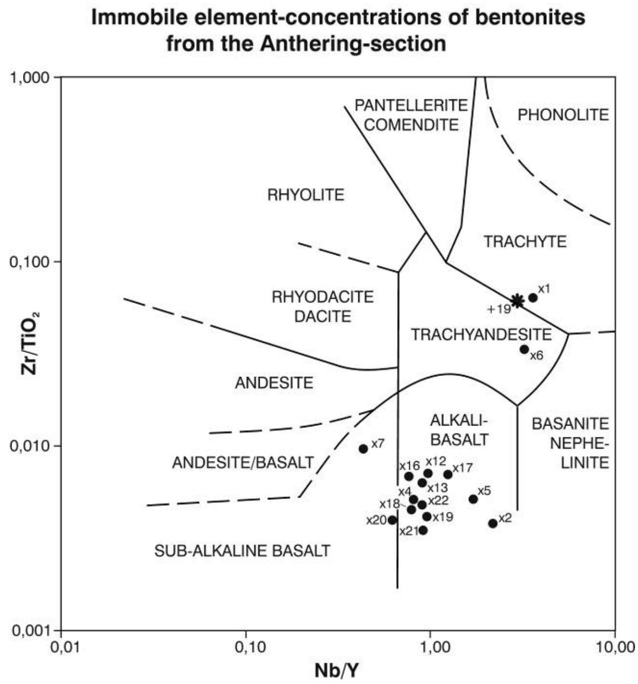
Below the CIE, the section consists primarily of turbidites (98 %) with bed-thicknesses between 0.1 m and 5 m and an average thickness of 1.08 m. The thicker beds show graded bedding with sand-sized fractions at the base. Altogether, sandstone makes up 29 % of the succession. This is an unusually high percentage, as this fraction counts for only 5 % in the entire Anthering section. Small isolated outcrops below the base of the measured section indicate that the onset of this thick-bedded facies is abrupt, without any transition to the underlying thinner-bedded facies. The turbidite facies displays a thinning and fining upward trend and a gradual transition into a clay-rich facies which dominates the upper part of the outcrop.

The carbon isotope and dinoflagellate data suggest that the CIE-interval at Anthering attains a thickness of 15 m, comprising turbidites and hemipelagites (Fig. 14). The thickness of the turbidites varies between 0.08 m and 2.25 m, although only the thickest layer exceeds 1 m thickness. The average thickness of the turbidite beds is 0.39 m and sand-grade material, which makes up 2 % of this facies, occurs only in the thickest layers. Excluding the turbidites the remaining thickness of hemipelagic claystone is 8.4 m. Using Fe– and Ca–intensity curves which probably represent precessional cycles, Röhl et al. (2000) calculated that the CIE interval lasted for 170 ky. From this, a hemipelagic sedimentation rate of 49 $mmky^{-1}$ has been calculated for the compacted sediment across the CIE.

This CIE-interval sedimentation rate is unusual high compared to the mean sedimentation rate of the Rhenodanubian Group, estimated at 25 $mmky^{-1}$ (Egger & Schwerd, 2008). This value incorporates both turbidites and hemipelagites. The rate of hemipelagic sedimentation in the Paleocene can also be calculated using the Strubach Tonstein, which was deposited during a period of ca. 5 my between the upper part of calcareous nannoplankton zone NP3 and the lower part of zone NP8 (Egger et al., 2002). About 25 % of this 50 m thick lithostratigraphic unit consists of turbidites. Excluding the turbidites, the rate of hemipelagic sedimentation has been calculated as 8 $mmky^{-1}$. Similar values (7 - 9 mm ky^{-1}) were determined for the middle and upper part of Zone NP10, whereas a hemipelagic accumulation rate of 13 $mmky^{-1}$ was calculated for the lower part of this zone (Egger et al., 2003). Thus, the CIE was associated with a six-fold increase in the siliciclastic hemipelagite sedimentation rate in the Penninic Basin.
Enhanced erosion of land areas around the CIE-interval can also be inferred from the composition of calcareous nannoplankton assemblages. Whereas, in general, reworked Cretaceous species form only 2-3 % of the calcareous nannoplankton assemblages of the Anthering section, substantial Cretaceous admixtures are present in many samples from across the CIE (Fig. 2). The oldest nannoplankton assemblage showing a high percentage (>50 %) of reworked specimens originates from a turbidite bed 22 m below the onset of the CIE. Three metres above the onset of this geochemical marker, the youngest assemblage with a similar percentage of reworked Cretaceous specimens has been found.
Most of the reworked specimens consist of species with long stratigraphic ranges (*Watznaueria barnesae*, *Micula staurophora*, *Retecapsa crenulata*, *Cribrosphaerella ehrenbergii*, *Eiffellithus turriseiffelii*). Biostratigraphically important species that were found in all of the counted samples include *Broinsonia parca*, *Arkhangelskiella cymbiformis* (small specimens), *Calculites obscurus*, *Lucianorhabdus cayeuxii* and *Eiffellithus eximius* whilst *Marthasterites furcatus*, *Eprolithus floralis* and *Lithastrinus grillii* were found only occasionally. This assemblage suggests that predominantly lower to middle Campanian deposits were reworked at the end of the Paleocene. The reworked Campanian nannoflora in the Penninic Basin primarily originates from the inner shelf of the European Plate, whereas the southerly Helvetic unit of the outer shelf displays a stratigraphically much more complete sedimentary record in the Upper Cretaceous and across the Cretaceous/Paleogene boundary.

In the lowermost Eocene (Subzone NP10a) at the Anthering section, 23 layers of altered volcanic ash (bentonites) originating from the North Atlantic Igneous Province have been recorded, about 1,900 km away from the source area (Fig. 15). The Austrian bentonites are distal equivalents of the "main ash-phase" in Denmark and the North Sea basin. Egger & Brückl (2006) have calculated the total eruption volume of this series as 21,000 km^3, which occurred in 600,000 years. The most powerful single eruption of this series took place 54.0 million years ago (Ma) and ejected ca. 1,200 km^3 of ash material which makes it one of the largest basaltic pyroclastic eruptions in geological history. The clustering of eruptions must have significantly affected the incoming solar radiation in the early Eocene by the continuous production of stratospheric dust and aerosol clouds. This hypothesis is corroborated by oxygen isotope values which indicate a global decrease of sea surface temperatures between 1–2°C during this major phase of explosive volcanism.





Sample (ppm)	Nb	Zr	Y	TiO_2
x1	146.0	486.0	40.0	7673
x2	33.0	244.0	15.0	63887
x4	28.0	238.0	36.0	46700
x5a	40.0	225.0	22.0	49700
x6	154.0	490.0	45.0	14000
x7	26.0	615.0	60.0	37000
x12	27.0	254.0	28.0	35696
x13	31.0	213.0	33.0	34028
x16	30.0	222.0	39.0	32360
x17	28.0	225.0	22.0	31786
x18	36.1	258.4	44.4	34432
x19	33.8	254.4	34.5	34342
x20	33.6	252.8	51.9	39103
x21	29.9	218.8	32.8	37819
x22	35.1	308.0	40.0	39954
+19(Fur)	121.0	684.0	42.0	11300

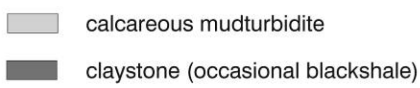


Fig. 15. Immobile element concentrations of the bentonites at Anthering.

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