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From shelf to abyss: Record of the Paleocene/Eocene-boundary in the Eastern Alps (Austria)

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ABSTRACT

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. These records indicate a two-step event starting with a prominent sea-level fall and followed by climatic changes. At the northern and southern shelves that fringed the Penninic Basin, the shallow-water sedimentary records are incomplete across the Paleocene/Eocene transition. Erosional surfaces indicate a major sea-level drop, which was terminated by an early Eocene (Ypresian) transgression within calcareous nannoplankton Zone NP12. As a proxy for the onset of this sea-level fall a strong increase in the terrestrially-derived input into the Penninic Basin can be used. The abyssal Anthering section from the northern part of the basin comprises a complete succession from NP9 to the upper part of NP10 (upper Thanetian-lower Ypresian). The thickest turbidite beds of this 250 m thick succession appear just before the carbon isotope event in the upper part of zone NP9, which is used to recognize the Paleocene/Eocene-boundary. A major lithological change from a sandstone-dominated facies to a claystone-dominated facies occurs at the onset of the carbon isotope event. This might be the result of a climatic change, resulting in increased intra-annual humidity gradients and increased physical erosion of the hinterland. Consequently, mainly fine-grained suspended material would have come into the basin and caused an increase in hemipelagic sedimentation rates by about a factor of 6. A similar value has been calculated for the bathyal Untersberg section, which was deposited on the southern slope of the basin, where an increased input of siliciclastic material is associated with a carbonate dissolution event during the carbon isotope event. At the southern shelf, a stratigraphic gap within the Gosau Group in the Krappfeld area (Carinthia) comprises the Maastrichtian and Paleocene. After a sea-level rise nummulitic marlstone and limestone were deposited in the lower part of zone NP12. 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.

KEYWORDS **Northwestern Tethys. Paleocene. Eocene. Calcareous nannoplankton. Palynomorphs. Carbon isotopes.**

INTRODUCTION

The base of the prominent (2-3‰) negative carbon isotope excursion (CIE) in the upper part of calcareous nannoplankton zone NP9 has been proposed by the International Subcommission of Paleogene Stratigraphy to recognize the Paleocene/Eocene-boundary (P/E-boundary) (Luterbacher et al., 2000). The CIE, which took place 55.5 Ma ago, has been related to either a massive thermogenetic methane release, or the dissociation of gas hydrates (see Dickens, 2004, for a review) or a comet impact (Kent et al., 2003). The CIE is associated with a global extinction event within deep-sea benthic foraminifera assemblages (see Thomas, 1998 for a review), a rapid diversification of planktonic foraminifera (Lu and Keller, 1993), a global bloom of the dinoflagellate genus *Apectodinium* (Crouch et al., 2001), a turnover in calcareous nannoplankton (Bybell and Self-Trail, 1994), a major turnover in land mammals (Wing et al., 1991), and a shoaling of the calcite compensation depth (Dickens et al., 1995).

In this paper, we focus on the correlation of P/E-boundary sections that were deposited in different marine paleodepths in the northwestern Tethyan realm (Fig. 1). Further, we evaluate the regional or global character of sea-level fluctuations in the latest Paleocene and earliest Eocene.

GEOLOGICAL AND PALEOGEOGRAPHIC SETTINGS

Several P/E-boundary sections (Frauengrube, Antherig, Untersberg and Krappfeld) and selected outcrops (Rote Kirche and Höhwirt) have been investigated along a north-south transect within four major tectonic units of the Eastern Alps, in the Salzburg and Carinthia provinces (Figs. 1 to 4).

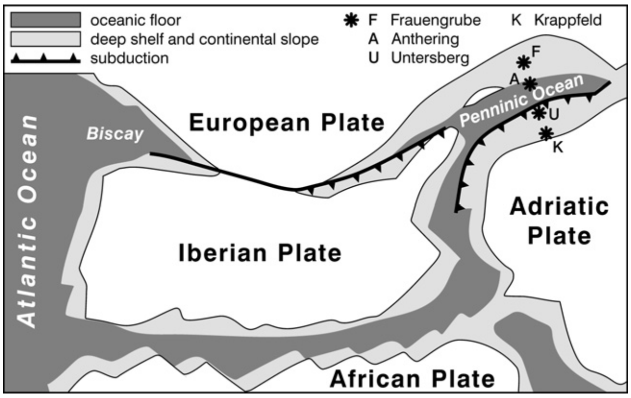

FIGURE 1 | **Schematic paleogeographic map of the NW Tethys and neighbouring areas showing the location of the Alpine environmental areas in the early Paleogene (simplified and modified after Stampfli et al., 1998). Notice the location of the sections studied from the southern European plate margin until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

The above-mentioned tectonic units represent different paleogeographic domains (Fig. 1) of the northwestern Tethys (Faupl and Wagreich, 2000): 1) the Helvetic domain, which comprises sedimentary strata of Middle Jurassic to Upper Eocene age, deposited on the shelf and upper slope of the southern European plate in a passive margin setting; 2) the Penninic domain, which developed due to extension and spreading between the European plate and the Adriatic microplate during Jurassic and Cretaceous times; 3) the Adriatic domain, including the Northern Calcareous Alps (Fig. 2B), which formed part of the northern, active margin of the Adriatic microplate, and 4) the Central Alpine Unit, which formed an interior part of this plate. Due to thrusting and strike-slip displacements in the Miocene, the original palinspastic distance between the sedimentary environments of the studied sections is not known.

METHODS

Calcareous nannoplankton assemblages were studied in smear slides with a light microscope under parallel and crossed polarisation filters at a magnification of 1000x. The reader is referred to Burnett (1998) and Perch-Nielsen (1985) for nannoplankton taxonomy. For the age assignment of the samples, the standard Paleogene nannoplankton zonation (NP zones) of Martini (1971) has been used. Three samples, Frauengrube 1/05, 2/05 and 3/05, were processed palynologically using standard techniques; between 86 and 117 grammes of sediment was used from each. Whole–rock carbon isotopic data were obtained following the procedures of Schmitz et al. (1997). All isotopic values are reported relative to the Peedee belemnite (PDB) standard.

RECORDS OF THE PALEOCENE/EOCENE BOUNDARY

Shelf of the European Plate: Frauengrube and Kroisbach sections

In the Haunsberg area, the Frauengrube section and the immediately adjoining Kroisbach section are both part of the South-Helvetic Thrust Unit (Figs. 1, 2B-C and 5). The base of the succession is a grey mica-bearing marlstone of the Maastrichtian Gerhartsreit Formation (Fm), which is overlain by silty claystones and clayey siltstones of the Paleocene Olching Fm (Fig. 5). Detailed nannoplankton studies at the Cretaceous/Paleogene-boundary indicate continuous sedimentation across the boundary, since the uppermost Maastrichtian (*Micula prinsii* Zone)

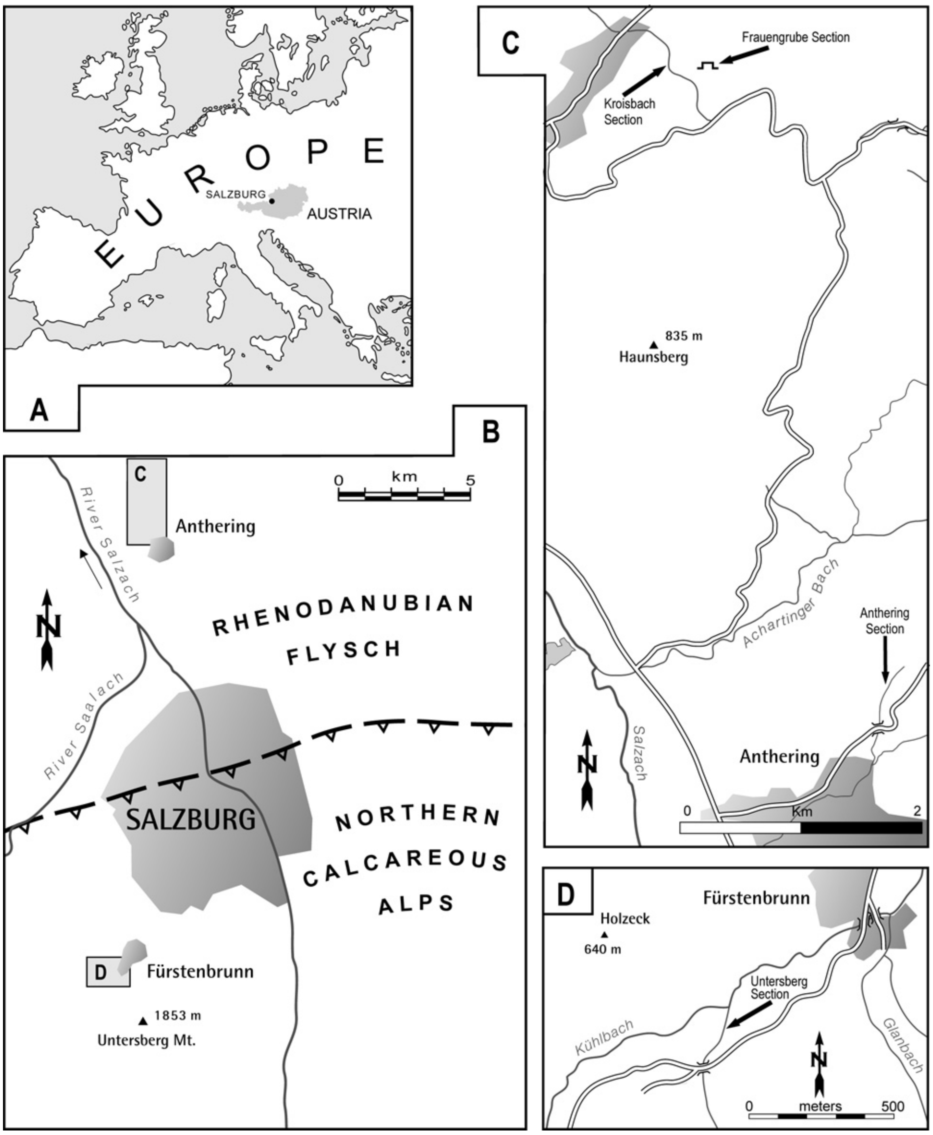

FIGURE 2 **Locations in the vicinity of Salzburg (A) of the Frauengrube-Kroisbach (B-C), Anthering (B-C) and Untersberg sections (D). See restored location in the paleogeographic sketch on Fig. 1.**

and the lowermost Paleocene (*Markalius inversus* Zone) have been discovered (Stradner, pers. comm. 2005). At the boundary, the amount of terrestrially-derived sediment input strongly increases at the expense of carbonate. This shift in the lithological composition defines the lithostratigraphic boundary between the Gerhartsreit and Olching formations.

The Olching Fm is overlain by the Kroisbach Member of the Kressenberg Fm. This member is characterized by glauconite-bearing quartz-sandstones with abundant brachiopods (*Crania austriaca* Traub) in the lower part and oysters (*Pycnodonte* spp.) in the upper part. The glauconitic matrix of the oyster-beds contains calcareous nannoplankton of the Upper Thanetian *Heliolithus riedelii* Zone (NP8) and very well preserved pollen and spores (Stradner, in Gohrbandt, 1963a; Kedves, 1980; Draxler, 2007).

The Kroisbach Member is overlain by the rhodolithic limestone of the Fackelgraben Member. Samples from thin intervening marlstone layers in the upper part of this member contained poorly preserved calcareous nannoplankton of the *Discoaster multiradiatus* Zone (NP9), of latest Paleocene age: *Chiasmolithus* sp., *Coccolithus pelagicus*, *Discoaster falcatus*, *Discoaster multiradiatus*, *Discoaster mohleri*, *Fasciculithus tympaniformis*, *Neochiastozygus perfectus*, *Thoracosphaera* sp., *Toweius callosus*, *Toweius pertusus*. Reworking of Cretaceous species has not been observed.

The Fackelgraben Member and the overlying Frauengrube Member (Figs. 5 and 6) are separated by an irregular erosional surface (Rasser and Piller, 1999), that has been described previously from other outcrops in the Salzburg area (Vogeltanz, 1977). Clasts of the Fackelgraben Member are reworked in the basal part of the Frauengrube Member (Rasser and Piller, 2001), which comprises 0.5 m of brownish sandstone with a marly matrix, that contains poorly preserved calcareous nannoplankton. Reworked species from the Campanian and Maastrichtian make up about 5% of the nannoplankton assemblage (*Arkhangelskiella cymbiformis*, *Broinsonia parca*, *Cribrosphaerella ehrenbergii*, *Cyclagelosphaera reinhardtii*, *Eiffellithus eximius*, *Markalius inversus*, *Micula staurophora*, *Prediscosphaera cretacea*, *Watznaueria barnesae*). The rest of the species observed have their first occurrence during the Paleocene (*Campylosphaera eodela*, *Chiasmolithus bidens*, *Chiasmolithus consuetus*, *Chiasmolithus danicus*, *Coccolithus pelagicus*, *Discoaster barbadiensis*, *Discoaster multiradiatus*, *Thoracosphaera* sp., *Toweius crassus*) or in the lower Eocene (*Neochiastozygus junctus*, *Pontosphaera versa*, *Pontosphaera duocava*, *Rhabdosphaera solus*, *Transversopontis pulcher*, *Zygrhablithus bijugatus*). Unfortunately, no marker species of the lowermost Eocene, in particular of the *Rhomboaster-Tribrachiatus* lineage, have been encountered in our samples. However, *Tribrachiatus orthostylus* (Type B=without bifurcated rays) has been described from the base of the Frauengrube Member from another outcrop in the Haunsberg area (Stradner in Gohrbandt, 1963b). This finding indicates that the onset of the transgression did not take place before the *Discoaster binodosus* Zone (NP11).

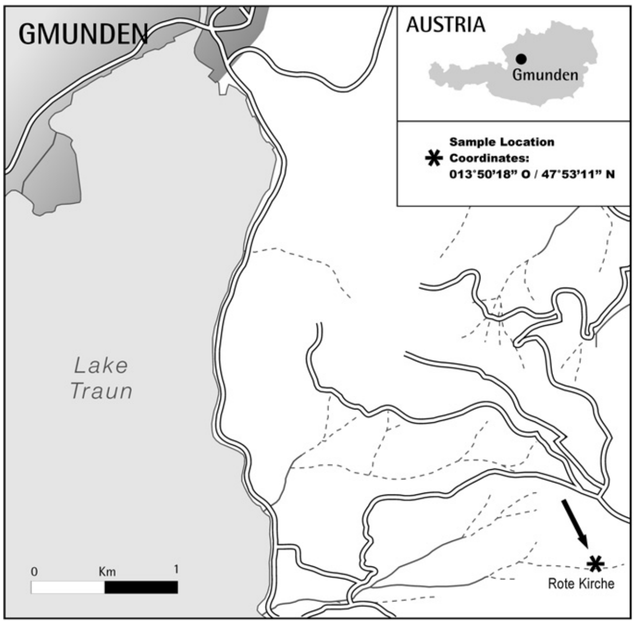

FIGURE 3 | **Location of the Rote Kirche outcrop (South Helvetic Unit) near Gmunden (Upper Austria). The nummulitic limestone of the Frauengrube Members and the underlying sandy marlstone, which yielded calcareous nannoplankton of zone NP12, crop out in this locality.**

Beside calcareous nannoplankton, the samples from the base of the Frauengrube Member contain marine and terrestrial palynomorphs. The terrestrial flora indicates a subtropical to tropical climate containing Sapotaceae and Matixiaceae pollen among other floral elements (*Dictyophyllidites* sp., *Pityosporites* sp., *Nudopollis* sp., *Subtriporopollenites* sp., *Cupuliferoidaepollenites liblarensis)*. Palmpollen have not yet been found (Draxler, pers. comm. 2006).

The marine flora contains very similar, relatively well preserved dinoflagellate assemblages dominated by *Homotryblium tenuispinosum* ("*tasmaniense*-type"), *Polysphaeridium zoharyi* and *Apectodinium* spp. (excluding *A. augustum*). The three taxa are equally common, and together are estimated to constitute 60-90% of the dinoflagellate assemblages. Of relevance for age-determination is the occurrence of the *Areoligera undulata - A. sentosa* group (present in each sample), *Glaphyrocysta* cf. *semitecta* (samples 1 and 3), *Deflandrea oebisfeldensis* (2 specimens in sample 1) and *Phthanoperidinium* cf. *echinatum* (1 or 2 specimens in sample 1). In addition to these taxa, the samples also include low abundances of several long ranging taxa without stratigraphic value. *Spiniferites* spp. and peridinioids, apart from *Apectodinium*, are rare.

The *Areoligera undulata - A. sentosa* group, *Glaphyrocysta* cf. *semitecta* and *Phthanoperidinium* cf. *echinatum* were not recorded in the Anthering Formation at Anthering, from where dinoflagellates were previously studied (Egger et al., 2000, 2003). This suggests a younger age for the Frauengrube Member. The *Areoligera undulata - A. sentosa* group is probably of inner neritic-lagoonal origin and has previously been recorded in the Lutetian in southern England (Eaton, 1976; Bujak et al., 1980). Little is known about its stratigraphical distribution elsewhere. The several specimens of *Glaphyrocysta* cf. *semitecta* are very close to, but perhaps not identical with *Glaphyrocysta semitecta*, a taxon previously recorded from NP15 to near the Eocene/Oligocene boundary in NW Europe (e.g., Bujak et al., 1980; Heilmann-Clausen and Van Simaeys, 2005). Nothing else in the samples suggests such a young age. The abundance of *Apectodinium* points to an age no younger than the Ypresian-Lutetian transition, most likely early Ypresian or older. The two specimens of *Deflandrea oebisfeldensis* also point to an early Ypresian or older age, as this form becomes extinct in the lower Ypresian in NW Europe (probably in or near top of NP11, e.g., Heilmann-Clausen and Costa, 1989; Luterbacher et al., 2004).

In summary, the calcareous nannoplankton and dinoflagellate assemblages of the Frauengrube section indicate an erosional gap across the P/E-boundary, spanning the upper part of zone NP9, the entire zone NP10, and at least a large part of zone NP11.

In order to refine and check the biostratigraphic data of the Frauengrube section (Fig. 2C), the easternmost outcrop of South-Helvetic deposits has been sampled. This outcrop is located close to the town of Gmunden in Upper Austria, about 50 km to the east of Salzburg (Fig. 3). In the "Rote Kirche" outcrop, the nummulitic limestone of the Frauengrube Member rests on marly sandstone (Prey, 1983), that contains calcareous nannoplankton of zone NP12: *Braarudosphaera bigelowii*, *Campylosphaera eodela*, *Chiasmolithus bidens*, *Coccolithus pelagicus*, *Discoaster barbadiensis*, *Discoaster binodosus*, *Discoaster lodoensis*, *Ellipsolithus macellus*, *Neochiastozygus protenus*, *Rhabdosphaera solus*, *Sphenolithus radians*, *Toweius pertusus*, *Tribrachiatus orthostylus* (Typ B), *Zygrhablithus bijugatus*. This nannoflora is an indicator that the Ypresian transgression on the shelf of the European Plate took place within Zone NP12.

The Penninic Basin: Anthering section

The 250 m thick Anthering section (Figs. 1, 2B-C and 7) 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,* including the presence of the distinctive species *A. augustum* in the upper part of zone NP9 (Heilmann-Clausen and Egger, 1997; Egger et al., 2000; Crouch et al., 2001). The outcrop across the CIE displays a two-fold lithological subvision (Fig. 7). 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.

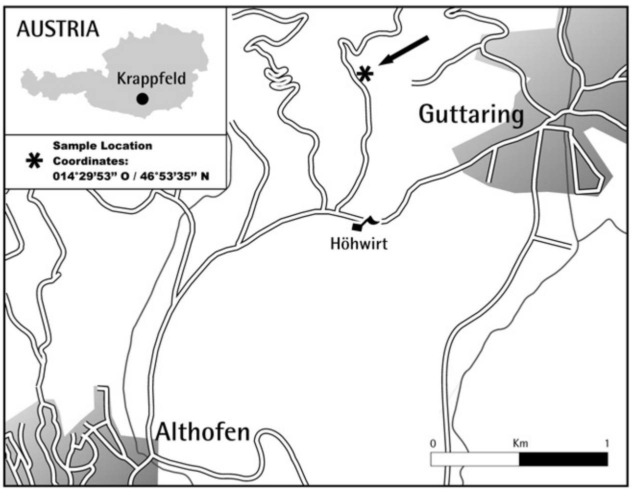

FIGURE 4 **Location of the outcrop of the Sittenberg Formation, to the north of Höhwirt (Krappfeld area). This fine-grained deposits yielded calcareous nannoplankton of zone NP12.**

The carbon isotope and dinoflagellate data presented in this paper (Fig. 7) allow a more precise definition of the CIE-interval at Anthering, which attains a thickness of 15 m, comprising turbidites and hemipelagites. 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 8.4m. 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 mm ky^{-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 mm ky^{-1} (Egger and Schwerd, 2007). 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 mm ky^{-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. In the lower part of zone NP10, the sedimentation rate was still slightly increased by a factor of 1.6, before it returned to the same values as before the event.

Enhanced erosion of land areas around the CIE-interval can also be inferred from the composition of calcare-

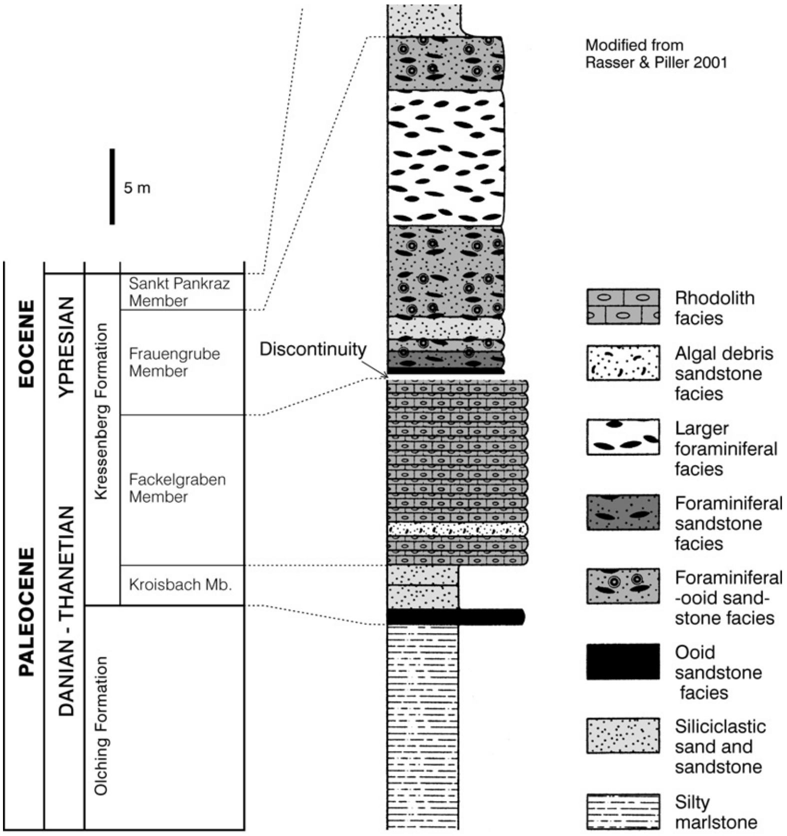

FIGURE 5 **Lithostratigraphy of the Kroisbach and Frauengrube sections (South Helvetic Unit). See location in Figs. 1 and 2B-C. See also Fig. 5 for a detail of the discontinuity between the Fackelgraben and Frauengrube Members at the Frauengrube locality.**

ous 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. 7). 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 a 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.

In the northern part of the Helvetic unit, Campanian deposits are unconformably overlain by Eocene strata (Hagn et al., 1982). This suggests that 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. The latest Thanetian and earliest Eocene was likely the most important episode for erosion of the Helvetic shelf. This is contrary to previously published papers (Trümpy, 1980; Oberhauser, 1995), which considered the Cretaceous/Paleogene boundary as the main erosional period for the Cretaceous shelf deposits.

The slope of the Adriatic Plate: Untersberg section

The 40 m thick Untersberg section of the Northern Calcareous Alps (Figs. 1, 2B-D) comprises the Paleocene-Eocene transition and spans the upper part of calcareous nannoplankton zone NP9 and the lower part of zone NP10 (sub-zone NP10a). The bathyal deposits are part of the Nierental Formation and were accumulated in a lower bathyal environment. In the dominant marlstone, a 5.5 m thick intercalation of red and green claystone and marly claystone represents the CIE-interval (Fig. 8). This indicates a substantial shallowing of the calcite compensation depth at that stratigraphic level. A 49% increase in detrital quartz and feldspar within the CIE-interval suggests enhanced continental run-off from a source area to the south of the basin. The highest values of detrital quartz and feldspar occur in the lower third of the CIE-interval.

The 5.5 m thickness of the CIE interval at Untersberg suggests a sedimentation rate of 32 mm ky^{-1}. Due to the absence of reliable age constraints below the CIE at Untersberg, it is difficult to estimate the increase in sedimentation rate during the CIE. A volcanic ash layer 25 m above the top of the CIE has been correlated with the +19 ash-layer of the North Sea Basin (Egger et al., 2005). The age of this ash has been determined as 54 million years (Chambers et al., 2003). Assuming that 25 m of marlstone were deposited during a 1.3 my long episode between the top of the CIE and the eruption of ash +19, a sedimentation rate of 19.2 mm ky^{-1} can be calculated. To compare this value with the claystone and marly claystone of the CIE interval the carbonate content (48% on average) has to be excluded. This indicates a sedimentation rate for the fine grained siliciclastic material of 9.6 mm ky^{-1} for the lower part of zone NP10. Taking into account that during this episode the sedimentation rate at Anthering was still 1.6 time higher than the "regular" rates of the Paleocene, the "regular" siliciclastic sedimentation rate for the Untersberg section can be inferred as 6 $mmky^{-1}$. This suggests an increase in the sediment accumulation rate by a factor of 5.2 across the CIE interval.

The shelf of the Adriatic Plate: Krappfeld section

In the southern part of Austria (Krappfeld, Carinthia), Upper Cretaceous to Paleogene deposits of the "Central Alpine Gosau Group" are preserved in the Gurktal Nappe, which represents a part of the former Adriatic plate (Figs. 1 and 4). Upper Campanian marlstone is unconformably overlain by coal bearing terrestrial deposits of the Paleogene Holzer Formation (Fig. 8). From these deposits a rich and well preserved tropical palynoflora has been described, indicating *Nypa*-dominated mangrove type forests, which reflect the early Eocene climate optimum

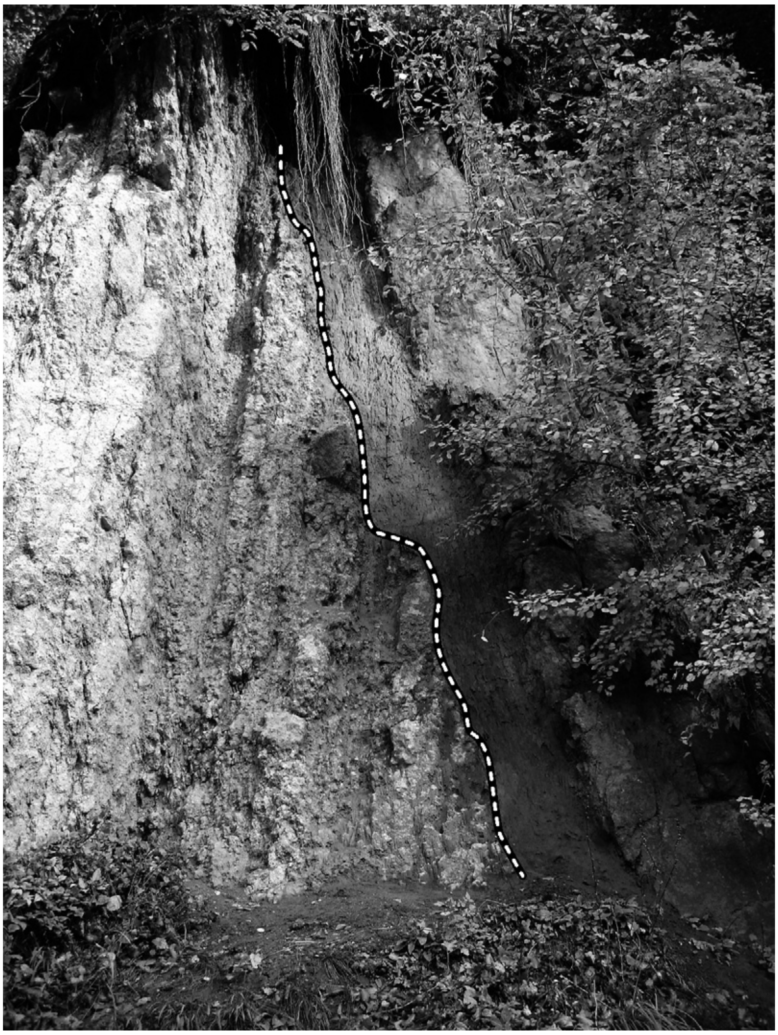

FIGURE 6 | **The discontinuity between the Fackelgraben and Frauengrube Members at the locality Frauengrube. See location in Fig. 2B-D.**

(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 Holzer Fm is overlain by the nummulitic limestone and marlstone of the Sittenberg Formation (Thiedig et al., 1999; Fig. 8)). From the base of this marine deposits *Assilina placentula*, *Nummulites burdigalensis kuepperi*, *Nummulites increscens*, and *Nummulites bearnensis* have been 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). This is consistent with our data on calcareous nannoplankton from a marlstone of the Sittenberg Formation, sampled at the outcrops to the north of Höhwirt (Fig. 4). Beside reworked Cretaceous specimens, *Braarudosphaera bigelowii*, *Campylosphaera eodela*, *Chiasmolithus consuetus*, *Coccolithus pelagicus*, *Discoaster barbadiensis*, *Discoaster lodoensis*, *Tribrachiatus orthostylus* (B), *Discoaster barbadiensis*, *Micrantolithus aequalis*, *Rhabdosphaera sp*., *Sphenolithus radians*, *Toweius pertusus*, *Transversopontis pulcher* are indicative for Zone NP12. Thus it appears that a sea-level rise in the lower part of this biostratigraphic zone triggered a transgression on the Adriatic Plate.

The sedimentation of the Gosau Group at Krappfeld ended in the Lutetian. 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).

CORRELATION BETWEEN MARGINAL AND BASINAL SETTINGS

Based on the results of this study, we suggest a correlation of the Ypresian transgression at the northern and southern shelves of the Penninic Basin. As this sea-level rise affected different tectonic plates with different subsidence histories it can be assumed that this was an eustatic event. This can be correlated with the highstand of the TA2 supercycle in the global sea-level curve (Haq et al., 1988). This interpretation is in contrast to previous papers, which have attributed the sea-level fluctuations in the lower Paleogene sedimentary record of the Helvetic domain to the loading of the southern margin of the European Plate by stacking of tectonic nappes (Herb, 1988; Menkveld-Gfeller, 1997; Kempf and Pfiffner, 2004).

The onset of the preceding regression, which is documented in both areas by erosional surfaces, cannot be dated in the shallow water sections because it is unknown how much of the succession was eroded during subaerial exposure. On the southern shelf, the Ypresian rests on Upper Campanian deposits. On the northern shelf the hiatus is largest in the northern part of the Helvetic Realm and decreases towards the south as the basin deepens. There, Thanetian deposits of zone NP9 are overlain by Ypresian deposits of zone NP12. This implies that the sea-level drop occurred between the latest Paleocene and the earliest Eocene.

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 of the Penninic Basin, the thickest turbidites of the Thanetian and Ypresian occur in the uppermost 13 m of the Thanetian. This suggests that the sea-level drop took place shortly before 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 an eustatic fluctuation.

With the exception of the Paleocene/Eocene transition, where the percentage of reworked Cretaceous material is very high, reworking is less than 5% in the turbidites at the Anthering section (Fig. 7). This suggests an episode of massive hinterland erosion in the latest Paleocene and earliest Eocene, during which a lithological shift from sandy to pelitic facies occurred. Starting with the onset of the CIE, mainly fine-grained suspended material came into the basin and caused an increase in hemipelagic sedimentation rates by a factor of 5 or 6. Such an increase associated with decreasing grain-sizes has already 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).

The correlation of the basinal Anthering and Untersberg sections (Fig. 8) is primarily based on calcareous nannoplankton stratigraphy and carbon isotopes. The CIE interval attains a thickness of 5.5 m and 15 m at Untersberg and Anthering, respectively. Excluding the turbidites of the Anthering section the remaining thickness of hemipelagic claystone is 8.4 m. The calculated hemipelagic sedimentation rates for the compacted sediment of 32 mmky^{-1} for the Untersberg section and 49 mmky^{-1} for the Anthering section suggest that sedimentation of very fine grained siliciclastic material from suspension load was 53% higher in the northern part of the basin than in the southern part. This difference in the sediment accu-

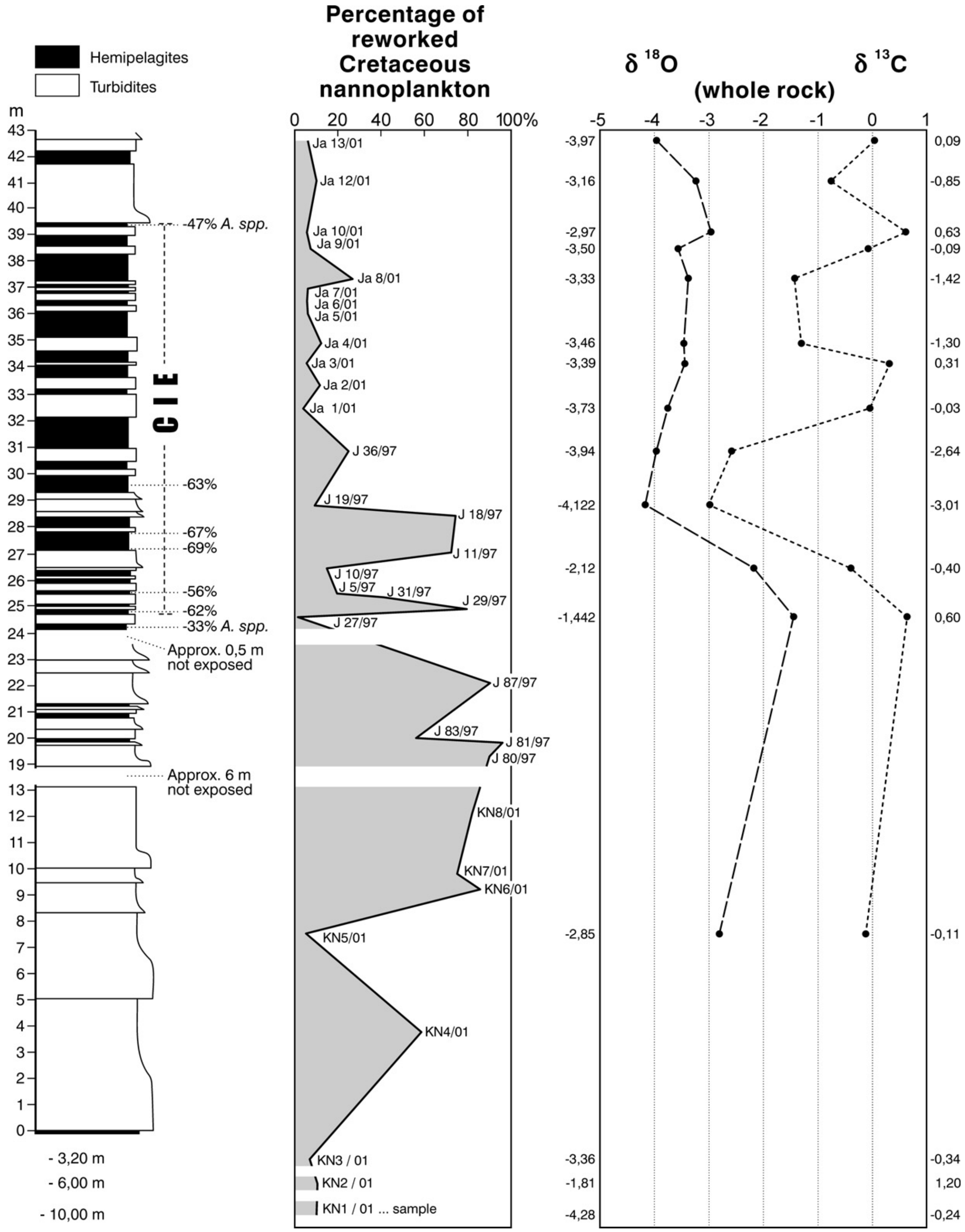

FIGURE 7 | **Lithostratigraphy, percentages of redeposited Cretaceous nannoplankton and stable isotope record of oxygen and carbon across the CIE-interval at Anthering. A. spp, percentages of the genus *Apectodinium* in the dinoflagellate assemblages. See location in Figs. 1 and 2B-C.**

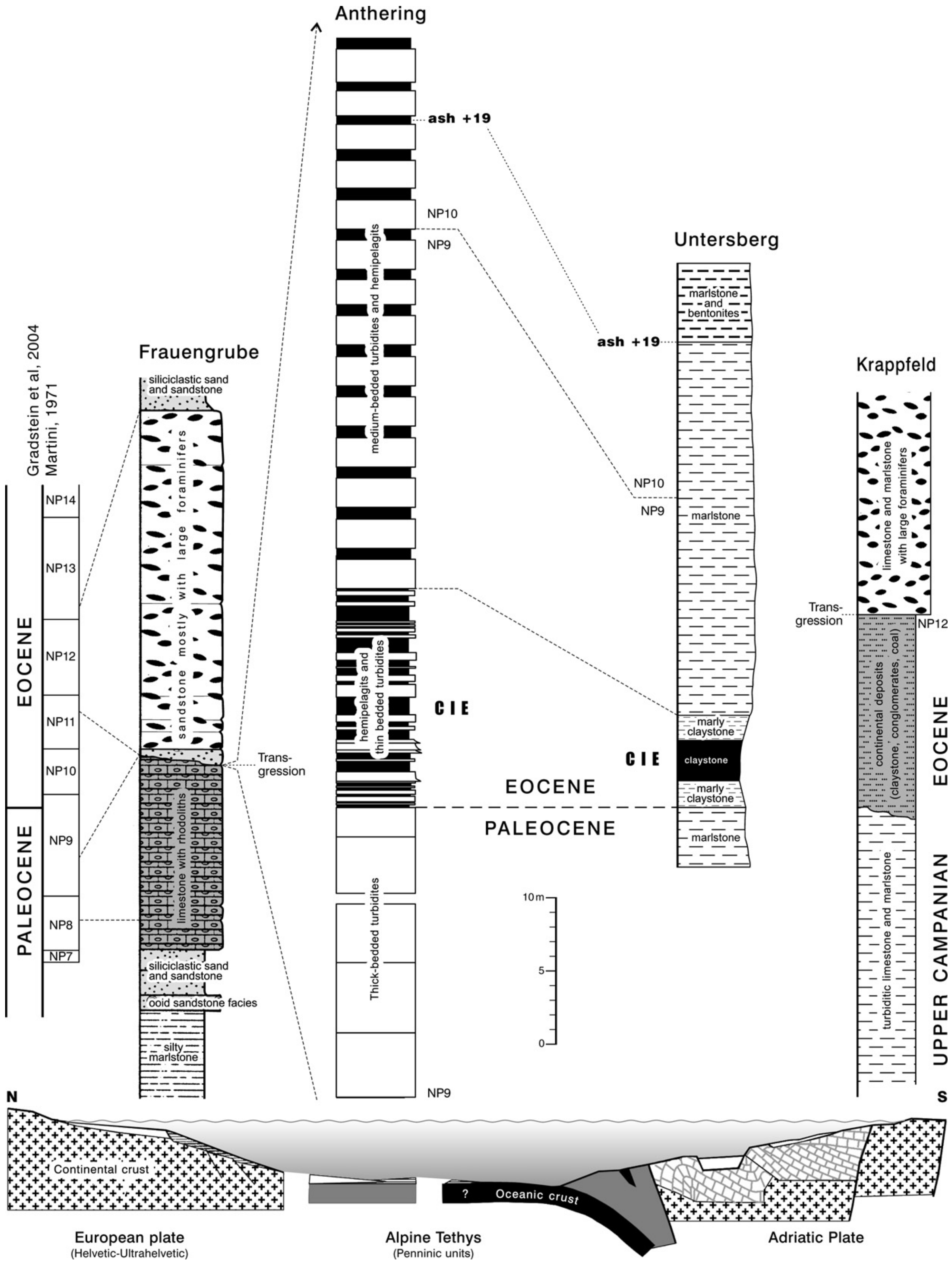

FIGURE 8 | **Correlation and paleogeographic position of the investigated sections. See location in Figs. 1, 2, and 4.**

mulation rate can be explained by the much larger size of the source area to the north of the basin.

CONCLUSION

In the latest Paleocene a strong increase in terrestrially derived input into the northern and southern part of the Penninic Basin can be used as a proxy for the onset of a major sea-level fall, which preceded the CIE. The erosion of shelf deposits ended in the Ypresian with a transgression of nummulitic limestone and marlstone. In tectonically active areas like the Alps it is a challenge to discriminate between eustatic changes in sea-level and sea-level fluctuations resulting from regional tectonic activity. However, the sea-level fluctuations in the early Paleogene show a good correlation to global sea-level fluctuations. Therefore we conclude that the effects of these eustatic changes in sea-level exceeded the effects of regional tectonic activity in the Penninic Basin and the bordering shelves of the European and Adriatic Plates.

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REFERENCES

Bujak, J.P., Downie, C., Eaton, G.L., Williams, G.L., 1980. Dinoflagellate cysts and acritarchs from the Eocene of Southern England. Palaeontology, Special Papers, 24, 3-100.

Burnett, J.A., with contributions by Gallagher, L.T., Hampton, M.J., 1998. Upper Cretaceous. In: Bown, P.R. (ed.). Calcareous Nannofossil Biostratigraphy, Cambridge, Chapman and Hall, 132-199.

Bybell, L.M. and Self-Trail, J.M., 1994. Evolutionary, biostratigraphic, and taxonomic study of calcareous nannofossils from a continuous Paleocene-Eocene boundary section in New Jersey. U.S. Geological Survey, Professional Papers, 1554, 1-107.

Chambers, L.M., Pringle, M., Fitton, G., Larsen, L.M, Pedersen, A.K. and Parrish, R., 2003. Recalibration of the Palaeocene-Eocene boundary (P-E) using high precision U-Pb and Ar-Ar isotope dating: Abstract, EGS-AGU-EGU Joint Assembly Nice.

Collinson, M.E., 2000. Fruit and seed floras from the Palaeocene/Eocene transition and subsequent Eocene in southern England: Comparison and palaeoenvironmental implications. In: Schmitz, B., Sundquist, B., Andreasson, F.P. (eds.). Early Paleogene. Warm Climates and Biosphere Dynamics, GFF-Journal of the Geological Society of Sweden, 122, 36-37.

Crouch, E.M., Heilmann-Clausen, C., Brinkhuis, H., Morgans, H.E.G., Rogers, K.M., Egger, H. and Schmitz, B., 2001, Global dinoflagellate event associated with the Late Paleocene Thermal Maximum. Geology, 29, 315-318.

Dickens, G.R., 2004. Hydrocarbon-driven warming. Nature, 429, 513-515.

Dickens, G.R., O'Neil, J.R., Rea, D.K. and Owen, R.M., 1995. Dissociation of oceanic methane hydrate as a cause of the carbon isotope excursion at the end of the Palaeocene. Paleoceanography, 10, 965-971.

Draxler, I., 2007. Significant Palynomorphs from the Thanetian Kroisbach-Member in Salzburg (Eastern Alps, Austria). Jahrbuch der Geologischen Bundesanstalt, 147, 357-377.

Eaton, G.L. 1976. Dinoflagellate cysts from the Bracklesham Beds (Eocene) of the Isle of Wight, Southern England. Bulletin of the British Museum (Natural History), Geology, 26(6), 227-332.

Egger, H., Schwerd, K., 2007. Stratigraphy and sedimentation rates of Upper Cretaceous deep-water systems of the Rhenodanubian Group (Eastern Alps, Germany). Cretaceous Research, doi: 10.1016/j.cretres.2007.03.002.

Egger, H., Heilmann-Clausen, C., Schmitz, B., 2000. The Paleocene/Eocene-boundary interval of a Tethyan deep-sea section and its correlation with the North Sea Basin. Société Géologique de France Bulletin, 171, 207-216.

Egger, H., Homayoun, M. and Schnabel, W., 2002. Tectonic and climatic control of Paleogene sedimentation in the Rhenodanubian Flysch Basin (Eastern Alps, Austria). Sedimentary Geology, 152, 147-162.

Egger, H., Homayoun, M., Huber, H., Rögl, F., Schmitz, B., 2005. Early Eocene climatic, volcanic, and biotic events in the northwestern Tethyan Untersberg section, Austria. Palaeogeography, Palaeoclimatology, Palaeoecology, 217, 243-264.

Egger, H., Fenner, J., Heilmann-Clausen, C., Rögl, F. Sachsenhofer, R.F., Schmitz, B., 2003. Paleoproductivity of the northwestern Tethyan margin (Anthering Section, Austria) across the Paleocene-Eocene transition. In: Wing, S.L., Gingerich, P., Schmitz, B., Thomas, E. (eds.). Causes and Consequences of Globally Warm Climates in the Early Paleogene. Geological Society of America, Special Paper, 369, 133-146.

Faupl, P., Wagreich, M., 2000. Late Jurassic to Eocene paleogeography and geodynamic evolution of the Eastern Alps. Mitteilungen der Österreichischen Geologischen Gesellschaft, 92, 79-94.

Gohrbandt, K., 1963a. Paleozän und Eozän des Helvetikums nördlich von Salzburg (Haltepunkte DI/1-DI/5). In: Grill, R., Kollmann, K., Küpper, H., Oberhauser, R. (eds.). Exkursionsführer für das achte mikropaläontologische Kolloquium in Österreich, Vienna, 47-57.

Gohrbandt, K., 1963b. Zur Gliederung des Paläogen im Helvetikum nördlich Salzburg nach planktonischen Foraminiferen. Mitteilungen der Geologischen Gesellschaft in Wien (Vienna), 56, 116 pp.

Gradstein, F., Ogg, J., Smith, A., 2004. A Geologic Time Scale, Cambridge University Press, 589 pp.

Hagn, H., Costa, L., Herm, D., 1981. Die Bayerischen Alpen und ihr Vorland in mikropaläontologischer Sicht. Geologica Bavarica, 82, 408 pp.

Haq, B.U., Hardenbol, J., Vail, P.R., 1988. Mesozoic and Cenozoic chronostratigraphy and eustatic cycles. Society of Economic Paleontologists and Mineralogists, Special Publication, 42, 71-108.

Heilmann-Clausen, C., 1995. Palæogene aflejringer over Danskekalken. In: Nielsen, O.B. (ed.). Danmarks geologi fra Kridt til i dag. Aarhus Geokompendier, 1, 70-114.

Heilmann-Clausen, C., Egger, H., 1997. An ash-bearing Paleocene/Eocene sequence at Anthering, Austria: biostratigraphical correlation with the North Sea Basin. Danmarks og Grønlands undersøgelse rapport, 1997/87, 13.

Heilmann-Clausen, C., Costa, L.I., 1989. Dinoflagellate Zonation of the Uppermost Paleocene? to Lower Miocene in the Wursterheide Research Well, NW Germany. Geologisches Jahrbuch, Reihe A, 111, 431-521.

Heilmann-Clausen, C., Van Simaeys, S., 2005. Dinoflagellate cysts from the Middle Eocene to ?lower most Oligocene succession in the Kysing research borehole, central Danish Basin. Palynology, 29, 141-204.

Herb, R., 1988. Eocaene Paläogeographie und Paläotektonik des Helvetikums. Eclogae geologicae Helveticae, 81, 611-657.

Hillebrandt, A.V., 1993. Nummuliten und Assilinen aus dem Eozän des Krappfeldes in Kärnten (Österreich). Zitteliana, 20, 277-293.

Kedves, M., 1980. Palynological investigations on Austrian Upper Cretaceous and Lower Tertiary sediments. Acta Biologica Szeged, 26, 63-77.

Kempf, O., Pfiffner, O.A., 2004. Early Tertiary evolution of the North Alpine Foreland Basin of the Swiss Alps and adjoining areas. Basin Research, 16, 549-567.

Kent, D.V., Cramer, B.S., Lanci, L., Wang, D., Wright, J.D. and Van der Voo, R., 2003. A case for a comet impact trigger for the Paleocene/Eocene thermal maximum and carbon isotope excursion. Earth and Planetary Science Letters, 211, 13-26.

Knox, R.W.O'B., 1998. Tectonic and volcanic history of the North Atlantic region during the Paleocene-Eocene transition: implications for NW European and global biotic events. In: Aubry, M.-P., Lucas, S., Berggren, W.A. (eds.). Late Paleocene-Early Eocene Climatic and Biotic Events in the Marine and Terrestrial Records. New York, Columbia University Press, 91-102.

Lu, G. and Keller, G., 1993. The Palaeocene-Eocene transition in the Antartic Indian Ocean: Inference from planktic foraminifera. Marine Micropalaeontology, 21, 101-142.

Luterbacher, H.P., Hardenbol, J., Schmitz, B., 2000. Decision of the voting members of the International Subcommission on Paleogene Stratigraphy on the criterion of recognition of the Paleocene/Eocene-boundary. Newsletter of the International Subcommission on Paleogene Stratigraphy, 9, 13.

Luterbacher, H.P., Ali, J.R., Brinkhuis, H., Gradstein, F.M., Hooker, J.J., Monechi, S., Ogg, J.G., Powell, J., Röhl, U., Sanfilippo, A., Schmitz, B., 2004. The Paleogene Period. In: Gradstein, F.M., Ogg, J.G., Smith, A.G. (eds.). A Geologic Time Scale 2004. Cambridge, Cambridge University Press, 384-408.

Martini, E., 1971. Standard Tertiary and Quaternary calcareous nannoplankton zonation. In: Farinacchi , A. (ed.). II Planktonic Conference Roma, Proceedings, 1970, 2, 739-785.

Menkveld-Gfeller, U., 1997. Die Bürgen-Fm. Und die Klimsenhorn-Fm: Formelle Definition zweier lithostratigraphischer Einheiten des Eozäns der helvetischen Decken. Eclogae Geologicae Helvetiae, 90, 245-261.

Monechi, S., Angori, E., von Salis, 2000. Calcareous nannofossil turnover around the Paleocene/Eocene transition at Alamedilla (southern Spain). Société Géologique de France Bulletin, 171, 477-489.

Oberhauser, R., 1995. Zur Kenntnis der Tektonik und Paläogeographie des Ostalpenraumes zur Kreide-, Paleozän- und Eozänzeit. Jahrbuch der Geologischen Bundesanstalt, 138, 369-432.

Perch-Nielsen, K. (1985). Cenozoic calcareous nannofossils. In: Bolli, H.M., Saunders, J.B. and Perch-Nielsen, K. (eds.). Plankton Stratigraphy, Cambridge, Cambridge University Press, 427-554.

Prey, S., 1983. Das Ultrahelvetikum-Fenster des Gschliefgrabens südsüdöstlich von Gmunden (Oberösterreich). Jahrbuch der Geologischen Bundesanstalt, 126, 95-127.

Pujalte, V., Schmitz, B., 2006. Abrupt climatic and sea level changes across the Paleocene-Eocene boundary, as recorded in an ancient coastal plain setting (Pyrenees, Spain). Climate and biota of the Early Paleogene Abstracts, p. 103.

Rasser, M.W., Piller, W.E., 1999. Kroisbachgraben und Frauengrube: Lithostratigraphische Typuslokalitäten für das paläogene Helvetikum in Salzburg. Abhandlugen der Geologischen Bundesanstalt, 56, 713-722.

Rasser, M.W., Piller, W.E., 2001. Facies patterns, subsidence and sea-level changes in ferriginous and glauconitic environments: The Paleogene Helvetic shelf in Austria and Bavaria. Österreichische Akademie der Wissenschaften Schriftenreihe der Erdwissenschaftlichen Kommissionen (Vienna), 14, 77-110.

Röhl, U., Bralower, T.J., Norris, R.D., Wefer, G., 2000. New chronology for the late Palaeocene thermal maximum and its environmental implications. Geology, 28, 927-930.

Schaub, H., 1981. Nummulites et Assilines de la Téthys Paléogène. Taxonomie, phylogénèse et biostratigraphie, Schweizerische Paläontologische Abhandlungen, 104, 236 pp.

Schmitz, B. and Pujalte, V., 2007. Abrupt increase in extreme seasonal precipitation at the Paleocene-Eocene boundary. Geology, 35, 215-218.

Schmitz, B., Pujalte V. and Núnez-Betelu K., 2001. Climate and sea-level perturbations during the Initial Eocene Thermal Maximum: Evidence from siliciclastic units in the Basque Basin (Ermua, Zumaya and Trabakua Pass), northern Spain. Palaeogeography, Palaeoecology, Palaeoclimatology, 165, 299-320.

Schmitz, B., Asaro, F., Molina, E., Monechi, S., von Salis, K. and Speijer, R., 1997. High resolution iridium, ?13C, ?18O, foraminifera and nannofossil profiles across the latest Palaeocene benthic extinction event at Zumaya, Spain. Palaeogeography, Palaeoclimatology, Palaeoecology, 133, 49-68.

Serra-Kiel, J., Hottinger, L., Caus, E., Drobne, K., Ferrández, C., Jaurhi, A.K., Less, G., Pavlovec, R., Pignatti, J., Samsó, J.M., Schaub, H., Sirel, E., Strougo, A., Tambareau, Y., Tosquella, J., Zakrevskaya, E., 1998. Larger foraminiferal biostratigraphy of the Tethyan Paleocene and Eocene. Société Géologique de France Bulletin, 169, 281-299.

Stampfli, G.M., Mosar, J., Marquer, D., Marchant, R., Baudin, T., Borel, G., 1998. Subduction and obduction processes in the Swiss Alps. Tectonophysics, 296, 159-204.

Steurbaut, E, Magioncalda, R., Dupuis, C, Van Simaeys, S., Roche, E., Roche, M., 2003. Palynology, paleoenvironments, and organic carbon isotope evolution in lagoonal Paleocene-Eocene boundary settings in North Belgium. In: Wing, S.L., Gingerich, P., Schmitz, B., Thomas, E. (eds.). Causes and Consequences of Globally Warm Climates in the Early Paleogene. Geological Society of America, Special Paper, 369, 291-317.

Svensen, H., Planke, S., Malthe-Sorenssen, A., Jamtveit, B., Myklebust, R., Eidem, T.R., Rey, S.S., 2004. Release of methane from a volcanic basin as a mechanism for initial Eocene global warming. Nature, 429, 542-545.

Thiedig, F., van Husen, D., Pistotnik, J., 1999. Geological map of Austria on the scale 1:50000. Sheet 186, Sankt Veit an der Glan (Geological Survey of Austria).

Thomas, E., 1998. Biogeography of the Late Paleocene benthic foraminiferal extinction. In: Aubry, M.–P., Lucas, S. and Berggren, W.A. (eds.). Late Paleocene-Early Eocene climatic and biotic events in the marine and terrestrial records. New York, Columbia University Press, 214-243.

Trümpy, R., 1980. Geology of Switzerland, Part A: An outline of the geology of Switzerland. A Guide-Book, 104 pp.

Vogeltanz, R., 1977. Geologie des Wartstein-Straßentunnels, Umfahrung Mattsee (Land Salzburg). Verhandlungen der Geologischen Bundesanstalt, Jahrgang, 279-291.

Wing, S.L, Bown, T.M. and Obradovic, J.D., 1991. Early Eocene biotic and climatic change in interior western North America. Geology, 19, 1189-1192.

Zetter, R. Hofmann, Ch.-Ch., 2001. New aspects of the palynoflora of the lowermost Eocene (Krappfeld Area, Carinthia). In: Piller, W.E., Rasser, M.W. (eds.). Paleogene of the Eastern Alps. Österreichische Akademie der Wissenschaften Schriftenreihe der Erdwissenschaftlichen Kommissionen, 14, 473-507.

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