Introduction

THE EARLY PALEOGENE HISTORY OF THE EASTERN ALPS

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The Eastern Alps, a 500 km long segment of the Alpine fold-and-thrust belt, originated from the northwestern Tethyan realm. The modern structure of the Eastern Alps is the result of the convergence between the European and the Adriatic plates (Fig. 1). Separation of these plates started by oblique rifting and spreading in the Permian and Triassic and continued during the Jurassic by the formation of oceanic lithosphere in the Penninic basin. The structural evolution of this basin was linked to the opening of the North Atlantic (e.g. Frisch, 1979; Stampfli et al., 2002). Due to the presence of lower Eocene sedimentary rocks in the Penninic units, it is clear that the final closure of the Penninic Ocean did not occur before the Eocene (see Neubauer et al., 2000 for a review).

As a result of the oblique collision of the European and Adriatic plates the elimination of the Penninic Ocean started in the West and prograded continuously to the East. E. g., thrusting in the Eastern Alps started at latest in the Middle Eocene whereas in the adjacent Western Carpathians the onset of thrust formation was around the Eocene-Oligocene boundary (see Decker & Peresson, 1996 for a review). In the Eastern Alps continuing convergence during the Miocene caused lateral tectonic escape of crustal wedges along strike slip faults, which strongly affected the nappe complex of the Eastern Alps. A recent review on the complicated structural development of the Eastern Alps is given by Brückl et al. (2010).

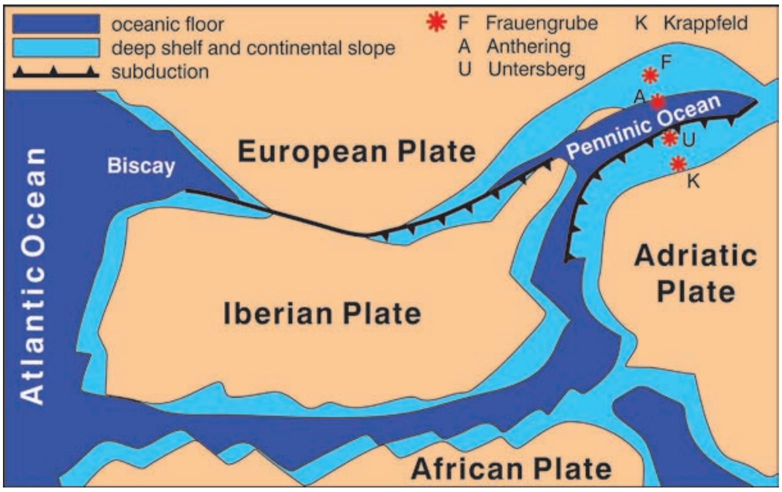

Figure 1 ▲
Schematic paleogeographic map of the NW Tethys and neigh-bouring areas showing the location of the Alpine environmental areas in the early Paleogene (simplified and modified after Stampfli et al., 1998). Notice the location of the sections studied from the southern European plate margin until the northern Adriatic plate margin, with the Penninic Basin in between.

The northern rim of the Eastern Alps consists of detached Jurassic to Paleogene deposits, which tectonically overlie Oligocene to lower Miocene Molasse sediments. From north to south these thrust units originated from (1) the southern shelf of the European Plate (Helvetic nappe complex), (2) the adjacent passive continental margin (Ultrahelvetic nappe complex), (3) the abyssal Penninic Basin (Rhenodanubian nappe complex) and (4) the bathyal slope of the Adriatic Plate (nappe complex of the Northern Calcareous Alps). Thrusting and wrenching from the Upper Eocene on destroyed the original configuration of these depositional areas and, therefore, the original palinspastic distance

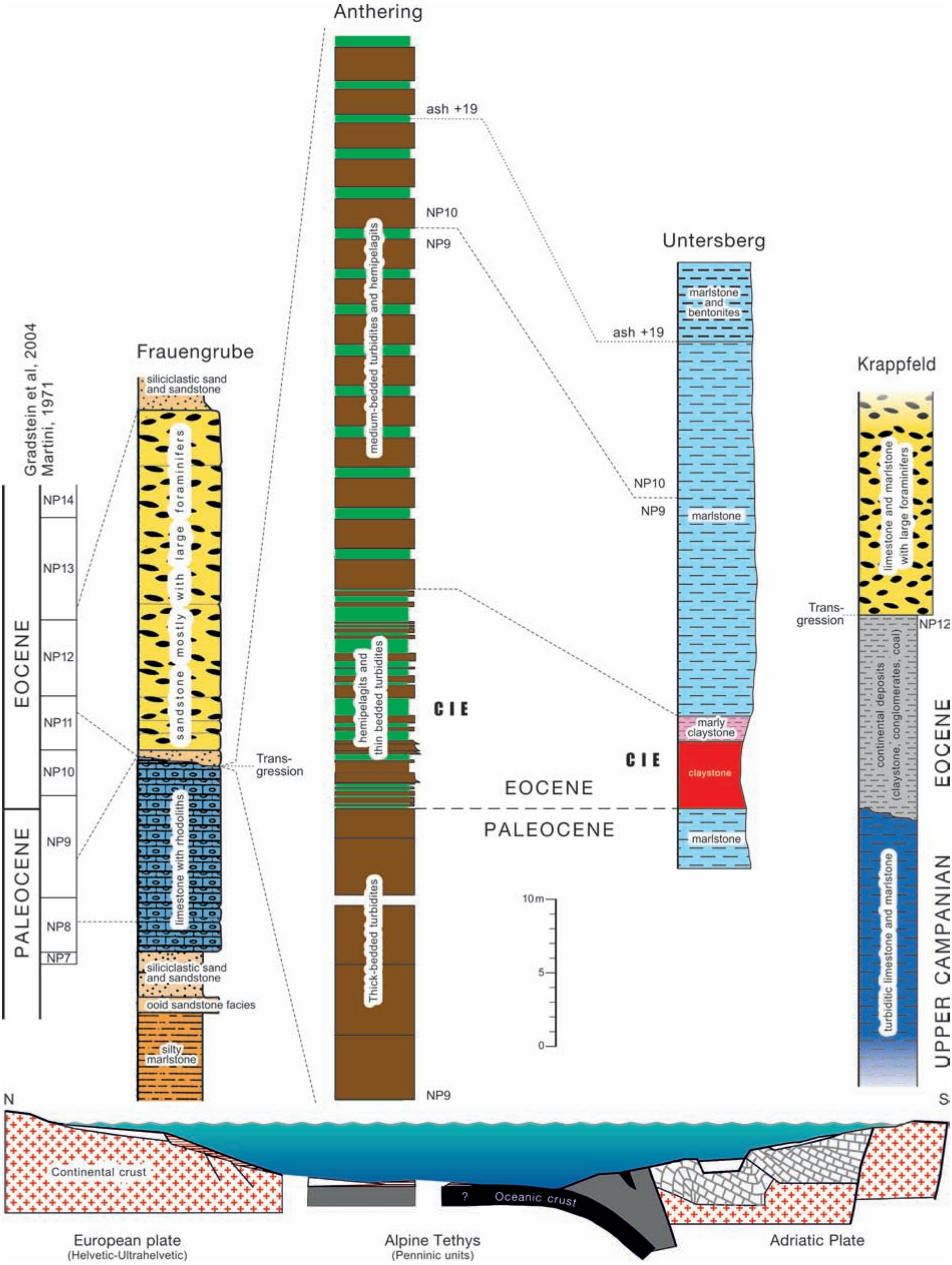

Figure 2 ▲
Correlation and paleogeographic position of Paleogene sections across the Penninic Basin.

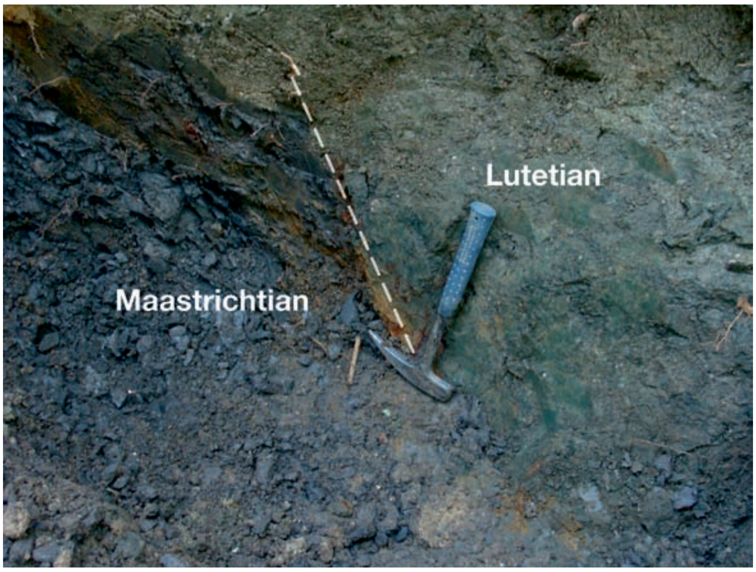

Figure 3 ▲
The transgressional contact between the Gerhardtsreit Formation (Maastrichtian) and the glauconitic sandstone of the Adelholzen Formation (Lutetian) at the Wimmern section (Bavaria).

between the sedimentary environments of the studied sections is not known. During the pre-conference field trips, Paleogene sections along a north-south transect within these four major nappe complexes will be visited. The shelf deposits of the Adriatic Plate (Gurktal nappe complex) will be visited during the post conference field trip in the Krappfeld area in Carinthia (Fig. 2).

The shallow water sedimentary record of the Helvetic shelf is punctuated by a number of stratigraphic gaps, which become more pronounced in direction to the coast of the European continent in the north. So, in the North-Helvetic realm, Paleocene deposits are absent because there, the basal Lutetian (calcareous nannoplankton Sub-Zone NP14b) of the Adelholzen beds (STOP A2/2) with an erosional unconformity overlies the Maastrichtian of the Gerhartsreith Formation (Fig. 3). The Adelholzen Beds are an equivalent of the Bürgen Formation in Switzerland (Schwerd, 2008) where an equivalent hiatus between the Cretaceous and the Eocene occurs (Menkveld-Gfellner, 1997). Basinward, this main hiatus is less extended and comprises only the uppermost Paleocene (upper part of Zone NP9) and the lowermost Eocene (Zones NP10 and NP11 - Egger et al., 2009b) in the southern part of the Helvetic shelf (Frauengrube section – STOP A1/4). A tectonically disturbed but continuous record exists across the K/Pg-boundary of the South-Helvetic domain (Kuhn & Weidich, 1987; Rasser & Piller, 1999).

Towards south, the Helvetic shelf gradually passed into the Ultrahelvetic continental slope. Depending on the paleodepth at this slope, the pelitic rocks of the Ultrahelvetic unit display varying contents of carbonate. Since Prey (1952), these pelitic deposits were assembled to the informal lithostratigraphic unit Buntmergelserie, which was thought to comprise Albian to upper Eocene. However, only very few small outcrops of Paleocene to middle Eocene (STOPA2/1 – Rögl & Egger, 2010) have been recognized and most of them have unclear tectonic positions due to a strong tectonic deformation.

Recently, Egger & Mohamed (2010) recognized a stratigraphic contact between upper Maastrichtian (calcareous nannoplankton Zone CC25) Buntmergelserie and the uppermost Maastrichtian (CC26) to lowermost Eocene (NP11, NP12?) turbidite succession of the Achthal Formation at the Goppling section (STOP A2/4). This 350 thick formation is interpreted as the infill of a slope basin, which formed as a result of block faulting of the continental margin. Deposition took place partly below the planktonic foraminiferal lysocline and partly below the CCD.

Sedimentary successions rich in turbidites other than the Achthal Formation, are known from a number of Ultrahelvetic sites. In Vorarlberg (westernmost Austria), grey turbidites and hemipelagic marlstone (Kehlegg beds) were assigned to the Ultrahelvetic unit by Oberhauser (1991). The base of the Kehlegg beds is situated around the K/Pg-boundary. The unit comprises the entire Paleocene (Egger, unpublished) and its top is tectonically truncated by an overthrust. In a more southerly paleogeographic position on the slope, the deep-water system of the Feuerstätt thrust unit was deposited, exposed in Vorarlberg and southwestern Germany (see Schwerd and Risch, 1983 for a review). There, turbidites and intervening red claystone (“Rote Gschlief-Schichten”) of Paleocene and early Eocene age may represent the in-fills of adjacent slope basins at different paleodepths on the continental slope (Weidich and Schwerd, 1987; Schwerd, 1996). Farther to the east, in Lower Austria, Paleocene to Eocene turbidite successions associated with Buntmergelserie are reported by Prey (1957).

In summary, the style of early Paleogene turbidite sedimentation on the European continental margin seen at the Goppling section was not a unique phenomenon. Rather, it occurred at several sites along the strike of the Ultrahelvetic thrust unit in the Eastern Alps. Nevertheless, it is unlikely that these deposits originated from the same basin. Instead, a number of small sub-basins can be assumed, which, due to the different subsidence histories and their different bathymetric positions, probably cannot be directly correlated.

The largely synchronous formation of different sub-basins along the strike of the Ultrahelvetic slope points to large-scale tectonic deformation of the European continental margin, starting in the late Maastrichtian. The subsidence of intra-slope basins can be related to an extensional tectonic regime. However, for the same period, Nachtmann and Wagner (1987), Wessely (1987), and Ziegler (2002) all document strong intra-plate compressional deformation of the foreland of the Eastern Alps. Together with the data from the Goppling section and other Ultrahelvetic sites, this implies that the southern European plate was simultaneously affected by extension and compression. Here, this style of deformation is typical for anastomosing strike-slip fault zones in convergent settings (e.g. Crowell, 1974).

The well-established contractional deformation event, which affected the European Plate in Late Cretaceous times, was explained by two different models. In the first one, strike-slip faulting was driven

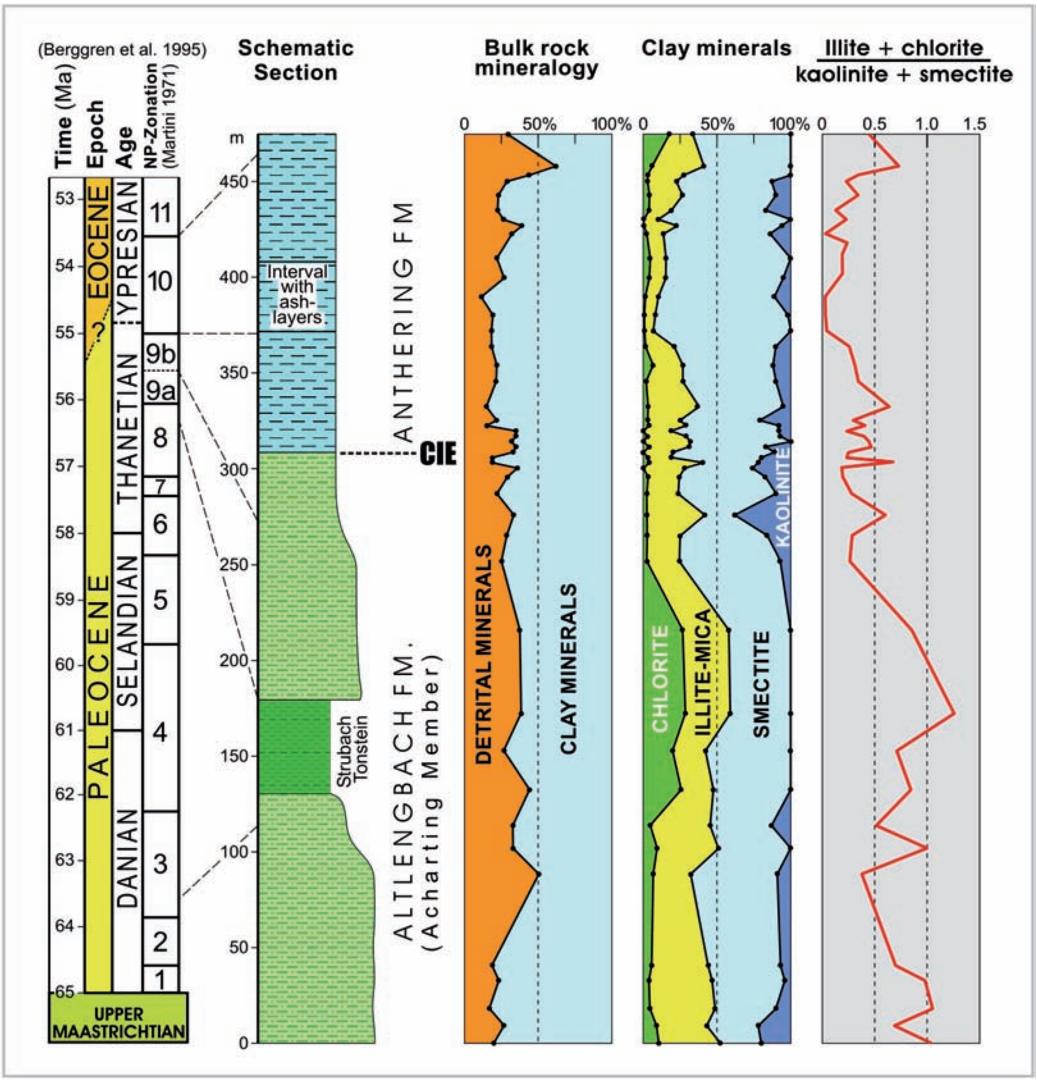

Figure 4 ▲
The Paleogene succession of the Rhenodanubian Flysch in Salzburg, including bulk rock mineralogy and compositon of clay mineral assemblages of upper Maastrichtian to Ypresian hemipelagic shales. CIE: negative carbon isotope excursion (from Egger et al., 2002)

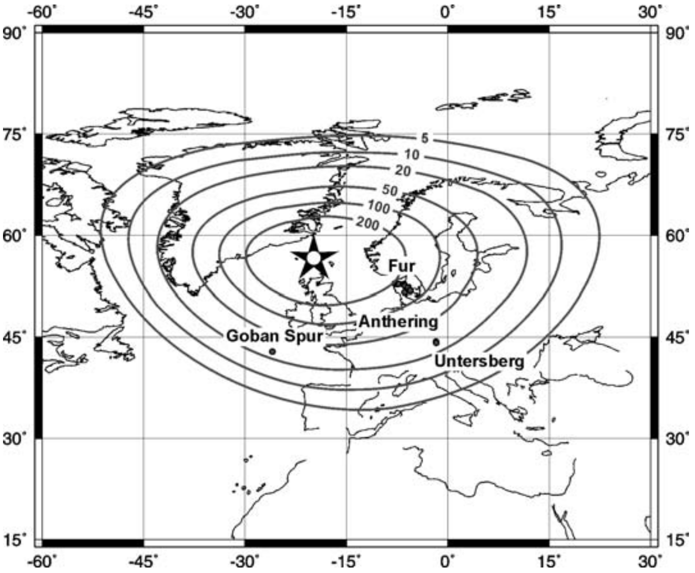

Figure 5 ▲
Map showing the plate tectonic situation at 54 Ma (rotated present day shore lines), the rotated locations where layer +19 has been found (solid spheres and locality names), and elliptical isopachs of layer +19 (grey contours, tephra thickness in mm) with the assumed NAIP-source (star) at one focus.

by the oblique convergence of the European and African plates resulting in a dextral transpressional tectonic regime subsequently to the onset of the collision (Ziegler, 1987). In the second model, this deformation is seen as the result of an important change in relative motion between the European and African plates causing pinching of Europe´s lithosphere between Africa and Baltica (Kley and Voigt, 2008). This model explains better than the collision model the uniform N to NE intraplate shortening of the European plate during the Late Cretaceous event and is also consistent with the NE-SW trending strike-slip faults, which affected the European margin and led to the formation of slope-basins.

Syndepositional faulting and the associated alteration in margin topography, changed sediment dispersal and accumulation not only on the slope but also in the adjacent “Rhenodanubian Flysch” of the Penninic basin. There, a dearth of turbidite sedimentation (= Strubach-Tonstein, STOP A1/3) has been recognized in the Paleocene of the Rhenodanubian Group (Egger, 1995). This was interpreted to be the result of tectonic activity that caused a cut-off of the basin from its source areas (Egger et al., 2002). More precisely, the data presented suggest that structurally controlled slope-basins acted as sediment traps and prevented turbidity current by-pass to the main basin.

The Rhenodanubian Flyschzone constitutes an imbricated nappe complex trending parallel to the northern margin of the Eastern Alps. The deep-water sediments of Barremian to Ypresian age were formalized as Rhenodanubian Group (RG) by Egger and Schwerd (2008). The RG consists primarily of siliciclastic and calcareous turbidites but thin, hemipelagic claystone layers occur in all formations of the RG and indicate a deposition below the local calcite compensation depth, probably at palaeodepths > 3000 m (Butt, 1981; Hesse, 1975). Paleocurrents and the pattern of sedimentation suggest that the deposition occurred on a flat, elongate, weakly inclined abyssal basin plain (Hesse, 1982, 1995). Compared to other turbidite basins, the depositional area of the Rhenodanubian Group is characterized by low sedimentation rates. An average sedimentation rate for the Cretaceous basin fill, incorporating both turbidites and hemipelagites, of only 25 mm kyr^{-1} has been calculated (Egger & Schwerd, 2008).

Lithostratigraphic classification of the Paleogene deposits of the Rhenodanubian Flysch has been proposed by Egger (1995) who distinguished three distinct lithological units in the area of Salzburg. A composite section of the ca. 500 m thick Paleocene to lowermost deposits of the Rhenodanubian Group in the Salzburg area is presented in Fig. 4. In the upper Maastrichtian and Danian the Acharting Member of the Altlengbach Formation is characterized by thin- to medium-bedded turbidites, which display base-truncated as well as complete Bouma sequences. Usually the upper part of the Bouma sequences consist of medium-grey clayey marl which represents c. 35 % of this member whereas the percentage of intervening green coloured hemipelagic shale layers is less than 15 %. A distinct feature of this turbidite facies is the intercalation of thick-bedded and coarse grained sandstones with high amounts of mica and quartz. These are marker beds for mapping the Altlengbach Formation. Calcareous nannoplankton zone NP3 was found in a sequence of very thin-bedded and fine-grained turbidites. Further up-section, hemipelagic claystone (Strubach Tonstein) becomes the dominant rock-type suggesting starvation of turbidite sedimentation. This claystone-rich interval is regarded as part of the Acharting Member.

The lower boundary of the 50 m thick Strubach Tonstein is within Zone NP3. New increased input of turbiditic material started within nannozone NP8 and continued until the upper part of zone NP10. In Zone NP8 and in the lower part of Zone NP9 the facies is very similar to that of the Danian part. In the upper part of zone NP9 graded silty marls of the Anthering Formation become the predominant rock type at the expense of sandstones and siltstones. The base of the Anthering Formation is at the P/E-boundary, which is characterized by the common occurrence of hemipelagic claystone.

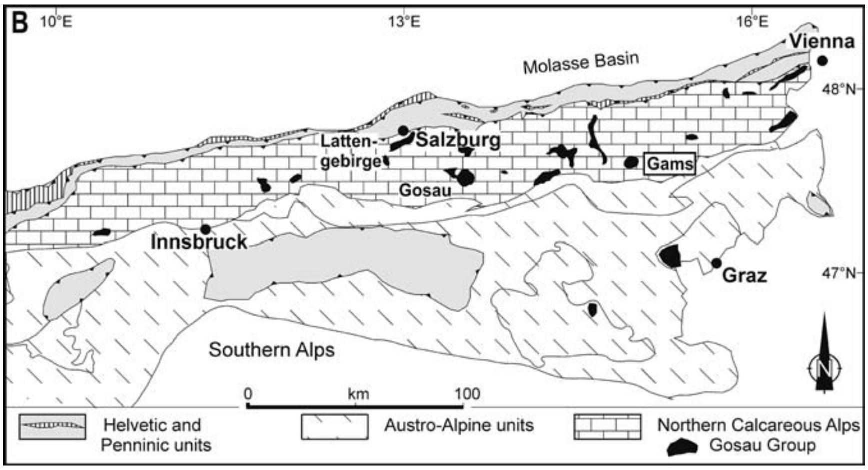

Figure 6 ▲
Location of Gosau deposits in the Eastern Alps

The rate of hemipelagic sedimentation in the Paleocene can be calculated using the Strubach Tonstein, which was deposited during a period of about 6 my between calcareous nannoplankton zones NP3 and NP8. Excluding the turbidites the rate of hemipelagic sedimentation has been calculated as ca. 8 mm ky^{-1}. Similar values (7 mm ky^{-1} resp. 9 mm ky^{-1}) were assessed for the middle and upper part of Zone NP10, whereas a hemipelagic sedimentation rate of 49 mm ky^{-1} has been calculated for the CIE-interval (Egger et al., 2003). From this it can be summarized that in the Penninic basin the CIE was associated with an increase in the sedimentation rate of siliciclastic hemipelagic material by a factor of six.

In general, the input of terrestrially derived material into the basins increases during episodes of low sea-level as a result of enhanced topographical relief. In the Anthering section, the thickest turbidites of the Thanetian and Ypresian occur in the uppermost 13 m of the Thanetian (Egger et al., 2009). This suggests an episode of massive hinterland erosion, indicating a sea-level drop just prior to the onset of the CIE. This is consistent with data from the Atlantic region (Heilmann-Clausen, 1995; Knox, 1998; Steurbaut et al., 2003; Pujalte and Schmitz, 2006; Schmitz and Pujalte, 2007). The synchroneity of this sea-level drop in the Atlantic and Tethys regions indicates a eustatic fluctuation. Starting with the onset of the CIE, mainly fine-grained suspended material came into the basin and caused a strong increase in hemipelagic sedimentation rates. Such an increase associated with decreasing grain-sizes has been reported from P/E-boundary sections elsewhere and interpreted as an effect of a climate change at the level of the CIE, affecting the hydrological cycle and erosion (Schmitz et al., 2001).

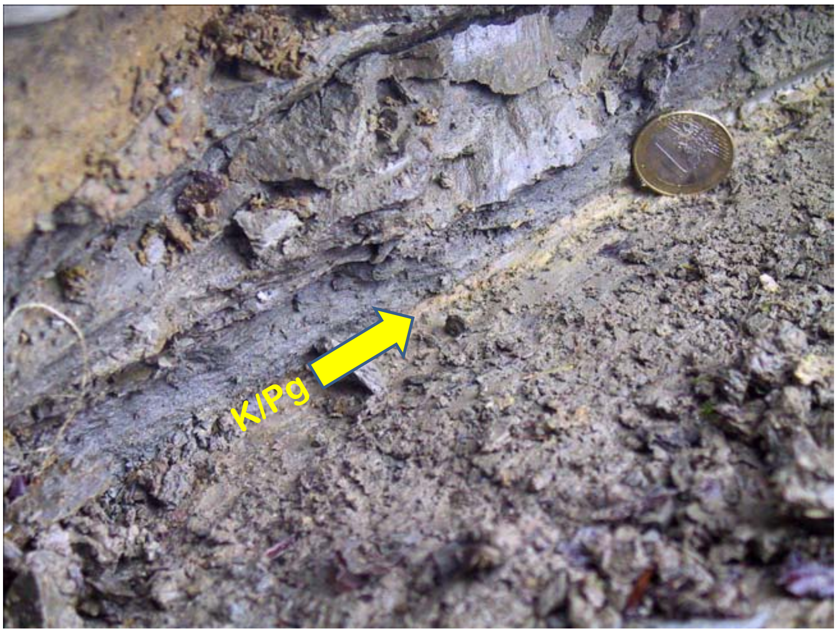

Figure 7 ▲
Image of the K/Pg-boundary at the Elendgraben section

In the lowermost Eocene of the eastern Alps (sub-Zone NP10a) twenty-three layers of altered volcanic ash (bentonites) originating from the North Atlantic Igneous Province have been recorded in lower Eocene deposits (calcareous nannoplankton Sub-Zone NP10a – STOPA1/2) at Anthering, about 1,900 km away from the source area (Egger et al., 2000). The Austrian bentonites are distal equivalents of the “main ash-phase” in Denmark and the North Sea basin. The total eruption volume of this series has been calculated as 21,000 km^3, which occurred in 600,000 years (Egger and Brückl, 2006). 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 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.

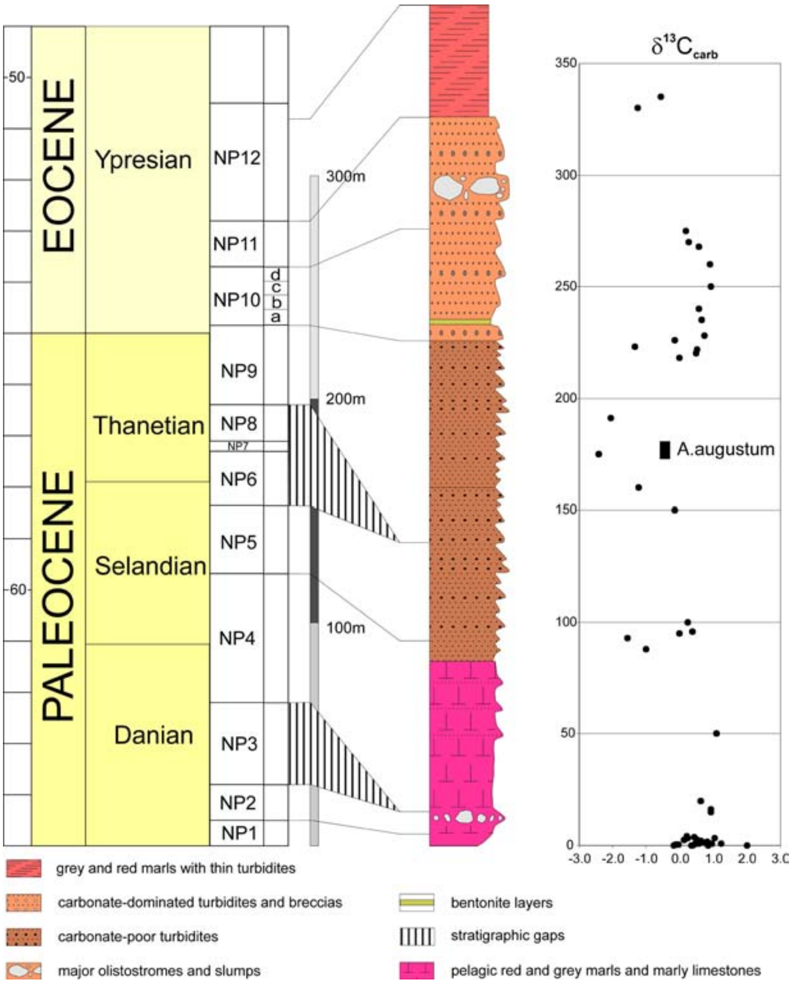

Figure 8 ▲
Stratigraphic and lithological log of the Paleogene part of the Gosau group at Gams, including bulk stable isotope values and the occurrences of *Apectodinium augustum* (Egger et al., 2009a).

Equivalents of these bentonites were found also in the sedimentary record of the northern Adriatic Plate within the succession of the Northern Calcareous Alps at Untersberg (STOP A1/1, Egger et al., 1996) and Gams (Egger et al., 2004). The Cretaceous to Paleogene deposits of the Adriatic Plate lithostratigraphically are formalized as Gosau Group. This Group comprises mainly siliciclastic and mixed siliciclastic-carbonate strata deposited after Early Cretaceous thrusting. The Gosau Group of the Northern Calcareous Alps can be divided into two parts – a lower part consisting of terrestrial and shallow-water sediments, including bauxites, coal seams, rudist biostromes, and several key stratigraphic horizons rich in ammonites and inoceramids (Lower Gosau Subgroup, Turonian to lower Campanian), and an upper part, comprising deep-water marlstone, claystone and turbidites (Upper Gosau Subgroup, upper Campanian to Priabonian). Deposition of the Gosau Group was the result of transtension, followed by rapid subsidence into deep-water environments due to subduction and tectonic erosion at the front of the Adriatic Plate (Wagreich, 1993).

The Cretaceous/Paleogene-boundary has been studied in five sections of the Nierental Formation of the Upper Gosau Subgroup of the Northern Calcareous Alps (Fig. 6). The first K/Pg boundary in the region was discovered in the Wasserfallgraben section of the Lattengebirge in Bavaria (Herm et al. 1981). Perch-Nielsen et al. (1982) reported on biostratigraphical and geochemical results, and Graup and Spettel (1989) measured bulk Ir contents of 4 – 5 ppb in the boundary clay from this section. The second K/Pg boundary site was identified in the Elendgraben section (Fig. 7) near the village of Rußbach in Salzburg (Preisinger et al. 1986; Stradner et al. 1987). The boundary is marked by a 2 – 4 mm thick yellowish clay layer, which contains up to 14.5 ppb iridium. The third K/Pg boundary site was recognized in the Knappengraben section at Gams (Stradner et al. 1987; see figs. 1B and 1C). Again, the boundary clay is of light yellow color and contains up to 7 pbb iridium. Lahodynsky (1988) studied the lithology of the Knappengraben and Elendgraben sections and interpreted their sedimentological and geochemical features as the result of extensive volcanic eruptions. Recently, Grachev et al. (2005, 2007, 2008) followed this interpretation. The fourth K/Pg boundary site has been described at the Rotwandgraben section also near the village of Gosau, about 2.5 km to the southeast of the Elendgraben section (Peryt et al. 1993, 1997). The maximum Ir content in the boundary clay has been determined to be 7 ppb. During the post-conference fieldtrip we will visit the Gamsbach section (STOP A3/1) near Gams (Egger et al., 2009), which is the best accessible and best exposed K/Pg-boundary site in the Eastern Alps.

In the Northern Calcareous Alps, Paleocene/Eocene-boundary sections were studied at Untersberg near Salzburg (Egger et al., 2005) and Gams in Styria (Egger et al., 2009; Wagreich et al., 2011). At the Untersberg section the P/E-boundary is characterized by grey and red claystone intercalated into the dominating marlstone of the succession. At its top, the claystone displays a gradual increase in calcium carbonate contents. This transition zone from the red claystone to the overlying grey marlstone indicates a deposition within the lysocline. The gradual change of carbonate content within the transition zones suggests a slow shift of the level of the lysocline and CCD at the end of the CIE and has been described also from other sections (e.g. Zachos et al., 2005).

Whereas turbidites are exceedingly rare at the Untersberg section, they are the dominant rock type at the Pichler section near Gams. There, 122 m of turbidite-dominated psammitic to pelitic deposits of the Zwieselalm Formation are exposed. Occasionally, thin layers and concretions occur consisting essentially of early diagenetic siderite. The Paleocene/Eocene-boundary at the base of the Pichler section is characterized by a negative excursion of carbon isotope values (CIE), the occurrences of the dinoflagellate cyst Apectodinium augustum and the calcareous nannoplankton species Discoaster araneus and Rhomboaster spp.. Foraminiferal assemblages are predominantly allochthonous and indicate deposition below the calcite compensation depth in the lower to middle part of the section. High sedimentation rates of ca. 20 cm kyr^{-1} are estimated. The pronounced input of sand fraction is different from most other sections showing the Paleocene-Eocene transition (e.g. Schmitz & Pujalte, 2007) and can be interpreted as a result of regional tectonic activity overprinting the effects of global environmental perturbations.

Like on the Helvetic shelf in the north of the Penninic basin (see above), a major stratigraphic gap exists in the sedimentary record of the shelf of the Adriatic plate at the southern rim of the basin. Lower Eocene deposits rest with an erosional unconformity on Upper Campanian marlstone of the Tranolithus phacelosus Zone (Sub-Zone CC23a). In the Pemberger quarry (unfortunately, this outcrop was destroyed by recultivation of the quarry during the last winter), from the base of the marine deposits Assilina placentula, Nummulites burdigalensis kuepperi, Nummulites increscens, and Nummulites bearnensis were described (Schaub, 1981; Hillebrandt, 1993). This fauna is indicative of the lower part of shallow benthic zone SBZ10, which has been correlated with calcareous nannoplankon zone NP12 (Serra-Kiel et al. 1998).

Due to their similar stratigraphic positions, Egger et al. (2009) assumed that the Ypresian transgressions at the shelves of the European and Adriatic Plates originated from the same eustatic event, which was the highstand of the TA2 supercycle in the global sea-level curve (Haq et al., 1988). At the Adriatic Plate, at the base of the marine transgression, black shales occur containing a rich and well preserved tropical palynoflora, indicating Nypa-dominated mangrove type forests, which reflect the early Eocene climate optimum (Zetter and Hofmann, 2001). The onset of this episode of tropical climate was near the top of magnetic Chron 24, which coincides with the NP11/NP12 zonal boundary (Collinson, 2000; Gradstein et al., 2004).

The youngest deposits of the Gosau Group at Krappfeld are of Lutetian age. Hillebrandt (1993) reported both Nummulites hilarionis and Nummulites boussaci, which indicate shallow benthic zone SBZ14, and Nummulites millecaput, which is indicative for shallow benthic zone SBZ15. These foraminiferal zones can be correlated with the upper part of calcareous nannoplankton Zone NP15 and the lower part of Zone NP16 (Serra-Kiel et al., 1998).